



The ATLAS^{3D} project – I. A volume-limited sample of 260 nearby early-type galaxies: science goals and selection criteria

Michele Cappellari,^{1*} Eric Emsellem,^{2,3} Davor Krajnović,² Richard M. McDermid,⁴ Nicholas Scott,¹ G. A. Verdoes Kleijn,⁵ Lisa M. Young,⁶ Katherine Alatalo,⁷ R. Bacon,³ Leo Blitz,⁷ Maxime Bois,^{2,3} Frédéric Bournaud,⁸ M. Bureau,¹ Roger L. Davies,¹ Timothy A. Davis,¹ P. T. de Zeeuw,^{2,9} Pierre-Alain Duc,¹⁰ Sadegh Khochfar,¹¹ Harald Kuntschner,¹² Pierre-Yves Lablanche,³ Raffaella Morganti,^{5,13} Thorsten Naab,¹⁴ Tom Oosterloo,^{5,13} Marc Sarzi,¹⁵ Paolo Serra¹³ and Anne-Marie Weijmans^{16†}

¹Sub-department of Astrophysics, Department of Physics, University of Oxford, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH

²European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching, Germany

³Université Lyon 1, Observatoire de Lyon, Centre de Recherche Astrophysique de Lyon and Ecole Normale Supérieure de Lyon, 9 avenue Charles André, F-69230 Saint-Genis Laval, France

⁴Gemini Observatory, Northern Operations Centre, 670 N. A'ohoku Place, Hilo, HI 96720, USA

⁵Kapteyn Astronomical Institute, University of Groningen, Postbus 800, 9700 AV Groningen, the Netherlands

⁶Physics Department, New Mexico Institute of Mining and Technology, Socorro, NM 87801, USA

⁷Department of Astronomy, Campbell Hall, University of California, Berkeley, CA 94720, USA

⁸Laboratoire AIM Paris-Saclay, CEA/IRFU/SAp CNRS Université Paris Diderot, 91191 Gif-sur-Yvette Cedex, France

⁹Sterrewacht Leiden, Leiden University, Postbus 9513, 2300 RA Leiden, the Netherlands

¹⁰Laboratoire AIM, CEA/DSM-CNRS-Université Paris Diderot, Dapnia/Service d'Astrophysique, CEA-Saclay, 91191 Gif-sur-Yvette Cedex, France

¹¹Max-Planck Institut für extraterrestrische Physik, PO Box 1312, D-85478 Garching, Germany

¹²Space Telescope European Coordinating Facility, European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching, Germany

¹³Netherlands Institute for Radio Astronomy (ASTRON), Postbus 2, 7990 AA Dwingeloo, the Netherlands

¹⁴Max-Planck Institut für Astrophysik, Karl-Schwarzschild-Str. 1, 85741 Garching, Germany

¹⁵Centre for Astrophysics Research, University of Hertfordshire, Hatfield, Herts AL1 9AB

¹⁶Dunlap Institute for Astronomy & Astrophysics, University of Toronto, 50 St. George Street, Toronto, ON M5S 3H4, Canada

Accepted 2010 December 8. Received 2010 December 6; in original form 2010 November 2

ABSTRACT

The ATLAS^{3D} project is a multiwavelength survey combined with a theoretical modelling effort. The observations span from the radio to the millimetre and optical, and provide multi-colour imaging, two-dimensional kinematics of the atomic (H I), molecular (CO) and ionized gas (H β , [O III] and [N II]), together with the kinematics and population of the stars (H β , Fe5015 and Mg b), for a carefully selected, volume-limited (1.16×10^5 Mpc 3) sample of 260 early-type (elliptical E and lenticular S0) galaxies (ETGs). The models include semi-analytic, N -body binary mergers and cosmological simulations of galaxy formation. Here we present the science goals for the project and introduce the galaxy sample and the selection criteria. The sample consists of nearby ($D < 42$ Mpc, $|\delta - 29^\circ| < 35^\circ$, $|b| > 15^\circ$) morphologically selected ETGs extracted from a parent sample of 871 galaxies (8 per cent E, 22 per cent S0 and 70 per cent spirals) brighter than $M_K < -21.5$ mag (stellar mass $M_\star \gtrsim 6 \times 10^9 M_\odot$). We analyse possible selection biases and we conclude that the parent sample is essentially complete and statistically representative of the nearby galaxy population. We present the size–luminosity relation for the spirals and ETGs and show that the ETGs in the ATLAS^{3D} sample define a

*E-mail: cappellari@astro.ox.ac.uk

†Dunlap fellow.

tight red sequence in a colour–magnitude diagram, with few objects in the transition from the blue cloud. We describe the strategy of the SAURON integral field observations and the extraction of the stellar kinematics with the ppxf method. We find typical 1σ errors of $\Delta V \approx 6 \text{ km s}^{-1}$, $\Delta\sigma \approx 7 \text{ km s}^{-1}$, $\Delta h_3 \approx \Delta h_4 \approx 0.03$ in the mean velocity, the velocity dispersion and Gauss–Hermite (GH) moments for galaxies with effective dispersion $\sigma_e \gtrsim 120 \text{ km s}^{-1}$. For galaxies with lower σ_e (≈ 40 per cent of the sample) the GH moments are gradually penalized by ppxf towards zero to suppress the noise produced by the spectral undersampling and only V and σ can be measured. We give an overview of the characteristics of the other main data sets already available for our sample and of the ongoing modelling projects.

Key words: galaxies: distances and redshifts – galaxies: elliptical and lenticular, cD – galaxies: evolution – galaxies: formation – galaxies: kinematics and dynamics – galaxies: structure.

1 INTRODUCTION

1.1 Scientific background

Observations of high-redshift galaxies and the cosmic microwave background (Spergel et al. 2007) have revealed the Universe to be dominated by dark matter and dark energy (Riess et al. 1998; Perlmutter et al. 1999), providing a working paradigm for the formation of structure (e.g. Springel et al. 2005b). However, the mechanisms that form the luminous content of the dark matter potential (i.e. the stars and galaxies that we observe) remain the key unknowns of modern extragalactic astronomy. These processes are driven by the hydrodynamics and chemistry of the gas, combined with complex radiative feedback processes. High-redshift observations alone are not sufficient to constrain these processes, lacking spectral information and spatial resolution (Faber et al. 2007). It is therefore necessary to complement these studies with detailed analysis of nearby objects, tracing the *fossil record* of the formation process. Early-type (elliptical E and lenticular S0) galaxies (ETGs) are especially useful as they are old, have smaller levels of star formation and limited amount of dust, which simplifies the interpretation of the observations. Significant progress has been made in this direction in the past few decades, building on the classic observational works that still capture much of our understanding of the structure of local ETGs (e.g. Hubble 1936; Faber & Jackson 1976; Davies et al. 1983; Djorgovski & Davis 1987; Dressler et al. 1987; Bender, Burstein & Faber 1992; Kormendy & Richstone 1995).

A major step forward was brought by the era of large galaxy surveys. Thanks to the unprecedented sample size, one of the most important contributions of the Sloan Digital Sky Survey (SDSS; York et al. 2000) was to firmly establish a statistically significant bimodality in the colour distribution of local galaxies, such that they can be clearly separated in a so-called ‘blue cloud’, generally consisting of star-forming spiral galaxies, and a ‘red sequence’, mostly of non-star-forming ETGs (Strateva et al. 2001; Baldry et al. 2004). Accurately quantifying this bimodality, and the realization that it can be traced back in time to higher redshift (Bell et al. 2004; Faber et al. 2007), allowed a dramatic improvement in the detailed testing of galaxy formation scenarios.

The bimodality can only be explained with the existence of a mechanism, which suppresses episodes of intense star formation by evacuating gas from the system, resulting in a rapid transition of galaxies from the blue cloud to the red sequence (Springel, Di Matteo & Hernquist 2005a; Faber et al. 2007). Many simulation groups have reproduced the bimodality qualitatively, though with

rather different assumptions for the star formation and feedback processes (Granato et al. 2004; Di Matteo, Springel & Hernquist 2005; Bower et al. 2006; Cattaneo et al. 2006; Croton et al. 2006). A generic feature of these models is that red-sequence galaxies form by dissipational ‘wet mergers’ of gas-rich blue-cloud galaxies, followed by quenching of the resulting intense star formation by rapid ejection of the gas, caused by the feedback from a central supermassive black hole, supernovae winds, by shock heating of the gas in the most massive haloes (Kereš et al. 2005; Dekel & Birnboim 2006) or gravitational gas heating (Naab et al. 2007; Khochfar & Ostriker 2008; Johansson, Naab & Ostriker 2009). The merging of the most massive blue galaxies, however, is not sufficient to explain the population of most massive red-sequence galaxies. Dissipationless ‘dry mergers’ of gas-poor, red-sequence galaxies is therefore also required, evolving galaxies *along* the red sequence as they increase in mass (Khochfar & Burkert 2003; Naab, Khochfar & Burkert 2006b; Hopkins et al. 2009; Khochfar & Silk 2009; Oser et al. 2010).

Both wet and dry major mergers generally produce red, bulge-dominated galaxies when feedback is included in the models. The kinematic structure of the remnants is however very different. In a major (1:1) merger between blue gas-rich galaxies, the gas tends to form a disc, so that the end result of the merger, after the gas has been removed from the system by ejection, heating or conversion to stars, will be a red stellar system dominated by rotation (Cox et al. 2006; Naab et al. 2006a; Robertson et al. 2006; Jesseit et al. 2009). In major mergers between red gas-poor galaxies, dissipationless processes dominate, resulting in a red galaxy with little or no net rotation (Barnes 1992; Hernquist 1992; Naab, Burkert & Hernquist 1999; Naab & Burkert 2003; Cox et al. 2006). Unlike major mergers, minor mergers (1:3 or less) retain more closely the structure of the progenitor, to an extent that depends on the amount of mass and gas accreted, so that the remnant of a spiral galaxy will always display significant rotation (Naab et al. 2006a; Robertson et al. 2006; Bournaud, Jog & Combes 2007; Jesseit et al. 2009). These simulations demonstrate that if galaxies assemble by mergers, the existence of the red/blue galaxies dichotomy therefore also suggests the existence of a *kinematical* differentiation *within* the red sequence between fast and slow rotating galaxies.

Various classic observational indicators of a ETGs dichotomy have been proposed in the past two decades. ETGs have been found to exhibit trends as a function of luminosity in terms of (i) their distribution on the $(V/\sigma, \varepsilon)$ diagram, which relates the ratio of ordered V and random σ stellar motion to the galaxy ellipticity ε (e.g. Illingworth 1977; Binney 1978; Davies et al. 1983), (ii) their

isophote shape (discy or boxy) (Bender et al. 1989; Kormendy & Bender 1996), (iii) the inner slope of their photometric profiles: cored/cuspy (Ferrarese et al. 1994; Lauer et al. 1995; Faber et al. 1997) or excess/deficit of core light (Graham 2004; Ferrarese et al. 2006; Kormendy et al. 2009). However, none of these signatures has been able to give clear evidence for a distinction between the two classes of red-sequence galaxies, primarily because they are all essentially secondary indicators of the galaxies' internal kinematic structure.

By the application of integral field spectroscopy to a representative sample of nearby ETGs, the SAURON survey (de Zeeuw et al. 2002) has revealed the full richness of the kinematics of these objects (Emsellem et al. 2004; McDermid et al. 2006; Krajnović et al. 2008). From the two-dimensional nature of this unique data set, two distinct morphologies of stellar rotation fields are clearly evident, corresponding to the above described fast- and slow rotators. In two companion papers of that survey a global quantitative measure of this morphology was defined, termed λ_R , that can be used to kinematically classify these galaxies in a way that is more robust than the $(V/\sigma, \varepsilon)$ diagram and is nearly insensitive to projection effects (Emsellem et al. 2007; Cappellari et al. 2007). λ_R relates directly to their formation, and is precisely reproducible in current cosmological simulations (Jesseit et al. 2009; Bois et al. 2010). This is the basic new finding we plan to exploit in the present project to improve our understanding of the structure and formation of ETGs. Additional results of the SAURON survey on ETGs include the robustness and empirical ‘calibration’ of the simple virial mass estimator to measure mass in the central parts of ETGs and a determination of their dark matter fraction (Cappellari et al. 2006). The survey found a high incidence of ionized gas in ETGs (Sarzi et al. 2006) and explained their ionization mechanism as mainly due to the evolved stellar population (Sarzi et al. 2010). It was shown that the stellar population gradients correlate well with the escape velocity, both locally within galaxies and globally among different ETGs (Scott et al. 2009). Star formation in ETGs only happens in fast rotators and follows two distinct modes: in discs or widespread (Shapiro et al. 2010), where the latter cases are in low-mass systems (Jeong et al. 2009; Kuntschner et al. 2010). Discs in fast rotators have enhanced metallicity, while kinematically distinct cores in slow rotators show no stellar population signatures (Kuntschner et al. 2006, 2010).

1.2 Goals of the project

Because of the exploratory character of the SAURON survey (de Zeeuw et al. 2002), the ETGs were selected to sample, with a relatively small number of objects, a wide range of masses, shapes and morphologies. This was done by selecting galaxies brighter than a total magnitude $M_B < -18$ mag equally subdivided into 24 E and 24 S0. Within each E/S0 subclass the selected objects sample uniformly a grid in the (M_B, ε) plane. Although that approach was crucial in bringing the fast/slow rotator dichotomy to light and in most of the findings mentioned in the previous section, the selection criteria impose complex biases and do not allow for a quantitative statistical comparisons of galaxy properties with simulations, which is a main goal of the ATLAS^{3D} project. Moreover, with only 48 galaxies, the statistical uncertainties are large.

The power of the kinematic classification based on λ_R is to be able to study differences in the formation process along the red-sequence galaxy population. The λ_R parameter describes in a compact way the present status of the galaxies, however, it is essential to obtain information on the formation history and the detailed dynamical structure as well. The stellar population contains a record of the

more distant history (a few Gyr). Recent gas accretion is recorded in the cold atomic gas components, generally detected on galaxy scales with radio observations of H_I, while the ongoing accretion and star formation activity is traced by cold molecular gas (e.g. CO), often detected in regular discs in the central regions. For comparison with theoretical predictions one needs to observe all these quantities for a statistically significant, volume-limited sample of galaxies complete to some useful lower limit in mass. With these ideas in mind we carefully selected the ATLAS^{3D} sample of ETGs and we systematically observed all the above quantities. The ATLAS^{3D} data set now provides a complete inventory of the baryon budget and a detailed two-dimensional description of stellar and gaseous kinematics, together with resolved stellar population within the main body of a complete and statistically significant sample of ETGs. Our goal is to use this data set to perform archaeological cosmology by specifically answering the following questions.

(i) How do slow rotators form? What are the physical processes that determine their kinematic and photometric features? What is the role of major and minor mergers in their formation history? This will be reflected in the kinematics, gas content and stellar population.

(ii) Why are most ETGs fast rotators? There seems to be a dominant formation mechanism that delivers galaxies with quite homogenous rotation properties. Can this be merging? Can significant major merging be excluded?

(iii) How is star formation in ETGs quenched? Is it different for fast- and slow-rotators ETGs? How does it depend on environment? Can we infer the quenching mechanism from the amount and distribution of the leftover gas, the presence of active galactic nuclei (AGN) or metallicity gradients? The distribution of stellar population and gas properties constitutes a stringent test for future galaxy formation models.

(iv) Most past studies have focused on single stellar population models of ETGs, but cosmological models predict more complex histories. Can we infer the star formation history in ETGs for detailed comparison with simulations?

(v) How do counter rotating cores in massive and old ETGs form and survive to the present time? Are these relics of the very early Universe?

(vi) Can we link the present day properties of ETGs to results from existing and upcoming surveys at higher redshift with respect to e.g. masses, sizes, stellar populations, gas fractions, star formation? Our study will constitute a $z = 0$ redshift benchmark to trace the time evolution of galaxies.

The ATLAS^{3D} sample includes all nearby ETGs observable from the northern Earth hemisphere, and for this reason we hope its homogeneous data set will ultimately constitute a legacy for future studies. We trust that our and other groups will exploit our data and sample well beyond what we had originally envisioned. Our first steps in the directions outlined above are presented in the following papers, while the other aspects will be presented in subsequent papers of this series:

(i) Krajnović et al. (2011, hereafter Paper II), which describes the morphology of the kinematics and the kinematical misalignment in ETGs;

(ii) Emsellem et al. (2011, hereafter Paper III), which presents a census of the stellar angular momentum in the central region of ETGs;

(iii) Young et al. (2011, hereafter Paper IV), which quantifies the distribution of molecular gas content in ETGs;

(iv) Davis et al. (2011, hereafter Paper V), which studies the Tully & Fisher (1977) relation from the width of the molecular lines in ETGs;

(v) Bois et al. (2011, hereafter Paper VI), which studies the formation of the fast- and slow-rotator galaxies via numerical simulations of binary mergers;

(vi) Cappellari et al. (2011, hereafter Paper VII), which revisits the morphology of nearby galaxies and presents the *kinematic* morphology–density relation;

(vii) Khochfar et al. (2011, hereafter Paper VIII), which studies the formation of ETGs using semi-analytic modelling.

Here in Section 2 we discuss the selection criteria for the *parent* sample of galaxies, from which the ATLAS^{3D} sample of ETGs was extracted (Section 3). In Section 4 we present the SAURON observing strategy for the survey, the integral field data and the kinematic extraction, while other additional data sets and simulations from our project are listed in Section 5. We give a summary in Section 6. In the paper we assume $H_0 = 72 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

2 THE PARENT SAMPLE

2.1 Selection criteria

Our final ATLAS^{3D} sample will focus on ETGs only, however, before any morphological classification, we want to select all galaxies in the nearby volume above a certain total stellar mass. As we did not have dynamical information for all galaxies in the local volume at the beginning of our survey, the best proxy for mass available was the near-infrared ($\sim 2.2 \mu\text{m}$) K_s -band luminosity provided by the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006), which is unique for its full sky completeness and excellent photometric homogeneity. The K_s band is 5–10 times less sensitive to dust absorption than optical wavelengths and therefore can be used to select both dust-rich spirals and dust-poor ETGs to a similar mass level. Moreover the mass-to-light ratio of the stars in the near-infrared varies only about a factor ≈ 2 , which is about three times less than at optical wavelengths (Bell & de Jong 2001; Maraston 2005), thus providing a better approximation to the stellar mass than an optical selection.

To derive luminosities from the observed apparent magnitudes we need distances. Numerous accurate determinations have been accumulated in the literature in the past few years. However, we will resort to redshift distances when a more accurate distance is not available. In addition we enforce obvious observability criteria. This leads to the following selection steps.

(i) Choose a representative local volume with radius $D = 42 \text{ Mpc}$. It approximates the redshift selection $cz < 3000 \text{ km s}^{-1}$ of the SAURON survey, for an adopted $H_0 = 72 \text{ km s}^{-1} \text{ Mpc}^{-1}$ (Dunkley et al. 2009). It makes sure that key spectral features, such as H β , [O III] and Mg b , fall within the SAURON wavelength range and allows for a significant overlap with previous observations.

(ii) Specify the observability criterion from the William Herschel Telescope (WHT) on La Palma $|\delta - 29^\circ| < 35^\circ$, where δ is the sky declination.

(iii) Exclude the dusty region near the Galaxy equatorial plane $|b| < 15^\circ$, with b the galactic latitude.

(iv) Select all galaxies from the 2MASS extended source catalog (XSC; Jarrett et al. 2000) with apparent total magnitude $K_T < 11.6$ mag (defined by the XSC parameter k_m_ext) and satisfying the observability criteria (ii) and (iii). Given the near completeness of the XSC down to $K_T \approx 13.5$ mag, this selection is essentially

Table 1. Selection criteria for the galaxies in the ATLAS^{3D} parent sample.

| | |
|---------------------------|----------------------------------|
| Distance: | $D < 42 \text{ Mpc}$ |
| Galaxies total mag: | $M_K < -21.5 \text{ mag}$ |
| Observability: | $ \delta - 29^\circ < 35^\circ$ |
| Galaxy zone of avoidance: | $ b > 15^\circ$ |

Table 2. Main characteristics of the ATLAS^{3D} parent sample.

| | |
|--|---|
| Survey volume: | $\text{Vol} = 1.16 \times 10^5 \text{ Mpc}^3$ |
| Galaxy K -band luminosity: | $L > 8.2 \times 10^9 L_{\odot, K}$ |
| Galaxy stellar mass: | $M_\star \gtrsim 6 \times 10^9 M_\odot$ |
| Galaxy B -band total mag: | $M_B \lesssim -18.0 \text{ mag}$ |
| Galaxy SDSS r -band total mag: | $M_r \lesssim -18.9 \text{ mag}$ |
| Total number of galaxies: | $N_{\text{gal}} = 871$ |
| Spiral and irregular galaxies: | $N_{\text{Sp}} = 611$ (70 per cent) |
| S0 galaxies in ATLAS ^{3D} ($T > -3.5$): | $N_{\text{S0}} = 192$ (22 per cent) |
| E galaxies in ATLAS ^{3D} ($T \leq -3.5$): | $N_E = 68$ (8 per cent) |

complete. It ensures that all candidate galaxies brighter than an absolute total magnitude $M_K = K_T - 5 \log D - 25 = -21.5 \text{ mag}$ are selected. This K_s -band luminosity limit roughly corresponds to a B -band selection $M_B \lesssim -18 \text{ mag}$, for the typical $B - K_s \approx 3.5 \text{ mag}$ colour of ETGs, at the faint end of our selection. This criterion is thus again similar to the one in the SAURON survey and allows for a significant overlap in the samples, reducing the required observing time. This step provides a sample of $\sim 20\,000$ extended objects classified as galaxies.

(v) Assign a distance to as many galaxies as possible in the selection and include in the ATLAS^{3D} parent sample the ones with $D < 42 \text{ Mpc}$ and $M_K < -21.5 \text{ mag}$. The distance selection requires some further explanation and may introduce incompleteness biases that are discussed in the next section.

A summary of the selection criteria is given in Table 1, while some of the main characteristics of the resulting galaxy sample are given in Table 2. This is the sample of galaxies, which includes both spiral and ETGs, from which the ATLAS^{3D} sample of ETGs will be extracted. The names and the characteristics of the resulting 871 galaxies in the ATLAS^{3D} parent sample are given in Tables 3 (for the ETGs) and 4 (for the spirals). As the evolution of spirals and ETGs are closely related, the spirals of the parent sample are critical to properly interpret the ATLAS^{3D} results on ETGs.

2.2 Sources of distances and errors

Numerous sources of distances for nearby galaxies have been accumulated over the past decades. In most cases the distances are based on redshift as provided by large redshift surveys, but a number of more accurate distances are available based on other methods (see e.g. the recent compilations of Tully et al. 2008, 2009; Karachentsev & Nasonova 2010). For the $\sim 20\,000$ 2MASS galaxies with $K_T < 11.6 \text{ mag}$ we tried to automatically assign the most accurate available distance according to the following order of priority.

(i) Distance obtained with the surface brightness fluctuation (SBF) method for the ACS Virgo Cluster Survey (Mei et al. 2007; Blakeslee et al. 2009) (91 values). These are claimed to be accurate to about 3 per cent in distance.

(ii) SBF distance from ground-based observation from Tonry et al. (2001) (300 values), which have a median error of 10 per cent in distance. These have been converted to the same zero-point of

Table 3. The ATLAS^{3D} sample of 260 early-type (E and S0) galaxies. A machine-readable version of this table is available (see Supporting Information).

| Galaxy | RA ($^{\circ}$) | Dec. ($^{\circ}$) | SBF | NED-D | Virgo | V_{hel} (km s $^{-1}$) | D (Mpc) | M_K (mag) | A_B (mag) | T type | $\log R_e$ (arcsec) |
|----------|----------------------|------------------------|-----|-------|-------|-------------------------------------|------------|----------------|----------------|--------|------------------------|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| IC 0560 | 146.472656 | -0.268221 | 0 | 0 | 0 | 1853 | 27.2 | -22.10 | 0.59 | -0.7 | 1.11 |
| IC 0598 | 153.202423 | 43.145546 | 0 | 0 | 0 | 2256 | 35.3 | -22.60 | 0.06 | -0.1 | 1.02 |
| IC 0676 | 168.165909 | 9.055736 | 0 | 0 | 0 | 1429 | 24.6 | -22.27 | 0.11 | -1.3 | 1.35 |
| IC 0719 | 175.077042 | 9.009861 | 0 | 0 | 0 | 1833 | 29.4 | -22.70 | 0.22 | -2.0 | 1.10 |
| IC 0782 | 185.404053 | 5.765672 | 0 | 0 | 0 | 2424 | 36.3 | -22.02 | 0.09 | 2.7 | 1.35 |
| IC 1024 | 217.863419 | 3.009107 | 0 | 0 | 0 | 1479 | 24.2 | -21.85 | 0.13 | -2.0 | 1.05 |
| IC 3631 | 189.950195 | 12.973927 | 0 | 0 | 0 | 2822 | 42.0 | -22.01 | 0.17 | -1.3 | 1.13 |
| NGC 0448 | 18.818876 | -1.626105 | 1 | 1 | 0 | 1908 | 29.5 | -23.02 | 0.26 | -2.5 | 1.05 |
| NGC 0474 | 20.027901 | 3.415270 | 0 | 1 | 0 | 2315 | 30.9 | -23.91 | 0.15 | -2.0 | 1.52 |
| NGC 0502 | 20.731415 | 9.049169 | 0 | 0 | 0 | 2524 | 35.9 | -23.05 | 0.17 | -2.0 | 1.07 |
| NGC 0509 | 20.850327 | 9.433469 | 0 | 0 | 0 | 2261 | 32.3 | -21.89 | 0.20 | -1.3 | 1.37 |
| NGC 0516 | 21.033607 | 9.551668 | 0 | 0 | 0 | 2437 | 34.7 | -22.21 | 0.29 | -1.5 | 1.16 |
| NGC 0524 | 21.198778 | 9.538793 | 1 | 10 | 0 | 2403 | 23.3 | -24.71 | 0.36 | -1.2 | 1.64 |
| NGC 0525 | 21.220442 | 9.703240 | 0 | 0 | 0 | 2139 | 30.7 | -21.86 | 0.38 | -2.0 | 1.06 |
| NGC 0661 | 26.060976 | 28.705988 | 0 | 1 | 0 | 3815 | 30.6 | -23.19 | 0.30 | -4.4 | 1.12 |
| NGC 0680 | 27.447035 | 21.970827 | 0 | 1 | 0 | 2928 | 37.5 | -24.17 | 0.34 | -4.0 | 1.16 |
| NGC 0770 | 29.806850 | 18.954695 | 0 | 0 | 0 | 2543 | 36.7 | -22.57 | 0.31 | -4.2 | 0.94 |
| NGC 0821 | 32.088123 | 10.994870 | 1 | 4 | 0 | 1718 | 23.4 | -23.99 | 0.48 | -4.8 | 1.60 |
| NGC 0936 | 36.906090 | -1.156280 | 1 | 4 | 0 | 1429 | 22.4 | -24.85 | 0.15 | -1.2 | 1.72 |
| NGC 1023 | 40.100052 | 39.063251 | 1 | 8 | 0 | 602 | 11.1 | -24.01 | 0.26 | -2.7 | 1.68 |
| NGC 1121 | 42.663387 | -1.734040 | 0 | 0 | 0 | 2558 | 35.3 | -22.70 | 0.29 | -1.8 | 0.87 |
| NGC 1222 | 47.236446 | -2.955212 | 0 | 0 | 0 | 2422 | 33.3 | -22.71 | 0.26 | -3.0 | 1.10 |
| NGC 1248 | 48.202328 | -5.224674 | 0 | 0 | 0 | 2217 | 30.4 | -22.90 | 0.27 | -2.0 | 1.20 |
| NGC 1266 | 49.003120 | -2.427370 | 0 | 0 | 0 | 2170 | 29.9 | -22.93 | 0.43 | -2.1 | 1.31 |
| NGC 1289 | 49.707592 | -1.973354 | 0 | 0 | 0 | 2792 | 38.4 | -23.46 | 0.37 | -2.1 | 1.26 |
| NGC 1665 | 72.071098 | -5.427655 | 0 | 0 | 0 | 2745 | 37.5 | -23.63 | 0.26 | -1.8 | 1.50 |
| NGC 2481 | 119.307182 | 23.767693 | 0 | 0 | 0 | 2157 | 32.0 | -23.38 | 0.28 | 0.4 | 1.02 |
| NGC 2549 | 124.743111 | 57.803108 | 1 | 1 | 0 | 1051 | 12.3 | -22.43 | 0.28 | -2.0 | 1.28 |
| NGC 2577 | 125.681137 | 22.553040 | 0 | 0 | 0 | 2062 | 30.8 | -23.41 | 0.23 | -3.0 | 1.15 |
| NGC 2592 | 126.783669 | 25.970339 | 1 | 1 | 0 | 1979 | 25.0 | -22.88 | 0.25 | -4.8 | 1.09 |
| NGC 2594 | 126.821609 | 25.878935 | 0 | 0 | 0 | 2362 | 35.1 | -22.36 | 0.24 | 0.0 | 0.82 |
| NGC 2679 | 132.887192 | 30.865419 | 0 | 0 | 0 | 2027 | 31.1 | -22.81 | 0.14 | -2.0 | 1.35 |
| NGC 2685 | 133.894791 | 58.734409 | 0 | 0 | 0 | 875 | 16.7 | -22.78 | 0.27 | -1.0 | 1.41 |
| NGC 2695 | 133.612778 | -3.067101 | 1 | 3 | 0 | 1833 | 31.5 | -23.64 | 0.08 | -2.1 | 1.21 |
| NGC 2698 | 133.902222 | -3.183882 | 0 | 0 | 0 | 1900 | 27.1 | -23.32 | 0.08 | -1.0 | 1.10 |
| NGC 2699 | 133.953415 | -3.127507 | 1 | 3 | 0 | 1868 | 26.2 | -22.72 | 0.08 | -5.0 | 1.06 |
| NGC 2764 | 137.072983 | 21.443447 | 0 | 0 | 0 | 2706 | 39.6 | -23.19 | 0.17 | -2.0 | 1.09 |
| NGC 2768 | 137.906265 | 60.037209 | 1 | 5 | 0 | 1353 | 21.8 | -24.71 | 0.20 | -4.4 | 1.80 |
| NGC 2778 | 138.101639 | 35.027424 | 1 | 1 | 0 | 2025 | 22.3 | -22.23 | 0.09 | -4.8 | 1.20 |
| NGC 2824 | 139.759277 | 26.269999 | 0 | 0 | 0 | 2758 | 40.7 | -22.93 | 0.14 | -2.0 | 0.86 |
| NGC 2852 | 140.810684 | 40.163879 | 0 | 0 | 0 | 1781 | 28.5 | -22.18 | 0.06 | 1.0 | 0.85 |
| NGC 2859 | 141.077286 | 34.513378 | 0 | 0 | 0 | 1690 | 27.0 | -24.13 | 0.09 | -1.2 | 1.43 |
| NGC 2880 | 142.394241 | 62.490620 | 1 | 1 | 0 | 1554 | 21.3 | -22.98 | 0.14 | -2.7 | 1.32 |
| NGC 2950 | 145.646317 | 58.851219 | 1 | 1 | 0 | 1322 | 14.5 | -22.93 | 0.07 | -2.0 | 1.19 |
| NGC 2962 | 145.224609 | 5.165820 | 0 | 3 | 0 | 1967 | 34.0 | -24.01 | 0.25 | -1.1 | 1.39 |
| NGC 2974 | 145.638611 | -3.699116 | 1 | 3 | 0 | 1887 | 20.9 | -23.62 | 0.23 | -4.2 | 1.58 |
| NGC 3032 | 148.034119 | 29.236279 | 1 | 2 | 0 | 1562 | 21.4 | -22.01 | 0.07 | -1.9 | 1.12 |
| NGC 3073 | 150.216843 | 55.618935 | 1 | 1 | 0 | 1173 | 32.8 | -21.78 | 0.05 | -2.8 | 1.13 |
| NGC 3098 | 150.569458 | 24.711092 | 0 | 0 | 0 | 1397 | 23.0 | -22.72 | 0.16 | -1.5 | 1.12 |
| NGC 3156 | 153.171692 | 3.129320 | 1 | 3 | 0 | 1338 | 21.8 | -22.15 | 0.15 | -2.5 | 1.24 |
| NGC 3182 | 154.887558 | 58.205818 | 0 | 0 | 0 | 2118 | 34.0 | -23.19 | 0.05 | 0.4 | 1.32 |
| NGC 3193 | 154.603683 | 21.893978 | 1 | 3 | 0 | 1381 | 33.1 | -24.63 | 0.11 | -4.8 | 1.42 |
| NGC 3226 | 155.862549 | 19.898439 | 1 | 3 | 0 | 1315 | 22.9 | -23.24 | 0.10 | -4.8 | 1.49 |
| NGC 3230 | 155.933090 | 12.567883 | 0 | 0 | 0 | 2795 | 40.8 | -24.18 | 0.16 | -1.8 | 1.26 |
| NGC 3245 | 156.826523 | 28.507435 | 1 | 1 | 0 | 1326 | 20.3 | -23.69 | 0.11 | -2.1 | 1.40 |
| NGC 3248 | 156.939270 | 22.847170 | 0 | 0 | 0 | 1481 | 24.6 | -22.43 | 0.09 | -2.0 | 1.20 |
| NGC 3301 | 159.233459 | 21.882166 | 0 | 0 | 0 | 1339 | 22.8 | -23.28 | 0.10 | -0.4 | 1.30 |
| NGC 3377 | 161.926666 | 13.985640 | 1 | 10 | 0 | 690 | 10.9 | -22.76 | 0.15 | -4.8 | 1.55 |
| NGC 3379 | 161.956665 | 12.581630 | 1 | 15 | 0 | 918 | 10.3 | -23.80 | 0.11 | -4.8 | 1.60 |
| NGC 3384 | 162.070404 | 12.629300 | 1 | 10 | 0 | 733 | 11.3 | -23.52 | 0.12 | -2.7 | 1.51 |
| NGC 3400 | 162.689590 | 28.468929 | 0 | 0 | 0 | 1441 | 24.7 | -21.82 | 0.08 | 0.7 | 1.23 |

Table 3 – *continued*

| Galaxy | RA ($^{\circ}$) | Dec. ($^{\circ}$) | SBF | NED-D | Virgo | V_{hel} (km s $^{-1}$) | D (Mpc) | M_K (mag) | A_B (mag) | T type | $\log R_e$ (arcsec) |
|----------|----------------------|------------------------|-----|-------|-------|-------------------------------------|------------|----------------|----------------|--------|------------------------|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| NGC 3412 | 162.722137 | 13.412142 | 1 | 5 | 0 | 860 | 11.0 | -22.55 | 0.12 | -2.0 | 1.49 |
| NGC 3414 | 162.817673 | 27.974968 | 1 | 1 | 0 | 1470 | 24.5 | -23.98 | 0.11 | -2.0 | 1.38 |
| NGC 3457 | 163.702591 | 17.621157 | 1 | 1 | 0 | 1148 | 20.1 | -21.89 | 0.13 | -5.0 | 1.13 |
| NGC 3458 | 164.006042 | 57.116970 | 0 | 0 | 0 | 1877 | 30.9 | -23.12 | 0.04 | -2.0 | 1.06 |
| NGC 3489 | 165.077454 | 13.901258 | 1 | 5 | 0 | 695 | 11.7 | -22.99 | 0.07 | -1.2 | 1.35 |
| NGC 3499 | 165.796280 | 56.221664 | 0 | 0 | 0 | 1535 | 26.4 | -21.88 | 0.04 | 0.0 | 0.94 |
| NGC 3522 | 166.668549 | 20.085621 | 0 | 1 | 0 | 1228 | 25.5 | -21.67 | 0.10 | -4.9 | 1.01 |
| NGC 3530 | 167.168411 | 57.230160 | 0 | 0 | 0 | 1894 | 31.2 | -22.00 | 0.04 | 0.0 | 0.87 |
| NGC 3595 | 168.856461 | 47.447147 | 0 | 0 | 0 | 2177 | 34.7 | -23.28 | 0.09 | -3.3 | 1.15 |
| NGC 3599 | 168.862305 | 18.110369 | 1 | 3 | 0 | 839 | 19.8 | -22.22 | 0.09 | -2.0 | 1.37 |
| NGC 3605 | 169.194260 | 18.017141 | 1 | 3 | 0 | 661 | 20.1 | -21.83 | 0.09 | -4.5 | 1.23 |
| NGC 3607 | 169.227737 | 18.051809 | 1 | 4 | 0 | 942 | 22.2 | -24.74 | 0.09 | -3.1 | 1.59 |
| NGC 3608 | 169.245697 | 18.148531 | 1 | 4 | 0 | 1226 | 22.3 | -23.65 | 0.09 | -4.8 | 1.47 |
| NGC 3610 | 169.605316 | 58.786247 | 1 | 4 | 0 | 1707 | 20.8 | -23.69 | 0.04 | -4.2 | 1.20 |
| NGC 3613 | 169.650543 | 57.999924 | 1 | 3 | 0 | 2051 | 28.3 | -24.26 | 0.05 | -4.7 | 1.42 |
| NGC 3619 | 169.840088 | 57.757683 | 0 | 0 | 0 | 1560 | 26.8 | -23.57 | 0.08 | -0.9 | 1.42 |
| NGC 3626 | 170.015808 | 18.356791 | 1 | 1 | 0 | 1486 | 19.5 | -23.30 | 0.08 | -1.0 | 1.41 |
| NGC 3630 | 170.070786 | 2.964170 | 0 | 0 | 0 | 1499 | 25.0 | -23.16 | 0.18 | -1.5 | 1.10 |
| NGC 3640 | 170.278549 | 3.234764 | 1 | 4 | 0 | 1298 | 26.3 | -24.60 | 0.19 | -4.9 | 1.49 |
| NGC 3641 | 170.286621 | 3.194489 | 1 | 1 | 0 | 1780 | 25.9 | -21.85 | 0.18 | -4.9 | 0.97 |
| NGC 3648 | 170.631195 | 39.876972 | 0 | 0 | 0 | 1970 | 31.9 | -23.06 | 0.09 | -2.0 | 1.12 |
| NGC 3658 | 170.992706 | 38.562424 | 0 | 0 | 0 | 2039 | 32.7 | -23.45 | 0.09 | -2.2 | 1.28 |
| NGC 3665 | 171.181793 | 38.762791 | 0 | 0 | 0 | 2069 | 33.1 | -24.92 | 0.08 | -2.1 | 1.49 |
| NGC 3674 | 171.610870 | 57.048290 | 0 | 0 | 0 | 2055 | 33.4 | -23.23 | 0.06 | -1.9 | 1.05 |
| NGC 3694 | 172.225571 | 35.413857 | 0 | 0 | 0 | 2243 | 35.2 | -22.35 | 0.10 | -5.0 | 1.02 |
| NGC 3757 | 174.261765 | 58.415649 | 0 | 0 | 0 | 1245 | 22.6 | -22.15 | 0.06 | -2.0 | 0.95 |
| NGC 3796 | 175.129776 | 60.298958 | 0 | 0 | 0 | 1250 | 22.7 | -21.84 | 0.06 | 0.0 | 1.06 |
| NGC 3838 | 176.057205 | 57.948101 | 0 | 0 | 0 | 1308 | 23.5 | -22.52 | 0.05 | 0.0 | 1.04 |
| NGC 3941 | 178.230667 | 36.986378 | 1 | 2 | 0 | 930 | 11.9 | -23.06 | 0.09 | -2.0 | 1.40 |
| NGC 3945 | 178.307190 | 60.675560 | 0 | 0 | 0 | 1281 | 23.2 | -24.31 | 0.12 | -1.2 | 1.45 |
| NGC 3998 | 179.484039 | 55.453564 | 1 | 2 | 0 | 1048 | 13.7 | -23.33 | 0.07 | -2.1 | 1.30 |
| NGC 4026 | 179.854950 | 50.961689 | 1 | 2 | 0 | 985 | 13.2 | -23.03 | 0.09 | -1.8 | 1.31 |
| NGC 4036 | 180.362045 | 61.895699 | 0 | 0 | 0 | 1385 | 24.6 | -24.40 | 0.10 | -2.6 | 1.46 |
| NGC 4078 | 181.198456 | 10.595537 | 0 | 0 | 0 | 2546 | 38.1 | -22.99 | 0.11 | -2.0 | 0.92 |
| NGC 4111 | 181.763031 | 43.065392 | 1 | 1 | 0 | 792 | 14.6 | -23.27 | 0.06 | -1.4 | 1.08 |
| NGC 4119 | 182.040176 | 10.378720 | 0 | 0 | 1 | 1656 | 16.5 | -22.60 | 0.12 | -1.3 | 1.60 |
| NGC 4143 | 182.400360 | 42.534218 | 1 | 2 | 0 | 946 | 15.5 | -23.10 | 0.05 | -1.9 | 1.39 |
| NGC 4150 | 182.640228 | 30.401487 | 1 | 4 | 0 | 208 | 13.4 | -21.65 | 0.08 | -2.1 | 1.20 |
| NGC 4168 | 183.071808 | 13.205354 | 0 | 1 | 0 | 2286 | 30.9 | -24.03 | 0.16 | -4.8 | 1.48 |
| NGC 4179 | 183.217087 | 1.299673 | 0 | 0 | 1 | 1300 | 16.5 | -23.18 | 0.14 | -1.9 | 1.30 |
| NGC 4191 | 183.459915 | 7.200842 | 0 | 0 | 0 | 2646 | 39.2 | -23.10 | 0.09 | -1.8 | 1.06 |
| NGC 4203 | 183.770935 | 33.197243 | 1 | 2 | 0 | 1087 | 14.7 | -23.44 | 0.05 | -2.7 | 1.47 |
| NGC 4215 | 183.977142 | 6.401132 | 0 | 0 | 0 | 2011 | 31.5 | -23.43 | 0.07 | -0.9 | 1.18 |
| NGC 4233 | 184.282043 | 7.624434 | 0 | 1 | 0 | 2306 | 33.9 | -23.88 | 0.10 | -2.0 | 1.19 |
| NGC 4249 | 184.497650 | 5.598720 | 0 | 0 | 0 | 2618 | 38.7 | -21.98 | 0.09 | -1.3 | 1.10 |
| NGC 4251 | 184.534607 | 28.175299 | 1 | 1 | 0 | 1066 | 19.1 | -23.68 | 0.10 | -1.9 | 1.29 |
| NGC 4255 | 184.734100 | 4.785923 | 0 | 0 | 0 | 1995 | 31.2 | -22.99 | 0.09 | -1.9 | 1.10 |
| NGC 4259 | 184.842468 | 5.376242 | 0 | 0 | 0 | 2497 | 37.2 | -22.19 | 0.08 | -2.0 | 0.89 |
| NGC 4261 | 184.846924 | 5.824710 | 1 | 5 | 0 | 2212 | 30.8 | -25.18 | 0.08 | -4.8 | 1.58 |
| NGC 4262 | 184.877426 | 14.877717 | 2 | 1 | 1 | 1375 | 15.4 | -22.60 | 0.16 | -2.7 | 1.10 |
| NGC 4264 | 184.899078 | 5.846804 | 0 | 0 | 0 | 2518 | 37.5 | -23.00 | 0.08 | -1.1 | 1.14 |
| NGC 4267 | 184.938675 | 12.798356 | 2 | 1 | 1 | 1021 | 15.8 | -23.18 | 0.20 | -2.7 | 1.58 |
| NGC 4268 | 184.946762 | 5.283650 | 0 | 0 | 0 | 2034 | 31.7 | -23.05 | 0.08 | -0.3 | 1.20 |
| NGC 4270 | 184.955978 | 5.463371 | 0 | 0 | 0 | 2331 | 35.2 | -23.69 | 0.08 | -2.0 | 1.21 |
| NGC 4278 | 185.028320 | 29.280619 | 1 | 9 | 0 | 620 | 15.6 | -23.80 | 0.13 | -4.8 | 1.50 |
| NGC 4281 | 185.089691 | 5.386430 | 0 | 1 | 0 | 2671 | 24.4 | -24.01 | 0.09 | -1.5 | 1.34 |
| NGC 4283 | 185.086609 | 29.310898 | 1 | 3 | 0 | 1056 | 15.3 | -21.80 | 0.11 | -4.8 | 1.09 |
| NGC 4324 | 185.775726 | 5.250488 | 0 | 0 | 1 | 1665 | 16.5 | -22.61 | 0.10 | -0.9 | 1.30 |
| NGC 4339 | 185.895599 | 6.081713 | 1 | 3 | 1 | 1266 | 16.0 | -22.49 | 0.11 | -4.7 | 1.48 |
| NGC 4340 | 185.897141 | 16.722195 | 0 | 2 | 1 | 933 | 18.4 | -23.01 | 0.11 | -1.2 | 1.57 |
| NGC 4342 | 185.912598 | 7.053936 | 0 | 0 | 1 | 761 | 16.5 | -22.07 | 0.09 | -3.4 | 0.82 |

Table 3 – continued

| Galaxy | RA ($^{\circ}$) | Dec. ($^{\circ}$) | SBF | NED-D | Virgo | V_{hel} (km s $^{-1}$) | D (Mpc) | M_K (mag) | A_B (mag) | T type | $\log R_e$ (arcsec) |
|-----------|----------------------|------------------------|-----|-------|-------|-------------------------------------|------------|----------------|----------------|--------|------------------------|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| NGC 4346 | 185.866425 | 46.993881 | 1 | 1 | 0 | 832 | 13.9 | -22.55 | 0.05 | -2.0 | 1.29 |
| NGC 4350 | 185.990891 | 16.693356 | 0 | 2 | 1 | 1210 | 15.4 | -23.13 | 0.12 | -1.8 | 1.23 |
| NGC 4365 | 186.117615 | 7.317520 | 2 | 13 | 0 | 1243 | 23.3 | -25.21 | 0.09 | -4.8 | 1.72 |
| NGC 4371 | 186.230957 | 11.704288 | 2 | 1 | 1 | 933 | 17.0 | -23.45 | 0.16 | -1.3 | 1.47 |
| NGC 4374 | 186.265747 | 12.886960 | 2 | 13 | 1 | 1017 | 18.5 | -25.12 | 0.18 | -4.3 | 1.72 |
| NGC 4377 | 186.301285 | 14.762218 | 2 | 1 | 1 | 1338 | 17.8 | -22.43 | 0.17 | -2.6 | 1.13 |
| NGC 4379 | 186.311386 | 15.607498 | 2 | 2 | 1 | 1074 | 15.8 | -22.24 | 0.10 | -2.8 | 1.27 |
| NGC 4382 | 186.350220 | 18.191080 | 2 | 7 | 1 | 746 | 17.9 | -25.13 | 0.13 | -1.3 | 1.82 |
| NGC 4387 | 186.423813 | 12.810359 | 2 | 3 | 1 | 565 | 17.9 | -22.13 | 0.14 | -4.9 | 1.20 |
| NGC 4406 | 186.549225 | 12.945970 | 2 | 15 | 1 | -224 | 16.8 | -25.04 | 0.13 | -4.8 | 1.97 |
| NGC 4417 | 186.710938 | 9.584117 | 2 | 1 | 1 | 828 | 16.0 | -22.86 | 0.11 | -1.9 | 1.25 |
| NGC 4425 | 186.805664 | 12.734803 | 0 | 0 | 1 | 1908 | 16.5 | -22.09 | 0.13 | -0.6 | 1.38 |
| NGC 4429 | 186.860657 | 11.107540 | 0 | 0 | 1 | 1104 | 16.5 | -24.32 | 0.14 | -1.1 | 1.62 |
| NGC 4434 | 186.902832 | 8.154311 | 2 | 5 | 0 | 1070 | 22.4 | -22.55 | 0.10 | -4.8 | 1.16 |
| NGC 4435 | 186.918762 | 13.079021 | 2 | 0 | 1 | 791 | 16.7 | -23.83 | 0.13 | -2.1 | 1.49 |
| NGC 4442 | 187.016220 | 9.803620 | 2 | 1 | 1 | 547 | 15.3 | -23.63 | 0.09 | -1.9 | 1.44 |
| NGC 4452 | 187.180417 | 11.755000 | 0 | 2 | 1 | 188 | 15.6 | -21.88 | 0.13 | -2.0 | 1.30 |
| NGC 4458 | 187.239716 | 13.241916 | 2 | 8 | 1 | 677 | 16.4 | -21.76 | 0.10 | -4.8 | 1.37 |
| NGC 4459 | 187.250107 | 13.978580 | 2 | 3 | 1 | 1192 | 16.1 | -23.89 | 0.19 | -1.4 | 1.56 |
| NGC 4461 | 187.262543 | 13.183857 | 0 | 0 | 1 | 1924 | 16.5 | -23.08 | 0.10 | -0.8 | 1.40 |
| NGC 4472 | 187.444992 | 8.000410 | 2 | 18 | 1 | 981 | 17.1 | -25.78 | 0.10 | -4.8 | 1.98 |
| NGC 4473 | 187.453659 | 13.429320 | 2 | 8 | 1 | 2260 | 15.3 | -23.77 | 0.12 | -4.7 | 1.43 |
| NGC 4474 | 187.473099 | 14.068673 | 2 | 1 | 1 | 1611 | 15.6 | -22.28 | 0.18 | -2.0 | 1.30 |
| NGC 4476 | 187.496170 | 12.348669 | 2 | 3 | 1 | 1968 | 17.6 | -21.78 | 0.12 | -3.0 | 1.20 |
| NGC 4477 | 187.509048 | 13.636443 | 0 | 0 | 1 | 1338 | 16.5 | -23.75 | 0.14 | -1.9 | 1.59 |
| NGC 4478 | 187.572662 | 12.328578 | 2 | 9 | 1 | 1375 | 17.0 | -22.80 | 0.10 | -4.8 | 1.20 |
| NGC 4483 | 187.669250 | 9.015665 | 2 | 1 | 1 | 906 | 16.7 | -21.84 | 0.09 | -1.3 | 1.24 |
| NGC 4486 | 187.705933 | 12.391100 | 2 | 15 | 1 | 1284 | 17.2 | -25.38 | 0.10 | -4.3 | 1.91 |
| NGC 4486A | 187.740540 | 12.270361 | 2 | 0 | 1 | 758 | 18.3 | -21.82 | 0.10 | -5.0 | 0.94 |
| NGC 4489 | 187.717667 | 16.758696 | 2 | 5 | 1 | 961 | 15.4 | -21.59 | 0.12 | -4.8 | 1.42 |
| NGC 4494 | 187.850143 | 25.774981 | 1 | 9 | 0 | 1342 | 16.6 | -24.11 | 0.09 | -4.8 | 1.69 |
| NGC 4503 | 188.025803 | 11.176434 | 0 | 0 | 1 | 1334 | 16.5 | -23.22 | 0.22 | -1.8 | 1.45 |
| NGC 4521 | 188.198853 | 63.939293 | 0 | 0 | 0 | 2511 | 39.7 | -23.92 | 0.08 | -0.1 | 1.21 |
| NGC 4526 | 188.512619 | 7.699140 | 1 | 5 | 1 | 617 | 16.4 | -24.62 | 0.10 | -1.9 | 1.65 |
| NGC 4528 | 188.525269 | 11.321266 | 2 | 0 | 1 | 1378 | 15.8 | -22.05 | 0.20 | -2.0 | 1.15 |
| NGC 4546 | 188.872940 | -3.793227 | 1 | 2 | 0 | 1057 | 13.7 | -23.30 | 0.15 | -2.7 | 1.40 |
| NGC 4550 | 188.877548 | 12.220955 | 2 | 3 | 1 | 459 | 15.5 | -22.27 | 0.17 | -2.1 | 1.19 |
| NGC 4551 | 188.908249 | 12.264010 | 2 | 5 | 1 | 1176 | 16.1 | -22.18 | 0.17 | -4.9 | 1.22 |
| NGC 4552 | 188.916183 | 12.556040 | 2 | 12 | 1 | 344 | 15.8 | -24.29 | 0.18 | -4.6 | 1.53 |
| NGC 4564 | 189.112473 | 11.439320 | 2 | 5 | 1 | 1155 | 15.8 | -23.08 | 0.14 | -4.8 | 1.31 |
| NGC 4570 | 189.222504 | 7.246663 | 2 | 1 | 1 | 1787 | 17.1 | -23.48 | 0.09 | -2.0 | 1.30 |
| NGC 4578 | 189.377274 | 9.555121 | 2 | 3 | 1 | 2292 | 16.3 | -22.66 | 0.09 | -2.0 | 1.51 |
| NGC 4596 | 189.983063 | 10.176031 | 0 | 0 | 1 | 1892 | 16.5 | -23.63 | 0.09 | -0.9 | 1.59 |
| NGC 4608 | 190.305374 | 10.155793 | 0 | 0 | 1 | 1850 | 16.5 | -22.94 | 0.07 | -1.9 | 1.42 |
| NGC 4612 | 190.386490 | 7.314782 | 2 | 1 | 1 | 1775 | 16.6 | -22.55 | 0.11 | -2.0 | 1.40 |
| NGC 4621 | 190.509674 | 11.646930 | 2 | 9 | 1 | 467 | 14.9 | -24.14 | 0.14 | -4.8 | 1.63 |
| NGC 4623 | 190.544601 | 7.676934 | 2 | 1 | 1 | 1807 | 17.4 | -21.74 | 0.10 | -1.5 | 1.31 |
| NGC 4624 | 191.274826 | 3.055684 | 0 | 0 | 1 | 912 | 16.5 | -23.67 | 0.10 | -0.6 | 1.64 |
| NGC 4636 | 190.707779 | 2.687780 | 1 | 11 | 0 | 930 | 14.3 | -24.36 | 0.12 | -4.8 | 1.95 |
| NGC 4638 | 190.697632 | 11.442459 | 2 | 2 | 1 | 1152 | 17.5 | -23.01 | 0.11 | -2.7 | 1.22 |
| NGC 4643 | 190.833893 | 1.978399 | 0 | 0 | 1 | 1333 | 16.5 | -23.69 | 0.13 | -0.6 | 1.38 |
| NGC 4649 | 190.916702 | 11.552610 | 2 | 11 | 1 | 1110 | 17.3 | -25.46 | 0.11 | -4.6 | 1.82 |
| NGC 4660 | 191.133209 | 11.190533 | 2 | 5 | 1 | 1087 | 15.0 | -22.69 | 0.15 | -4.7 | 1.09 |
| NGC 4684 | 191.822861 | -2.727538 | 1 | 1 | 0 | 1560 | 13.1 | -22.21 | 0.12 | -1.2 | 1.32 |
| NGC 4690 | 191.981323 | -1.655975 | 0 | 0 | 0 | 2765 | 40.2 | -22.96 | 0.13 | -3.0 | 1.25 |
| NGC 4694 | 192.062881 | 10.983624 | 0 | 0 | 1 | 1171 | 16.5 | -22.15 | 0.17 | -2.0 | 1.47 |
| NGC 4697 | 192.149612 | -5.800850 | 1 | 8 | 0 | 1252 | 11.4 | -23.93 | 0.13 | -4.4 | 1.79 |
| NGC 4710 | 192.412323 | 15.165490 | 0 | 0 | 1 | 1102 | 16.5 | -23.53 | 0.13 | -0.9 | 1.48 |
| NGC 4733 | 192.778259 | 10.912103 | 1 | 1 | 1 | 925 | 14.5 | -21.80 | 0.09 | -3.8 | 1.52 |
| NGC 4753 | 193.092133 | -1.199690 | 1 | 3 | 0 | 1163 | 22.9 | -25.09 | 0.14 | -1.4 | 1.69 |
| NGC 4754 | 193.073181 | 11.313660 | 2 | 3 | 1 | 1351 | 16.1 | -23.64 | 0.14 | -2.5 | 1.50 |
| NGC 4762 | 193.233536 | 11.230800 | 0 | 2 | 0 | 986 | 22.6 | -24.48 | 0.09 | -1.8 | 1.64 |

Table 3 – *continued*

| Galaxy | RA ($^{\circ}$) | Dec. ($^{\circ}$) | SBF | NED-D | Virgo | V_{hel} (km s $^{-1}$) | D (Mpc) | M_K (mag) | A_B (mag) | T type | $\log R_e$ (arcsec) |
|------------|----------------------|------------------------|-----|-------|-------|-------------------------------------|------------|----------------|----------------|--------|------------------------|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| NGC 4803 | 193.890289 | 8.240547 | 0 | 0 | 0 | 2645 | 39.4 | -22.28 | 0.13 | 0.0 | 0.94 |
| NGC 5103 | 200.125229 | 43.084015 | 0 | 0 | 0 | 1273 | 23.4 | -22.36 | 0.08 | 0.0 | 1.02 |
| NGC 5173 | 202.105301 | 46.591572 | 0 | 0 | 0 | 2424 | 38.4 | -22.88 | 0.12 | -4.9 | 1.01 |
| NGC 5198 | 202.547546 | 46.670830 | 0 | 0 | 0 | 2519 | 39.6 | -24.10 | 0.10 | -4.8 | 1.38 |
| NGC 5273 | 205.534943 | 35.654240 | 1 | 2 | 0 | 1085 | 16.1 | -22.37 | 0.04 | -1.9 | 1.57 |
| NGC 5308 | 206.751633 | 60.973038 | 0 | 6 | 0 | 1998 | 31.5 | -24.13 | 0.08 | -2.1 | 1.25 |
| NGC 5322 | 207.313339 | 60.190411 | 1 | 5 | 0 | 1780 | 30.3 | -25.26 | 0.06 | -4.8 | 1.60 |
| NGC 5342 | 207.857910 | 59.863014 | 0 | 0 | 0 | 2189 | 35.5 | -22.61 | 0.05 | -2.0 | 0.97 |
| NGC 5353 | 208.361420 | 40.283123 | 0 | 0 | 0 | 2198 | 35.2 | -25.11 | 0.05 | -2.1 | 1.30 |
| NGC 5355 | 208.439850 | 40.338795 | 0 | 0 | 0 | 2344 | 37.1 | -22.40 | 0.05 | -2.1 | 1.06 |
| NGC 5358 | 208.501801 | 40.277420 | 0 | 0 | 0 | 2412 | 38.0 | -22.01 | 0.04 | -0.2 | 1.05 |
| NGC 5379 | 208.893112 | 59.742825 | 0 | 0 | 0 | 1774 | 30.0 | -22.08 | 0.08 | -2.0 | 1.32 |
| NGC 5422 | 210.175262 | 55.164478 | 0 | 0 | 0 | 1838 | 30.8 | -23.69 | 0.06 | -1.5 | 1.33 |
| NGC 5473 | 211.180176 | 54.892620 | 0 | 0 | 0 | 2022 | 33.2 | -24.25 | 0.05 | -2.7 | 1.32 |
| NGC 5475 | 211.301437 | 55.741802 | 0 | 0 | 0 | 1671 | 28.6 | -22.88 | 0.05 | 1.0 | 1.22 |
| NGC 5481 | 211.671722 | 50.723320 | 0 | 2 | 0 | 1989 | 25.8 | -22.68 | 0.08 | -3.9 | 1.35 |
| NGC 5485 | 211.797134 | 55.001518 | 1 | 3 | 0 | 1927 | 25.2 | -23.61 | 0.07 | -2.0 | 1.45 |
| NGC 5493 | 212.872421 | -5.043663 | 0 | 0 | 0 | 2665 | 38.8 | -24.49 | 0.15 | -2.1 | 1.14 |
| NGC 5500 | 212.563522 | 48.546066 | 0 | 0 | 0 | 1914 | 31.7 | -21.93 | 0.09 | -4.9 | 1.18 |
| NGC 5507 | 213.332825 | -3.148860 | 0 | 0 | 0 | 1851 | 28.5 | -23.19 | 0.26 | -2.3 | 1.09 |
| NGC 5557 | 214.607117 | 36.493690 | 0 | 3 | 0 | 3219 | 38.8 | -24.87 | 0.03 | -4.8 | 1.46 |
| NGC 5574 | 215.233109 | 3.237995 | 1 | 1 | 0 | 1589 | 23.2 | -22.30 | 0.13 | -2.8 | 1.13 |
| NGC 5576 | 215.265381 | 3.271049 | 1 | 3 | 0 | 1506 | 24.8 | -24.15 | 0.13 | -4.8 | 1.34 |
| NGC 5582 | 215.179703 | 39.693584 | 1 | 3 | 0 | 1430 | 27.7 | -23.28 | 0.06 | -4.9 | 1.44 |
| NGC 5611 | 216.019897 | 33.047501 | 1 | 1 | 0 | 1968 | 24.5 | -22.20 | 0.05 | -1.9 | 1.00 |
| NGC 5631 | 216.638687 | 56.582664 | 1 | 1 | 0 | 1944 | 27.0 | -23.70 | 0.09 | -1.9 | 1.32 |
| NGC 5638 | 217.418289 | 3.223443 | 1 | 3 | 0 | 1652 | 25.6 | -23.80 | 0.14 | -4.8 | 1.45 |
| NGC 5687 | 218.718201 | 54.475685 | 1 | 1 | 0 | 2143 | 27.2 | -23.22 | 0.05 | -3.0 | 1.36 |
| NGC 5770 | 223.312653 | 3.959721 | 1 | 1 | 0 | 1471 | 18.5 | -22.15 | 0.17 | -2.0 | 1.23 |
| NGC 5813 | 225.296936 | 1.701970 | 1 | 4 | 0 | 1956 | 31.3 | -25.09 | 0.25 | -4.8 | 1.76 |
| NGC 5831 | 226.029266 | 1.219917 | 1 | 3 | 0 | 1645 | 26.4 | -23.69 | 0.25 | -4.8 | 1.40 |
| NGC 5838 | 226.359467 | 2.099356 | 0 | 0 | 0 | 1341 | 21.8 | -24.13 | 0.23 | -2.6 | 1.40 |
| NGC 5839 | 226.364471 | 1.634633 | 1 | 1 | 0 | 1220 | 22.0 | -22.53 | 0.23 | -2.0 | 1.22 |
| NGC 5845 | 226.503281 | 1.633824 | 1 | 2 | 0 | 1472 | 25.2 | -22.92 | 0.23 | -4.9 | 0.80 |
| NGC 5846 | 226.621887 | 1.605637 | 1 | 6 | 0 | 1712 | 24.2 | -25.01 | 0.24 | -4.7 | 1.77 |
| NGC 5854 | 226.948853 | 2.568560 | 0 | 0 | 0 | 1663 | 26.2 | -23.30 | 0.23 | -1.1 | 1.26 |
| NGC 5864 | 227.389786 | 3.052741 | 0 | 0 | 0 | 1874 | 29.0 | -23.62 | 0.19 | -1.7 | 1.35 |
| NGC 5866 | 226.623169 | 55.763309 | 1 | 3 | 0 | 755 | 14.9 | -24.00 | 0.06 | -1.3 | 1.56 |
| NGC 5869 | 227.456055 | 0.469967 | 0 | 1 | 0 | 2065 | 24.9 | -23.27 | 0.24 | -2.3 | 1.31 |
| NGC 6010 | 238.579773 | 0.543033 | 0 | 0 | 0 | 2022 | 30.6 | -23.53 | 0.45 | 0.4 | 1.16 |
| NGC 6014 | 238.989105 | 5.931838 | 0 | 0 | 0 | 2381 | 35.8 | -22.99 | 0.22 | -1.9 | 1.35 |
| NGC 6017 | 239.314529 | 5.998364 | 1 | 1 | 0 | 1788 | 29.0 | -22.52 | 0.23 | -5.0 | 0.85 |
| NGC 6149 | 246.851151 | 19.597290 | 0 | 0 | 0 | 2427 | 37.2 | -22.60 | 0.30 | -1.9 | 1.03 |
| NGC 6278 | 255.209763 | 23.010956 | 0 | 0 | 0 | 2832 | 42.9 | -24.19 | 0.27 | -1.9 | 1.22 |
| NGC 6547 | 271.291748 | 25.232645 | 0 | 0 | 0 | 2677 | 40.8 | -23.60 | 0.50 | -1.3 | 1.06 |
| NGC 6548 | 271.496826 | 18.587217 | 1 | 1 | 0 | 2208 | 22.4 | -23.19 | 0.35 | -1.9 | 1.35 |
| NGC 6703 | 281.828522 | 45.550648 | 1 | 4 | 0 | 2373 | 25.9 | -23.85 | 0.37 | -2.8 | 1.34 |
| NGC 6798 | 291.013306 | 53.624752 | 0 | 0 | 0 | 2360 | 37.5 | -23.52 | 0.57 | -2.0 | 1.23 |
| NGC 7280 | 336.614899 | 16.148266 | 1 | 2 | 0 | 1845 | 23.7 | -22.83 | 0.24 | -1.3 | 1.33 |
| NGC 7332 | 339.352173 | 23.798351 | 1 | 1 | 0 | 1197 | 22.4 | -23.75 | 0.16 | -1.9 | 1.24 |
| NGC 7454 | 345.277130 | 16.388371 | 1 | 3 | 0 | 2020 | 23.2 | -23.00 | 0.33 | -4.7 | 1.41 |
| NGC 7457 | 345.249725 | 30.144892 | 1 | 3 | 0 | 844 | 12.9 | -22.38 | 0.23 | -2.6 | 1.56 |
| NGC 7465 | 345.503967 | 15.964876 | 0 | 0 | 0 | 1960 | 29.3 | -22.82 | 0.33 | -1.9 | 0.90 |
| NGC 7693 | 353.293671 | -1.292010 | 0 | 0 | 0 | 2502 | 35.4 | -21.58 | 0.15 | -1.0 | 1.11 |
| NGC 7710 | 353.942261 | -2.880941 | 0 | 0 | 0 | 2407 | 34.0 | -21.99 | 0.15 | -1.9 | 0.92 |
| PGC 016060 | 72.143387 | -3.867104 | 0 | 0 | 0 | 2764 | 37.8 | -22.64 | 0.19 | -0.6 | 1.01 |
| PGC 028887 | 149.931290 | 11.660812 | 0 | 0 | 0 | 2833 | 41.0 | -22.26 | 0.17 | 0.0 | 1.08 |
| PGC 029321 | 151.463226 | 12.961213 | 0 | 0 | 0 | 2816 | 40.9 | -21.66 | 0.16 | 0.0 | 0.89 |
| PGC 035754 | 173.614716 | 33.178913 | 0 | 0 | 0 | 2534 | 39.0 | -21.90 | 0.11 | -3.0 | 0.83 |
| PGC 042549 | 190.316513 | -5.009177 | 0 | 0 | 0 | 2822 | 40.7 | -22.71 | 0.11 | -5.0 | 1.06 |
| PGC 044433 | 194.578110 | 13.391409 | 0 | 0 | 0 | 2675 | 40.1 | -22.25 | 0.13 | 0.0 | 0.71 |
| PGC 050395 | 211.913544 | 54.794575 | 0 | 0 | 0 | 2322 | 37.2 | -21.92 | 0.05 | 0.0 | 1.04 |

Table 3 – continued

| Galaxy | RA ($^{\circ}$) | Dec. ($^{\circ}$) | SBF | NED-D | Virgo | V_{hel} (km s $^{-1}$) | D (Mpc) | M_K (mag) | A_B (mag) | T type | $\log R_e$ (arcsec) |
|------------|----------------------|------------------------|-----|-------|-------|-------------------------------------|------------|----------------|----------------|--------|------------------------|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| PGC 051753 | 217.310318 | 44.699104 | 0 | 0 | 0 | 2418 | 38.3 | -21.92 | 0.05 | 0.0 | 1.01 |
| PGC 054452 | 228.894180 | 2.248187 | 0 | 0 | 0 | 1918 | 29.5 | -21.59 | 0.18 | -2.0 | 1.14 |
| PGC 056772 | 240.548340 | 7.085953 | 0 | 0 | 0 | 2655 | 39.5 | -22.06 | 0.19 | -2.0 | 0.93 |
| PGC 058114 | 246.517838 | 2.906550 | 0 | 0 | 0 | 1507 | 23.8 | -21.57 | 0.29 | -2.0 | 0.97 |
| PGC 061468 | 272.360748 | 19.117682 | 0 | 0 | 0 | 2371 | 36.2 | -21.68 | 0.35 | 0.0 | 1.06 |
| PGC 071531 | 352.121338 | 19.863962 | 0 | 0 | 0 | 2030 | 30.4 | -21.74 | 0.53 | -4.0 | 0.88 |
| PGC 170172 | 176.731720 | -5.187745 | 0 | 0 | 0 | 2562 | 37.1 | -21.89 | 0.08 | -5.0 | 0.89 |
| UGC 03960 | 115.094856 | 23.275089 | 0 | 0 | 0 | 2255 | 33.2 | -21.89 | 0.20 | -4.9 | 1.24 |
| UGC 04551 | 131.024582 | 49.793968 | 0 | 0 | 0 | 1728 | 28.0 | -22.92 | 0.10 | -2.0 | 1.03 |
| UGC 05408 | 150.966095 | 59.436138 | 0 | 0 | 0 | 2998 | 45.8 | -22.03 | 0.06 | -3.3 | 0.84 |
| UGC 06062 | 164.656662 | 9.050468 | 0 | 0 | 0 | 2634 | 38.7 | -22.82 | 0.13 | -2.0 | 1.05 |
| UGC 06176 | 166.852753 | 21.657185 | 0 | 0 | 0 | 2677 | 40.1 | -22.66 | 0.08 | -2.0 | 1.03 |
| UGC 08876 | 209.241943 | 45.973179 | 0 | 0 | 0 | 2085 | 33.9 | -22.37 | 0.04 | -0.1 | 0.93 |
| UGC 09519 | 221.588028 | 34.370651 | 0 | 0 | 0 | 1631 | 27.6 | -21.98 | 0.09 | -1.9 | 0.87 |

Note. Column (1): the name is the principal designation from LEDA, which is used as standard designation for our project. Column (2): right Ascension in degrees and decimal (J2000.0). Column (3): declination in degrees and decimals (J2000.0). As the galaxy names may not be always consistent between different catalogues, these coordinate define the galaxies of the sample. Column (4): SBF = 1 if the galaxy is in Tonry et al. (2001) and SBF = 2 if it is in Mei et al. (2007) or both. Column (5): number of redshift-independent distance determinations listed in the NED-D catalogue, excluding the ones based on kinematical scaling relations. Column (6): Virgo = 1 if the galaxies is contained within a sphere of radius $R = 3.5$ Mpc from the centre of the cluster assumed at coordinates RA = $12^{\text{h}}28^{\text{m}}19^{\text{s}}$ and Dec. = $+12^{\circ}40'$ (Mould et al. 2000) and distance $D = 16.5$ Mpc (Mei et al. 2007). Column (7): heliocentric velocity measured from the SAURON integral field stellar kinematics (1σ error $\Delta V_{\text{hel}} = 5$ km s $^{-1}$). Column (8): distance in Mpc; when SBF = 1 the distance comes from Tonry et al. (2001), corrected by subtracting 0.06 mag to the distance modulus (Mei et al. 2007); when SBF = 2 the distance comes from Mei et al. (2007); when SBF = 0 and NED-D > 0 the distance is the median of the NED-D values, excluding the ones based on kinematical scaling relations; when SBF = NED-D = 0 and the galaxy is in Virgo (Virgo = 1) then it is assigned the cluster distance $D = 16.5$ Mpc (Mei et al. 2007); otherwise $D = V_{\text{cosmic}}/H_0$, with $H_0 = 72$ km s $^{-1}$ Mpc $^{-1}$, where V_{cosmic} is the velocity derived from V_{hel} via the local flow field model of Mould et al. (2000) using only the Virgo attractor. Column (9): total galaxy absolute magnitude derived from the apparent magnitude K_T (2MASS keyword k_m_ext) at the adopted distance D and corrected for the foreground galactic extinction: $M_K = K_T - 5 \log_{10} D - 25 - A_B/11.8$, which assumes $A_B/A_K = 11.8$. Column (10): B -band foreground galactic extinction from Schlegel, Finkbeiner & Davis (1998). Column (11): morphological T type from HyperLeda. E: $T \leq -3.5$; S0: $-3.5 < T \leq -0.5$. This morphology was not the one used for the sample selection, but is printed in Figs 5 and 6. Column (12): projected half-light effective radius. It was derived from a combination of RC3 and 2MASS determinations, which both use growth curves, as described in Section 4.1, but it was normalized to agree on average with RC3.

Table 4. The 611 spiral galaxies in the ATLAS^{3D} parent sample.

| Galaxy | RA ($^{\circ}$) | Dec. ($^{\circ}$) | SBF | NED-D | Virgo | V_{hel} (km s $^{-1}$) | D (Mpc) | M_K (mag) | A_B (mag) | T type | $\log R_e$ (arcsec) |
|---------|----------------------|------------------------|-----|-------|-------|-------------------------------------|------------|----------------|----------------|--------|------------------------|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| IC 0065 | 15.230966 | 47.681984 | 0 | 0 | 0 | 2614 | 39.7 | -23.54 | 0.64 | 4.0 | 1.38 |
| IC 0163 | 27.312431 | 20.711317 | 0 | 0 | 0 | 2749 | 39.7 | -22.38 | 0.36 | 8.0 | 1.35 |
| IC 0239 | 39.116250 | 38.970000 | 0 | 0 | 0 | 903 | 15.7 | -22.23 | 0.31 | 6.0 | 1.90 |
| IC 0540 | 142.542755 | 7.902529 | 0 | 0 | 0 | 2035 | 30.0 | -21.89 | 0.26 | 3.5 | 1.08 |
| IC 0591 | 151.865479 | 12.274520 | 0 | 0 | 0 | 2839 | 41.2 | -21.82 | 0.15 | 6.0 | 1.19 |
| IC 0610 | 156.618179 | 20.228252 | 0 | 0 | 0 | 1170 | 19.6 | -21.53 | 0.09 | 3.9 | 1.02 |
| IC 0750 | 179.717606 | 42.722404 | 0 | 1 | 0 | 701 | 36.8 | -24.71 | 0.09 | 2.1 | 1.24 |
| IC 0777 | 184.849228 | 28.309881 | 0 | 0 | 0 | 2541 | 39.0 | -21.92 | 0.10 | 2.6 | 0.95 |
| IC 0800 | 188.486313 | 15.354542 | 0 | 0 | 0 | 2326 | 35.8 | -22.20 | 0.16 | 5.2 | 1.56 |
| IC 0851 | 197.143127 | 21.049742 | 0 | 0 | 0 | 2615 | 39.8 | -21.82 | 0.15 | 3.1 | 1.31 |

Note. The meaning of the columns is the same as in Table 3, except for column (7), which contain here the heliocentric velocity taken from NED. Only the first 10 rows are shown; the full 611 will be published electronically (see Supporting Information). Both Tables 3 and 4 are available from our project website <http://purl.org/atlas3d>

Mei et al. (2007) by subtracting 0.06 mag to the distance moduli (see discussion in Blakeslee et al. 2010).

(iii) Distances from the NED-D compilation¹ by Madore, Steer and the NED team (V3.0 June 2010, about 2000 values). The list includes accurate determinations using (1) SBF, (2) the tip of the red giant branch (TRGB), (3) Cepheids variables, with a claimed com-

parable accuracy of ~ 10 per cent, but the list also includes various other methods like the ones based on the (4) Tully & Fisher (1977) or (5) Fundamental Plane (Djorgovski & Davis 1987; Dressler et al. 1987) relations, on the (6) luminosity of Type Ia Supernovae, or on the luminosity functions of (7) globular clusters and (8) planetary nebulae. The latter methods are expected to be accurate to better than $\lesssim 20$ per cent (Tully et al. 2008). For a number of galaxies more than one independent distance was available and we adopted the median of the values.

¹ <http://nedwww.ipac.caltech.edu/Library/Distances/>

(iv) When no better distance was available, for galaxies within 12° of the projected centre of the Virgo cluster (defined by the galaxy M87) with heliocentric radial velocities $V_{\text{hel}} < 2300 \text{ km s}^{-1}$, we assigned the distance of the cluster (assumed to be 16.5 Mpc from Mei et al. 2007). These distances should be accurate to ~ 7 per cent, considering the intrinsic depth of the cluster. Two galaxies were later removed from Virgo as that distance implied a too high and non-physical dynamical M/L as determined in Cappellari et al. (2010).

(v) Finally, if none of the above criteria was met, we assigned a distance based on the observed heliocentric radial velocities V_{hel} , which we converted to velocities V_{cosmic} characteristic of the expansion of the universe following Mould et al. (2000),² but only including the contribution of the Virgo attractor, and assuming $H_0 = 72 \text{ km s}^{-1} \text{ Mpc}^{-1}$ (Dunkley et al. 2009). We repeated our sample selection using heliocentric velocities extracted from either the HyperLeda³ (Paturel et al. 2003) or NED⁴ data bases and obtained identical final ATLAS^{3D} samples. We compared the V_{hel} of galaxies from NED and HyperLeda and found a general very good agreement in the two data bases, with a biweight rms scatter of 0.4 per cent, as expected given that in most cases the redshifts come from the same source. However in some cases significant differences exists: we found 83/5398 galaxies (1.5 per cent) with V_{hel} differences larger than 20 per cent. For our V_{hel} in the parent sample we adopted NED (2010 June), which currently includes as major sources the Center for Astrophysics Redshift Catalog (Huchra et al. 1983), the RC3 (de Vaucouleurs et al. 1991), the ZCAT compilation (Huchra et al. 1992) and the Sloan Digital Sky Survey DR7 (Abazajian et al. 2009). After obtaining our new accurate SAURON redshifts (Section 4.3) we updated the redshift-based distances and this lead to the removal of one observed galaxy. However, we retained in the sample two observed galaxies formally with $D > 42 \text{ Mpc}$, but still inside our volume within the distance errors.

To estimate the representative errors of the redshift distances we correlated them against the direct distance estimates in the NED-D compilation. Specifically we selected the 285 galaxies in common with our sample with at least three independent distance determinations (in most cases including SBF distances), and we correlated the median of their $d_{\text{NED-D}} \times H_0$ values against the V_{cosmic} (Fig. 1). We found a biweight dispersion of 24 per cent in the residuals. The minimum value in the median residual was obtained with $H_0 = 72 \text{ km s}^{-1} \text{ Mpc}^{-1}$, consistent with the adopted *Wilkinson Microwave Anisotropy Probe* estimate. Assuming a typical rms error of 10 per cent for the best set of NED-D distances, this implies an intrinsic rms error of ~ 21 per cent in the redshift distances. However, a significant number of outliers exist. If we repeat the comparison for all the 692 galaxies in common, with a NED-D distance, the biweight dispersion increases to 29 per cent, which would imply a redshift error of ~ 27 per cent. If we only consider the Local Group's peculiar velocity into Virgo in the calculation of V_{cosmic} , the scatter increases significantly and systematic deviations appear. Including the infall of galaxies into the Virgo attractor improves the agreement. However including other attractors as done by Mould et al. (2000) does not appear to further reduce the scatter. For this reason we only included the more secure Virgo attractor contribution in our redshift distances corrections.

² Corrected as described in the corresponding erratum.

³ <http://leda.univ-lyon1.fr/>

⁴ <http://nedwww.ipac.caltech.edu/>

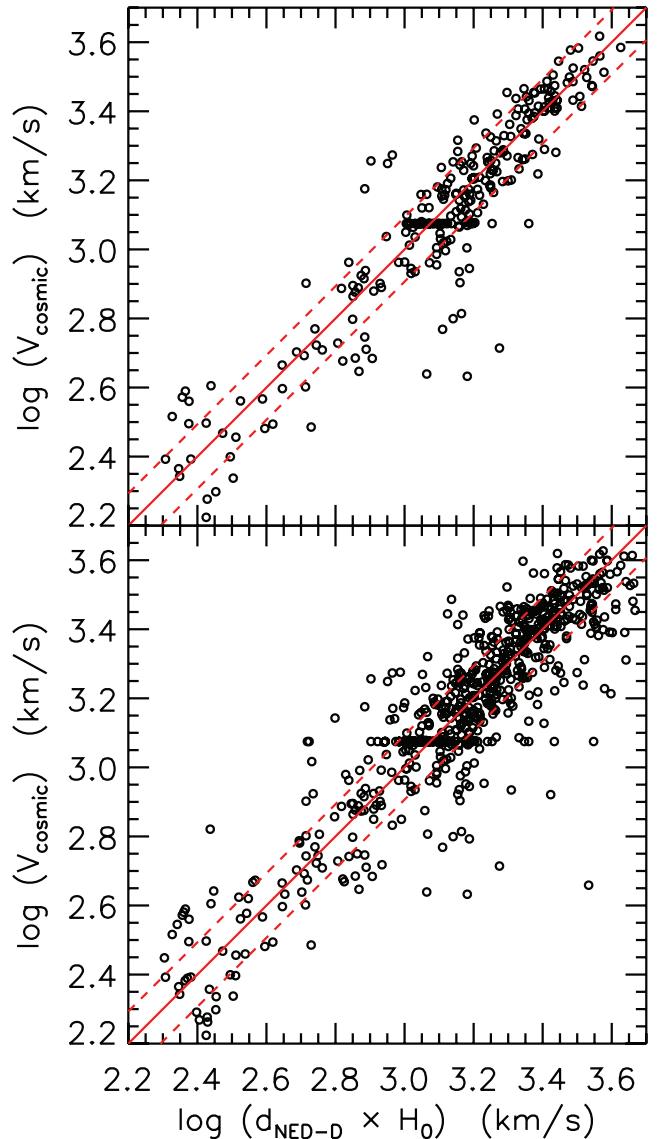


Figure 1. Accuracy of redshift distances. Top panel: recession velocities, converted into velocities V_{cosmic} characteristic of the expansion of the universe, against the median of the NED-D redshift-independent distances for 291 galaxies with at least three independent determination (in most cases including SBF distances). The solid line is a one-to-one relation, while the dashed lines indicate ± 24 per cent deviations. Bottom panel: same as in the top panel for 705 galaxies with at least one distance determination in NED-D.

2.3 Estimating redshift incompleteness

Not all the $\sim 20\,000$ 2MASS galaxies satisfying our observability criteria and with $K_T < 11.6$ mag have a redshift measurement. This may introduce biases in our volume-limited sample selection. Specifically 4146/14461 (29 per cent) of the galaxies in the faintest magnitude bin $10.6 < K_T < 11.6$ mag do not have a redshift in NED.⁵ The redshift completeness quickly improves for brighter apparent magnitudes, and in fact only 4 per cent of the galaxies

⁵ The situation will change in the near future when the 2MASS Redshift Survey will become available, which is already complete down to $K_s = 11.25$ (Crook et al. 2007) and ultimately aims for a redshift completeness down to $K_s = 13.0$ (Huchra et al. 2005).

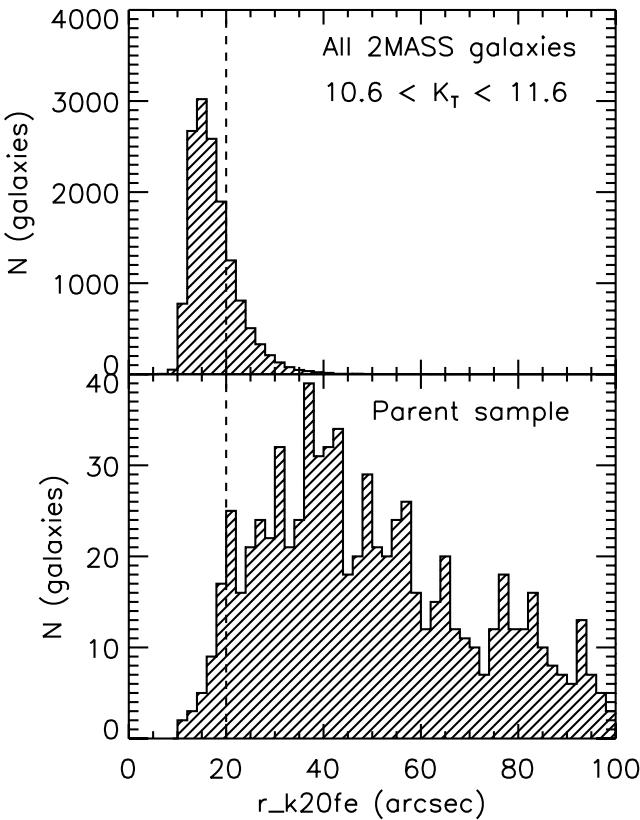


Figure 2. Apparent size distribution of 2MASS galaxies. Top panel: the apparent size, as described by the 2MASS XSC parameter $r_{\text{k}20\text{fe}}$, for all the galaxies satisfying our observability criteria and with $10.6 < K_T < 11.6$. Bottom panel: same as in the top panel for the galaxies in the parent sample ($D < 42 \text{ Mpc}$ and $M_K < -21.5 \text{ mag}$).

with $K_T < 10.6$ mag have no redshift. One way to estimate how many of these galaxies are likely to be within our selection criteria is to look at their size distribution as measured by 2MASS. In fact one expects many of the apparently faint and small galaxies to be intrinsically brighter and larger, but to appear faint and small due to the large distance.

To quantify the galaxy angular sizes we use the 2MASS XSC parameter $r_{\text{k}20\text{fe}}$, which gives the semimajor axis of the 20 mag arcsec^{-2} surface brightness isophote at K_s . The size distribution for the galaxies in the faintest magnitude bin, according to this size parameter is shown in the top panel of Fig. 2. As expected the distribution presents a dramatic increase in the numbers for very small objects. For comparison we show in the bottom panel the size distribution of the 2MASS galaxies which satisfy our selection criteria $D < 42 \text{ Mpc}$ and $M_K < -21.5 \text{ mag}$. The latter sample has a peak in the size distribution around $r_{\text{k}20\text{fe}} \approx 40 \text{ arcsec}$, while the number of objects sharply drops for $r_{\text{k}20\text{fe}} \lesssim 20 \text{ arcsec}$ (only 4 per cent of the objects have sizes below that limit). This lack of apparently small objects is not due to any redshift selection criteria. In fact among all the galaxies with measured redshift, about equal numbers have size larger or smaller than $r_{\text{k}20\text{fe}} = 20 \text{ arcsec}$. The apparent galaxy size is just an efficient way to select, without redshift information, galaxies unlikely to belong to our volume-limited sample.

Excluding all objects apparently smaller than $r_{\text{k}20\text{fe}} < 20 \text{ arcsec}$, likely outside the limits of our local volume, we find a redshift incompleteness of 478/3383 (14 per cent) in the faintest

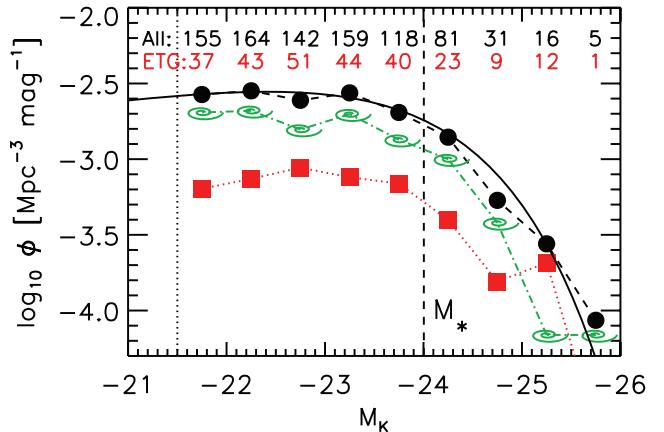


Figure 3. K_s -band luminosity function (LF) of the ATLAS^{3D} parent sample of 871 galaxies (black filled circles). The LF for the spiral galaxies (green spirals) and the 260 ETGs which constitute the ATLAS^{3D} sample (red squares) separately are also shown. The solid curve shows the Schechter (1976) function derived by Bell et al. (2003) from a fit to 6282 galaxies. It was not fitted to our data! The black numbers above the symbols indicate the total number of galaxies included in each 0.5-mag bin, while the red ones are the corresponding numbers for the ETGs of the ATLAS^{3D} sample. There is no evidence of incompleteness down to the magnitude limit of the survey (vertical dotted line), which is ≈ 2.5 mag below M_* (vertical dashed line).

magnitude bin. Among the galaxies that *do* have redshift in this set, only 68/2905 (2 per cent) satisfy the selection criteria for the parent sample (most of the others are still outside the local volume). This implies that statistically we may expect ~ 11 galaxies (1 per cent of the parent sample) to be possibly missed from the parent sample due to redshift incompleteness in the faintest magnitude bin. We conclude that we can safely ignore this possible bias from any conclusion derived from the sample.

2.4 Luminosity function

The ATLAS^{3D} parent sample was carefully selected to provide a volume-limited sample of galaxies in the nearby universe. It should be representative of the galaxy population at low redshift, apart from the unavoidable cosmic variance, due to the relatively limited size of the volume. A first test of the representativeness of our parent sample is to compare its K_s -band luminosity function against that measured from larger volumes. For this we compare in Fig. 3 the luminosity function of the parent sample against that derived from a much larger sample, at a mean redshift $\langle z \rangle \approx 0.08$, by Bell et al. (2003), using 2MASS K_s -band photometry as we do, and SDSS redshifts. It agrees well with the ones by Kochanek et al. (2001) and Cole et al. (2001). The comparison shows excellent agreement between the two luminosity functions, both in shape and normalization, and indicates that our parent sample is representative of the general galaxy population. In particular this test shows no sign of incompleteness at the faint end, in agreement with the discussion of Section 2.3.

2.5 Size–luminosity relations for spirals and ETGs

To illustrate the general characteristic of the galaxies in the parent sample Fig. 4 shows the K -band size–luminosity relation and the effective surface brightness $\Sigma_{50} \equiv L_{\odot K}/(2\pi R_e^2)$ for different morphological types. This plot shows a similar distribution as the

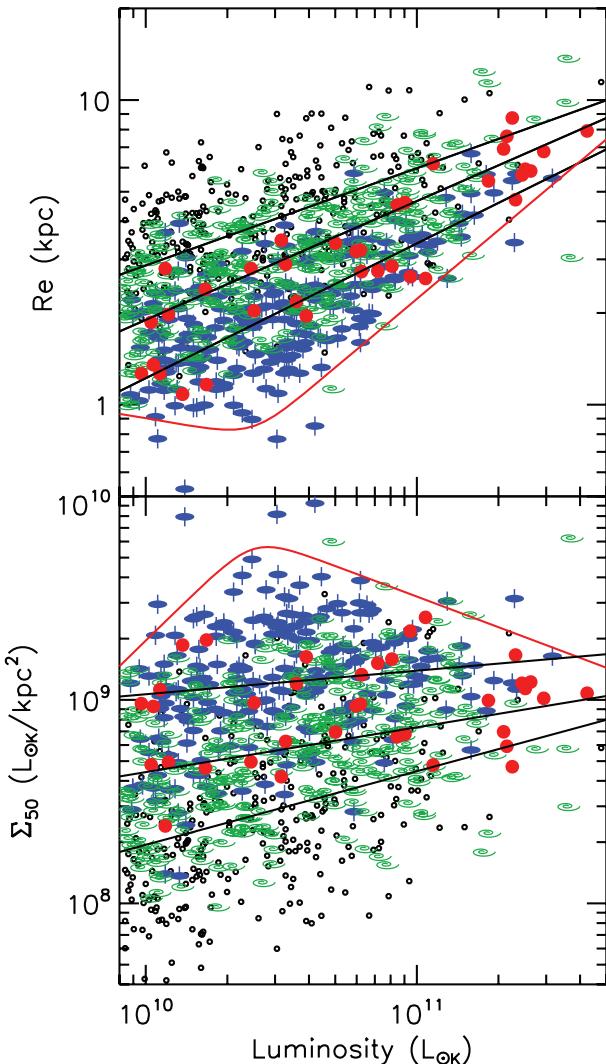


Figure 4. Top panel: size–luminosity relation for the parent sample. The K -band luminosity of all the galaxies in the parent sample is plotted against the effective radius R_e (Section 4.1). Red filled circles are slow rotators, blue ellipses with vertical axis are fast rotators. These 260 objects constitute the ATLAS^{3D} sample. The green spirals represent spiral galaxies of type Sa–Sb ($-0.5 < T \leq 4$), while later spiral types ($T > 4$) are plotted as small open circles. The solid lines are the best-fitting relations described in the text. From the bottom to the top they are fit to the fast rotators ETGs, to the Sa–Sb and to the later spiral types. The red curve approximates the boundary of the zone of avoidance in the observed galaxy distribution. Bottom panel: effective surface brightness versus luminosity. The symbols and the lines are the same as in the top panel.

one inferred from much larger galaxy samples based on SDSS photometry, further confirming the representativeness of our sample (compare Fig. 4 with fig. 2 of van Dokkum et al. 2008). In our plot we show the fast/slow rotator classification for the 260 ETGs of the ATLAS^{3D} sample (Paper III) together with the early spirals (Sa–Sb) and later spiral types (Sc–Irr) of the parent sample. There is a clear trend in the R_e-L_K diagram as a function of galaxy morphology. To quantify this trend we fitted linear relations to the logarithmic coordinates assuming the same fractional errors for both axes and requiring $\chi^2/\text{DOF} = 1$. The fit was performed using the FITEXY routine which is based on the algorithm by Press et al. (1992) and

is part of the IDL Astronomy User’s Library⁶ (Landsman 1993). The best-fitting power-law R_e-L_K relations are

$$\log \left[\frac{R_e(\text{FR})}{\text{kpc}} \right] = 0.53 + 0.44 \log \left[\frac{L_K(\text{FR})}{10^{11} L_{\odot,K}} \right], \quad (1)$$

$$\log \left[\frac{R_e(\text{Sa–Sb})}{\text{kpc}} \right] = 0.67 + 0.39 \log \left[\frac{L_K(\text{Sa–Sb})}{10^{11} L_{\odot,K}} \right], \quad (2)$$

$$\log \left[\frac{R_e(\text{Sc–Irr})}{\text{kpc}} \right] = 0.78 + 0.32 \log \left[\frac{L_K(\text{Sc–Irr})}{10^{11} L_{\odot,K}} \right] \quad (3)$$

for fast rotators, Sa–Sb spirals and Sc or later spiral types, respectively. The slopes for the early and late spirals bracket the trend $R_e \propto L_K^{0.35}$ found by Courteau et al. (2007). There is a clear known zone of avoidance at small sizes and large luminosities, which is also well defined in our parent sample and approximated above our luminosity limit by a double power law (cf. Lauer et al. 1995):

$$R_e = 2^{(\gamma-\beta)/\alpha} R_{e,b} \left(\frac{L_K}{L_{K,b}} \right)^\gamma \left[1 + \left(\frac{L_K}{L_{K,b}} \right)^\alpha \right]^{(\beta-\gamma)/\alpha}. \quad (4)$$

This equation defines a minimum effective radius $R_{e,b} = 0.85$ kpc and a corresponding maximum effective surface brightness at a characteristic galaxy luminosity $L_{K,b} = 2.5 \times 10^{10} L_{\odot,K}$ (cf. Graham & Worley 2008). The logarithmic power slope for $L_K \ll L_{K,b}$ is $\gamma = -0.15$, while for $L_K \gg L_{K,b}$ it is $\beta = 0.75$, so that for large luminosities $R_e \propto L_K^{0.75}$. A sharp transition between the two regimes is set by $\alpha = 8$.

Consistently with other larger local galaxy samples (van Dokkum et al. 2008; Trujillo et al. 2009; Taylor et al. 2010), we find no massive and superdense ($L_K \gtrsim 10^{11} L_{\odot,K}$ and $R_e \lesssim 2$ kpc) ETGs in our parent sample, contrary to what is found from photometry of ETGs at redshift $z \gtrsim 1.5$ (e.g. Daddi et al. 2005; Trujillo et al. 2006; Cimatti et al. 2008; van Dokkum et al. 2008). Similar R_e-L relations were derived by Shen et al. (2003) for early-type and late-type galaxies, defined as those having a Sersic (1968) index larger or smaller than $n = 2.5$, respectively. Their relation also showed a trend for late types to have larger sizes (by definition, due to the smaller n) at given luminosity (or mass) and a more shallow R_e-L relations, as we find using the morphological selection. A trend in the R_e-M relation involving colours, with red-sequence galaxies having smaller sizes, can be seen in van Dokkum et al. (2008). While a trend involving age was presented by van der Wel et al. (2009) and Shankar & Bernardi (2009), and confirmed by Valentiniuzzi et al. (2010), who find smaller sizes for older objects, at given stellar mass. All these trends are consistent with our finding using fast/slow rotators ETGs, in combination with traditional morphology of spiral galaxies (see also Bernardi et al. 2010), when one considers that later galaxy types tend to be more gas rich and have a younger stellar population. However here we interpret the observed trends as due to a variation in the bulge fraction, with bulges progressively increasing (by definition) from Sd–Sc to Sb–Sa and to fast rotators ETGs (see Paper VII). A detailed study of scaling relations in our sample will be presented in a subsequent paper.

⁶ Available from <http://idlastro.gsfc.nasa.gov/>

3 THE ATLAS^{3D} SAMPLE

3.1 Morphological selection

We established that the ATLAS^{3D} parent sample is essentially complete within the selection criteria and representative of the nearby galaxy population. We also verified that its luminosity function agrees with the one derived from much larger volumes of the Universe. The ATLAS^{3D} survey however is focused on the study of the fossil record of galaxy formation as recorded in the structure of ETGs. The ATLAS^{3D} sample is a subset of the parent sample, consisting of all the ETGs in that sample.

The distinction between red-sequence and blue-cloud galaxies is related, but different from the early type versus spiral morphological separation. E and S0 galaxies invariably lie on the red sequence, while late-type spirals are generally on the blue cloud. However large fractions of spirals populate the red sequence as well and overlap with ETGs (Strateva et al. 2001; Conselice 2006; van den Bergh 2007; Bernardi et al. 2010). An accurate morphology is easier to obtain for nearby galaxies and it is more robust than colour to dust and inclination effects. For these reasons a morphological classification is our preferred selection criterion.

To perform the morphological selection we considered using the morphological classification provided in available catalogues like the RC3 or its ongoing evolution HyperLeda. A problem with those classifications is the possible non-homogeneity of the classification process. Moreover the classification in those catalogues was performed using photometry in a single band, often from photographic plates. Given that for the majority of the galaxies in our parent sample excellent quality multiband photometry is available from the SDSS Data Release 7 (DR7; Abazajian et al. 2009), we decided to revisit the classification of the whole parent sample using the best available imaging.

The morphological classification of a given galaxy using multi-colour imaging may differ from the one obtained from photographic plates of the same object. None the less we tried as much as possible to be consistent with the currently accepted morphological criteria. We just need to separate the parent sample into two classes: ETGs and spirals. This makes our task much simpler and reproducible than a more detailed morphological classification into E, S0 and spiral subclasses Sa–Sd.

Since the introduction of the classic tuning-fork diagram by Hubble (1936), for the past half-century, essentially all authors have converged on a simple criterion to differentiate ETGs from spirals. The criterion, which defines the *revised* Hubble classification scheme, is outlined by Sandage (1961) in the Hubble Atlas and is based entirely on the presence of spiral arms (or dust lanes when seen edge-on): ‘the transition stages, S0 and SB0, are firmly established. In both sequences, the nebulae may be described as systems definitely later than E7 but showing no spiral structure’. This same criterion was adopted unchanged in the extension to the classification scheme by de Vaucouleurs (1959, 1963), which was applied to the widely used RC2 and RC3 catalogues (de Vaucouleurs, de Vaucouleurs & Corwin 1976; de Vaucouleurs et al. 1991) and HyperLeda (Paturel et al. 2003). Although other characteristics of galaxies change with morphological classification (e.g. the bulge/disc ratio), they are ignored in the separation between early types and spiral galaxies (see review by Sandage 1975). We adopted the same criterion here to select the ETGs belonging to the ATLAS^{3D} sample from the parent sample.

Our morphological selection was done by visual inspection of the true-colour red–green–blue images (Lupton et al. 2004) provided

by the SDSS DR7 which are available for 82 per cent of the galaxies in the parent sample. For the remaining objects we used the *B*-band DSS2-blue images in the Online Digitized Sky Survey.⁷ We revisited the classification for the galaxies without SDSS DR7 data after obtaining our own Isaac Newton Telescope (INT) imaging (Section 5.1) and this lead to the removal of a couple of galaxies from the ETGs sample. At the end of our classification we compared the agreement between our separation into early types and spirals and the one provided by the *T* type given by HyperLeda, which defines as ETGs (E and S0) those having $T \leq -0.5$. We found agreement in 97 per cent of the cases, confirming the robustness and reproducibility of the morphological selection. The few disagreements with HyperLeda could all be easily explained by the high quality of the multicolour SDSS images, which allowed for a better detection of faint spiral structures. The ATLAS^{3D} sample of 260 ETGs obtained from this selection is given in Table 3 and illustrated in Figs 5 and 6, together with the HyperLeda morphological classification as provided by their *T* type (E: $T \leq -3.5$; S0: $-3.5 < T \leq -0.5$; S0/a: $-0.5 < T \leq 0.5$).

3.2 Colour–magnitude diagram

The decision to select the ATLAS^{3D} sample based on morphology instead of colour was based on (i) the broad similarity of the two criteria, (ii) the non-availability of reliable colours for the whole parent sample and (iii) the robustness of morphology, as opposed to colours, against dust extinction. Still, we expect the ATLAS^{3D} sample to include mainly galaxies on the red sequence in a colour–magnitude diagram. This is verified in Fig. 7. The ATLAS^{3D} sample of ETGs indeed defines a narrow colour–magnitude sequence approximated, in SDSS magnitudes, by

$$u - r = 2.53 - 0.097(M_r + 20). \quad (5)$$

As found by previous authors there is little scatter in the relation at the high-mass end, while at the lower mass end some galaxies appear to be still in transition between the blue and red sequence (Strateva et al. 2001; Conselice 2006; van den Bergh 2007; Bernardi et al. 2010). The 31 ETGs with SDSS colour and defined as slow rotators in Paper III all lie close to the red sequence with an rms scatter of 0.13 mag from the best-fitting relation. All the deviants ETGs are classified as fast rotators in Paper III. The nature of these objects will be investigated in detail in subsequent papers of this series. Spiral galaxies span the full region of the diagram, both on the red sequence and the blue clouds, as found by previous studies.

4 SAURON DATA FOR THE ATLAS^{3D} SURVEY

4.1 Observing strategy

The main aim of the SAURON (Bacon et al. 2001) observations of the ATLAS^{3D} sample is to obtain global galaxy quantities like the specific stellar angular momentum λ_R , the $(V/\sigma, \varepsilon)$ the global kinematical misalignment, the luminosity-weighted second moment σ_e , the stellar and total mass-to-light ratio, the mean stellar population and the ionized gas emission. To be representative of the galaxies as a whole, these quantities need to be measured at least within one projected half-light radius R_e . Moreover for a given observed area, more accurate values of the kinematical quantities are obtained when the quantities are measured within ellipses instead of

⁷ <http://archive.eso.org/dss>

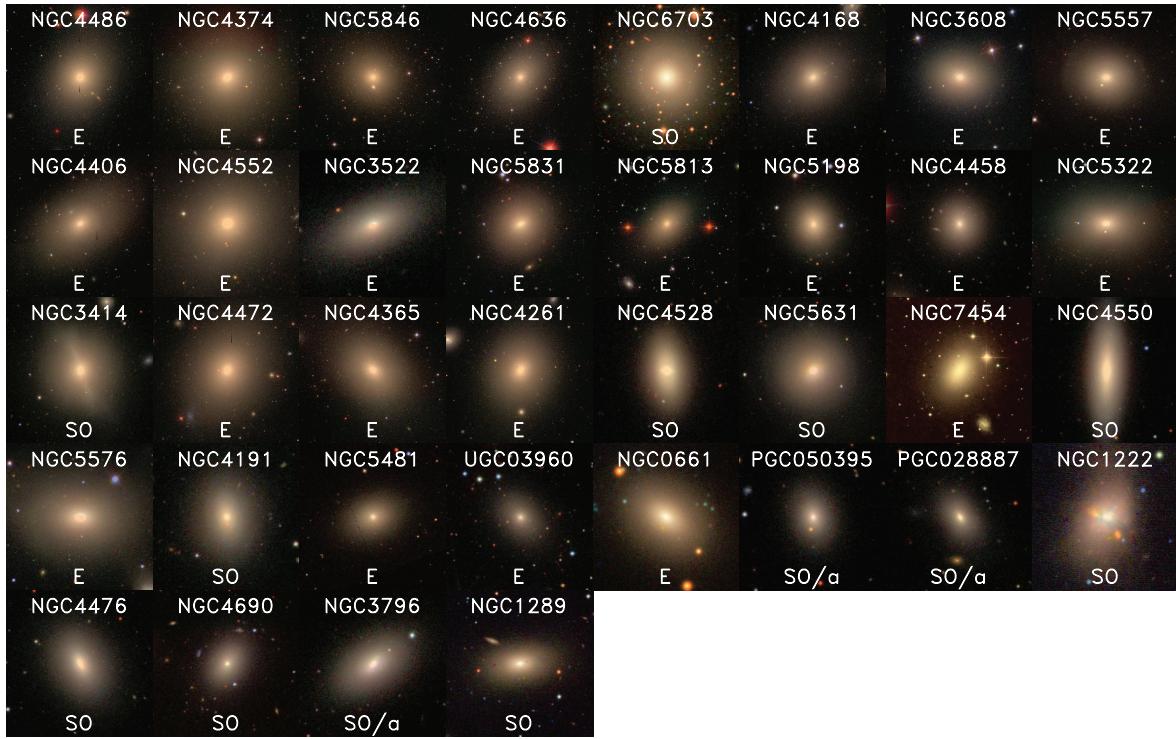


Figure 5. Morphology of slow-rotators ETGs sorted by increasing λ_R . Postage stamps of the SDSS DR7 and INT red–green–blue composite images of slow rotators in the ATLAS^{3D} sample. The image of each galaxy was scaled so that the plot side is equal to $10R_e$, where R_e is the projected half-light radius given in Table 3. From left to right and from top to bottom the panels are sorted according to their specific stellar angular momentum, as measured by the parameter λ_R given in Paper III. The galaxy name is given at the top of each panel and the morphological classification from HyperLeda at the bottom. At this scale slow-rotator ETGs appear generally featureless except for the synchrotron jet in NGC 4486 and obvious signs of interactions in NGC 1222, NGC 3414 and NGC 5557. The only significant flat galaxy in this class is NGC 4550, while two other galaxies NGC 3796 and NGC 4528 show evidence of bar perturbations, which is typically associated to stellar discs. All these three objects contain counter-rotating stellar discs (Paper II). (This figure is better appreciated on a computer screen rather than on printed paper.) A version of Figs 5 and 6 sorted by name is available at <http://purl.org/atlas3d>.

circles, with ellipticity given by the galaxy photometry and the position angle defined by the stellar kinematics (see appendix B of Cappellari et al. 2007). In addition, when galaxies are barred, the SAURON survey has shown that the kinematics are generally still aligned with the position angle of the galaxy photometry at large radii PA_{phot} (Krajnović et al. 2008), which defines the position of the line-of-nodes of the disc. These requirements, which derive from our experience with the SAURON survey (de Zeeuw et al. 2002), lead to the following optimized observing strategy, which we systematically applied for the SAURON observation of the ATLAS^{3D} sample.

- (i) When $R_e \leq 30$ arcsec take a single SAURON field and orient the SAURON major axis with the large radii PA_{phot} .
- (ii) When $R_e > 30$ arcsec then we take a mosaic of two SAURON fields. Given the size of the SAURON field of 33×41 arcsec 2 , the criterion of maximizing the area of the largest isophote, of axial ratio q' , enclosed within the observed field-of-view, becomes
 - (a) if $q' < 0.55$ the SAURON long axis is aligned with PA_{phot} and the mosaic is made by matching the two SAURON pointings along the short side;
 - (b) if $q' \geq 0.55$ the SAURON short axis is aligned with PA_{phot} and the mosaic is made by matching the two SAURON pointings along the long side.

At the time of the SAURON observations the only photometry available to us for the whole sample was from 2MASS. We adopted the R_e provided by the 2MASS XSC, which is determined via

growth curves within elliptical apertures. Specifically, in terms of the XSC catalog parameters, we defined

$$R_e^{\text{2MASS}} = \text{MEDIAN}(j_r_{\text{eff}}, h_r_{\text{eff}}, k_r_{\text{eff}}) \sqrt{k_{\text{ba}}}, \quad (6)$$

as the median of the three 2MASS values in the J , H and K_s band, where the factor $\sqrt{k_{\text{ba}}}$ takes into account the fact that the 2MASS values are the semimajor axes of the ellipses enclosing half of the galaxy light and we want the radius of the circle with the same area. This R_e^{2MASS} was compared to the R_e^{RC3} provided by the RC3 catalogue and measured via growth curves within circular apertures. The two values correlate well, with an observed rms scatter of 0.12 dex in R_e , which implies an error of about 22 per cent in each R_e determination (assuming they have similar errors). However there is a general offset by a factor $R_e^{\text{RC3}} \approx 1.7 R_e^{\text{2MASS}}$ between the two determinations (Fig. 8). The rms scatter in the $R_e^{\text{RC3}} - R_e^{\text{2MASS}}$ correlation is close to the one (0.11 dex) we obtain when comparing R_e^{RC3} to 46 values determined using growth curves in the I band for the SAURON survey (Cappellari et al. 2006; Kuntschner et al. 2006). In that case however the offset in the values is negligible (factor 0.95). We conclude that the 2MASS R_e determinations have comparable accuracy to the RC3 and SAURON determination, when they are increased by a factor of 1.7 to account for the differences in the observed photometric band and in the depth of the photometry data. All three values are consistent with having a similar error of ≈ 22 per cent in R_e . This rather large error is consistent with the findings of Chen et al. (2010) from another extensive comparison of R_e values. To further improve the accuracy we adopted



Figure 6. Same as in Fig. 5 for the fast-rotators ETGs in the ATLAS^{3D} sample, sorted by increasing λ_R . The first panel contains mostly round objects. Many of them are barred (Paper II), nearly face-on, S0 galaxies and often contain stellar rings (e.g. NGC 4608), while others appears face-on from the geometry of their dust. This suggests that the round shape and low λ_R of these objects is not intrinsic, but due to their low inclination ($i = 90^\circ$ being edge on). On the contrary the last panel is dominated by nearly edge-on discs, which explains their high λ_R .



Figure 6 – Continued

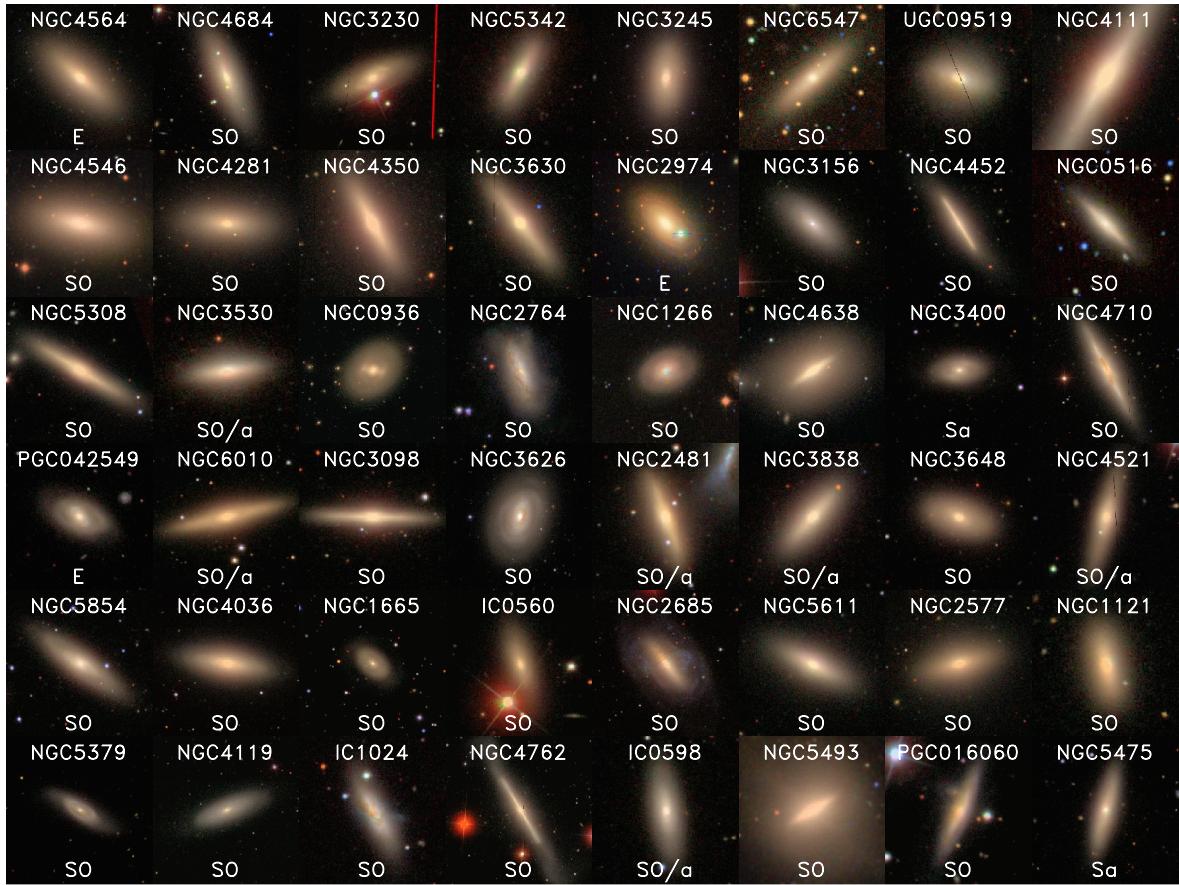


Figure 6 – Continued

$R_e = (1.7 R_e^{\text{2MASS}} + R_e^{\text{RC3}})/2$ for the 412/871 galaxies with both 2MASS and RC3 determinations and $R_e = 1.7 R_e^{\text{2MASS}}$ when only 2MASS was available. The values of R_e for the full parent sample, divided into ETGs and spirals, are given in Tables 3 and 4.

4.2 Integral field spectroscopic observations

The SAURON integral field spectrograph was first mounted at the WHT at the Observatory of El Roque des Los Muchachos on La Palma in 1999. It has been used extensively in particular in the course of the SAURON survey, but also in separate smaller efforts (e.g. Bower et al. 2004; Allard, Peletier & Knapen 2005; Dumas et al. 2007; Weijmans et al. 2010). Given that the ATLAS^{3D} selection criteria are by design very similar to the ones in the SAURON survey, a total of 64 ETGs had been observed before the beginning of the ATLAS^{3D} observing campaign. 49 ETGs were part of the main survey (de Zeeuw et al. 2002), out of which 47 were presented in the subsample of ETGs (Emsellem et al. 2004) and two in the early-spirals subsample (Falcón-Barroso et al. 2006). 14 ‘special’ ETGs within the ATLAS^{3D} volume had been observed with SAURON in the course of other projects (table 3 of Cappellari et al. 2007). All these galaxies were observed before the volume phase holographic (VPH) grating came into use and were taken with an exposure time of 2 h on source, in some cases with multiple spatial pointings to cover galaxies to roughly one effective (projected half-light R_e) radius. All the observations were obtained in the low spatial resolution mode in which the instrument has a field-of-view of $33 \times 41 \text{ arcsec}^2$ sampled with 0.94 arcsec^2 lenslets and with a

spectral resolution of 4.2 \AA full width at half-maximum (FWHM); $\sigma_{\text{instr}} = 105 \text{ km s}^{-1}$), covering the wavelength range $4800\text{--}5380 \text{ \AA}$.

To observe the additional 196 galaxies we were allocated 38 observing nights comprising four observing runs spread over three consecutive semesters as part of a long-term project at the WHT (Table 5). The time allocation was split equally between Dutch and UK time. We had excellent weather with just 16 per cent of nights lost due to clouds, compared to a normal average for the period of around 30 per cent. This fact, combined with an efficient observing strategy allowed us to complete all observations of the ATLAS^{3D} sample galaxies in the allocated time.

The optimal scheduling of the observations of the 196 galaxies, in some cases using multiple spatial pointings, was performed with a dedicated IDL script which gave higher priority to the intrinsically brightest galaxies, took into account the galaxy coordinates, the need for multiple pointings, the dates of the four observing runs and the moon position and phase. The script could be easily re-run to modify the scheduling to account for time lost due to bad weather. The observations were performed with the VPH grating, which provides a resolution of 3.9 \AA FWHM ($\sigma_{\text{instr}} = 98 \text{ km s}^{-1}$), about 7 per cent better than for the SAURON survey. The adopted on-source exposure time was 1 h, split into two equal 30-min exposure dithered by a couple of arcseconds.

4.3 Data reduction and stellar kinematics extraction

The SAURON data reduction followed standard procedures and used the dedicated XSAURON software developed at Centre de

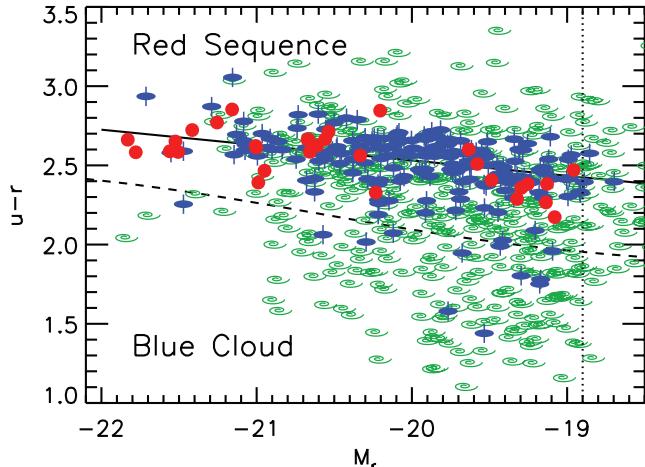


Figure 7. $u - r$ versus M_r colour-magnitude diagram for the morphologically selected ATLAS^{3D} parent sample with SDSS photometry. The blue ellipses with axis are fast-rotator ETGs, the red filled circles are slow-rotators ETGs, while the green spirals are spiral galaxies. The dashed line indicates the separation between red sequence and blue cloud established by Baldry et al. (2004, 2006), from a sample of 151 642 galaxies. The vertical dotted line indicates our approximate survey completeness limit in r band $M_r \lesssim -18.9$ mag. The solid line is a linear robust fit to the ETGs only, minimizing the sum of the absolute residuals.

Recherche Astronomique de Lyon (CRAL) and was already described in Bacon et al. (2001) and Emsellem et al. (2004). However some details of our approach have been improved after the original publication of the data. For this reason we re-extracted all the stellar kinematics using the improved and completely homogeneous approach for the entire ATLAS^{3D} data set. We describe here the minor differences with respect to what was published before.

The data were spatially binned with the adaptive Voronoi method⁸ of Cappellari & Copin (2003), which optimally solves the problem of preserving the maximum spatial resolution of two-dimensional data, given a constraint on the minimum signal-to-noise ratio (S/N). We adopted a target S/N = 40 for all the data used in the ATLAS^{3D} survey, including the previous SAURON observations, which were re-extracted adopting for consistency this lower S/N instead of the S/N = 60 as originally published in Emsellem et al. (2004).

The stellar kinematics were extracted with the penalized pixel-fitting (pPXF) software⁸ (Cappellari & Emsellem 2004), which simultaneously fits the stellar kinematics and the optimal linear combination of spectral templates to the observed spectrum, using a maximum-likelihood approach to suppress noisy solutions. The line-of-sight velocity distribution (LOSVD) is described via the Gauss–Hermite parametrization up to h_3-h_4 (Gerhard 1993; van der Marel & Franx 1993). We employed as stellar template an optimal linear combination of stars from the MILES library⁹ (Sánchez-Blázquez et al. 2006), which was separately determined for every galaxy. We did not allow the template to change in every bin to eliminate small artefacts in the kinematics due imperfections in the velocity alignment of the MILES stars. A resolution of 2.56 Å FWHM was adopted for the stars. We adjusted the penalty in pPXF to a value $\lambda = 0.5$, optimized for the adopted S/N. Following the pPXF documentation we determined the optimal λ by requiring the maximum bias in the Gauss–Hermite parameters h_3 and h_4 to

⁸ Available from <http://purl.org/cappellari/idl>

⁹ Available from <http://miles.iac.es/>

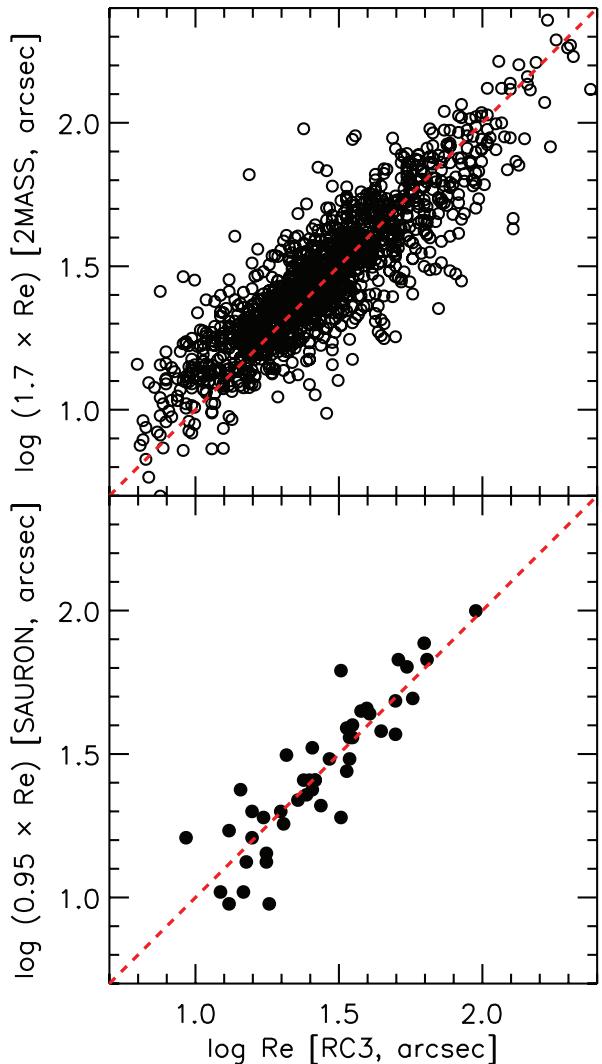


Figure 8. Testing the accuracy of R_e determinations. Top panel: comparison between 1353 values of R_e given by RC3 and the ones given by 2MASS (computed as described in the text), scaled by the best-fitting factor of 1.7. Bottom panel: same as in the top panel for the RC3 R_e and the ones for 46 ETGs of the SAURON survey. Once corrected for systematic differences, all three R_e determinations are consistent with a similar error of ≈ 22 per cent.

Table 5. SAURON observing runs for the ATLAS^{3D} sample.

| Run | Dates | Clear |
|-----|---------------------------|-------|
| 1 | 2007 April 10–23 | 12/14 |
| 2 | 2007 August 13–15 | 3/3 |
| 3 | 2008 January 9–15 | 6/7 |
| 4 | 2008 February 27–March 11 | 11/14 |

be equal to $\text{rms}/3$, where the rms is the scatter of the measurements obtained from a Monte Carlo simulations with the adopted S/N = 40 and a well resolved stellar dispersion $\sigma \gtrsim 180 \text{ km s}^{-1}$ (Fig. 9). In a handful of cases we could not reach the required S/N without employing excessively large Voronoi bins. In those cases we further reduced the target S/N. For those galaxies we correspondingly adapted the penalty in pPXF according to the empirical relation of Fig. 10. For usage in cases where we need to approximate the stellar

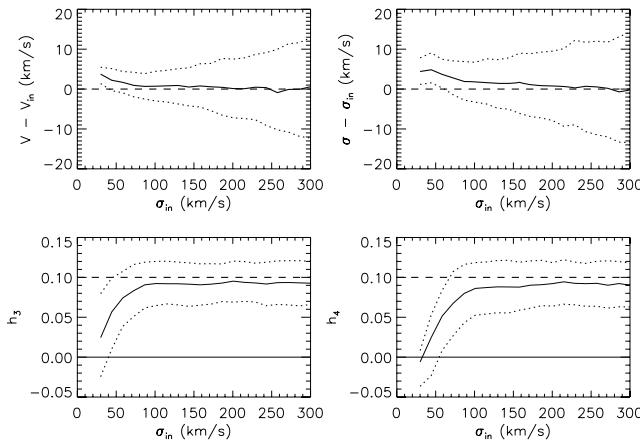


Figure 9. Testing penalization in ppxf. We simulated spectra with the S/N = 40 of our data and an LOSVD with $h_3 = 0.1$, $h_4 = 0.1$ and σ in the range between 30 and 300 km s $^{-1}$. We extracted the kinematics with ppxf and a penalty $\lambda = 0.5$. The lines in the top two panels show the 50th (median, solid line), 16th and 84th percentiles (1σ errors, dotted lines) of the differences between the measured values and the input values of the mean velocity V_{in} and the velocity dispersion σ_{in} . The bottom panels show the same lines for the recovered values of h_3 and h_4 , compared to the input values (dashed line). The h_3 and h_4 parameters can only be recovered when $\sigma_{\text{in}} \gtrsim 100$ km s $^{-1}$. Typical statistical errors in the kinematics parameter for $\sigma_{\text{in}} \approx 200$ km s $^{-1}$ are 6 km s $^{-1}$, 7 km s $^{-1}$, 0.03 and 0.03 for V , σ , h_3 and h_4 , respectively.

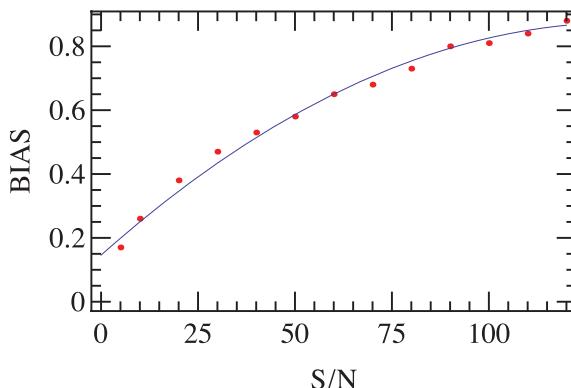


Figure 10. Relation between the S/N of the SAURON spectrum and the optimal penalty parameter λ (keyword BIAS) in ppxf. The solid line is the polynomial $\text{BIAS} = 0.15 + 0.0107 \text{S/N} - 0.00004 (\text{S/N})^2$.

velocity second moments and not the full LOSVD – e.g. to fit models based on the Jeans (1922) equations or measure λ_R or V/σ – we separately extracted the kinematics assuming a simple Gaussian LOSVD. In that case the ppxf penalty is ignored. In all cases the errors on the kinematics were determined via bootstrapping (Efron & Tibshirani 1993), by randomly resampling the ppxf fit residuals of the best fit and repeating the kinematic fit for 100 realizations, with a zero penalty (see section 3.4 of Cappellari & Emsellem 2004). The homogeneous set of integral field SAURON kinematics introduced in this paper, together with the stellar population parameters, the characteristics of the ionized gas and the entire data cubes for the full ATLAS^{3D} sample will be made available via the project web page¹⁰ at the end of our project.

As discussed in detail in Cappellari & Emsellem (2004) and illustrated in Fig. 9, the SAURON spectroscopic data allow the

¹⁰ <http://purl.org/atlas3d>

extraction of the full stellar LOSVD, including the Gauss–Hermite parameters, only for observed velocity dispersions $\sigma \gtrsim 120$ km s $^{-1}$. Below this value the h_3 and h_4 start becoming unconstrained by the data, due to the spectral undersampling and for this reason the ppxf method automatically and gradually penalizes them towards zero to keep the noise on the mean velocity V and velocity dispersion σ under control. As the minimum S/N of our data is defined by our Voronoi binning criterion, the level of bias depends only on σ as illustrated in the Monte Carlo simulation of Fig. 9. This effect is also illustrated for ATLAS^{3D} data in Fig. 11, for a small set of galaxies with a range of luminosity-weighted σ_e within $1R_e$ (defined as in Cappellari et al. 2006). The figure shows the range of data quality for the stellar kinematical data for the ATLAS^{3D} survey. At high σ_e the data have a quality which is comparable to the one for the SAURON survey presented in Emsellem et al. (2004). The shorter exposure time of the ATLAS^{3D} survey is in part compensated by the use of the VPH grating and in part by the adoption of larger Voronoi bins. However at $\sigma_e \lesssim 120$ km s $^{-1}$ there is not enough information in the data to constrain h_3 and h_4 . Contrary to the SAURON survey the volume-limited ATLAS^{3D} survey is dominated by the more common low-luminosity galaxies, which also tend to have low dispersion. In practice we find that ≈ 40 per cent of the galaxies in the sample have $\sigma_e \lesssim 120$ km s $^{-1}$ and for those objects we can only recover reliable V and σ values. Although the kinematics are not sufficient to constrain general dynamical models for the full sample, they still provide very reliable global values of specific angular momenta and galaxy masses for all galaxies (e.g. Cappellari et al. 2010).

We also used the SAURON stellar kinematic to measure extremely robust heliocentric recession velocities V_{hel} for all galaxies in the sample. Repeated determinations indicate a 1σ accuracy $\Delta V_{\text{hel}} \approx 5$ km s $^{-1}$. The values were derived from the integral field stellar kinematics by finding the value which needs to be subtracted from the observed velocity field to best fit a bi-antisymmetric version of the velocity field.¹¹ This technique does not suffer from the uncertainties due to the slit centring, which affects spectroscopic surveys, or from the possibility of the gas not being associated to the galaxy, which affects H I determinations. The observed velocities were converted into velocities V_{hel} relative to the barycentre of the Solar system via the IDL routine BARYVEL, which implements the algorithm by Stumpff (1980) and is part of the IDL Astronomy User’s Library (Landsman 1993). The measured V_{hel} values are given in Table 3.

5 ADDITIONAL ATLAS^{3D} DATA AND SIMULATIONS

5.1 H I, CO and optical observations

Apart from the SAURON integral field spectroscopic observations presented in detail in Section 4, the ATLAS^{3D} survey includes other multiwavelength observations obtained with different instruments and facilities. These data sets will be presented in subsequent papers, however, a summary of the main ones is presented in Table 6, and more information are given below.

(i) *H I interferometry.* We have observed the H I properties of all galaxies in the ATLAS^{3D} sample above $\delta = 10^\circ$ (due to the

¹¹ This was performed with the IDL routine FIT_KINEMATICS_PA described in appendix C of Krajnović et al. (2006) and available at <http://purl.org/cappellari/idl>

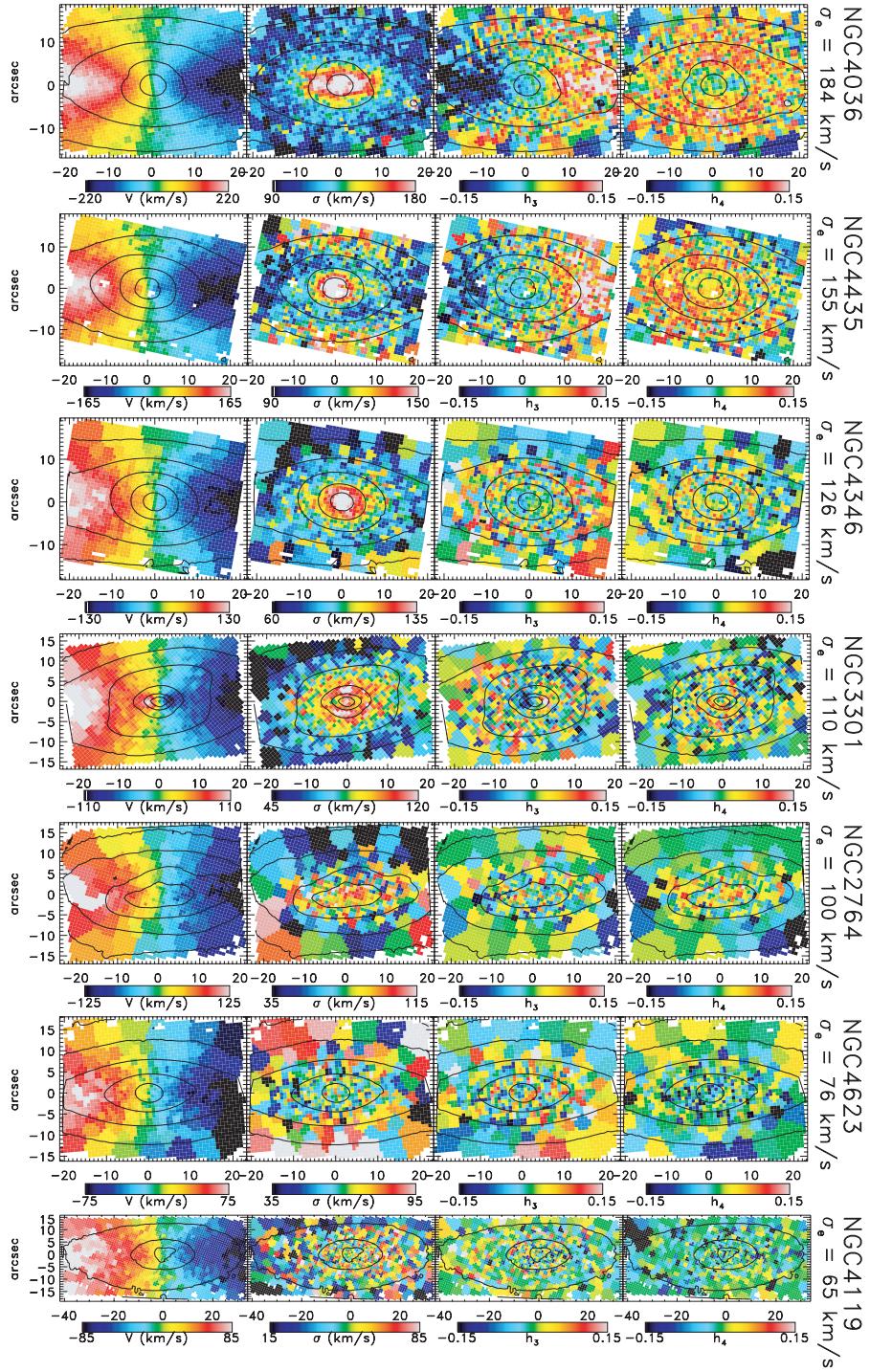


Figure 11. Quality of the SAURON stellar kinematics in the ATLAS^{3D} survey. Each column from left to right shows the Voronoi binned kinematic moments extracted via ppxf from the SAURON data: mean velocity, V , velocity dispersion, σ , and higher Gauss–Hermite moments, h_3 and h_4 . From top to bottom the data for seven newly observed fast rotators in the ATLAS^{3D} sample are sorted according to the luminosity-weighted dispersion σ_e within $1R_e$. Below $\sigma_e \lesssim 120 \text{ km s}^{-1}$ the data have insufficient information to constrain the full LOSVD and the Gauss–Hermite moments are automatically and gradually suppressed by ppxf towards zero to reduce the noise in V and σ , which can still be reliably recovered. About 40 per cent of the galaxies in the sample have $\sigma_e \lesssim 120 \text{ km s}^{-1}$.

telescope latitude). This subsample includes 170 galaxies – 43 inside and 127 outside the Virgo cluster. We observed all galaxies outside Virgo, and galaxies inside Virgo detected by the Alfalfa survey (Giovanelli et al. 2005), with the Westerbork Synthesis Radio Telescope (WSRT). Some of the galaxies were observed with the WSRT as part of previous studies (Morganti et al. 2006; Józsa et al.

2009; Oosterloo et al. 2010). The integration time for all galaxies observed with the WSRT is 12 h, providing H I cubes at a resolution of ~ 30 arcsec and 16 km s^{-1} over a field of view of $\sim 1 \text{ deg}^2$ and a velocity range of $\sim 4000 \text{ km s}^{-1}$. We detect H I gas down to a column density of a few times 10^{19} cm^{-2} . The upper limits on $M(\text{H I})$ derived from these data ranges between 10^6 and a few times

Table 6. Multiwavelength ATLAS^{3D} data.

| Instrument | Tracer/band/res. | Number of objects | Selection | Reference | Time allocation |
|------------|--------------------------------------|-------------------|-------------------------------|---|-----------------|
| WSRT | H _I @ 21 cm | 170 | $\delta > 10^\circ$ | Serra et al. (in preparation) | 1212 h |
| IRAM 30-m | ¹² CO $J = 1-0$ and $2-1$ | 259 | All | Paper IV | 211 h |
| CARMA | ¹² CO $J = 1-0$ | 32 | $f > 19 \text{ Jy km s}^{-1}$ | Alatalo et al. (in preparation) | 467 h |
| INT + SDSS | <i>u, g, r, i, z</i> | 35 + 225 | All | Scott et al. (in preparation) + Abazajian et al. (2009) | 5 n |
| SAURON | 480–538 nm; $R = 1300$ | 260 | All | This paper | 38 n |

$10^7 M_\odot$ depending on galaxy distance. This is typically about five times lower than upper limits derived from Alfalfa spectra. These observations and a discussion of the H_I properties will be presented in Serra et al. (in preparation). Interesting objects, like extended discs, have been followed-up for deeper H_I observations.

(ii) *CO single dish*. All of the ATLAS^{3D} galaxies have been searched for ¹²CO $J = 1-0$ and $2-1$ emission with the IRAM 30-m telescope, including 204 new observations with the remainder collected from the recent literature. The data consist of a single pointing at the galaxy centre, covering a bandwidth of 1300 km s⁻¹ centred on the optical velocity. The rms noise levels of the 1–0 spectra are 3 mK (T_A^*) or better after binning to 31 km s⁻¹ channels, so that the 3σ upper limit for a sum over a 300 km s⁻¹ linewidth corresponds to a H₂ mass $\sim 1 \times 10^7 M_\odot$ for the most nearby sample members and $\sim 1 \times 10^8 M_\odot$ for the most distant members. A detailed description of the observations and the corresponding measurements is presented in Paper IV.

(iii) *CO interferometry*. The brighter CO detections have been, observed in the 1–0 line with the BIMA, Plateau de Bure, and CARMA millimeter interferometers in order to map the distribution and kinematics of the molecular gas. These observations are designed to provide the molecular surface densities and angular momenta for 80 per cent of all of the molecular gas found in the ATLAS^{3D} sample, typically at resolutions of 5 arcsec. Some additional data at higher and lower resolutions are obtained as necessary to probe the structure of the gas and recover the bulk of the emission detected in the single dish data. On-source integration times range from 4 to 20 h and are also adjusted as necessary for high-quality detections. A detailed description of the observations and the corresponding measurements is presented in Alatalo et al. (in preparation).

(iv) *INT optical imaging*. Observations with the Wide-Field Camera (WFC) at the 2.5-m INT were carried out to obtain *u, g, r, i* and *z*-band imaging for galaxies not observed by the SDSS. Images were taken through the five filters for 55 galaxies from the ATLAS^{3D} sample. Integration times were typically 60 to 160 s reaching sensitivities comparable or deeper than the SDSS. Galaxies already observed by SDSS were observed in the runs as a cross-check in general and to bring the INT imaging on to the same photometric system as SDSS in particular. The images have been reduced and calibrated using the Astro-WISE system (Valentijn et al. 2007). A detailed description of the observations and the corresponding measurements is presented in Scott et al. (in preparation).

(v) *Targeted follow-ups*. We are also obtaining data for targeted subsets of the sample: deep optical images of ATLAS^{3D} galaxies were obtained with the MegaCam camera installed on the Canada–France–Hawaii Telescope. This imaging part of the project aims to reach surface brightness limits as low as 28.5 mag arcsec² in the *g* band. Reaching such values allows to disclose very faint, diffuse structures in the outskirts of the ETGs, such as shells and tidal tails, that tell about their past mass accretion history. We have also started an observing campaign to obtain stellar kinematics and

absorption line strengths out to large radii (3–5 R_e) with integral field units (IFUs; e.g. SAURON, VIRUS-P) for a number of ATLAS^{3D} galaxies. Following the methods outlined in Weijmans et al. (2009) we will construct dynamical models to trace the halo mass profiles. We primarily target galaxies that have been detected in H_I to have a regularly rotating disc and ring, so that the H_I kinematics can be added to the dynamical modelling.

5.2 Numerical simulations

The ATLAS^{3D} project includes a theoretical effort to interpret the observations using models of galaxy formation. We are attacking the problem via three parallel approaches as described below.

(i) *Binary mergers*. An extensive set of ‘idealized’ (i.e. without the cosmological context) numerical simulations is being conducted. These simulations have been made at an unmatched resolution (softening length of 58 pc and a total number of particles of 1.2×10^7) with the goal to better understand the role of mergers in the formation and evolution of galaxies of the red sequence and to understand in details the physical processes involved during a merger (e.g. the formation of the kinematically decoupled components, the energy and angular momentum exchanges). These simulations are also a powerful tool to perform direct comparisons with observations such as e.g. the morphology via the ellipticity, the kinematics via λ_R , the redistribution of the gas at large scales, the metallicity gradients and the Mg $b - V_{\text{esc}}$ relation (Davies, Sadler & Peletier 1993; Scott et al. 2009). The detailed description of the simulations and their associated results are presented in Bois et al. (2010) and Paper VI. Other idealized simulations of ATLAS^{3D} galaxies are performed with the RAMSES high-resolution grid-based hydrodynamical code (Teyssier 2002). Following the technique developed in Bournaud et al. (2010), we model the dynamics of atomic and molecular gas discs in ETGs with parsec-scale resolution, based on accurate mass models extracted from the ATLAS^{3D} data. These models aim at understanding the dynamics, stability and star formation activity of the interstellar medium in ETGs.

(ii) *Semi-analytic modelling*. In a second strand of simulations we address the formation of elliptical galaxies within a large-scale cosmological setting using a semi-analytic modelling (SAM) approach. Using the knowledge gained from idealized high-resolution simulations of mergers and the formation of a limited number of cosmologically simulated ETGs we test formation scenarios within our SAM making full use of the completeness of the ATLAS^{3D} sample. The SAM we use is an extension of earlier work by Khochfar & Burkert (2005) and Khochfar & Silk (2006). Within the SAM we follow the individual history of a large statistical sample of galaxies to the present day, taking into account their merging history and physical processes related to e.g. gas cooling or star formation. In addition the SAM is used to make predictions on the evolution of these classes of ETGs that can be tested with future observations (Paper VIII).

(iii) *Cosmological simulations*. We will also make use of high-resolution simulations of individual galaxies in a full cosmological context (i.e. Naab et al. 2007; Naab, Johansson & Ostriker 2009) to investigate the physical processes setting the present day kinematical properties of ETGs. We will use a new sample of simulations (Oser et al. 2010) covering the full mass range of the ATLAS^{3D} galaxies. From these simulated galaxies we will construct two-dimensional kinematical maps (Jesseit et al. 2007) to compare directly to the ATLAS^{3D} observations. The use of cosmological simulations is advantageous as we can link the present day properties to the evolutionary history embedded in the favoured cosmology. We will also be able to investigate the influence of the merging history, dark matter and various feedback mechanisms on kinematic properties and the stellar populations.

6 SUMMARY

We described the motivation and goals of the ATLAS^{3D} project, which aims at constraining models of galaxy formation by obtaining two-dimensional observations of the distribution and kinematics of the atomic ($\text{H}\alpha$), molecular (CO) and ionized gas, together with the stellar population and kinematics, for a volume-limited nearly mass-selected (K_s band) sample of ETGs.

We defined the selection criteria for the volume-limited ($1.16 \times 10^5 \text{ Mpc}^3$) *parent* sample of 871 galaxies with $D < 42 \text{ Mpc}$ and $M_K < -21.5$ mag, satisfying our observability criteria, and investigated possible selection biases, especially due to redshift incompleteness. We found that incompleteness cannot amount to more than a couple of per cent, making the sample essentially complete and representative of the nearby population. We additionally tested the representativeness of the sample by comparing its K_s -band luminosity function with the one derived from a much larger sample (Bell et al. 2003) and found a very good agreement. We described the morphological selection used to extract the 260 ETGs of the ATLAS^{3D} sample from the parent sample and showed that the ETGs define a narrow red sequence, on a colour–magnitude diagram, with few objects in transition from the blue cloud. We presented the size–luminosity relation for the ATLAS^{3D} sample and the full parent sample to illustrate the general characteristic of our galaxies.

We described the strategy for the SAURON integral field observations, the data reduction, the extraction of the stellar kinematics and their typical errors. We gave an overview of the additional data set already available for our sample, which include interferometric observations of the atomic gas as traced by $\text{H}\alpha$, single dish and interferometric observations of molecular gas as traced by the CO lines and multiband optical photometry. We summarized the ongoing semi-analytic modelling and the cosmological and binary-merger N-body simulations we are performing to interpret our observations.

This is the first paper of a series devoted to our understanding of the formation of ETGs. Key additional elements are provided by the kinematics, ages and chemical composition of the stars in the galaxies, the presence of cold atomic or molecular gas, the photometric profiles and the dynamical masses, as a function of environment. The observations for the ATLAS^{3D} sample will be compared against the model predictions to test formation scenarios and to tune the model parameter. This will be the topic of future papers of this series. The ATLAS^{3D} project aims to constitute a zero redshift baseline, against which one can investigate the evolution of galaxy global parameters with redshift, to trace galaxy evolution back in time. Future studies should extend this effort to more dense environment than can be explored in the nearby universe, and to

increasingly higher redshifts to explore the time evolution of the structure of ETGs.

ACKNOWLEDGMENTS

We thank to the anonymous referee for a useful report. MC acknowledges support from a STFC Advanced Fellowship PP/D005574/1 and a Royal Society University Research Fellowship. This work was supported by the rolling grants ‘Astrophysics at Oxford’ PP/E001114/1 and ST/H002456/1 and visitors grants PPA/V/S/2002/00553, PP/E001564/1 and ST/H504862/1 from the UK Research Councils. RLD acknowledges travel and computer grants from Christ Church, Oxford and support from the Royal Society in the form of a Wolfson Merit Award 502011.K502/jd. RLD also acknowledges the support of the ESO Visitor Programme that funded a 3-month stay in 2010. SK acknowledges support from the Royal Society Joint Projects Grant JP0869822. RMM is supported by the Gemini Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., on behalf of the international Gemini partnership of Argentina, Australia, Brazil, Canada, Chile, the United Kingdom and the United States of America. TN and MBo acknowledge support from the DFG Cluster of Excellence ‘Origin and Structure of the Universe’. MS acknowledges support from a STFC Advanced Fellowship ST/F009186/1. NS and TAD acknowledge support from an STFC studentship. The authors acknowledge financial support from ESO. We acknowledge the usage in ppxf of the mpfit routine by Markwardt (2009). The SAURON observations were obtained at the WHT, operated by the Isaac Newton Group in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias. We are grateful to the ING staff for their excellent support and creativity in quickly solving technical problem during the SAURON runs. We are grateful to Jesús Falcon-Barroso for useful discussions and help with the observations. MC is grateful to the NED staff for prompt support. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. We acknowledge the usage of the HyperLeda data base (<http://leda.univ-lyon1.fr>). Funding for the SDSS and SDSS-II was provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, the US Department of Energy, the National Aeronautics and Space Administration, the Japanese Monbukagakusho, the Max Planck Society and the Higher Education Funding Council for England. The SDSS was managed by the Astrophysical Research Consortium for the Participating Institutions. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

REFERENCES

- Abazajian K. N. et al., 2009, ApJS, 182, 543
- Allard E. L., Peletier R. F., Knapen J. H., 2005, ApJ, 633, L25
- Bacon R. et al., 2001, MNRAS, 326, 23
- Baldry I. K., Glazebrook K., Brinkmann J., Ivezić Ž., Lupton R. H., Nichol R. C., Szalay A. S., 2004, ApJ, 600, 681
- Baldry I. K., Balogh M. L., Bower R. G., Glazebrook K., Nichol R. C., Bamford S. P., Budavari T., 2006, MNRAS, 373, 469
- Barnes J. E., 1992, ApJ, 393, 484

- Bell E. F., de Jong R. S., 2001, ApJ, 550, 212
 Bell E. F. et al., 2003, ApJS, 149, 289
 Bell E. F. et al., 2004, ApJ, 608, 752
 Bender R., Surma P., Doebeleiner S., Moellenhoff C., Madejsky R., 1989, A&A, 217, 35
 Bender R., Burstein D., Faber S. M., 1992, ApJ, 399, 462
 Bernardi M., Shankar F., Hyde J. B., Mei S., Marulli F., Sheth R. K., 2010, MNRAS, 404, 2087
 Binney J., 1978, MNRAS, 183, 501
 Blakeslee J. P. et al., 2009, ApJ, 694, 556
 Blakeslee J. P. et al., 2010, ApJ, 724, 657
 Bois M. et al., 2010, MNRAS, 406, 2405
 Bois M. et al., 2011, MNRAS, submitted (Paper VI)
 Bournaud F., Jog C. J., Combes F., 2007, A&A, 476, 1179
 Bournaud F., Elmegreen B. G., Teyssier R., Block D. L., Puerari I., 2010, MNRAS, 409, 1088
 Bower R. G. et al., 2004, MNRAS, 351, 63
 Bower R. G., Benson A. J., Malbon R., Helly J. C., Frenk C. S., Baugh C. M., Cole S., Lacey C. G., 2006, MNRAS, 370, 645
 Cappellari M., Copin Y., 2003, MNRAS, 342, 345
 Cappellari M., Emsellem E., 2004, PASP, 116, 138
 Cappellari M. et al., 2006, MNRAS, 366, 1126
 Cappellari M. et al., 2007, MNRAS, 379, 418
 Cappellari M. et al., 2010, Highlights Astron., 15, 81
 Cappellari M. et al., 2011, MNRAS, submitted (Paper VII)
 Cattaneo A., Dekel A., Devriendt J., Guiderdoni B., Blaizot J., 2006, MNRAS, 370, 1651
 Chen C., Côté P., West A. A., Peng E. W., Ferrarese L., 2010, ApJS, 191, 1
 Cimatti A. et al., 2008, A&A, 482, 21
 Cole S. et al., 2001, MNRAS, 326, 255
 Conselice C. J., 2006, MNRAS, 373, 1389
 Courteau S., Dutton A. A., van den Bosch F. C., MacArthur L. A., Dekel A., McIntosh D. H., Dale D. A., 2007, ApJ, 671, 203
 Cox T. J., Dutta S. N., Di Matteo T., Hernquist L., Hopkins P. F., Robertson B., Springel V., 2006, ApJ, 650, 791
 Crook J. R. et al., 2007, ApJ, 655, 790
 Croton D. J. et al., 2006, MNRAS, 365, 11
 Daddi E. et al., 2005, ApJ, 626, 680
 Davies R. L., Efstathiou G., Fall S. M., Illingworth G., Schechter P. L., 1983, ApJ, 266, 41
 Davies R. L., Sadler E. M., Peletier R. F., 1993, MNRAS, 262, 650
 Davis T. A. et al., 2011, MNRAS, in press (Paper V)
 Dekel A., Birnboim Y., 2006, MNRAS, 368, 2
 de Vaucouleurs G., 1959, Handb. Phys., 53, 311
 de Vaucouleurs G., 1963, ApJS, 8, 31
 de Vaucouleurs G., de Vaucouleurs A., Corwin J. R., 1976, Second Reference Catalogue of Bright Galaxies. Univ. Texas Press, Austin
 de Vaucouleurs G., de Vaucouleurs A., Corwin H. G., Jr., Buta R. J., Paturel G., Fouque P., 1991, Third Reference Catalogue of Bright Galaxies, Vols 1–3. Springer-Verlag, Berlin
 de Zeeuw P. T. et al., 2002, MNRAS, 329, 513
 Di Matteo T., Springel V., Hernquist L., 2005, Nat, 433, 604
 Djorgovski S., Davis M., 1987, ApJ, 313, 59
 Dressler A., Lynden Bell D., Burstein D., Davies R. L., Faber S. M., Terlevich R., Wegner G., 1987, ApJ, 313, 42
 Dumas G., Mundell C. G., Emsellem E., Nagar N. M., 2007, MNRAS, 379, 1249
 Dunkley J. et al., 2009, ApJS, 180, 306
 Efron B., Tibshirani R., 1993, An Introduction to the Bootstrap. Chapman & Hall, New York
 Emsellem E. et al., 2004, MNRAS, 352, 721
 Emsellem E. et al., 2007, MNRAS, 379, 401
 Emsellem E. et al., 2011, MNRAS, submitted (Paper III)
 Faber S. M., Jackson R. E., 1976, ApJ, 204, 668
 Faber S. M. et al., 1997, AJ, 114, 1771
 Faber S. M. et al., 2007, ApJ, 665, 265
 Falcón-Barroso J. et al., 2006, MNRAS, 369, 529
 Ferrarese L., van den Bosch F. C., Ford H. C., Jaffe W., O’Connell R. W., 1994, AJ, 108, 1598
 Ferrarese L. et al., 2006, ApJ, 644, L21
 Gerhard O. E., 1993, MNRAS, 265, 213
 Giovanelli R. et al., 2005, AJ, 130, 2598
 Graham A. W., 2004, ApJ, 613, L33
 Graham A. W., Worley C. C., 2008, MNRAS, 388, 1708
 Granato G. L., De Zotti G., Silva L., Bressan A., Danese L., 2004, ApJ, 600, 580
 Hernquist L., 1992, ApJ, 400, 460
 Hopkins P. F., Hernquist L., Cox T. J., Keres D., Wuyts S., 2009, ApJ, 691, 1424
 Hubble E. P., 1936, Realm of the Nebulae. Yale Univ. Press, New Haven
 Huchra J., Davis M., Latham D., Tonry J., 1983, ApJS, 52, 89
 Huchra J. P., Geller M. J., Clemens C. M., Tokarz S. P., Michel A., 1992, Bull. d’Inf. Cent. Donnees Stellaires, 41, 31
 Huchra J. P. et al., 2005, in Colless M., Staveley-Smith L., Stathakis R., eds, Proc. IAU Symp. 216, Maps of the Cosmos. Astron. Soc. Pac., San Francisco, p. 170
 Illingworth G., 1977, ApJ, 218, L43
 Jarrett T. H., Chester T., Cutri R., Schneider S., Skrutskie M., Huchra J. P., 2000, AJ, 119, 2498
 Jeans J. H., 1922, MNRAS, 82, 122
 Jeong H. et al., 2009, MNRAS, 398, 2028
 Jesseit R., Naab T., Peletier R. F., Burkert A., 2007, MNRAS, 376, 997
 Jesseit R., Cappellari M., Naab T., Emsellem E., Burkert A., 2009, MNRAS, 397, 1202
 Johansson P. H., Naab T., Ostriker J. P., 2009, ApJ, 697, L38
 Józsa G. I. G., Oosterloo T. A., Morganti R., Klein U., Erben T., 2009, A&A, 494, 489
 Karachentsev I. D., Nasonova O. G., 2010, MNRAS, 405, 1075
 Kereš D., Katz N., Weinberg D. H., Davé R., 2005, MNRAS, 363, 2
 Khochfar S., Burkert A., 2003, ApJ, 597, L117
 Khochfar S., Burkert A., 2005, MNRAS, 359, 1379
 Khochfar S., Ostriker J. P., 2008, ApJ, 680, 54
 Khochfar S., Silk J., 2006, ApJ, 648, L21
 Khochfar S., Silk J., 2009, MNRAS, 397, 506
 Khochfar S. et al., 2011, MNRAS, submitted (Paper VIII)
 Kochanek C. S. et al., 2001, ApJ, 560, 566
 Kormendy J., Bender R., 1996, ApJ, 464, L119
 Kormendy J., Richstone D., 1995, ARA&A, 33, 581
 Kormendy J., Fisher D. B., Cornell M. E., Bender R., 2009, ApJS, 182, 216
 Krajnović D., Cappellari M., de Zeeuw P. T., Copin Y., 2006, MNRAS, 366, 787
 Krajnović D. et al., 2008, MNRAS, 390, 93
 Krajnović D. et al., 2011, MNRAS, submitted (Paper II)
 Kuntschner H. et al., 2006, MNRAS, 369, 497
 Kuntschner H. et al., 2010, MNRAS, 408, 97
 Landsman W. B., 1993, in Hanisch R. J., Brissenden R. J. V., Barnes J., eds, ASP Conf. Ser. Vol. 52, Astronomical Data Analysis Software and Systems II. Astron. Soc. Pac., San Francisco, p. 246
 Lauer T. R. et al., 1995, AJ, 110, 2622
 Lupton R., Blanton M. R., Fekete G., Hogg D. W., O’Mullane W., Szalay A., Wherry N., 2004, PASP, 116, 133
 McDermid R. M. et al., 2006, MNRAS, 373, 906
 Maraston C., 2005, MNRAS, 362, 799
 Markwardt C. B., 2009, in Bohlender D. A., Durand D., Dowler P., eds, ASP Conf. Ser. Vol. 411, Astronomical Data Analysis Software and Systems XVIII. Astron. Soc. Pac., San Francisco, p. 251
 Mei S. et al., 2007, ApJ, 655, 144
 Morganti R. et al., 2006, MNRAS, 371, 157
 Mould J. R. et al., 2000, ApJ, 529, 786
 Naab T., Burkert A., 2003, ApJ, 597, 893
 Naab T., Burkert A., Hernquist L., 1999, ApJ, 523, L133
 Naab T., Jesseit R., Burkert A., 2006a, MNRAS, 372, 839
 Naab T., Khochfar S., Burkert A., 2006b, ApJ, 636, L81
 Naab T., Johansson P. H., Ostriker J. P., Efstathiou G., 2007, ApJ, 658, 710

- Naab T., Johansson P. H., Ostriker J. P., 2009, *ApJ*, 699, L178
- Oosterloo T. et al., 2010, *MNRAS*, 409, 500
- Oser L., Ostriker J. P., Naab T., Johansson P. H., Burkert A., 2010, *ApJ*, 725, 2312
- Paturel G., Petit C., Prugniel P., Theureau G., Rousseau J., Brouty M., Dubois P., Cambrésy L., 2003, *A&A*, 412, 45
- Perlmutter S. et al., 1999, *ApJ*, 517, 565
- Press W. H., Teukolsky S. A., Vetterling W. T., Flannery B. P., 1992, *Numerical Recipes in FORTRAN. The Art of Scientific Computing*, 2nd edn. Cambridge Univ. Press, Cambridge
- Riess A. G. et al., 1998, *AJ*, 116, 1009
- Robertson B., Bullock J. S., Cox T. J., Di Matteo T., Hernquist L., Springel V., Yoshida N., 2006, *ApJ*, 645, 986
- Sánchez-Blázquez P. et al., 2006, *MNRAS*, 371, 703
- Sandage A., 1961, *The Hubble Atlas*. Carnegie Inst., Washington
- Sandage A., 1975, in Sandage A., Sandage M., Kristian J., eds, *Galaxies and the Universe*. Univ. Chicago Press, Chicago, p. 1
- Sarzi M. et al., 2006, *MNRAS*, 366, 1151
- Sarzi M. et al., 2010, *MNRAS*, 402, 2187
- Schechter P., 1976, *ApJ*, 203, 297
- Schlegel D. J., Finkbeiner D. P., Davis M., 1998, *ApJ*, 500, 525
- Scott N. et al., 2009, *MNRAS*, 398, 1835
- Sersic J. L., 1968, *Atlas de Galaxias Australes*. Obser. Astron., Córdoba, Argentina
- Shankar F., Bernardi M., 2009, *MNRAS*, 396, L76
- Shapiro K. L. et al., 2010, *MNRAS*, 402, 2140
- Shen S., Mo H. J., White S. D. M., Blanton M. R., Kauffmann G., Voges W., Brinkmann J., Csabai I., 2003, *MNRAS*, 343, 978
- Skrutskie M. F. et al., 2006, *AJ*, 131, 1163
- Spergel D. N. et al., 2007, *ApJS*, 170, 377
- Springel V., Di Matteo T., Hernquist L., 2005a, *ApJ*, 620, L79
- Springel V. et al., 2005b, *Nat*, 435, 629
- Strateva I. et al., 2001, *AJ*, 122, 1861
- Stumpff P., 1980, *A&AS*, 41, 1
- Taylor E. N., Franx M., Glazebrook K., Brinchmann J., van der Wel A., van Dokkum P. G., 2010, *ApJ*, 720, 723
- Teyssier R., 2002, *A&A*, 385, 337
- Tonry J. L., Dressler A., Blakeslee J. P., Ajhar E. A., Fletcher A. B., Luppino G. A., Metzger M. R., Moore C. B., 2001, *ApJ*, 546, 681
- Trujillo I. et al., 2006, *MNRAS*, 373, L36
- Trujillo I., Cenarro A. J., de Lorenzo-Cáceres A., Vazdekis A., de la Rosa I. G., Cava A., 2009, *ApJ*, 692, L118
- Tully R. B., Fisher J. R., 1977, *A&A*, 54, 661
- Tully R. B., Shaya E. J., Karachentsev I. D., Courtois H. M., Kocevski D. D., Rizzi L., Peel A., 2008, *ApJ*, 676, 184
- Tully R. B., Rizzi L., Shaya E. J., Courtois H. M., Makarov D. I., Jacobs B. A., 2009, *AJ*, 138, 323
- Valentijn E. A. et al., 2007, in Shaw R. A., Hill F., Bell D. J., eds, *ASP Conf. Ser. Vol. 376, Astronomical Data Analysis Software and Systems XVI*. Astron. Soc. Pac., San Francisco, p. 491
- Valentinuzzi T. et al., 2010, *ApJ*, 712, 226
- van den Bergh S., 2007, *AJ*, 134, 1508
- van der Marel R. P., Franx M., 1993, *ApJ*, 407, 525
- van der Wel A., Bell E. F., van den Bosch F. C., Gallazzi A., Rix H.-W., 2009, *ApJ*, 698, 1232
- van Dokkum P. G. et al., 2008, *ApJ*, 677, L5
- Weijmans A. et al., 2009, *MNRAS*, 398, 561
- Weijmans A., Bower R. G., Geach J. E., Swinbank A. M., Wilman R. J., de Zeeuw P. T., Morris S. L., 2010, *MNRAS*, 402, 2245
- York D. G. et al., 2000, *AJ*, 120, 1579
- Young L. M. et al., 2011, *MNRAS*, submitted (Paper IV)

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table 3. The ATLAS^{3D} sample of 260 early-type (E and S0) galaxies.

Table 4. The 611 spiral galaxies in the ATLAS^{3D} parent sample.

Please note: Wiley-Blackwell are not responsible for the content or functionality of any supporting materials supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.