Near-IR Atlas of S0-Sa galaxies (NIRS0S)

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ABSTRACT

An atlas of $K_s$-band images of 206 early-type galaxies is presented, including 160 S0-S0/a galaxies, 12 ellipticals, and 33 Sa galaxies (+ one later type). A majority of the Atlas galaxies belong to a magnitude-limited ($m_B \leq 12.5$ mag) sample of 185 NIRS0S (Near-IR S0 galaxy Survey) galaxies. To assure that mis-classified S0s are not omitted, 25 ellipticals from RC3 classified as S0s in the Carnegie Atlas were included in the sample. The observations were carried out using 3-4 m class telescopes with sub-arcsecond pixel resolution ($\sim 0.25''$), and were obtained in good seeing conditions (FWHM $\sim 1''$). The images are 2-3 mag deeper than 2MASS images, allowing the detection of faint outer disks in S0s. Both visual and photometric classifications are made, largely following the classification criteria of de Vaucouleurs [1959]. Special attention is paid to the classification of lenses, which are coded in a more systematic manner than in any of the previous studies. A new lens-type, called a 'barlens', is introduced, possibly forming part of the bar itself. Also, boxy/peanut/x-shaped structures are identified in many barred galaxies, even-though the galaxies are not seen in edge-on view, indicating that vertical thickening is not enough to explain these structures, indicating that vertical thickening is not enough to explain them. Photometric classification includes detection of exponential outer disks or other structures not directly visible in the images, but becoming clear in unsharp masking or residual images in decompositions. In our photometric classification, nuclear bars are assigned...
for 15 galaxies, which are overshadowed by bulges in visual classification. The mean Hubble stage is found to be similar in the near-IR and in the optical. We give dimensions of structure components, and radial profiles of the position angles and ellipticities, and show deviations from perfect elliptical isophotes. Shells and ripples, generally assumed to be manifestations of recent mergers, are detected only in 6 galaxies. However, multiple lenses appear in as much as 25% of the Atlas galaxies, which is a challenge to the hierarchical evolutionary picture of galaxies. Such models need to explain how the lenses were formed, and then survived in multiple merger events that galaxies may have suffered during their lifetimes.

**Key words:** galaxies: elliptical and lenticular - galaxies: evolution - galaxies: structure - galaxies: individual

1 **INTRODUCTION**

In the early classification by Hubble (1936), the S0s were an enigmatic group of galaxies between the ellipticals and the early-type spirals, and since then they have been subject to many kinds of interpretations. The classification of S0s depends on recognizing the presence of a disk, but having no spiral arms. The interface between E and S0 galaxies was somewhat obscured by the detection of boxy and disky ellipticals (Bender 1988), based on deviations of the outer isophotes from simple elliptical shape. Kinematic observations by Dressler & Sandage (1983) had already shown earlier that the lower luminosity ellipticals are more rotationally supported than the bright ellipticals. Bender et al. (1989) then discovered that both galaxy luminosity and the degree of rotational support correlate with the isophotal shapes of the elliptical galaxies. A similar sequence of increasing dominance of rotational support towards the lower-luminosity galaxies was found also for the S0s (Dressler & Sandage 1983). However, as the amount of rotation is significantly larger in S0s, this kinematically links the S0s to the spiral galaxies. All this caused some early-type galaxy observers to question the morphological classification of S0s, an attitude which culminated in 1990 when King (1992) and Djorgovski (1992) announced that the Hubble sequence was breaking down, and should be replaced by a classification based on measured physical parameters. Despite the early discovery of S0s, new kinematic observations have put them once again at the forefront of research. Recent IFU-kinematic observations by Emsellem et al. (2007) have shown that the

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fast rotators are morphologically assigned to a mix of E and S0 galaxies, which leads to further questions about the meaning of their morphological classification.

On the other hand, there are morphological structures in S0s which can be connected successfully to real dynamical processes. Inner, outer and nuclear rings can be either bar-induced resonance rings, or accretion rings related to accumulation of external gas into the galactic disks (see review by Buta 2011). Recently new theories of ring formation have also been presented, like the “manifold orbits” emanating from Lagrangian points in barred potentials (Romero-Gómez et al. 2006; Athanassoula et al. 2010). Merger-built structures such as shells, ripples (Malin & Carter 1980) and polar rings (Schweizer et al. 1983; in 2% of S0s) appear in S0 galaxies, but they are not very common. The first attempt to include bar morphology, e.g., boxy, peanut or x-shaped structures into galaxy classification was made by Buta et al. (2010). Bar morphology is an important characteristic of galaxy morphology, which in theoretical models has been associated with secular dynamical evolution of galaxies (Athanassoula & Misioritis 2002; Athanassoula 2003).

Lenses formed part of the early classification scheme of S0s (Sandage 1961; Sandage & Tammann 1981), but were not initially assigned any classification symbols. Inner and outer lenses in barred S0s were discussed by Kormendy (1979), and Laurikainen et al. (2009) showed that a large majority of S0s, both barred and non-barred, have lenses. Moreover, some S0s have complicated multi-lens systems, which have not yet been theoretically explained. Overall, the origin of lenses is not well understood: they can form as part of the disk formation process (Bosma 1983), be triggered by bars (Kormendy 1979), or by the accretion of small companions. In fact, lenses and other fine-structures of S0s might be important imprints of possible secular evolution of galaxies. The only major galaxy atlas that recognizes lenses in the classification is the de Vaucouleurs Atlas of Galaxies (Buta et al. 2007; hereafter dVA).

In this paper we present the NIRS0S (Near-IR S0 galaxy Survey) atlas in the $K_s$-band, and use it for detailed morphological classification. To our knowledge, this is the first attempt of detailed classification of S0s using deep near-IR images. The 2.2 $\mu$m wavelength used traces the old stellar population of galaxies and is relatively free of internal extinction, which makes it ideal for the classification of structures. The sample was selected from the Third Reference Catalogue of Bright Galaxies (de Vaucouleurs et al. 1991; hereafter RC3). In order to study the interfaces of S0s with ellipticals and spirals, Sa galaxies in RC3, and those ellipticals classified as S0s in the Revised Shapley-Ames Catalogue of Bright Galaxies (Sandage & Tammann 1981; RSA), were also included in the sample. Our images are several
magnitudes deeper than the images in the Two-Micron All-Sky Survey (2MASS, Skrutskie et al. 2006), which is the largest near-IR survey obtained previously. Two large mid-IR galaxy surveys using the *Spitzer Space Telescope* are the Spitzer Infrared Nearby Galaxies Survey (SINGS; Kennicutt et al. 2003), and the Local Volume Legacy project (LVL; Kennicutt et al. 2007), both providing deep images at 3.6 $\mu$m. However, these surveys contain only a few S0s. A more comprehensive nearby galaxy survey is the *Spitzer* Survey of Stellar Structure in galaxies ($S^4G$; Sheth et al. 2010), which consists of 2331 nearby galaxies. This survey exceeds the image depth of NIRS0S, but NIRS0S is more complete in respect of the S0s, and the pixel resolution is higher than in $S^4G$.

The NIRS0S atlas consists of images of 206 galaxies, a sample which, after our revised classification, has 12 ellipticals, 160 S0-S0/a, and 33 Sa galaxies. Section 2 describes the sample and observations, data reductions are explained in Section 3, and the image atlas in Section 4. Visual and photometric classifications are presented, starting from the de Vaucouleurs’ (1959) classification criteria, but going beyond that in classifying the detail of structures (Section 5). The dimensions of the structure components are given in Section 6, and the radial profiles of the position angles, ellipticities, and of the parameter $b_4$, describing deviations from perfect ellipticity of the isophotal contours, are shown in the Atlas (Fig. 5). In this paper, the image Atlas is presented, whereas the number statistics and more thorough discussion of the structure components will appear in forthcoming papers.

We find that multiple lenses are common in S0s, appearing even in 25% of the Atlas galaxies. However, shells or ripples were detected only in 6 galaxies. Of the 25 RC3 ellipticals in our original sample, 7 were re-classified as S0s by us. Bars and bulges in subsamples of NIRS0S have been previously discussed by Laurikainen, Salo & Buta (2003); Laurikainen et al. (2006, 2007, 2009) and Buta et al. (2006), the properties of bulges by Laurikainen et al. (2010), and the distribution of bar strengths by Buta et al. (2010).

## 2 SAMPLE AND OBSERVATIONS

We have carried out a large, magnitude-limited imaging survey, the Near-IR S0 galaxy Survey (NIRS0S) in the nearby Universe. The sample selection criteria are as follows: morphological type $-3 \leq T \leq 1$, total magnitude of $B_T \leq 12.5$ mag, and inclination less than 65°. Applying these criteria to RC3, and including also 25 ellipticals (including late-type E+) classified as
S0s in RSA, yields a sample of 185 galaxies (marked with an asterisk in Table 3). These ellipticals were included, in order not to miss any potentially misclassified S0s. The sample includes 30 additional galaxies not fulfilling the original selection criteria, mostly S0-Sa galaxies which slightly exceed the magnitude limit, or in some cases the inclination limit. These galaxies were observed when it was not possible to observe the primary targets, due to unsuitable wind direction, or because no primary targets were visible. Including these galaxies yields a sample of 215 galaxies. In total, after our re-classifications, the full sample includes 13 ellipticals, 139 S0s, 30 S0/a galaxies, 33 Sa galaxies and one later-type spiral. The selection criteria in our magnitude-limited NIRS0S sample are similar to those in the Ohio State University Bright Spiral Galaxy Survey (Eskridge et al. 2002; OSUBSGS), but going half a magnitude deeper.

The observations were carried out during the period 2003-2009 using various ground-based telescopes in the two hemispheres, with sizes between 2.5-4.2 m. The observing campaigns are shown in Table 1, listing the pixel scale and field of view (FOV) of the telescope/instrument setup used. The telescopes used were the 2.5m Nordic Optical telescope (NOT, La Palma) using NOTCam, the 3.6m New Technology Telescope (NTT, ESO) using SOFI, the 4.2m William Herschel Telescope (WHT, La Palma) using LIRIS, the 3.6m Telescopio Nazionale Galileo (TNG, La Palma) using NICS, the 2.1m telescope at Kitt Peak National Observatory using Flamingos, and the 4m telescope at Cerro Tololo Inter-American observatory (CTIO, Chile). Most of the galaxies fitted in the typical 4-5 arcmin FOV, whereas for the largest galaxies the 19.5’ FOV of Flamingos was used. The total on-source integration time was 1800-2400 sec, taken in exposures of 3-30 sec, depending on galaxy brightness and telescope/instrument setup. Owing to the high sky brightness in the near-IR, and because the galaxies typically occupied a large fraction of the FOV, an equal amount of time was spent on the target and on the sky. The target and the sky fields were alternated after every 1-2 minutes using a dithering box of 20” for the target. Either sky or dome flatfields were obtained, depending on what was recommended at each telescope. The seeing conditions were generally good (see Table 2), the full width at half maximum (FWHM) being typically around 1”. Seeing was worst at KPNO (for 10 galaxies) where FWHM was between 2-3”, whereas at the NTT the FWHM was below 1” for most of the

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1 Our current NIRS0S sample differs from that specified by Laurikainen, Salo & Buta (2005) and Buta et al. (2006) in that we use $B_T$ or the photographic value $m_B$, or the average of these two when both are available. This was done to eliminate contamination of the original sample by total $V$ magnitudes in RC3, which occupy the same column as $B_T$ in that catalogue.
time (57 galaxies). As the flux calibrations were done using 2MASS images, flux calibration standards were observed only occasionally.

In total, 206 galaxies were observed, including 172 galaxies of the magnitude-limited sample of 185 galaxies. Of the non-observed 13 galaxies, ESO 137-34 is most probably a distant galaxy having two bright stars in the field. Two of the late-type ellipticals (NGC 147 and NGC 185) appeared to be dwarf galaxies, and NGC 404 could not be observed due to the bright star in the immediate vicinity of the galaxy. NGC 205, NGC 1808 and NGC 5128 were too large to be observed with our typical FOV, and at Kitt Peak these galaxies were not visible during the period when time was allocated. IC 5250/5250A is an advanced merger and therefore not useful for our analysis. Four of the galaxies, NGC 1291, NGC 1316, NGC 1546 and NGC 1947, were not observed because of a lack of observing time. However, for NGC 1291 and NGC 1316 SINGS Spitzer Space Telescope images at 3.6 µm are available (Kennicutt 2003). In conclusion, in our magnitude-limited sample there are only five galaxies of interest (NGC 205, NGC 1808, NGC 5128, NGC 1546 and NGC 1947) for which we lack NIR observations. Of these NGC 205 is a low surface brightness galaxy, most probably an S0 with a central lens. NGC 1808 is a dusty Sa-type spiral, whereas NGC 5128, NGC 1546 and NGC 1947 have strong dust lanes in a nearly featureless spheroidal component, and are classified as $T=-2$, $-1$ and $-3$, respectively. Of the S0-S0/a galaxies in the magnitude-limited sample observations for only four galaxies are missing, which means that the completeness of our observations is 98%.

3 DATA REDUCTION

3.1 Combining the images

The images were combined using IRAF routines. The main reduction steps consisted of subtracting the sky from each science image, flatfielding the difference image, combining the images after correcting the shifts between the images, and fine-turning the sky subtraction. The sky images taken immediately before and after the target observation generally worked best for the sky subtraction. For flatfielding normalized master flat-fields were used, made as an average of the differences of high and low ADU-level images (ADU=digital counts). In the dome flats obtained at the NTT, scattered light sometimes produced a shade pattern which

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2 IRAF is distributed by the National Optical Astronomy Observatories, which are operated by AURA, Inc., under cooperative agreement with the National Science Foundation.
was corrected using the correction frames offered by ESO. While combining the images a 3 sigma clipping factor was used to reduce the noise. The images obtained at the WHT, TNG and NTT showed “crosstalk”, appearing as vertical or horizontal stripes in the images. For the ES0/NTT images the script crosstalk.cl (available at ESO) corrected the stripes effectively. For the WHT images this problem was more severe, and the stripes were corrected manually using the IRAF routines IMCOPY and BACKGROUND. For some of the galaxies bad lines/columns and sky gradients were also corrected. Foreground stars were removed using the DAOPHOT package in IRAF, and the cleaning was completed with the IMEDIT routine. The images were transposed to have north up and west to the right.

### 3.2 Flux calibrations

Flux calibrations were done using the $K_s$ aperture photometry of galaxies given in 2MASS\(^3\). We write

$$\mu = -2.5 \log_{10} \frac{F}{\text{pix}^2} + \mu_0,$$

where $\mu$ is the surface brightness in units of mag arcsec\(^{-2}\), $F$ is the flux in digital units (normalized to 1 second), pix is the pixel size in arcsecs, and $\mu_0$ is the magnitude zeropoint.

After sky background subtraction and removal of foreground stars, the total flux within a 14 arcsec (diameter) circular aperture around the galaxy center was measured, and compared to the corresponding 2MASS aperture magnitude, $m_{14}$, available via NED. The zeropoint $\mu_0$ was calculated from the equation

$$\mu_0 = m_{14} + 2.5 \log_{10} \left( \sum_{r_i<7'} F_i \right),$$

where $r_i$ is the distance from the galaxy center. In the calculation of the total flux inside the aperture, bilinear interpolation was used for the pixels falling on the aperture border. Also, the images were first degraded to have the same seeing as the 2MASS images, to compensate for the possible leaking of light in the original 2MASS aperture measurements. We thus applied a convolution with a Gaussian PSF with

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\(^3\) 2MASS 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.
\[ \text{FWHM}_{\text{conv}} = \sqrt{(2.5")^2 - \text{FWHM}^2}, \]

where FWHM corresponds to the original NIRS0S image, and 2.5" is the typical value for 2MASS images. In practice, the uncertainties in the photometric zeropoint due to sky subtraction, centering of the aperture, or the applied bilinear interpolation are all negligible (<0.001 mag). Likewise, the effect of different FWHM’s is quite small (<0.02 mag), and thus the formal error of our zeropoints corresponds to the accuracy of the 2MASS absolute calibration, ∼2-3% (Jarrett et al. 2000).

As an additional check, and to minimize possible human errors (e.g., use of wrong image, wrong centering, pixel size etc.), we also used the 2MASS \(k_{20}\) and \(k_{\text{ext}}\) magnitudes to check the consistency of our zeropoint calibration. These quantities were loaded from NASA/IPAC infrared science archive (IRSA) via GATOR: \(k_{20}\) is the total magnitude inside \(\mu_k=20\) mag isophotal ellipse, and \(k_{\text{ext}}\) is the extrapolated total magnitude. IRSA lists the isophotal radius \(a_{k20}\), position angle \(\phi_{k20}\) and axial ratio \((b/a)_{k20}\), and the radius \(r_{\text{ext}}\) corresponding to \(k_{\text{ext}}\) (isophotal orientation and shape are the same as for \(k_{20}\)).

Figure 1 displays a typical example of flux calibration (similar plots for all galaxies are available at the NIRS0S website), displaying the cumulative magnitudes using both circular (left) and elliptical (right) apertures. Also shown are the NIRS0S images: on the left the cleaned image, convolved to FWHM=2.5", and in the right the original image before removal of foreground stars. The elliptical aperture plot includes cumulative magnitudes from both the cleaned (black line) and the original image (red dashed line), to illustrate the possible effect of individual bright stars. As described above, the circular aperture growth curve is adjusted to go exactly through the \(m_{14}\) point at \(r=7"\), while the elliptical aperture fluxes measured at \(r_{k20}\) and \(r_{\text{ext}}\) usually deviate slightly from the tabulated \(k_{20}\) and \(k_{\text{ext}}\). We use the deviations of these quantities to control the possible inaccuracy of the flux calibration, and list them in Table 2 for each galaxy. Note that even large deviations do not indicate errors in our calibration, based solely on the \(m_{14}\) aperture magnitude: in some cases the deviations are connected to bright stars near the galaxy, or to the presence of a nearby galaxy. For a few cases, where reliable background subtraction was difficult due to the small FOV compared to the galaxy size, we made small adjustments to the sky background based on matching the 2MASS \(k_{20}\) value.

In case 2MASS data was not available (NGC 1161), or when there were reasons to believe
that the above calibration is not reliable (interacting systems), we adopted the average 
zeropoint value derived for the NIRS0S observing run in question (see Fig. 2). For some 
interacting pairs the difference in \( \mu_0 \), compared to that obtained directly from the 2MASS 
m_{14} calibration, is less than 0.1 magnitudes (NGC 2292/2293, NGC 4105/4106), but in some 
cases the difference is larger (NGC 5353/5354, NGC 5636, NGC 6438). For NGC 4474, for 
which the 2MASS values \( m_{14}, k_{20}, \) and \( k_{\text{ext}} \) are mutually inconsistent, the 2MASS calibration 
was not used.

For comparison, standard stars were observed during one campaign, at the NTT in 2004. 
Flux calibration standards of Persson et al. (1998) were used: 10 standards at each night 
were observed, using an observing block where the star was integrated in the four corners 
of the frame. The images were combined in a similar manner as the science images. Using 
the standard star measurements the following zero-points and extinction coefficients were 
obtained for the three nights:

\[
\begin{align*}
K_s &= k_s + 22.399 \pm 0.072 - 0.062 \pm 0.061 \times X \quad \text{(first night)} \\
K_s &= k_s + 22.350 \pm 0.036 - 0.020 \pm 0.029 \times X \quad \text{(second night)} \\
K_s &= k_s + 22.392 \pm 0.041 - 0.065 \pm 0.03 \times X \quad \text{(third night)},
\end{align*}
\]

where \( K_s \) is the total magnitude in the photometric system, \( k_s = -2.5 \log_{10}(\sum F_{i,\text{star}}) \) is the 
instrumental magnitude of the star, and \( X \) is the airmass. The zero-points and extinction 
coefficients are very similar for the first and the third nights, which were photometric. 
Comparison with the 2MASS-based calibration (Fig. 3) shows very good agreement: at 
most there is a marginal 0.02 magnitude systematic shift, which, however, is comparable 
to the internal scatter of the two sets of calibrations. Without the convolution to FWHM 
= 2.5", the systematic difference would be clear, about 0.04 mags. Based on this observing 
campaign, we estimate that any possible systematic error in \( \mu_0 \) introduced by using the 
2MASS-based calibration is less than 0.05 magnitudes.

The NIRS0S images are deep: Table 2 lists the 1-sigma sky deviation per square arcsec, 
calculated from

\[
\sigma_{\text{sky}} = -2.5 \log_{10}(\Delta F_{\text{sky}}/\text{pix}) + \mu_0,
\]

where \( \Delta F_{\text{sky}} \) is the sky rms-variation, obtained by measuring it at several locations outside 
the galaxy. Depending on the telescope, exposure time and sky conditions, the values range 
from 21 to 23 mag arcsec\(^{-2}\), with mean \( < \sigma_{\text{sky}} > \approx 22.2 \) mag arcsec\(^{-2}\). However, the az-
mutually averaged surface brightness profiles are more illustrative than $\sigma_{\text{sky}}$ to show the real image depth, extending to 23-24 mag arcsec$^{-2}$, depending on the galaxy. A typical example is shown in Figure 4 for NGC 584 (with $\sigma_{\text{sky}}=21.8$ mag arcsec$^{-2}$), with profiles from the 2MASS Atlas image (Jarrett et al. 2000) and from the SINGS survey 3.6 micron image (Kennicutt 2003) overlaid for comparison. For NGC 584 the useful NIRS0S profile ($\Delta \mu \leq 0.2$) extends to about 23.5 mag arcsec$^{-2}$, or 2-3 magnitudes deeper than 2MASS. Allowing for the difference in the band and magnitude system, it is only about 2 mag shallower than the deep Spitzer image (see the insert in Figure 4). In $B$-magnitudes, 23.5 mag arcsec$^{-2}$ in the $K_s$-band translates roughly to a surface brightness of 27.5 mag arcsec$^{-2}$. However, not all of the galaxies in our sample are visible at this surface brightness level, for-instance because the FOV is too small, the galaxies are strongly interacting, or in a very few cases because the sky background is not stable enough, in which case the sky gradients limit the useful image depth. In radial extent our example galaxy is 1.4-1.6 times larger than the 2MASS image, and 0.8 times of the extent of the SINGS image.

4 THE IMAGE ATLAS

4.1 The Atlas images

The flux-calibrated image Atlas is shown in Figure 5. Examples of atlas images are shown for the galaxies discussed in the text, whereas the complete Atlas is available in Supporting information with the online version of the article. The images are shown in logarithmic form, in units of mag arcsec$^{-2}$, maintaining the full pixel resolution (upper panel). The magnitude range is given in the right hand bar, which is selected individually for each galaxy so that the full scale of structures is visible. In order not to add any artifacts due to bad foreground star removal, the images before star removal are shown. Our visual and photometric (in brackets) classifications (see Section 5) are marked in the figures. A drawback of this layout is that it does not give full justice to the real image depth, failing to show the faint outer regions.

These faint outer structures are shown in one of the small panels, where rebinned images cleaned of foreground stars are shown. The galaxies are shown in many different radial and brightness scales, the number of frames depending on the complexity of a galaxy’s morphology. In some of the galaxies faint bars, lenses or dust lanes are overshadowed by prominent bulges. These components were made visible using 2D multi-component structural
decompositions previously given for the Atlas galaxies by Laurikainen et al. (2010): the bulge model was subtracted from the original image leaving the faint structures visible in the residual images. Alternatively, unsharp masked images are shown. They were created by smoothing the images by 5-20 pixels, and then subtracting smoothed images from the original images. The upper left small panel shows the image rebinned by a factor that best demonstrates the faint outer structure of the galaxy, whereas the lower right panel generally shows either the residual image or the unsharp masked image. In such cases a text “bsub” or “unsharp” is overlayed on the image. The detected faint structures form part of our photometric classification.

4.2 Ellipse fitting

The atlas figures show also isophotal analysis results, which consist of fitting elliptical isophotes to the images using the *ellipse* routine in IRAF. This routine uses a technique in which Fourier series are fitted to concentric isophotes (Jedrzejewski 1987). The quality of the fit is evaluated by inspecting the one-dimensional brightness distribution as a function of position angle, so that the harmonic content of this distribution is analyzed. The fourth order coefficient $b_4$ of the best fit Fourier series then measures the isophote’s deviations from perfect ellipticity. We calculate the radial profiles of the position angle PA, the ellipticity $\epsilon = 1-q$ (where $q=b/a$ is the minor-to-major axis ratio), and the parameter $b_4$. Non-rebinned images were used and the center was fixed to the value estimated by the IMCNTR routine in IRAF. Logarithmic radial spacing was used along semi-major axis while fitting the elliptical isophotes. In order to minimize the effects of noise and contamination by bad pixels and cosmic rays, deviant pixels above $3 \sigma$ were rejected.

The surface brightness profiles and the radial profiles of PA, $\epsilon$ and $b_4$ are shown in Figure 5. The full green vertical line shows $r_{20}$, which is the 2MASS isophotal radius of the 20 mag arcsec$^{-2}$ contour in $K_s$-band. The radius $r_{20}$ is marked with a black ellipse in the upper left panel, using 2MASS position angle $\phi_{k20}$ and axis ratio $(b/a)_{k20}$. The dashed vertical lines show the radii of the bars in our classification (see Section 5). In some cases the $r_{20}$ isophotal orientations from 2MASS deviate from the orientations in our images. This is because for these galaxies the 2MASS images trace only the inner components of the galaxies, the outermost components detected by us having different orientations.
5 MORPHOLOGICAL CLASSIFICATION

5.1 Brief history

The identification of S0s traces back to Lundmark (1926) and Reynolds (1927), who recognized a group of amorphous galaxies without any sign of spiral arms, a group of galaxies which form the modern class of E+S0 galaxies. Early-type galaxies were seen as a sequence of increasing flattening towards later types. In *Realm of the Nebulae* Hubble (1936) described hypothetical S0s which, based on Hubble’s notes, Sandage (1961) included in the Hubble sequence as *transition types between the ellipticals and the spirals*. As a real physical scenario this idea was abandoned when it was found that S0s have a similar flattening distribution as spirals, which clearly deviates from that for the elliptical galaxies (Sandage, Freeman & Stokes 1970).

De Vaucouleurs (1959) further refined the Hubble/Sandage classification by adding the *stage* (S0−, S00, S0+)/*family* (A, AB, B), and *variety* (s, r), as well as the outer ring/pseudoring designation to the S0 class. Concerning spiral arms, he was less restrictive in the sense that the (r) and (s) varieties were carried even into the earliest S0 classification, called S0−, although such cases are difficult to recognize. In the classification by Sandage & Tammann (1981) the stage was given in a similar manner as in de Vaucouleurs’ classification, only different symbols were used (S01, S02, S03). They also added flattening of a galaxy into their coding. Outer ring classification was fine-tuned by Buta & Crocker (1991) and Buta (1995). The morphology of bars in terms of boxy/peanut/x-shaped structures were included in the classification by Buta et al. (2010) for 200 galaxies using Spitzer mid-infrared images (S4G; Sheth et al. 2010). Buta et al. also suggested a notation ‘nb’ for nuclear bars, and ‘nr’ for nuclear rings. Kinematic observations for edge-on galaxies (Kuijken & Merrifield 1995; Bureau & Freeman 1999) have shown that boxy/peanut/x-shaped structures are inner parts of bars. Although lenses form part of the classification of S0s they were not coded into the morphological classification. For lenses, Kormendy (1979) suggested a coding where ‘l’ stands for an inner, and ‘L’ for an outer lens (as used in the dVA), whereas Buta et al. (2010) suggested a notion ‘nl’ for nuclear lenses.

The classification has been developed along with new ideas of galaxy formation and evolution. That was already the case when Baade (1963) suggested that S0s are stripped spirals formed in galaxy interactions. The idea was developed by van den Bergh (1976) leading to a classification where the S0s form a sequence from early- to late-types, similar
to that used for the spirals (S0a, S0b, S0c). It was based on the supposition that there may exist anemic S0s, which have similar surface brightness distributions as the Sa, Sb and Sc-type spirals. In this scenario, also small low luminosity bulges are expected among S0s. The hypothesis was tested by Sandage & Bedke (1994) for 200 bright S0s, but no such S0s were found. However, multi-component structure analysis has cast new light on this approach (see Laurikainen et al. 2010). A dust-penetrated classification was suggested by Buta & Block (2001), where a bar-induced torque forms part of the classification. This was based on the idea that bars are a driving force of secular evolution, thus modifying galaxy morphology.

Early-type disk galaxies typically have faint structures that are easily missed in visual classification. In particular, late-type ellipticals and early-type S0s are difficult to distinguish due to the subtle oval or twisted structures, or due to faint outer disks in S0s. Indeed, Sandage & Bedke (1994) report many misclassified S0s in the RC3. Therefore, sometimes photometric classification is also used. For example, Kormendy et al. (2009) used isophotal analysis to show the appearance of disks in galaxies in which the disks were not obvious in the direct images. It was assumed that disks are more flattened than bulges.

In the current study, both visual and photometric classification is made, given in Tables 3 and 4. For comparison, in Table 3 we give also the classifications from the RC3 and the RSA. Our classification is purely morphological, and no assumptions of possible formative processes of galaxies are made. Although our images do not have the resolution of the Hubble Space Telescope, they are still good enough for detecting also nuclear bars, rings and lenses.

5.2 Visual classification

We use classification, based on de Vaucouleurs’ revised Hubble-Sandage system (de Vaucouleurs 1959) (see also the dVA and Buta 2011), which includes the stage (S0−, S0°, S0+, Sa), the family (SA, SAB, SB), the variety (r, rs, s), the outer ring or pseudoring (R, R’), possible spindle shape (sp, meaning edge-on or near edge-on orientation), and the presence of peculiarity (pec). We use also a notation for shells and ripples. The underline notation (e.g., SAB, SABrs, rs) as used by de Vaucouleurs (1963) is used to emphasize the more likely phenomenon in a galaxy. Notice that in the atlas images (in Fig. 5), for technical reasons, the underline notation is emphasized by slanted font instead. Following Buta & Crocker (1991) and Buta (1995) we also recognize subcategories of pseudorings (R1, R1’, R2, R1R2). Representative examples of stage and family for barred and non-barred atlas galaxies are
shown in Figure 6. De Vaucouleurs’ classification does not include the morphology of bars in terms of boxy/peanut/x-shaped structures (B_x), which is included in our classification. Bars can also have classical rectangular structures, or ansae at the two ends of the bar (Laurikainen et al. 2007; Martinez-Valpuesta, Knapen & Buta 2007), which ansae types are coded by B_a in our classification. Examples of bar and ring morphologies in S0s are shown in Figure 7. It is worth noticing that the x-shaped structures inside the bars in our study, and in dVA, appear in fairly face-on galaxies, not in edge-on systems where they are generally reported (see for example IC 5240 and NGC 4429 in Fig. 5).

Nuclear, inner and outer lenses are denoted by ‘nl’, ‘l’ and ‘L’, respectively. Nuclear bars and nuclear rings, denoted as ‘nb’ and ‘nr’, have similar sizes as nuclear lenses. In the classification, intermediate types between rings and lenses are also used (nrl, rl, RL). Additionally, a new lens type is introduced which we propose to call “barlenses” with a notion of ‘bl’. These appear in the central regions of many NIRS0S galaxies, but are generally distinct from nuclear lenses by their much larger sizes. From visual appearance these ‘bl’ features can be mistaken for large bulges. The appearance of ‘bl’ is demonstrated for NGC 2983 in Figure 8, where both the original and the residual images are shown: the residual image is created by subtracting from the original image the bulge+bar model obtained from 2D structural decomposition. A manifestation of ‘bl’ appears also in NGC 4314 (Fig. 9): the fine-structure in the central regions confirms that the component cannot be a bulge. Also, as the galaxy is in nearly face-on orientation the fat bar component cannot be interpreted as a boxy bar structure seen nearly edge-on orientation. This needs to be explained by the theoretical models, in which the boxy/peanut structures are generally induced by vertical thickening of the bar (Athanassoula & Misioritis 2002).

Due to our selection criteria the sample should not contain edge-on galaxies. However, several misclassified galaxies appear in the RC3. We have moved the following galaxies in our sample to the spindle category: ESO 208-21, IC 1392, NGC 2685, NGC 3414, NGC 4220, NGC 4435, NGC 4474, NGC 4546, NGC 5087 NGC 6861 and NGC 7029. On the other hand, the galaxies NGC 4281 and NGC 5353 which were classified as spindle in the RC3, were considered as more face-on systems in this work. Notice that the galaxies NGC 4638, NGC 5493 and NGC 7029 have an edge-on disk clearly shorter than the outskirts of the IR spheroidal components, which have boxy outer isophotes (Fig. 5). We use the notation of Kormendy and Bender (1996) for the boxy elliptical parts of these galaxies with bright
embedded S0 disks, although these galaxies do not fit very well to the scheme by Kormendy and Bender.

Our classification is similar to that used by Buta et al. (2010), except that lenses are coded in a systematic manner in the present work. We have 12 galaxies in common with that sample. As expected, the agreement is generally good, except that in six of the galaxies we detect lenses (NGC 4203, Fig. 14; NGC 4245, Fig. 5; NGC 4314, Fig. 9; NGC 4649, Fig. 5; NGC 5377, Fig. 7; NGC 5846, Fig. 5), which were not recognized by Buta et al. Also, for NGC 5353 (Fig. 5) we recognize an x-shaped bar which was not included in the classification by Buta et al. On the other hand, for NGC 4369 (Fig. 5) Buta et al. detect an outer ring, which we don’t see in the $K_s$-band image, most probably because the image used by us is not as deep as the Spitzer image at 3.6 mµ of Buta et al.

Compared with the optical classification in the RC3, the Hubble stage differs for some individual galaxies. However, deviations appear in both directions, so that there is no systematic shift in the mean Hubble stage ($< T > = -1.57$ and $-1.51$ in near-IR and optical, respectively). The scatter plot of the optical and NIR-types is shown in Fig. 10. Both Eskridge et al. (2002) and Buta et al. (2010) found that intermediate-type (S0/a-Sc) galaxies are on average one stage earlier in the infrared than in the optical. The reason why we don’t see such a shift is partly because we study early-type galaxies which have only a small amount of dust, whereas the samples by Eskridge et al. and Buta et al. are more concentrated on dusty spirals. Another reason is that, although some of the galaxies in our sample were shifted towards an earlier stage, that is partly compensated by shifting some ellipticals that were misclassified in the RC3 into S0s in our classification.

### 5.3 Photometric classification

By photometric classification we mean including faint structure components, even if they were not obvious in visual classification, for example because they were outshone by luminous bulges. Also, galaxies that are late-type ellipticals (E+) in visual classification, can turn out to be early-type S0s in photometric classification if exponential outer disks are detected from surface brightness profiles. Our classification is based on morphology alone, and does not include any kinematic observations or parameters measured from the images (ellipticities, bulge-to-total flux ratios, or bar strengths). Also, no assumptions on the formative processes of galaxies were made, for example by assigning features like shells/ripples, assumed to be
merger-built structures, to elliptical galaxies alone. The photometric classification is given only if it deviates from the visual classification.

5.3.1 Subtle features not identified visually

In order to identify faint structures we use (1) unsharp masks (see Section 4.1), or (2) residuals from structural decompositions. We use 2D multi-component decompositions obtained previously for the Atlas galaxies by Laurikainen et al. (2005, 2006, 2010). The decompositions were made by fitting a Sérsic function for the bulge, an exponential function for the disk, and a Ferrers function for the bar. In some of the galaxies more than one bar was fitted. Lenses were fitted either by Ferrers or Sérsic functions. Faint structures are visible in the residual images after subtracting a bulge model. Such structures can be bars, rings, inner disks or dust lanes. Lenses were identified directly from the images or from the surface brightness profiles: they were included to the parameter fitting of the structure components and therefore generally do not appear in the residual images.

The identification of lenses is an important part of our classification, and the main lens types are shown in Figure 11. For the galaxies in that figure the structural decompositions are also shown, taken from Laurikainen et al. (2010). Prominent lenses, like the one in NGC 2902, are directly visible in the images. Faint or very extended lenses and ring/lens systems may not be immediately obvious in the images, but can be identified as broad bumps or exponential subsections in the surface brightness profiles (e.g., Laurikainen et al. 2010).

NGC 1533 (Fig. 11) is a good example of a galaxy having an outer ring/lens structure. In the surface brightness profile it is manifested as a Sérsic profile with $n$ parameter smaller than one. In NGC 2902 (Figs. 6, 11), the inner ring/lens (rl) feature is manifested in a similar manner, causing a bump in the surface brightness profile. In NGC 524 (see Figs. 11 and 15), the lenses are weaker and appear as exponential subsections in the surface brightness profile.

NGC 524 is one of the best examples of a largely face-on (L)SA(l, nl) system, others being NGC 5846 (Fig. 5) and 5898 (see Fig. 5), with related examples being NGC 1411 (see Fig. 16) and 7192 (Fig. 15). Our image of NGC 1411 is not deep enough to detect the outer lens, seen in the dVA image in the optical region. In the decomposition of NGC 524, the inner (l) and nuclear (nl) lenses are fitted by Ferrers functions. NGC 2983 (Figs. 11, 14, 16) is an example of a barred galaxy having an outer lens (L), and also a bar lens (bl).

In Figure 12, images and structural decompositions are shown for NGC 4459 and NGC
4696. In visual classification these galaxies are ellipticals, but the surface brightness profiles show perfect exponential shapes, which changes the classification into S0. For these galaxies we have also $B - K$ colour maps (H. Salo et al. 2011, in preparation), where the lenses can be identified as colour changes in the interface regions between lenses and disks.

In our classification we do not code ovals as a distinct morphological feature, because they are often difficult to distinguish from lenses. Ovals are global deviations from an axisymmetric shape in galactic disks (see Kormendy & Kennicutt 2004 and Buta 2011). In isophotal and Fourier analysis they appear in a similar manner as bars (with higher Fourier modes, see Laurikainen et al. 2007), but with lower ellipticities. In contrast to lenses, they have less shallow surface brightness distributions.

5.3.2 Comparison with Kormendy et al. (2009)

We have five galaxies in common with the sample of Kormendy et al. (2009), who studied mainly ellipticals and Sph type spheroidals, but whose sample also includes some bright S0s. The common galaxies are NGC 4382, 4472, 4552 and 4649 (Fig. 5), and NGC 4459 (Fig. 12), which were classified as ellipticals (mainly E2) by Kormendy et al., and as S0s by us. They are S0s also in the classification by Sandage & Tammann (1981). For the last four galaxies the decompositions by Laurikainen et al. (2010) have shown that the galaxies can be fitted by a Sérsic bulge and an exponential disk. In NGC 4649 a lens was also identified by us. Except for NGC 4459, Kormendy et al. report these galaxies as ellipticals that miss light in the nuclear regions.

NGC 4382 is peculiar and therefore difficult to classify. Kormendy et al. showed that the galaxy has extra light at intermediate radii above a single Sérsic fit, and also distorted isophotes. However, in their view the extra light cannot be associated with a large-scale disk as is typical for S0s. The galaxy has shells/ripples, which is why Kormendy et al. interpreted it as a merger remnant that has not yet fully settled into an equilibrium. The reason why we consider it to be a disk galaxy and not an elliptical, is the detection of dispersed spiral arm segments, but the exponential nature of the outer profile is not clear. However, there are other S0s with shells/ripples which do have clear extended exponential disks. Such galaxies are, for example, NGC 2782 and NGC 7585 (Fig. 5).
6 DIMENSIONS OF THE STRUCTURES

The dimensions, orientations (PA), and minor-to-major axis ratios (q) of the structure components in our classification were measured, and are given for rings and lenses in Table 5, and for bars in Table 6. The dimensions of the structure components are semi-major axis lengths. To measure the rings and lenses the following strategy was used: after displaying the image rebinned by a factor of two, the classified features were mapped visually, at least three times in succession. If a feature is a clear ring, the cursor was used with IRAF routine TVMARK to outline the ridge-line. If the feature is a lens, oval, or a bar, the edge was mapped instead. After obtaining x,y coordinates of the feature’s location mapped in azimuth, an ellipse-fitting program was used to fit the points to get the central coordinates, the position angle of the major axis, the major and minor axis radii, and the axis ratio. As an illustration of our strategy the fitted ellipses for four features superimposed on the galaxy image are shown for NGC 1543 in Figure 13. For this particular galaxy the nuclear bar is also shown. Similar figures for the complete sample are available in electronic form (address given by MNRAS; [http://cdsarc.u-strasbg.fr/cats](http://cdsarc.u-strasbg.fr/cats)).

For measuring bar lengths three methods were used: (1) they were estimated visually by marking the outskirts of the bar and drawing an ellipsoid to that distance (r\textsubscript{vis} in Table 6). A line was also drawn along the bar major axis which gave a visual estimate of the bar orientation. (2) Radial profiles of the ellipticities were used: bar length was taken to be the radial distance where the maximum ellipticity in the bar region appeared (following, e.g., Wozniak & Pierce 1991; Wozniak et al. 1995; r\textsubscript{ell} in Table 6). (3) As a third estimate, the bar length was taken to be (Erwin & Sparke 2003):

\[ r_L = r_{\text{ell}} + (r_{\text{ellmin}} - r_{\text{ell}})/2, \]

where \( r_{\text{ellmin}} \) is the radial distance where the first minimum appears after the ellipticity maximum in the bar region. In galaxies with complicated morphological structures no minimum appears after the maximum ellipticity; in those cases no \( r_L \) is given. \( r_{\text{ell}} \) is not given if the ellipticity maximum was very broad, and also when the bar orientation in respect of the disk orientation was not favorable.

This is the case, for example for NGC 3384 (Figs. 5 and 13 in electronic form), having a bar perpendicular to the disk which bar is also inside a lens. As a consequence there is a minimum in the ellipticity profile and in the \( b4 \)-profile at the edge of the bar, and a maximum in the position angle (this also means that the method based on detecting maxima in the
ellipticity profile miss bars in unfavorable orientation). An other similar case is NGC 4546 (Fig. 5, electronic Fig. 13). If the bars are very weak and appear only in the unsharp masks or in the residual images, only visual estimation of the length can be given. Typically \( r_{\text{vis}} \) is close to \( r_{\text{ell}} \), whereas \( r_L \) gives an upper limit for bar length. The standard deviations given in column 7 of Table 6 were calculated for \( r_{\text{vis}} \) and \( r_{\text{ell}} \). The bar orientation is generally the position angle near the ellipticity maximum in the bar region, but for very weak bars, bars seen inside prominent lenses, or in unfavorable viewing angle, the position angle from ellipse fitting could not be used. For those galaxies visually estimated bar orientation is given. Visually estimated orientation and those obtained from ellipse fitting generally agree well, the variations typically being around 2 degrees.

7 DISCUSSION

It has been suggested that galactic disks are primary components of galaxy formation, and that their surface brightness distribution reflects the specific angular momentum distribution of protogalaxies (e.g. Fall & Efstathiou 1980; Dutton & van den Bosch 2009). There can also be angular momentum exchange between material at different radii, in which case the exponential surface brightness distribution is a result of disk viscosity (Lin & Pringle 1987). Bosma (1983) suggested that lenses might be primary components formed soon after the disk formation: the outer edges of lenses may have formed when the initial amount of gas suddenly dropped and star formation abruptly ceased. Lenses may also form by disk instabilities in a similar manner as bars (Athanassoula 1983).

On the other hand, in the hierarchical picture of galaxy formation present-day galactic disks are merger-built structures, which have been significantly restructured in galaxy collisions (White & Rees 1978; Kauffmann et al. 1999). It has been suggested that even up to \( \sim 50\% \) of all spiral disks might come from disk rebuilding from recent mergers, the other half of the disks being formed in some earlier mergers (Hammer et al. 2009). If S0s are descendants of these spirals, it needs to be understood how the multi-component bar/lens structures that we find in up to 25\% of the S0s were formed and maintained. The statistics and a more thorough discussion of possible formative processes of lenses will appear in forthcoming papers. Here we give only tentative examples of possible morphological sequences of lens formation, and discuss possible candidates of S0\(_e\) galaxies.
7.1 Morphological evidence of lens formation?

1. *Lenses might be highly evolved star forming zones or highly evolved stellar rings* (Fig. 14a). The upper panels show the full images, whereas the lower panels show the inner regions of the residual images, obtained after subtracting the bulge models from the original images, for NGC 3998 and NGC 4203. In this scenario, gas is used by star formation in the disk, leading to a dynamical heating so that the spiral arms disappear, first in the outer disk (NGC 7371). However, in the presence of a weak bar some of the material in the spiral arms may be trapped into the resonances of the bar before all the gas is consumed. Consequently, a ring or a double ring may form outside the bar (NGC 3998). When the rest of the gas is consumed and the inner disk is dynamically heated, the rings are expected to lose their identity and a lens forms (NGC 4203). Notice that in NGC 4203 the lens clearly has a larger radius than the bar. In [Laurikainen et al. (2009)](#), NGC 3998 was interpreted as a possible candidate of bar destruction in a spiral galaxy that was formerly barred.

2. The sequence NGC 5953 -> NGC 7742 -> NGC 7213 (Fig. 14b) is similar to the sequence above, except that the galaxies have no bars. NGC 5953 has prominent flocculent spiral arms in the inner part of the disk. If there is enough gas in these spiral arms a starburst may occur, leading to a rapid increase in the stellar mass, which may take the form of a lens with the dimension of the current extension of the spiral arms. As an intermediate stage the spirals may take the form of rings, which is clear in NGC 7742 (the ring in this galaxy is counter-rotating; de Zeeuw et al. 2002), and to some extent also in NGC 7213.

3. *Lenses might be triggered by bars*, which is illustrated in Figure 14c. Bars are known to excite resonance rings, which can be full classical rings, or of R′ type rings, or of which NGC 6654 is a good example. When the gas is consumed the disk is dynamically heated, and the ring in NGC 6654 may evolve into a lens, similar to that surrounding the bar of NGC 2983. An alternative progenitor type of NGC 2983 could be NGC 1326 (see Fig. 7), which has a prominent dispersed ring surrounding the bar. When evolved over time the ring may evolve into a lens.

Several stripping mechanisms in spiral galaxies are suggested leading to significant decay of star formation and heating of the disk, which is required while transferring spiral galaxies into S0s. According to numerical simulations (Bekki & Couch 2011) reduced star formation is particularly important among barred interacting galaxies: galaxy interactions trigger gas infall in the bar, leading to repetitive starbursts in the spiral galaxy disk, followed by sub-
sequent fading. However, there exist also non-barred S0s having significant star formation in their inner rings, if which NGC 4138 is an example (Pogge & Eskridge 1993; see also Grouchy et al. 2010). It is possible that galaxy interactions/mergers play an important role also in the formation of these galaxies, in a sense that gas rich small companions might be swallowed by the more massive spiral galaxies. If the galaxy had an inner ring, the gas might have fallen into the potential well of the ring leading to a starburst in the ring. NGC 4138 has also a counter-rotating component (Jore et al. 1996; see also discussion in Comerón at al. 2010), which supports the merger hypothesis. Or alternatively, star forming rings were formed in a process, where vertical satellite collision triggers the star forming ring (Mapelli et al. 2008).

7.2 Prototypical multiple bar/lens structures

The galaxies NGC 1543, NGC 6782 and NGC 3081 are prototypical examples of double barred galaxies (Fig. 15a). The scales in the upper panels are selected to illustrate the main bars and lenses, whereas the lower panels show the nuclear bars and lenses in the same galaxies. NGC 1543 has two bars and lenses surrounding the bars, extending to the same radius as the bar. Intuitively it seems plausible that the lenses were triggered by the bars. NGC 6782 also has two bars, but a ring/lens is surrounding the main bar, and a nuclear ring surrounds the nuclear bar. It is possible that the galaxy also has a weak lens inside the nuclear ring, but that is difficult to verify. NGC 3081 has two weak bars, but in this galaxy the nuclear and inner rings at the outskirts of the two bars are the dominant features. NGC 1317 is also double-barred. We find two nearly orthogonal nuclear rings with a nuclear bar and nuclear lens inside these features.

In Figure 15b, prototypical examples of multiple lenses in non-barred galaxies are shown. The lenses can be intermediate types between rings and lenses as in NGC 3032, or full lenses as in NGC 524 and NGC 7192. As we previously noted, NGC 524 is an example of a non-barred S0 galaxy having a series of circular lenses, the three lenses being clearly visible in this case. Depending on the prominence of the lenses the galaxies are classified either S0° or S0−. These kind of galaxy illustrates interesting borderline cases between S0s and ellipticals: if the lenses are weak the galaxies can be easily misclassified as elliptical galaxies, because their surface brightness profiles are fairly similar. For a full discussion of their nature, kinematic observations are also needed.
There are many questions related to multiple lenses in S0s that need to be answered. For example: (1) are lenses primarily formed soon after the disc formation or are they rather bar-related products of secular evolution in galaxies. (2) If produced mainly by secular evolution, are lenses former bars dissolved into lenses, or more likely structures triggered by bars, for example via ring formation? (3) What are the possible secular evolutionary processes producing the multiple lenses in non-barred galaxies? And finally, (4) How can the multiple bar/lens systems be maintained in the current hierarchical picture of galaxy formation? We discuss these issues in a forthcoming paper.

### 7.3 S0c Galaxies?

Candidates of S0c type galaxies, which group of galaxies was suggested by van den Bergh (1976), were searched from the NIRS0S sample. The appearance of this kind of galaxies having disks with no spiral arms, but bulge-to-total ($B/T$) flux ratios as small as typically found in Sc type spirals, was noticed by Erwin et al. (2003) and Laurikainen et al. (2006, 2010). In Figure 16 we show representative examples of these galaxies. Using the structure decompositions of Laurikainen et al. (2010), and allowing for $B/T \leq 0.1$, 14 S0s were found. This limit was selected because it is the mean $B/T$ value for Sc type spirals, based on the decompositions for spirals, made in a similar manner as for the NIRS0S galaxies. The bulge flux is taken to be that fitted by a Sersic function, whereas the disk flux is a sum of all the disk components, including bars and lenses. All the galaxies in Fig. 16 have a small bulge manifested as a narrow peak in the surface brightness profile, and a prominent extended disk. These galaxies have similar, or at most only slightly fainter total absolute $K$-band magnitudes (for the 9 galaxies in the figure $< M_K > = -23.6$ mag, whereas for the 14 galaxies $< M_K > = -23.9$) than the S0 galaxies in general ($< M_K > \sim -24.0$). The absolute magnitudes were calculated using the $K$-band magnitudes from 2MASS, corrected for Galactic extinction taken from NED, based on the maps of Schlegel, Finkbeiner & Davies (1998), and using galaxy distances from the Catalog of Nearby Galaxies by Tully (1988). A Hubble constant of $H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$ is used.

Of the non-barred galaxies (see Fig. 16) NGC 4138 and NGC 5273 have very narrow peaks in the surface brightness profiles, and either ring or subtle spiral features, which might be manifestations of earlier spiral stage of these galaxies. NGC 1411 has more mass in the central regions, due to a very prominent lens. The three barred galaxies, NGC 3081,
NGC 4429 and NGC 4220 have obviously very small bulges embedded in large disks. The last three galaxies, NGC 2983, NGC 3892 and NGC 5838, are examples of barred galaxies having prominent barlenses, the small bulges embedded inside these lenses. Our example galaxies can be former Sc spirals in which gas is either stripped or consumed by star formation, as originally suggested by Baade (1963) and van den Bergh (1976): due to dynamical heating of the disk the spiral arms have disappeared, but the other disk structures like bars, lenses and rings are still visible, in a similar manner as in spirals.

8 CONCLUSIONS

The NIRS0S atlas of 206 early-type disk galaxies is presented in the Ks-band, including 160 S0-S0/a galaxies. In order to discuss the borderline of S0s with ellipticals and spirals, late-type ellipticals classified as S0s in the RSA, and Sa spirals were also included in the sample. A sub-sample of 185 galaxies forms a magnitude-limited sample, having total magnitudes of $B_T \leq 12.5$ mag and inclinations less than $65^\circ$. The obtained images are deep, typically reaching a surface brightness level of 23.5 mag arcsec$^{-2}$ (exceptions are galaxies having too small FOV). A sub-arcsecond pixel scale ($\sim 0.25''$) was used and the observations were generally carried out in good seeing conditions (FWHM $\sim 1''$). The flux calibrated images are shown in many different scales, optimized to show the multi-component nature of many of the galaxies. In the Atlas panels the radial profiles of the position angle, the ellipticity, and the deviation of the isophotes from perfect ellipticities (b4) are also shown.

A detailed morphological classification was made using the criteria of de Vaucouleurs (1959). Special attention was paid to the recognition of lenses in NIRS0S galaxies, which has been done in more systematic manner than in any of the previous studies. Lenses are coded in a similar manner as nuclear, inner and outer rings were previously coded by Buta et al. (2010). A new lens type called a 'barlens', was also introduced, referring to the intermediate-sized, bulge-looking component that seems prominent in many early-type barred galaxies, presumably forming part of the bar itself. When elongated along the bar it has the appearance of the so called 'boxy bar'. Bar morphology is included in the classification: ansae morphology was detected in 33 bars, and x-shaped bar structure in 9 non-edge-on galaxies.

Besides visual classifications we present also photometric classifications, which means that exponential outer disks or faint inner structures were considered even if they were not directly visible in the images. The faint structures were identified from unsharp masked or
residual images after subtracting a bulge model taken from the structural decompositions of Laurikainen et al. (2010). Our visual and photometric classifications deviate for 42 galaxies: for example, 15 faint bars, outshone by bulges in visual classification, were detected, and 7 elliptical galaxies were moved into the S0 stage. However, the mean Hubble stage in our visual classification in the near-IR is the same as that in the RC3, determined in the optical wavelength range.

We confirm the previous result by Laurikainen et al. (2009) that most early-type disk galaxies have lenses, which we find to be the case in both barred (61%) and non-barred (38%) galaxies. Most importantly, we find that up to 25% of the Atlas galaxies, including the S0-S0/a galaxies, have multiple lenses. However, only six galaxies (4%) have shells or ripples, which are expected to be direct manifestations of recent mergers. The detection of multiple lenses in a large number of S0-S0/a galaxies is a challenge to the hierarchical formative processes of galaxies: it needs to be explained how such lens systems were formed and survived in the merger events that galaxies might have suffered several times in their lifetimes. We discuss tentative morphological sequences of possible formative processes of lenses. Possible candidates of S0c galaxies are shown, which galaxies are expected to be former Sc-type spirals stripped out of gas.

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| Tel.+instrument     | date            | resolution [arcsec/pix] | FOV [arcmin] |
|---------------------|-----------------|-------------------------|--------------|
| **Near-IR:**        |                 |                         |              |
| NOT(2.5m)/NOTCam    | 17-20 Jan 2003  | 0.233                   | 4.0 x 4.0    |
| NOT(2.5m)/NOTCam    | 28-29 Sept 2003 | 0.233                   | 4.0 x 4.0    |
| NOT(2.5m)/NOTCam    | 08-11 Jan 2004  | 0.233                   | 4.0 x 4.0    |
| NTT(3.6m)/SOFI      | 20-23 Dec 2004  | 0.288                   | 4.9 x 4.9    |
| NOT(2.5m)/NOTCam    | 19-23 May 2005  | 0.233                   | 4.0 x 4.0    |
| WHT(4.2m)/LIRIS     | 11-14 May 2006  | 0.250                   | 4.3 x 4.3    |
| NTT(3.6m)/SOFI      | 17-21 July 2006 | 0.288                   | 4.9 x 4.9    |
| WHT(4.2m)/LIRIS     | 03-05 March 2007| 0.250                   | 4.3 x 4.3    |
| CTIO(4m)            | 27-29 Oct 2007  | 0.306                   | 5.2 x 5.2    |
| TNG(3.6m)/NICS      | 17-19 Nov 2007  | 0.252                   | 4.2 x 4.2    |
| TNG(3.6m)/NICS      | 16-17 Jun 2008  | 0.252                   | 4.2 x 4.2    |
| NTT(3.6m)/SOFI      | 10-14 Jun 2008  | 0.288                   | 4.9 x 4.9    |
| WHT(4.2m)/LIRIS     | 02-03 Dec 2008  | 0.250                   | 4.3 x 4.3    |
| TNG(3.6m)/NICS      | 10-12 Apr 2009  | 0.252                   | 4.2 x 4.2    |
| KPNO(2.1m)/FLMN     | 04-07 May 2009  | 0.606                   | 19.5 x 19.5  |
Table 2. The image quality. Galaxy identification and telescope are indicated, together with Full-Width at Half-Maximum (FWHM) and estimated 1-σ sky variation ($\sigma_{\text{sky}}$). $\Delta \mu_0$ indicates the difference of the zeropoint derived for the galaxy based on 2MASS $m_{14}$, with respect to the campaign mean for the same airmass, $\Delta k_{20}$ and $\Delta k_{\text{ext}}$ indicate the differences of the measured isophotal magnitudes with respect to 2MASS values.

| Galaxy | telescope | FWHM [arcsec] | $\sigma_{\text{sky}}$ [mag/arcsec$^2$] | $\Delta \mu_0$ [mag] | $\Delta k_{20}$ [mag] | $\Delta k_{\text{ext}}$ [mag] |
|--------|-----------|---------------|-----------------------------------|----------------|----------------|----------------|
| 2MASS  |           |               |                                   |                |                |                |
| ESO 137-10 | NTT | 1.25          | 22.7                             | 0.06           | -0.13         | -0.15         |
| ESO 337-10 | NTT | 0.89          | 22.2                             | -0.00         | -0.02         | 0.00          |
| ESO 208-21 | NTT | 0.63          | 22.2                             | 0.11           | -0.03         | -0.04         |
| IC 1392 | TNG     | 0.97          | 22.9                             | -0.06         | -0.04         | -0.03         |
| IC 4214 | NTT     | 0.84          | 21.9                             | -0.02         | -0.02         | 0.01          |
| IC 4329 | NTT     | 0.79          | 22.4                             | -0.01         | -0.02         | 0.00          |
| IC 4889 | CTIO    | 0.83          | 21.9                             | -0.01         | 0.00          | 0.03          |
| IC 4991 | NTT     | 0.75          | 21.9                             | 0.22           | -0.08         | -0.06         |
| IC 5240 | NTT     | 1.15          | 22.3                             | 0.14           | -0.10         | -0.13         |
| IC 5267 | CTIO    | 1.00          | 21.7                             | 0.06           | 0.02          | 0.15          |
| IC 5328 | NTT     | 1.06          | 23.3                             | -0.14         | -0.05         | -0.02         |
| IC 1161a | NOT     | 0.82          | 21.4                             | 0.06           | 0.03          | 0.12          |
| IC 1201 | NOT     | 1.06          | 21.0                             | 0.06           | 0.00          | -0.00         |
| IC 1302 | NOT     | 1.16          | 21.2                             | 0.01           | -0.07         | -0.06         |
| IC 1317 | NTT     | 0.67          | 22.1                             | 0.00           | -0.03         | -0.05         |
| IC 1326 | NTT     | 0.72          | 22.0                             | -0.00         | -0.05         | -0.03         |
| IC 1344 | CTIO    | 0.99          | 22.1                             | -0.02         | 0.03          | 0.14          |
| IC 1350 | NTT     | 0.75          | 22.5                             | 0.13           | 0.01          | 0.10          |
| IC 1351 | NTT     | 0.89          | 22.3                             | -0.06         | 0.05          | 0.11          |
| IC 1371 | CTIO    | 1.03          | 22.0                             | -0.01         | 0.00          | 0.00          |
| IC 1380 | CTIO    | 1.14          | 22.0                             | 0.00           | -0.01         | 0.07          |
| IC 1387 | NTT     | 0.69          | 21.8                             | 0.01           | 0.02          | 0.02          |
| IC 1389 | CTIO    | 1.08          | 22.0                             | -0.01         | 0.00          | 0.05          |
| IC 1400 | NOT     | 1.07          | 21.7                             | -0.01         | 0.00          | 0.03          |
| IC 1411 | NTT     | 0.81          | 22.2                             | 0.02           | -0.00         | -0.01         |
| IC 1415 | NOT     | 1.05          | 21.5                             | 0.07           | 0.00          | 0.00          |
| IC 1440 | NOT     | 1.00          | 21.7                             | -0.06         | 0.00          | 0.01          |
| IC 1452 | NOT     | 1.05          | 21.8                             | -0.04         | -0.01         | 0.02          |
| IC 1512 | NTT     | 0.63          | 22.2                             | -0.02         | -0.13         | -0.10         |
| IC 1533 | NTT     | 0.70          | 22.2                             | 0.01           | -0.00         | -0.03         |
| IC 1537 | CTIO    | 0.98          | 21.8                             | 0.03           | -0.04         | 0.01          |
| IC 1543 | CTIO    | 1.17          | 21.9                             | 0.01           | 0.04          | 0.18          |
| IC 1553 | NTT     | 1.01          | 22.7                             | 0.01           | 0.02          | 0.07          |
| IC 1574 | NTT     | 0.75          | 21.8                             | -0.00         | 0.01          | 0.04          |
| IC 1617 | CTIO    | 1.01          | 22.0                             | -0.04         | -0.04         | -0.05         |
| IC 2196 | NOT     | 1.40          | 21.4                             | 0.00           | 0.00          | 0.00          |
| IC 2217 | NOT     | 1.23          | 21.2                             | -0.05         | 0.04          | 0.04          |
| IC 2273 | NOT     | 1.33          | 21.9                             | -0.04         | 0.02          | 0.00          |
| NGC 2292b | TNG   | 1.39          | 22.5                             |                |                |                |
| NGC 2293b | TNG   | 1.39          | 22.5                             |                |                |                |
| NGC 2300 | TNG     | 1.92          | 22.7                             | -0.01         | 0.03          | 0.06          |
| NGC 2380 | TNG     | 1.31          | 22.6                             | -0.06         | 0.03          | 0.08          |
| NGC 2460 | NOT     | 1.00          | 21.7                             | 0.04           | -0.01         | -0.01         |
| NGC 2523 | NOT     | 1.14          | 21.9                             | -0.04         | -0.13         | -0.09         |
| NGC 2549 | NOT     | 1.00          | 21.2                             | -0.07         | -0.02         | -0.00         |
| NGC 2655 | TNG     | 1.16          | 22.6                             | -0.03         | -0.03         | -0.04         |
| NGC 2681 | NOT     | 1.15          | 21.8                             | 0.01           | 0.04          | 0.03          |
| NGC 2685 | WHIT    | 0.62          | 22.4                             | 0.02           | -0.07         | -0.03         |
| Galaxy   | telescope | FWHM  | $\sigma_{sky}$ | $\Delta \mu_0$ | $\Delta k_0$ | $\Delta k_{ext}$ |
|----------|-----------|-------|---------------|----------------|-------------|--------------|
|          |           | [arcsec] | [mag/arcsec$^2$] | [mag] | [mag] | [mag] |
| NGC 2782 | WHT       | 1.12   | 22.7          | -0.09 | 0.01  | 0.04 |
| NGC 2787 | NOT       | 1.10   | 21.3          | 0.05  | -0.02 | -0.02 |
| NGC 2855 | NOT       | 0.93   | 21.7          | 0.01  | -0.03 | -0.00 |
| NGC 2859 | NOT       | 0.93   | 21.7          | -0.03 | -0.03 | 0.13 |
| NGC 2880 | WHT       | 0.93   | 22.9          | -0.06 | 0.03  | 0.07 |
| NGC 2902 | WHT       | 1.12   | 22.8          | 0.14  | 0.01  | 0.04 |
| NGC 2911 | NOT       | 0.79   | 21.0          | 0.05  | 0.01  | 0.04 |
| NGC 2950 | NOT       | 0.98   | 21.4          | -0.02 | -0.03 | -0.01 |
| NGC 2983 | NOT       | 0.98   | 21.7          | -0.03 | -0.03 | 0.00 |
| NGC 3032 | WHT       | 1.00   | 23.6          | -0.01 | 0.02  | 0.05 |
| NGC 3081 | NTT       | 0.63   | 22.0          | -0.00 | -0.02 | -0.06 |
| NGC 3100J| NTT       | 0.83   | 23.0          | -0.08 | -0.14 |       |
| NGC 3166 | WHT       | 1.00   | 22.8          | -0.01 | -0.02 | -0.03 |
| NGC 3169 | WHT       | 1.08   | 23.1          | -0.03 | 0.01  | 0.00 |
| NGC 3226$^b$ | KPNO | 2.12   | 23.0          |       |       |       |
| NGC 3227$^b$ | KPNO | 2.12   | 23.0          |       |       |       |
| NGC 3245 | WHT       | 1.12   | 22.6          | -0.00 | -0.01 | -0.03 |
| NGC 3358 | NTT       | 0.69   | 21.8          | 0.00  | -0.04 | 0.06 |
| NGC 3384 | WHT       | 0.55   | 23.1          | 0.02  | -0.03 | -0.06 |
| NGC 3412 | TNG       | 1.89   | 22.7          | 0.04  | 0.09  | 0.09 |
| NGC 3414 | WHT       | 0.88   | 22.3          | 0.00  | 0.01  | 0.03 |
| NGC 3489 | WHT       | 1.25   | 23.2          | 0.01  | -0.04 | -0.06 |
| NGC 3516 | NOT       | 0.91   | 22.1          | -0.05 | -0.05 | -0.01 |
| NGC 3607 | WHT       | 1.20   | 22.7          | 0.11  | 0.02  | -0.03 |
| NGC 3619 | KPNO      | 2.06   | 21.4          | 0.03  | 0.10  | 0.14 |
| NGC 3626 | NOT       | 0.84   | 21.8          | 0.05  | 0.04  | 0.07 |
| NGC 3665 | NOT       | 1.12   | 22.0          | 0.00  | -0.02 | 0.00 |
| NGC 3706 | NTT       | 0.81   | 22.2          | -0.03 | -0.03 | 0.01 |
| NGC 3718 | TNG       | 1.13   | 23.2          | 0.01  | 0.05  | 0.08 |
| NGC 3729 | NOT       | 1.33   | 21.7          | 0.03  | 0.00  | 0.16 |
| NGC 3892 | NTT       | 1.29   | 22.4          | 0.03  | 0.02  | 0.03 |
| NGC 3900 | NOT       | 0.91   | 22.3          | -0.00 | -0.01 | -0.01 |
| NGC 3941 | NOT       | 0.89   | 21.8          | -0.01 | 0.03  | 0.05 |
| NGC 3945 | WHT       | 1.08   | 22.9          | -0.04 | -0.04 | -0.07 |
| NGC 3998 | WHT       | 1.02   | 23.0          | -0.03 | -0.00 | 0.00 |
| NGC 4073 | TNG       | 1.46   | 22.7          | -0.03 | -0.02 | 0.02 |
| NGC 4105$^b$ | NTT | 1.12   | 22.5          |       |       |       |
| NGC 4106$^b$ | NTT | 1.12   | 22.5          |       |       |       |
| NGC 4138 | NOT       | 1.04   | 21.4          | -0.00 | -0.01 | 0.01 |
| NGC 4143 | TNG       | 1.15   | 23.1          | 0.04  | -0.01 | -0.02 |
| NGC 4150 | WHT       | 1.12   | 23.1          | -0.01 | 0.13  | 0.17 |
| NGC 4203 | WHT       | 1.33   | 22.8          | -0.02 | -0.03 | -0.06 |
| NGC 4220 | WHT       | 1.05   | 22.7          | 0.02  | -0.02 | -0.05 |
| NGC 4245 | WHT       | 1.00   | 23.1          | 0.00  | -0.02 | -0.01 |
| NGC 4262 | WHT       | 0.88   | 22.9          | 0.01  | -0.04 | -0.05 |
| NGC 4267 | TNG       | 0.89   | 23.2          | -0.00 | -0.02 | -0.01 |
| NGC 4281 | TNG       | 1.13   | 22.8          | -0.04 | -0.02 | -0.03 |
| NGC 4293 | WHT       | 1.52   | 22.6          | -0.03 | -0.05 | 0.01 |
| NGC 4314 | WHT       | 0.82   | 22.8          | -0.03 | -0.07 | -0.07 |
| NGC 4339 | TNG       | 1.51   | 22.9          | -0.01 | 0.02  | 0.05 |
| NGC 4340 | NOT       | 1.05   | 21.3          | 0.12  | 0.02  | 0.03 |
| NGC 4350 | TNG       | 1.13   | 22.7          | -0.01 | 0.02  | 0.05 |
| NGC 4369 | NOT       | 1.05   | 21.5          | -0.11 | 0.01  | 0.03 |
| NGC 4371 | TNG       | 1.10   | 23.4          | -0.02 | -0.00 | 0.01 |
| NGC 4373 | NTT       | 1.17   | 22.3          | 0.08  | -0.07 | 0.02 |
| NGC 4378 | NTT       | 1.17   | 22.5          | -0.10 | -0.01 | 0.01 |
| NGC 4382 | KPNO      | 1.58   | 21.3          | 0.02  | 0.13  | 0.22 |
| NGC 4406 | KPNO      | 1.70   | 21.0          | 0.02  | 0.14  | 0.40 |
| NGC 4424 | WHT       | 1.52   | 22.4          | 0.03  | 0.01  | 0.04 |
| NGC 4429 | WHT       | 1.17   | 22.5          | 0.03  | -0.02 | -0.02 |
| NGC 4435 | WHT       | 1.62   | 22.9          | -0.01 | -0.29 | -0.38 |
| NGC 4457 | WHT       | 1.40   | 22.5          | -0.03 | -0.04 | -0.02 |
**Galaxy** | **telescope** | **FWHM [arcsec]** | $\sigma_{\text{sky}}$ [mag/arcsec$^2$] | $\Delta\mu_0$ [mag] | $\Delta k_{20}$ [mag] | $\Delta k_{\text{ext}}$ [mag]
---|---|---|---|---|---|---
NGC 4459 | WHT | 0.68 | 23.0 | -0.01 | -0.09 | -0.09
NGC 4472 | KPNO | 2.30 | 21.2 | 0.04 | 0.15 | 0.32
NGC 4474$^a$ | TNG | 1.36 | 22.1 | 0.02 | 0.02 | 0.04
NGC 4477 | WHT | 1.00 | 23.5 | -0.02 | 0.01 | 0.00
NGC 4503 | TNG | 1.26 | 22.6 | 0.06 | 0.01 | 0.00
NGC 4531 | WHT | 1.50 | 22.2 | 0.02 | -0.04 | -0.05
NGC 4546 | WHT | 1.00 | 23.5 | -0.01 | -0.01 | -0.00
NGC 4552 | KPNO | 2.12 | 21.2 | 0.04 | 0.13 | 0.29
NGC 4578 | TNG | 1.26 | 22.8 | 0.01 | -0.04 | -0.03
NGC 4596 | WHT | 1.00 | 22.9 | 0.02 | 0.02 | 0.07
NGC 4608 | NOT | 1.12 | 21.8 | -0.21 | 0.02 | 0.10
NGC 4612 | TNG | 0.98 | 23.4 | 0.01 | -0.01 | -0.01
NGC 4638 | TNG | 2.39 | 22.9 | 0.02 | 0.07 | 0.11
NGC 4643 | NOT | 0.98 | 21.5 | 0.03 | -0.03 | -0.00
NGC 4649 | KPNO | 2.12 | 21.5 | 0.01 | 0.14 | 0.29
NGC 4665 | TNG | 2.02 | 23.0 | 0.02 | 0.09 | 0.15
NGC 4691 | TNG | 1.59 | 22.9 | 0.01 | 0.01 | 0.06
NGC 4694 | WHT | 0.97 | 22.8 | -0.02 | -0.08 | -0.09
NGC 4696 | NTT | 1.14 | 22.6 | -0.25 | -0.01 | 0.03
NGC 4754 | WHT | 1.25 | 22.6 | 0.01 | 0.03 | -0.03
NGC 4772 | WHT | 1.55 | 22.7 | 0.01 | -0.02 | -0.03
NGC 4880 | WHT | 1.29 | 22.7 | 0.01 | -0.09 | -0.21
NGC 4914 | TNG | 1.39 | 22.6 | -0.01 | -0.07 | -0.07
NGC 4976 | NTT | 1.02 | 22.0 | 0.03 | 0.06 | 0.18
NGC 4984 | NOT | 1.51 | 21.5 | 0.06 | 0.01 | -0.01
NGC 5026 | NTT | 0.83 | 21.9 | 0.02 | -0.02 | 0.01
NGC 5078 | KPNO | 1.82 | 21.0 | -0.00 | 0.04 | 0.09
NGC 5087 | NTT | 1.06 | 22.5 | 0.04 | -0.01 | 0.03
NGC 5101 | AAT | 1.39 | 20.4 | 0.02 | 0.04 | 0.04
NGC 5121 | NTT | 0.86 | 22.6 | 0.00 | -0.02 | -0.02
NGC 5206 | NTT | 0.89 | 22.1 | 0.05 | -0.00 | 0.16
NGC 5266 | NTT | 1.03 | 22.5 | 0.03 | -0.02 | -0.01
NGC 5273 | TNG | 1.49 | 23.1 | 0.06 | 0.01 | -0.01
NGC 5308 | WHT | 1.00 | 22.5 | 0.03 | -0.03 | -0.04
NGC 5333 | NTT | 0.37 | 22.1 | -0.05 | -0.05 | -0.05
NGC 5352$^b$ | TNG | 1.26 | 22.2 | 0.02 | 0.01 | 0.18
NGC 5354$^b$ | TNG | 1.26 | 23.2 | 0.02 | 0.01 | 0.18
NGC 5365 | NTT | 0.66 | 22.2 | -0.05 | 0.02 | 0.12
NGC 5377 | TNG | 1.18 | 23.2 | -0.00 | 0.00 | 0.00
NGC 5419 | NTT | 1.02 | 22.3 | -0.10 | -0.04 | -0.02
NGC 5448 | WHT | 0.95 | 22.8 | -0.02 | 0.00 | -0.01
NGC 5473 | NOT | 0.82 | 21.6 | -0.14 | 0.00 | 0.00
NGC 5485 | NOT | 0.93 | 21.5 | -0.01 | -0.04 | -0.04
NGC 5493 | WHT | 1.36 | 22.4 | -0.00 | 0.00 | 0.01
NGC 5631 | NOT | 0.82 | 21.9 | 0.10 | 0.00 | 0.00
NGC 5638$^b$ | WHT | 0.80 | 23.1 | 0.00 | -0.06 | -0.06
NGC 5701 | TNG | 1.13 | 23.2 | 0.00 | -0.06 | -0.06
NGC 5728 | NTT | 0.95 | 21.8 | 0.09 | -0.04 | 0.01
NGC 5750 | NTT | 0.72 | 22.2 | -0.02 | -0.04 | -0.09
NGC 5838 | WHT | 1.62 | 22.8 | -0.01 | -0.03 | -0.02
NGC 5846 | NTT | 0.72 | 20.6 | 0.41 | -0.23 | -0.36
NGC 5898 | NTT | 0.81 | 22.2 | -0.06 | -0.01 | 0.03
NGC 5953 | WHT | 1.12 | 22.7 | 0.02 | 0.01 | 0.23
NGC 5982 | NOT | 0.82 | 21.7 | -0.05 | -0.13 | -0.17
NGC 6012 | KPNO | 2.42 | 21.4 | -0.06 | 0.03 | 0.11
NGC 6340 | NOT | 0.72 | 21.6 | 0.06 | 0.13 | 0.23
NGC 6407 | NTT | 0.66 | 22.2 | -0.04 | -0.00 | 0.02
NGC 6438$^b$ | NTT | 1.44 | 22.4 | 0.01 | 0.13 | 0.19
NGC 6482 | KPNO | 1.39 | 21.2 | 0.01 | 0.13 | 0.19
NGC 6646 | NOT | 0.82 | 21.9 | 0.23 | 0.04 | 0.08
NGC 6654 | NOT | 1.00 | 21.8 | 0.06 | 0.11 | 0.17
NGC 6684 | NTT | 0.81 | 22.2 | -0.05 | -0.11 | -0.12
NGC 6703 | NOT | 1.10 | 22.0 | -0.11 | 0.06 | 0.11
| Galaxy   | telescope | FWHM [arcsec] | $\sigma_{\text{sky}}$ [mag/arcsec$^2$] | $\Delta \mu_0$ [mag] | $\Delta k_{20}$ [mag] | $\Delta k_{\text{ext}}$ [mag] |
|----------|-----------|---------------|-------------------------------------|---------------------|---------------------|---------------------|
| NGC 6782 | NTT       | 0.63          | 22.3                                | -0.05              | -0.05              | -0.06              |
| NGC 6861 | NTT       | 0.66          | 22.4                                | -0.05              | -0.03              | -0.00              |
| NGC 6958 | CTIO      | 0.91          | 22.0                                | -0.03              | 0.01               | 0.06               |
| NGC 7029 | NTT       | 0.69          | 22.4                                | -0.07              | -0.07              | -0.05              |
| NGC 7049 | NTT       | 0.72          | 22.4                                | 0.06               | -0.01              | 0.07               |
| NGC 7079 | NTT       | 0.66          | 22.4                                | -0.07              | -0.04              | -0.09              |
| NGC 7098 | NTT       | 0.84          | 21.7                                | 0.01               | -0.21              | -0.22              |
| NGC 7192 | NTT       | 0.81          | 22.1                                | -0.05              | 0.06               | 0.11               |
| NGC 7213 | NTT       | 0.75          | 22.3                                | -0.03              | -0.05              | -0.06              |
| NGC 7217 | KPNO      | 2.42          | 21.2                                | -0.01              | 0.13               | 0.18               |
| NGC 7332 | WHT       | 1.00          | 22.9                                | -0.02              | -0.02              | -0.03              |
| NGC 7339 | WHT       | 0.95          | 22.1                                | -0.00              | -0.04              | -0.05              |
| NGC 7371 | NTT       | 0.60          | 22.3                                | -0.05              | 0.04               | 0.06               |
| NGC 7377 | NOT       | 0.91          | 21.0                                | -0.04              | 0.00               | 0.02               |
| NGC 7457 | WHT       | 0.93          | 22.6                                | -0.01              | -0.06              | -0.07              |
| NGC 7585 | NTT       | 1.11          | 22.7                                | 0.05               | 0.07               | 0.15               |
| NGC 7727 | NTT       | 0.90          | 22.8                                | 0.01               | -0.01              | 0.06               |
| NGC 7742 | NOT       | 0.77          | 21.1                                | 0.03               | -0.01              | 0.01               |
| NGC 7743 | NOT       | 0.82          | 20.9                                | 0.24               | 0.09               | 0.08               |
| NGC 7796 | NTT       | 0.72          | 22.3                                | -0.05              | -0.01              | 0.02               |

*a* 2MASS data missing - use campaign zeropoint

*b* interacting - use campaign zeropoint

*c* 2MASS data inconsistent - use campaign zeropoint
### Table 3. Visual classification in the near-IR, compared with optical classification (RC3 and RSA).

| Galaxy     | type (2.2μm) | type (RC3) | type (RSA) | T (2.2μm) | T (RC3) |
|------------|--------------|------------|------------|-----------|---------|
| IC 1392    | E(b)4/S0−   | L...^-     | -1.0       | -4.0      | -3.0    |
| IC 4214    | (R_1)SAB(R_1,n)0+ | PSBR2-     | -1.0       | -3.0      |         |
| IC 4329    | SA0° shells/ripples | LXS-..     | S01(5)     | -2.0      | -3.0    |
| IC 4889    | SA0      | E.5+..     | S01/2(5)   | -5.0      | -5.0    |
| IC 4991    | coreE      | LAR0?P     | -5.0       | -5.0      | -2.0    |
| IC 5240    | SB(r)/a    | SBR1-..    | S00(r)     | -1.0      | -1.0    |
| IC 5267    | (R)LSA(l,0)/a | SA0..      | S00(r)     | 0.0       | -2.0    |
| IC 5318    | SA0-       | E.4-..     | S01(3)     | -3.0      | -5.0    |
| ESO 208-21 | E±/S0+     | LXT-..     | E5         | -3.0      | -3.3    |
| ESO 137-10 | SA0+       | PLXS-..    | -1.0       | -2.7      |         |
| ESO 337-10 | E^+3/S0A-  | L.?..      | -3.5       |         |         |
| NGC 040    | SA0-       | LXT-?      | -3.0       | -3.0      |         |
| NGC 0474   | (RL)SAB0/a shells/ripples | LSA0..    | RS0/a      | 0.0       | -2.0    |
| NGC 0484   | SA0-       | L.A..      | -3.0       | -3.0      |         |
| NGC 0507   | (L)SA0-    | LAR0-      | -1.0       | -2.0      |         |
| NGC 0524   | (L)SA(l,n)0° | LAT+..     | S02/Sa     | -2.0      | -1.0    |
| NGC 0584   | SAB(l)0°   | E.4-..     | S01(3,5)   | -3.0      | -5.0    |
| NGC 0678   | (R')SAB(rs,nl)a | SXSI-    | Sa         | 1.0       | 1.0     |
| NGC 0890   | SA0       | LXR-$\lambda$ | S00(5)     | -3.0      | -3.0    |
| NGC 0936   | SB(g,b)0+  | LBT+..     | SB2/3/SBa  | -1.0      | -1.0    |
| NGC 1022   | SAB(r1,b)l/a | PSBS1-..   | SBa(r) pec | 1.0       | 1.0     |
| NGC 1079   | (RL)SAB(r,b)0+ | RSXTP0-  | Sa(s)      | -1.0      | 0.0     |
| NGC 1101   | SAB(r)/0°  | L.....     | Sa         | -2.0      | -2.0    |
| NGC 1201   | SAB(r1,l,mb)0° | LAR0*     | S01(6)     | -2.0      | -2.0    |
| NGC 1309   | SAB(r)/0°  | RSBRO-     | Sa         | -1.0      | 0.0     |
| NGC 1317   | SAB(r1,lr1,nr2,nl,mb)0/a | SXR1-.. | 0.0       | 1.0       |         |
| NGC 1326   | (R)SAB(r,nr,nb,bl)0+ | RLBR+.. | RSBa     | -1.0      | -1.0    |
| NGC 1344   | SA0-       | E.5..      | S01(5)     | -3.0      | -5.0    |
| NGC 1350   | (R')SABb(g,b)l/a | PSBR2.. | Sa(r)      | 1.0       | 1.0     |
| NGC 1351   | E6        | L.A.-P*    | S01(6)/E6  | -5.0      | -3.0    |
| NGC 1371   | (RL)SAB(rs,l)l/a | SXT1-.. | Sa(s)      | 1.0       | 1.0     |
| NGC 1380   | SAB(s)0/a  | L.A..      | S02(7)/Sa  | 0.0       | -2.0    |
| NGC 1387   | SB(rl)0°   | LXS-..     | SB02(pec)  | -3.0      | -3.0    |
| NGC 1389   | SAB(lab)0° | LXS-..     | S01(5)/SB01 | -3.0      | -3.3    |
| NGC 1400   | E°2/S0°   | L.A.-c..   | E1/S01(1)  | -3.5      | -3.0    |
| NGC 1411   | SA(l,n)0°  | LAR-..     | S02(4)     | -2.0      | -3.0    |
| NGC 1415   | (RL)SABb(r3,lr1)0+ | RSX0-.. | Sa/SBa late | -1.0     | 0.0     |
| NGC 1440   | (L)SB(rg,b)l)0° | PLBTO*.. | S01(5)/SB01 | -2.0      | -1.9    |
| NGC 1452   | (R')SBb(r1,l)l/a | PSBR0-.. | Sa(b)      | 1.0       | .4      |
| NGC 1512   | SBa(g,r,mb)l/a | SBR1-.. | SBr(s)I pec | 1.0       | 1.0     |
| NGC 1553   | (RL)SB(b)0°  | L.B-..     | SB02(2)/SBa | -2.0      | -3.0    |
| NGC 1537   | SB(rl)0°   | L.X.-P?    | E6         | -2.0      | -2.5    |
| NGC 1543   | (R)SB(l,nr,nb)0° | RLBS0-.. | RSB02/3(0)/a | -1.0      | -2.0    |
| NGC 1553   | SA(rl,nr,nb)0° | LAR0-.. | S01/2(5) pec | -2.0      | -2.0    |
| NGC 1574   | (L)SB(l)0°   | LAS-.*     | SB02(3)    | -3.0      | -2.7    |
| NGC 1617   | (R')SABa(r)0/a | SBS1-.. | Sa(s)      | 0.0       | 0.0     |
| NGC 2196   | SA(l)      | PSAS1-..   | Sa(s)      | 1.0       | 1.0     |
| NGC 2217   | (R)SB(g,mb,rl)0/a | RLBT+.. | SBa(s)     | 0.0       | -1.0    |
| Galaxy      | type(2.2μm) | type(RC3) | type(RSA) | T(2.2μm) | T(RC3) |
|------------|-------------|-----------|-----------|----------|--------|
| NGC 2273 * | (R)SAB(rs,bl,na) | SBR1*   |           | 1.0      | .5     |
| NGC 2292 * |             | LX0.0P   |           | −5.0     | −2.0   |
| NGC 2293 * | SABa(bl,na) | LXS+P.   |           | 0.0      | −1.0   |
| NGC 2300 * | (R'L)SA(a)0* | LA.0.    | E3        | −2.0     | −2.0   |
| NGC 2380 * | SA(l,na)0*  | LX.0*    |           | −3.0     | −1.7   |
| NGC 2460  | SAB(rs,a)   | SAS1.    | Sab(s)    | 1.0      | 1.0    |
| NGC 2523  | SB(r)ab     | SBB4.    | SBB(r)I   | 2.0      | 4.0    |
| NGC 2549  | SB0.0* sp   | LAR0./   | S0b1/2(7) | −2.0     | −2.0   |
| NGC 2655 *| SAB(s)0/a pec| SXS0..   | Sa pec    | 0.0      | .0     |
| NGC 2681 *| (RL)SAB(ng,ob)0/a | PSXT0.. | Sa        | 0.0      | .0     |
| NGC 2685  | S0*: sp polar ring | RLB.+P. | S0b1(7) pec | −1.0     | −1.0   |
| NGC 2768  | E(d)6       | E.6.*    | S0b1/2(6) | −5.0     | −5.0   |
| NGC 2781 *| (RL)SAB(r,na)0* | LXR+.    | Sa(r)     | −1.0     | −1.0   |
| NGC 2782 *| SA(r,na) pec | SXT1P.   | Sa(s) pec | 1.0      | 1.0    |
| NGC 2787  | SBa(ml,bl)0* | LBR+.    | SBO/a     | −2.0     | −1.0   |
| NGC 2855  | SA(s)0*     | RSAT0..  | Sa(r)     | −2.0     | .0     |
| NGC 2859 *| (R)SABa(l,ml,na,bl)0* | RLBR+. | RSBb2(3) | −1.0     | −1.0   |
| NGC 2880  | SB(r)0*     | LB...    | SBO1      | −3.0     | −3.0   |
| NGC 2902  | SA(2)0*     | LAS0*    | S0b(1)    | −1.0     | −2.0   |
| NGC 2911  | SA0*        | LAS.*P   | S0b2(2) or S0pec | −3.0     | −2.0   |
| NGC 2950  | SBa(l,ml,na)0* | RLBR0.0 | RSBb2/3   | −2.0     | −2.0   |
| NGC 2983  | (L)SBa(s,bl)0* | LBT+.   | SBA SB 1  | −1.0     | −1.0   |
| NGC 3092  | SA(r1,rl2)0* | LXR0..   | S0b1(2)/Sa | −2.0     | −2.0   |
| NGC 3081  | (R1)SAB(r,na)0* | RSX0.0. | SBA(s)    | −1.0     | .0     |
| NGC 3100  | SAB(s)0*    | LX0SP.   |           | −2.0     | −2.0   |
| NGC 3166  | SABa(l,ml,na) | SX0..    | Sa(s)     | −1.0     | .0     |
| NGC 3169  | SA0/a pec   | SAS1P.   | Sb(r)I-II (tides) | 0.0      | 1.0    |
| NGC 3226  | SA0*        | E.2.*P   | S0b(1)    | −3.0     | −5.0   |
| NGC 3227  | SABa(s)     | SX1P.    | Sb(s)III | 1.0      | 1.0    |
| NGC 3245  | (L)SABa(r,ml)0* | LAR0*+ | S0b1(5)   | −2.0     | −2.0   |
| NGC 3358  | (R1)SABa(r) | RSX0.0.  | Sa(r)I    | 1.0      | .0     |
| NGC 3384  | (L)SBa(lb,bl)0* | LBS+.* | S0b(5)    | −3.0     | −3.0   |
| NGC 3412  | (L)SBa0*    | LBS0.0.  | S0b1/2(5) | −3.0     | −2.0   |
| NGC 3414  | S0*/E(d)1 sp | L..P.    | S0b1      | −4.0     | −2.0   |
| NGC 3489  | (RL)SBa(r,bl)0/a | LXT+.  | S0b1/Sa   | 0.0      | −1.0   |
| NGC 3516  | (R)SBa1(r)0* | RLBS0*   | RSBb2    | −2.0     | −2.0   |
| NGC 3607  | (L)SAB0*    | LAS0*    | S0b(3)    | −3.0     | −2.0   |
| NGC 3608  | SA0* shells/ripples | RLAS+.* | Sa        | −3.0     | −1.0   |
| NGC 3608  | (R)SABa(r,ml,bl)0/a | RLAT+. | Sa        | 0.0      | −1.0   |
| NGC 3605 *| E2          | LAS0..   | S0b(3)    | −5.0     | −2.0   |
| NGC 3706 *| SA0*        | LAT+..   | E4        | −2.0     | −3.0   |
| NGC 3718  | SBS0(a)     | SBS1P.   | Sa pec    | 1.0      | 1.0    |
| NGC 3729  | SB(r)0/a    | SBR1P.   | SBring pec | 0.0      | 1.0    |
| NGC 3892  | (L)SBa(r)0* | LBT+.    | S0b3     | −1.0     | −1.0   |
| NGC 3900  | SA(r)0/a    | LAR+.    | Sa(r)     | 0.0      | −1.0   |
| NGC 3941 *| (R1)SBa(s,bl)0* | LBS0.. | S0b1/2/a | −2.0     | −2.0   |
| NGC 3945 *| (R)SBa1(r,ml,bl)0* | RLBT+. | RSBb2    | −1.0     | −1.0   |
| NGC 3998  | SA(r,ml)0*  | LAB0*    | S0b1(3)  | −2.0     | −2.0   |
| NGC 4073 *| E*5/SAB0*   | E+,...   | E5        | −3.5     | −3.8   |
| NGC 4105 *| E*5/SA0*    | E.3,...  | S0b1/2(3) | −3.5     | −5.0   |
| Galaxy   | type(2.2μm) | type(RC3) | type(RSA) | T(2.2μm) | T(RC3) |
|----------|-------------|-----------|-----------|----------|--------|
| NGC 4106 | SAB(s,nl)a  | .LBS+.    | SB0/a     | 1.0      | 1.0    |
| NGC 4138 | SA(r)0+     | .LAR+.    | Sab(r)    | −1.0     | −1.0   |
| NGC 4143 | (L,R′L)SABa(s,nb,bl)0− | .LXS0. | S01(5)/Sa | −3.0     | −2.0   |
| NGC 4150 | (L)SA(nl)0− | .LAR08.  | S03(4)/Sa | −3.0     | −2.0   |
| NGC 4203 | (L,R′L)SBa(l,rl)0− | .LX−.±*   | S02(1)    | −3.0     | −3.0   |
| NGC 4220 | (RL)SABr(s)0+ sp | .LAR+.    | Sa(r) S R1 | −1.0     | −1.0   |
| NGC 4245 | (Rl)SB(r,nr,bl)0+ | .SBR0*.  | S0b(s)    | −1.0     | .0     |
| NGC 4262 | (IOl,OOL)SBa(s,nl,bl)0+ | .LBS−.  | SB0/3    | −2.0     | −3.0   |
| NGC 4267 | (L)SAB0− | .LBS−.  | SB01     | −3.0     | −3.0   |
| NGC 4281 | E+5/SA0− | .L+.±/   | S0b(6)    | −3.5     | −1.0   |
| NGC 4293 | (RL)SBa(s)0/a | RSBS0.  | Sa pec    | 0.0      | .0     |
| NGC 4314 | (R)′SB(s1,l,r′,bl)a | .SBT1.  | SBa(r)pec | 1.0      | 1.0    |
| NGC 4339 | SA(r,l)0°  | .E.0°   | S01/2(0) | −2.0     | −5.0   |
| NGC 4340 | SBa(r,nb,bl)0+ | .LBR+. | SB02(r)  | −1.0     | −1.0   |
| NGC 4350 | S0− sp | .LA−/    | S01(8) | −3.0     | −2.0   |
| NGC 4369 | SBa(r)sa:pec | RSAT1.  | Sc(s)III-IV | 1.0    | 1.0    |
| NGC 4371 | SBa(r,nr)0+ | .LBR+.   | SB02/3(3) | −1.0     | −1.0   |
| NGC 4373 | SA0−: (shells/ripples?) | .LXT−. | E(4,2)  | −3.0     | −3.0   |
| NGC 4378 | (R)′SA1.la  | RSAS1.  | Sa(s)    | 1.0      | 1.0    |
| NGC 4382 | SA0/ac pec | .LAS+P. | S01(3)pec | 0.0      | −1.0   |
| NGC 4406 | E+3 | .E.3°   | S01(3)/E3 | −4.0     | −5.0   |
| NGC 4424 | SBa/ac:pec | .SBS1*. | Sapec     | 0.0      | 1.0    |
| NGC 4429 | SABa(r,nl)0+ | .LAR+. | S0b3(6) | −1.0     | −1.0   |
| NGC 4435 | S0+ sp | .LBS0.  | SB01(7) | −2.0     | −2.0   |
| NGC 4457 | (R)′SAB(l,nl,bl)0+ | RSXS0.  | RSb(rs)II | −1.0   | .0     |
| NGC 4459 | E2 | .LAR+. | S0b3(3) | −5.0     | −1.0   |
| NGC 4472 | SA0− | .E.2°   | E1/S01(1) | −3.0     | −5.0   |
| NGC 4474 | S0− sp | .L+.P+ | S01(8) | −3.0     | −2.0   |
| NGC 4477 | (RL)SB(r?)a | .LBS+.± | SB01/2/SBa | 1.0     | −2.0   |
| NGC 4503 | SABa(s,bl)0° | .LB.−. | Sa       | −2.0     | −3.0   |
| NGC 4531 | (RL)SA(r)sa | .LB.+*   | .0       | −1.0     | −5.0   |
| NGC 4546 | SAB0− sp | .LBS−. | SB01/Sa | −3.0     | −3.0   |
| NGC 4552 | S0− | .E.0+.. | S01(0) | −3.0     | −5.0   |
| NGC 4578 | SAB− | .LAR+. | S01/2(4) | −3.0     | −2.0   |
| NGC 4596 | (RL)SB(r,bl)0/a | .LBR+. | SBa(very early) | 0.0     | −1.0   |
| NGC 4608 | SB(r,bl)0+ | .LBR0. | SB03/a | −1.0     | −2.0   |
| NGC 4612 | (RL)SBa(r)0+ | .RLX.0. | RSB01/2 | −2.0     | −2.0   |
| NGC 4638 | S0− /E(b)4 sp | .L.−.. | S01(7) | −4.0     | −3.0   |
| NGC 4643 | (L)SB(r,bl,bl)0+ | .SBT0. | SB03/SBa | −1.0     | .0     |
| NGC 4649 | SA(1)0° | .E.2° | S01(2) | −3        | −5.0   |
| NGC 4665 | (R′L)SBa(s)0+ | .SB01. | SB01/3/SBa: | −1.0   | .0     |
| NGC 4691 | SBa(s)dm/SB0/a | RSBS0P. | SBb pec | 0.0      | .0     |
| NGC 4694 | SA0−(nb) | .LB.P. | Amorphous | −3.0     | −2.0   |
| NGC 4696 | E+2 | .E+1.P. | (E3) | −4.0     | −4.0   |
| NGC 4754 | (L)SBa(s,bl)0− | .LBR.−. | SB01(5) | −3.0     | −3.0   |
| NGC 4772 | (R′)SA(r)sa | .SAS1. | Sa      | 1.0      | 1.0    |
| NGC 4880 | (R′)SBa(s)a | .LAR+. | E4/S01(4) | 1.0      | −1.0   |
| NGC 4914 | SA0− | .E.++++ | [S01(5)] | −3.0     | −4.0   |
| NGC 4976 | E+5/SA0− | .E.4.P+ | S01(4) | −3.5     | −5.0   |
| NGC 4984 | (R)SABa(1,nr,l)0° | RLXT+. | Sa(s) | −2.0     | −1.0   |

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| Galaxy       | type(2.2\,\mu{}m) | type(RC3) | type(RSA) | T(2.2\,\mu{}m) | T(RC3) |
|--------------|-------------------|-----------|-----------|----------------|--------|
| NGC 5026 *  | (L)SB(rs,nl,bl)a  | PSBT0.    |           | 1.0            |        |
| NGC 5078 *  | Sa sp             | .SAS1*/    |           | 1.0            | 1.0    |
| NGC 5087 *  | E2/S04− sp        | .LA.*      | S03(5)    | −4.0           | −3.0   |
| NGC 5101 *  | (RR)SB(rs,nl,bl)0/a | RSBT0. | SBa       | 0.0            |        |
| NGC 5121 *  | (RL)SB(r)0+       | PSI1..     | S04(1)/Sa | −1.0           | 1.0    |
| NGC 5206 *  | dSB0,N            | PLBT0P*    |           | −2.0           | −2.5   |
| NGC 5266 *  | SA0−              | .LA...     | S05(5) pec (prolate) | −3.0 | −3.0 |
| NGC 5273 *  | 1                     | .LAS0.     | S09/a     | −2.0           | −2.0   |
| NGC 5308    | S0− sp            | .La...     | S01(8)    | −3.0           | −3.0   |
| NGC 5333 *  | (RL)SB(r,bl)0+    | .LBRO*     |           | −2.0           | −2.0   |
| NGC 5353 *  | SB0+ sp           | .La...     | S01(7)/E7 | −1.0           | −2.0   |
| NGC 5354 *  | E1                | .La...     |           | −5.0           | −2.0   |
| NGC 5365 *  | (RL)SB(rs,bl)0+   | RLBS...    | RSBO1/3  | −2.0           | −3.0   |
| NGC 5377 *  | (R1)SB(r,bl)0/a   | RSBS1..    | SBa or Sa | 0.0            | 1.0    |
| NGC 5419 *  | SA(n)0−           | E.....     | S01(2)    | −3.0           | −4.7   |
| NGC 5448 *  | (R′)SB(rs,bl)a    | RSXR1..    | Sa(s)     | 1.0            | 1.0    |
| NGC 5473 *  | (L)SB0−           | .LXS*      | SB01(3)   | −3.0           | −3.0   |
| NGC 5485 *  | E(dust lane)/SA0− | .La..      | S02(1) pec (prolate) | −4.0 | −2.0 |
| NGC 5493 *  | S0−/E(b)3 sp    | .La..P/    | E7/S02(7) | −3.0           | −2.0   |
| NGC 5631 *  | SA0−              | .LAS0.     | S02(2)/Sa | −3.0           | −2.0   |
| NGC 5638    | SA(i)0−           | .E1...     | E1        | −3.0           | −5.0   |
| NGC 5701 *  | (R′)SB(r,bl)0/a   | RSBT0.     | (PR)SBa   | 0.0            | 0.0    |
| NGC 5728 *  | (R1)SB(rs,bl)0/a  | .SXIR1*    | SB(a)II  | 1.0            | 1.0    |
| NGC 5750    | (RL)SB(rs,bl)0/a  | SBR0..     | SBa(s)     | 0.0            | 0.0    |
| NGC 5838    | (L)SB(rs,bl)0+    | .La...     | S02(5)    | −2.0           | −3.0   |
| NGC 5846 *  | (L)SA(nl)0−       | .E0+..     | S01(0)    | −2.0           | −5.0   |
| NGC 5898 *  | (L)SA(nl)0−       | .E0..      | S02/3(0)  | −3.0           | −5.0   |
| NGC 5953    | SA(rs)a pec       | .SA1.1P    |           | 1.0            | 1.0    |
| NGC 5982    | SA0−              | .E3...     | E3        | −3.0           | −5.0   |
| NGC 6012    | SB(xr,bl)0+       | RSBR2*     |           | −1.0           | 2.0    |
| NGC 6340 *  | (RL)SA(nl)0/a     | .SA0..     | Sa(r)I    | 0.0            | 0.0    |
| NGC 6407 1  | E+/SA0−           | .LA0?P     | −3.5       | −2.0           |        |
| NGC 6438 *  | SA0−              | .RNGA.     |           | −3.0           | −2.0   |
| NGC 6482 1  | E(d)2             | .E1...*    | E2        | −5.0           | −5.0   |
| NGC 6646    | (R′)SAB(r,s):     | .S1..     |           | 1.0            | 1.0    |
| NGC 6654 1  | (R′)SB(s,bl)0/a  | PSBSO1..   |           | 1.0            | 0.0    |
| NGC 6684 *  | (R′)SAB(rs,bl)0/a | PLBSO1..   | SBa(s)     | 0.0            | −2.0   |
| NGC 6703 *  | (RL)SB(i)0+       | .La...     | −2.0       | −2.5           |        |
| NGC 6782    | (R)SB(rs,bl,bl)0+ | RSXR1..    | SBa(s)     | −1.0           | 0.8    |
| NGC 6861    | E(d)15-6/S04− sp  | .LAS*..    | S02(6)    | −4.0           | −3.0   |
| NGC 6958 *  | SA(i)0−           | .E+.....   | R7S03(3)  | −3.0           | −3.8   |
| NGC 7029 *  | E(b)4/S0− sp      | .E6.*      | S01(5)    | −4.0           | −5.0   |
| NGC 7049    | E3                | .LAS0.     | S03(4)/Sa | −5.0           | −2.0   |
| NGC 7079 *  | (RL)SB(a,bl)0+    | .LBSO1..   | SBa       | −1.0           | −2.0   |
| NGC 7098 *  | (R′)SABa(l,bl)0+  | RSXT1..    |           | 1.0            | 1.0    |
| Galaxy            | type(2.2µm)     | type(RC3) | type(RSA) | T(2.2µm) | T(RC3) |
|-------------------|-----------------|-----------|-----------|----------|--------|
| NGC 7192 *        | (L)SA(l)0−      | .E+..*    | S02(0)    | −3.0     | −4.3   |
| NGC 7213 * 1      | SA(r,rl)0       | .SAS1*    | Sa(S)    | −2.0     | 1.0    |
| NGC 7217          | (R')SA(1,al)0/a | RSAR2..   | Sb(r)II-III | 0.0 | 2.0    |
| NGC 7332          | SB4,0° sp       | .L...P    | S02/3(8)  | −2.0     | −2.0   |
| NGC 7339          | SA(s)bc sp      | .SX54*$   |          | 4.0      | 4.0    |
| NGC 7371 *        | SAB(s)a         | RSAR0*    | Sb(r)II 1.0 | 1.0 | 0      |
| NGC 7377 *        | SA(l)0−         | .LAS+..   | S02/3/Sa pec | −3.0 | −1.0  |
| NGC 7457 *        | SA(s)0−         | .LAT-$*$  | S01(5)    | −3.0     | −3.0   |
| NGC 7585 *        | SA,0/a pec shells/ripples | PLAS+P | S01(3)/Sa | 0.0 | −1.0  |
| NGC 7727 *        | SAB(s,nr)a pec  | .SX51P    | Sa pec    | 1.0      | 1.0    |
| NGC 7742          | (L)SAB(r1,r2)0/a | SAR3..    | Sa(r1)   | 0.0      | 3.0    |
| NGC 7743 *        | SAB(s)a         | RLBS+..   | SbA       | 1.0      | −1.0   |
| NGC 7790 * 1      | E+1             | .E+....   | E1        | −4.0     | −3.8   |

* Form part of the complete magnitude-limited NIRS0S sample.
| Galaxy       | type (2.2 μm)       | T(2.2μm) |
|--------------|---------------------|----------|
| IC 4214      | (R1) SAB(g1,nr,nb)0/+| -1       |
| IC 4991      | SA0−               | -3       |
| IC 5267      | (RL) SA(l,nr)0/a    | 0        |
| ESO 337-10   | SA0−               | -3       |
| NGC 0484     | SA(ab)0−           | -3       |
| NGC 0507     | (L) SAB(ab)0−      | -3       |
| NGC 1022     | SAB(r1,nb,bl)a     | 1        |
| NGC 1079     | (RL) SABa(rs,nb,bl)0/+ | -1   |
| NGC 1344     | SA(l)0−            | -3       |
| NGC 1350     | (R1) SABa(r1,nb,bl)a | 1     |
| NGC 1400     | SA0−               | -3       |
| NGC 2292     | SA0−               | -3       |
| NGC 2681     | (RL) SAB(rs,ob,nr,nb)0/a | 0 |
| NGC 2782     | SA(r, nr, nb) a pec | 1        |
| NGC 2902     | SA(g1, nb)0+       | -1       |
| NGC 3166     | SABa(r1,nl,nb)a    | -1       |
| NGC 3665     | E2(d)              | -5       |
| NGC 3706     | SA(nd)0o           | -2       |
| NGC 3941     | (R'L) SBa(s,bl,nb)0o | -2   |
| NGC 3945     | (R) SBa(r, nl, nb, bl)0+ | -1  |
| NGC 4105     | SA0−               | -3       |
| NGC 4106     | SAB(s, nl, nb)a    |         |
| NGC 4150     | (L) SA(l, nl, nr)0− | -3       |
| NGC 4281     | SA0−               | -3       |
| NGC 4406     | SA0−               | -3       |
| NGC 4435     | SB0o sp            | -2       |
| NGC 4459     | SA(l)0−            | -3       |
| NGC 4503     | SAB(s, nd, bl)0o   | -2       |
| NGC 4552     | SA(l)0−            | -3       |
| NGC 4696     | S0−                | -3       |
| NGC 4754     | (L) SBa(s, nb, bl)0− | -3   |
| NGC 4976     | SA0−               | -3       |
| NGC 4984     | (R) SBa(l, nr1, nb)0o | -2 |
| NGC 5273     | SA(s)0o            | -2       |
| NGC 5328     | (L) SAB( nl, bl, nb)0o | -2  |
| NGC 5377     | (R1) SABa(r1, nl, nr)0/a | 0  |
| NGC 5485     | SA(l)0−            | -3       |
| NGC 5631     | SA(l)0−            | -3       |
| NGC 6407     | SA0−               | -3       |
| NGC 6654     | (R') SBa(s, nb, nl)a | 1     |
| NGC 7079     | (RL) SBa(s; nb, bl)0+ | -1  |
| NGC 7213     | SA(r, rl)0o         | -2       |
| NGC 7796     | SA0−               | -3       |
Table 5. Ring and lens dimension.

| Galaxy   | feature type | major axis radius | q      | PA       |
|---------|--------------|-------------------|--------|----------|
|         |              | [arcsec]          |        | [degrees]|
| IC 4214 | R1           | 59.3±0.04         | 0.590±.001 | 179.8± 0.06 |
| IC 4214 | l            | 28.1±0.04         | 0.483±.001 | 159.9± 0.05 |
| IC 4214 | nr           | 6.4±0.01          | 0.674±.001 | 156.6± 0.15 |
| IC 5240 | r            | 38.9±0.03         | 0.651±.001 | 107.0± 0.06 |
| IC 5267 | l            | 44.7±0.10         | 0.740±.002 | 142.3± 0.20 |
| IC 5267 | RL           | 78.0±0.05         | 0.771±.001 | 134.6± 0.07 |
| IC 5328 | l            | 18.5±0.09         | 0.817±.005 | 41.0± 0.74 |
| NGC 0474| RL           | 66.6±0.13         | 0.944±.002 | 7.6± 1.40  |
| NGC 0507| L            | 39.4±0.10         | 0.865±.003 | 43.2± 0.57 |
| NGC 0524| l            | 24.8±0.10         | 0.963±.005 | 36.4± 3.83 |
| NGC 0524| nl           | 6.5±0.02          | 0.962±.004 | 41.7± 2.78 |
| NGC 0524| L            | 57.1±0.12         | 0.988±.003 | 165.5± 7.48 |
| NGC 0584| l            | 17.5±0.22         | 0.583±.008 | 57.4± 0.56 |
| NGC 0718| rs           | 19.9±0.11         | 0.630±.004 | 147.1± 0.34 |
| NGC 0718| R'           | 43.2±0.24         | 0.783±.005 | 28.0± 0.75 |
| NGC 0718| nl           | 3.1±0.01          | 0.914±.005 | 17.5± 1.64 |
| NGC 0936| bl           | 25.0±0.08         | 0.845±.003 | 142.2± 0.58 |
| NGC 0936| R            | 45.2±0.06         | 0.786±.001 | 129.4± 0.16 |
| NGC 1022| r'l          | 27.8±0.06         | 0.861±.002 | 35.3± 0.50 |
| NGC 1022| bl           | 9.1±0.06          | 0.772±.006 | 131.2± 0.72 |
| NGC 1079| rs           | 41.6±0.08         | 0.560±.001 | 86.9± 0.14 |
| NGC 1079| bl           | 17.5±0.04         | 0.694±.002 | 91.4± 0.26 |
| NGC 1079| RL           | 111.8±0.11        | 0.583±.001 | 78.6± 0.06 |
| NGC 1161| l            | 9.8±0.01          | 0.577±.001 | 20.5± 0.06 |
| NGC 1201| bl           | 16.8±0.03         | 0.700±.002 | 5.9± 0.19  |
| NGC 1201| r'l          | 32.8±0.06         | 0.595±.001 | 12.2± 0.14 |
| NGC 1302| rl           | 34.0±0.05         | 0.968±.002 | 65.2± 1.95 |
| NGC 1317| nr1          | 12.3±0.01         | 0.834±.001 | 57.1± 0.15 |
| NGC 1317| nr2          | 15.2±0.01         | 0.930±.001 | 144.1± 0.25 |
| NGC 1317| nl           | 6.7±0.01          | 0.905±.002 | 67.5± 0.53 |
| NGC 1317| r'l          | 58.0±0.03         | 0.950±.001 | 81.6± 0.48 |
| NGC 1326| nr           | 5.7±0.01          | 0.743±.001 | 84.6± 0.15 |
| NGC 1326| r            | 33.5±0.03         | 0.807±.001 | 38.8± 0.14 |
| NGC 1326| R            | 84.5±0.03         | 0.645±.000 | 83.4± 0.04 |
| NGC 1326| bl           | 20.2±0.02         | 0.830±.001 | 67.0± 0.21 |
| NGC 1350| rs           | 65.9±0.06         | 0.542±.001 | 18.9± 0.04 |
| NGC 1350| R'           | 157.9±0.07        | 0.501±.000 | 0.2± 0.03  |
| NGC 1350| bl           | 32.0±0.07         | 0.626±.002 | 9.1± 0.19  |
| NGC 1371| l            | 92.9±0.11         | 0.669±.001 | 128.4± 0.07 |
| NGC 1371| RL           | 129.8±0.14        | 0.633±.001 | 133.3± 0.05 |
| NGC 1371| rs           | 38.0±0.08         | 0.696±.002 | 121.0± 0.17 |
| NGC 1387| nrl          | 8.3±0.01          | 0.986±.001 | 43.4± 2.04 |
| NGC 1389| l            | 18.8±0.02         | 0.765±.001 | 11.2± 0.17 |
| NGC 1411| nl           | 12.3±0.02         | 0.784±.001 | 9.4± 0.23  |
| NGC 1411| l            | 46.1±0.05         | 0.670±.001 | 6.3± 0.10  |
| NGC 1415| nr           | 5.9±0.03          | 0.404±.002 | 150.1± 0.08 |
| NGC 1415| r'l          | 47.9±0.22         | 0.399±.002 | 145.1± 0.07 |
| NGC 1415| RL           | 91.8±0.30         | 0.508±.003 | 145.0± 0.16 |
| Galaxy    | feature type | major axis radius [arcsec] | q            | PA [degrees] |
|-----------|--------------|----------------------------|--------------|-------------|
| NGC 1440  | L            | 43.7±0.03                  | 0.753±0.001  | 19.9±0.10   |
| NGC 1440  | r            | 24.7±0.07                  | 0.765±0.002  | 33.8±0.32   |
| NGC 1452  | bl           | 10.0±0.02                  | 0.804±0.002  | 48.4±0.29   |
| NGC 1452  | r            | 48.7±0.04                  | 0.596±0.001  | 109.7±0.05  |
| NGC 1452  | bl           | 18.3±0.01                  | 0.887±0.001  | 103.2±0.32  |
| NGC 1452  | R'           | 76.8±0.14                  | 0.554±0.001  | 114.2±0.09  |
| NGC 1512  | nr           | 8.5±0.01                   | 0.784±0.001  | 79.4±0.15   |
| NGC 1512  | rs           | 71.0±0.12                  | 0.820±0.002  | 53.4±0.28   |
| NGC 1512  | bl           | 41.3±0.13                  | 0.626±0.002  | 52.9±0.17   |
| NGC 1533  | RL           | 56.9±0.05                  | 0.870±0.001  | 134.0±0.20  |
| NGC 1533  | bl           | 14.7±0.02                  | 0.962±0.002  | 78.9±1.59   |
| NGC 1537  | rl           | 7.9±0.02                   | 0.511±0.001  | 81.1±0.13   |
| NGC 1543  | R            | 159.9±0.12                 | 0.942±0.001  | 2.9±0.60    |
| NGC 1543  | l            | 92.7±0.07                  | 0.753±0.001  | 100.2±0.12  |
| NGC 1543  | nl           | 10.7±0.01                  | 0.955±0.001  | 99.1±1.04   |
| NGC 1553  | rl           | 36.4±0.03                  | 0.577±0.001  | 150.4±0.04  |
| NGC 1553  | nl           | 8.5±0.02                   | 0.604±0.002  | 153.0±0.16  |
| NGC 1574  | L            | 108.7±0.03                 | 0.979±0.000  | 66.2±0.61   |
| NGC 1574  | l            | 22.1±0.03                  | 0.991±0.002  | 29.8±6.00   |
| NGC 1617  | R'           | 95.8±0.19                  | 0.467±0.001  | 108.9±0.07  |
| NGC 1617  | rs           | 60.0±0.34                  | 0.411±0.003  | 106.3±0.20  |
| NGC 2196  | l            | 23.7±0.07                  | 0.734±0.002  | 45.1±0.24   |
| NGC 2217  | R            | 96.9±0.07                  | 0.884±0.001  | 22.8±0.22   |
| NGC 2217  | gs           | 42.6±0.04                  | 0.898±0.001  | 127.7±0.30  |
| NGC 2217  | nl           | 9.1±0.02                   | 0.994±0.003  | 59.4±16.55  |
| NGC 2273  | R            | 61.4±0.12                  | 0.528±0.001  | 56.4±0.06   |
| NGC 2273  | rs           | 21.0±0.02                  | 0.792±0.001  | 81.9±0.14   |
| NGC 2273  | bl           | 12.4±0.02                  | 0.878±0.002  | 71.4±0.49   |
| NGC 2293  | bl           | 17.3±0.02                  | 0.794±0.001  | 89.6±0.23   |
| NGC 2300  | R' L         | 48.3±0.05                  | 0.898±0.001  | 65.3±0.35   |
| NGC 2380  | l            | 24.7±0.04                  | 0.964±0.002  | 98.1±2.07   |
| NGC 2380  | nl           | 8.4±0.02                   | 0.967±0.004  | 85.7±3.92   |
| NGC 2460  | rs           | 8.1±0.02                   | 0.703±0.002  | 11.4±0.27   |
| NGC 2523  | r            | 28.9±0.03                  | 0.763±0.001  | 61.0±0.11   |
| NGC 2681  | gs           | 18.7±0.02                  | 0.957±0.001  | 79.8±0.86   |
| NGC 2681  | RL           | 77.1±0.05                  | 0.945±0.001  | 100.8±0.54  |
| NGC 2781  | R' L         | 87.4±0.17                  | 0.470±0.001  | 73.3±0.07   |
| NGC 2781  | rl           | 32.7±0.03                  | 0.468±0.000  | 78.9±0.04   |
| NGC 2781  | nr           | 7.4±0.01                   | 0.578±0.001  | 75.5±0.13   |
| NGC 2782  | r            | 29.8±0.03                  | 0.972±0.001  | 77.9±1.35   |
| Galaxy     | feature type | major axis radius | q      | PA [degrees] |
|------------|--------------|-------------------|--------|-------------|
|            | (1)          | (2) [arcsec]      | (3)    | (4)         |
| NGC 2782   | nr           | 5.6±0.01          | 0.464±.001 | 87.7±0.11   |
| NGC 2787   | nrl          | 45.5±0.08         | 0.531±.001 | 104.8±0.09  |
| NGC 2787   | bl           | 21.3±0.06         | 0.507±.002 | 106.3±0.14  |
| NGC 2859   | R            | 107.9±0.13        | 0.701±.001 | 83.2±0.15   |
| NGC 2859   | rl           | 39.3±0.03         | 0.875±.001 | 84.8±0.28   |
| NGC 2859   | nl           | 6.7±0.01          | 0.946±.002 | 82.8±1.52   |
| NGC 2859   | bl           | 20.6±0.02         | 0.974±.001 | 110.3±1.56  |
| NGC 2880   | r            | 13.6±0.05         | 0.622±.003 | 149.0±0.20  |
| NGC 2902   | gl           | 13.8±0.02         | 0.924±.001 | 9.4±0.70    |
| NGC 2950   | l            | 35.6±0.09         | 0.630±.002 | 126.6±0.13  |
| NGC 2950   | nrl          | 5.2±0.02          | 0.693±.003 | 130.8±0.28  |
| NGC 2983   | L            | 51.7±0.04         | 0.598±.001 | 88.4±0.06   |
| NGC 2983   | bl           | 14.4±0.02         | 0.747±.002 | 89.6±0.26   |
| NGC 3032   | rl           | 8.4±0.01          | 0.900±.002 | 80.5±0.55   |
| NGC 3032   | rl           | 17.0±0.01         | 0.886±.001 | 101.3±0.25  |
| NGC 3081   | R1           | 71.5±0.07         | 0.813±.001 | 128.2±0.14  |
| NGC 3081   | r            | 33.0±0.02         | 0.687±.001 | 72.5±0.06   |
| NGC 3081   | nrl          | 6.0±0.01          | 0.750±.002 | 104.4±0.26  |
| NGC 3166   | rl           | 29.9±0.03         | 0.671±.001 | 89.9±0.13   |
| NGC 3166   | nl           | 5.9±0.03          | 0.504±.003 | 87.6±0.27   |
| NGC 3245   | L            | 59.2±0.07         | 0.514±.001 | 177.4±0.07  |
| NGC 3245   | rs           | 15.3±0.03         | 0.481±.001 | 177.8±0.08  |
| NGC 3245   | nl           | 6.0±0.01          | 0.636±.002 | 175.6±0.17  |
| NGC 3358   | R1           | 87.7±0.20         | 0.486±.001 | 139.4±0.05  |
| NGC 3358   | rl           | 24.8±0.08         | 0.540±.002 | 139.5±0.10  |
| NGC 3384   | L            | 115.4±0.13        | 0.483±.001 | 51.8±0.03   |
| NGC 3384   | l            | 19.9±0.02         | 0.905±.001 | 51.6±0.41   |
| NGC 3384   | bl           | 9.5±0.01          | 0.863±.001 | 49.9±0.25   |
| NGC 3412   | L            | 77.2±0.18         | 0.518±.001 | 147.4±0.07  |
| NGC 3489   | RL           | 55.4±0.14         | 0.348±.001 | 69.2±0.05   |
| NGC 3489   | r            | 20.2±0.03         | 0.721±.001 | 62.8±0.15   |
| NGC 3489   | bl           | 11.9±0.08         | 0.546±.004 | 79.3±0.37   |
| NGC 3516   | R            | 29.0±0.03         | 0.733±.001 | 56.9±0.13   |
| NGC 3516   | l            | 16.8±0.02         | 0.829±.001 | 25.7±0.19   |
| NGC 3607   | L            | 49.4±0.07         | 0.962±.002 | 117.8±1.52  |
| NGC 3626   | R            | 44.5±0.04         | 0.666±.001 | 151.8±0.07  |
| NGC 3626   | rl           | 18.6±0.04         | 0.610±.002 | 172.9±0.17  |
| NGC 3626   | nrl          | 4.1±0.02          | 0.905±.006 | 161.5±2.01  |
| Galaxy   | feature type | major axis radius  | q       | PA      |
|----------|--------------|--------------------|---------|---------|
|          |              | [arcsec]           | [degrees] |         |
| NGC 3718 | rs           | 88.4±0.11          | 0.736±.001 | 156.0±0.14 |
| NGC 3718 | l            | 60.8±0.07          | 0.823±.001 | 168.2±0.27 |
| NGC 3718 | nl           | 14.6±0.02          | 0.973±.002 | 119.1±2.14 |
| NGC 3729 | r            | 38.3±0.13          | 0.462±.002 | 159.8±0.12 |
| NGC 3892 | L            | 83.1±0.04          | 0.922±.001 | 27.8±0.23  |
| NGC 3892 | rs           | 37.6±0.04          | 0.800±.001 | 95.3±0.22  |
| NGC 3900 | r            | 32.2±0.03          | 0.402±.000 | 178.5±0.04 |
| NGC 3941 | R'/L         | 44.9±0.07          | 0.599±.001 | 7.3±0.11   |
| NGC 3941 | bl           | 18.1±0.07          | 0.659±.003 | 5.5±0.35   |
| NGC 3945 | R            | 121.2±0.11         | 0.569±.001 | 160.0±0.05 |
| NGC 3945 | rl           | 46.4±0.05          | 0.680±.001 | 157.3±0.08 |
| NGC 3945 | bl           | 25.6±0.02          | 0.917±.001 | 157.3±0.42 |
| NGC 3945 | nl           | 11.5±0.03          | 0.555±.002 | 156.2±0.14 |
| NGC 3998 | rl           | 37.3±0.06          | 0.826±.002 | 125.6±0.27 |
| NGC 4106 | nl           | 6.5±0.01           | 0.831±.002 | 84.2±0.48  |
| NGC 4138 | r            | 20.8±0.03          | 0.574±.001 | 153.7±0.07 |
| NGC 4143 | L            | 63.7±0.13          | 0.592±.001 | 144.6±0.09 |
| NGC 4143 | R'/L         | 39.0±0.22          | 0.466±.003 | 145.3±0.13 |
| NGC 4143 | bl           | 6.2±0.01           | 0.771±.002 | 145.0±0.25 |
| NGC 4150 | L            | 36.5±0.13          | 0.627±.002 | 143.3±0.18 |
| NGC 4150 | nl           | 3.0±0.02           | 0.794±.005 | 143.4±0.72 |
| NGC 4203 | l            | 20.8±0.08          | 0.879±.004 | 1.6±1.26   |
| NGC 4203 | L            | 70.7±0.08          | 0.978±.002 | 30.5±2.04  |
| NGC 4203 | rl           | 33.3±0.04          | 0.974±.002 | 35.9±1.89  |
| NGC 4203 | R'/L         | 57.5±0.05          | 0.807±.001 | 6.7±0.17   |
| NGC 4220 | RL           | 85.9±0.75          | 0.313±.003 | 138.2±0.06 |
| NGC 4220 | r            | 33.3±0.51          | 0.216±.003 | 137.8±0.05 |
| NGC 4245 | RL           | 84.3±0.08          | 0.772±.001 | 0.7±0.16   |
| NGC 4245 | r            | 36.9±0.04          | 0.749±.001 | 152.4±0.13 |
| NGC 4245 | nr           | 4.6±0.01           | 0.766±.002 | 174.9±0.28 |
| NGC 4245 | bl           | 18.7±0.04          | 0.775±.002 | 152.1±0.27 |
| NGC 4262 | OOL          | 49.9±0.02          | 0.861±.000 | 133.3±0.09 |
| NGC 4262 | IOL          | 29.6±0.02          | 0.841±.001 | 142.2±0.12 |
| NGC 4262 | nl           | 3.7±0.02           | 0.773±.005 | 149.4±0.72 |
| NGC 4262 | bl           | 8.5±0.03           | 0.914±.004 | 117.3±2.16 |
| NGC 4267 | L            | 83.8±0.06          | 0.949±.001 | 124.1±0.54 |
| NGC 4293 | RL           | 124.4±0.14         | 0.549±.001 | 64.1±0.05  |
| NGC 4314 | R'_j         | 108.5±0.07         | 0.858±.001 | 67.5±0.16  |
| NGC 4314 | r'1          | 66.4±0.11          | 0.786±.002 | 159.3±0.27 |
| NGC 4314 | bl           | 30.4±0.04          | 0.797±.001 | 145.9±0.16 |
| NGC 4314 | nr'          | 7.1±0.01           | 0.719±.002 | 135.6±0.16 |
| NGC 4339 | l            | 16.7±0.03          | 0.910±.002 | 20.7±0.86  |
| NGC 4339 | r            | 27.9±0.04          | 0.917±.002 | 21.6±0.64  |
| NGC 4340 | r            | 65.9±0.05          | 0.552±.000 | 99.8±0.04  |
| Galaxy     | feature type | major axis radius | q     | PA   |
|------------|--------------|-------------------|-------|------|
|            | (1)          | [arcsec]          | (3)   | [degrees] |
| NGC 4340   | bl           | 25.6±0.07         | 0.579±0.002 | 104.4±0.17 |
| NGC 4340   | nr           | 7.3±0.04          | 0.662±0.004 | 110.7±0.39 |
| NGC 4369   | rs           | 9.5±0.02          | 0.908±0.003 | 65.7±0.87  |
| NGC 4371   | r            | 57.1±0.05         | 0.553±0.001 | 91.2±0.07  |
| NGC 4371   | nr           | 10.9±0.03         | 0.474±0.002 | 89.1±0.16  |
| NGC 4378   | R'           | 90.6±0.04         | 0.829±0.000 | 2.5±0.10   |
| NGC 4378   | l            | 45.3±0.03         | 0.829±0.001 | 159.4±0.15 |
| NGC 4429   | r            | 80.5±0.08         | 0.368±0.000 | 96.8±0.04  |
| NGC 4429   | nl           | 4.4±0.02          | 0.587±0.003 | 91.2±0.28  |
| NGC 4457   | R            | 72.8±0.05         | 0.945±0.001 | 101.7±0.48 |
| NGC 4457   | l            | 49.0±0.08         | 0.751±0.002 | 73.9±0.22  |
| NGC 4457   | nl           | 4.1±0.01          | 0.768±0.003 | 81.3±0.46  |
| NGC 4477   | RL           | 62.1±0.02         | 0.926±0.000 | 64.3±0.19  |
| NGC 4477   | r?           | 39.3±0.03         | 0.853±0.001 | 29.4±0.20  |
| NGC 4503   | bl           | 25.3±0.08         | 0.423±0.002 | 0.5±0.13   |
| NGC 4531   | rs           | 9.7±0.04          | 0.642±0.003 | 133.7±0.19 |
| NGC 4531   | RL           | 53.5±0.08         | 0.652±0.001 | 152.4±0.11 |
| NGC 4596   | RL           | 105.0±0.07        | 0.809±0.001 | 128.0±0.10 |
| NGC 4596   | rs           | 56.1±0.04         | 0.718±0.001 | 97.0±0.09  |
| NGC 4596   | bl           | 28.2±0.06         | 0.906±0.003 | 92.0±0.93  |
| NGC 4608   | r            | 49.3±0.02         | 0.921±0.001 | 101.7±0.25 |
| NGC 4608   | bl           | 26.3±0.04         | 0.933±0.002 | 88.0±0.10  |
| NGC 4612   | RL           | 76.8±0.09         | 0.663±0.001 | 145.1±0.08 |
| NGC 4612   | l            | 40.1±0.08         | 0.701±0.002 | 147.6±0.17 |
| NGC 4643   | rs           | 51.6±0.05         | 0.905±0.001 | 61.3±0.37  |
| NGC 4643   | bl           | 25.6±0.05         | 0.945±0.003 | 75.3±1.55  |
| NGC 4643   | nrl          | 3.2±0.01          | 0.799±0.004 | 39.2±0.62  |
| NGC 4643   | L            | 94.3±0.16         | 0.822±0.002 | 50.9±0.27  |
| NGC 4649   | l            | 22.8±0.03         | 0.843±0.002 | 117.4±0.32 |
| NGC 4665   | R' L         | 78.2±0.09         | 0.891±0.001 | 100.3±0.42 |
| NGC 4754   | L            | 127.9±0.32        | 0.467±0.001 | 21.3±0.09  |
| NGC 4754   | bl           | 22.1±0.09         | 0.756±0.003 | 37.0±0.39  |
| NGC 4772   | R'           | 113.8±0.15        | 0.514±0.001 | 145.2±0.04 |
| NGC 4772   | r            | 70.4±0.47         | 0.280±0.002 | 145.8±0.05 |
| NGC 4880   | R'           | 60.2±0.05         | 0.769±0.001 | 156.5±0.12 |
| NGC 4984   | R            | 94.5±0.15         | 0.611±0.001 | 13.8±0.12  |
| NGC 4984   | l            | 49.6±0.06         | 0.843±0.001 | 40.1±0.22  |
| NGC 4984   | nrl          | 4.7±0.02          | 0.746±0.004 | 33.4±0.49  |
| NGC 5026   | L            | 105.4±0.33        | 0.540±0.002 | 64.0±0.13  |
| NGC 5026   | rs           | 35.9±0.09         | 0.577±0.001 | 51.6±0.09  |
| NGC 5026   | bl           | 18.5±0.06         | 0.730±0.003 | 52.9±0.30  |
| NGC 5026   | nl           | 3.1±0.02          | 0.679±0.006 | 49.0±0.51  |
| Galaxy  | feature type | major axis radius [arcsec] | q  | PA [degrees] |
|--------|--------------|---------------------------|----|-------------|
| NGC 5101 | OOR          | 160.1±0.07                | 0.886±0.000 | 148.7±0.12  |
| NGC 5101 | IOR          | 104.1±0.10                | 0.805±0.001 | 166.0±0.18  |
| NGC 5101 | nL           | 5.1±0.01                  | 0.972±0.004 | 42.0±3.65   |
| NGC 5101 | bl           | 30.5±0.07                 | 0.975±0.003 | 86.1±3.64   |
| NGC 5121 | RL           | 34.2±0.02                 | 0.830±0.001 | 23.8±0.12   |
| NGC 5121 | rl           | 11.9±0.02                 | 0.703±0.001 | 24.7±0.12   |
| NGC 5333 | RL           | 21.9±0.06                 | 0.556±0.002 | 50.4±0.09   |
| NGC 5333 | rl           | 8.4±0.05                  | 0.521±0.003 | 43.5±0.16   |
| NGC 5365 | RL           | 93.8±0.07                 | 0.537±0.001 | 4.5±0.05    |
| NGC 5365 | rs           | 32.7±0.04                 | 0.907±0.002 | 18.2±0.56   |
| NGC 5377 | R1           | 113.4±0.13                | 0.554±0.001 | 24.0±0.05   |
| NGC 5377 | nl           | 4.2±0.03                  | 0.587±0.004 | 27.7±0.31   |
| NGC 5377 | rl           | 66.6±0.25                 | 0.388±0.001 | 36.0±0.05   |
| NGC 5419 | nl           | 10.0±0.03                 | 0.824±0.004 | 89.1±0.85   |
| NGC 5448 | R'           | 102.9±0.19                | 0.406±0.001 | 113.9±0.04  |
| NGC 5448 | nL           | 49.1±0.22                 | 0.390±0.002 | 110.2±0.11  |
| NGC 5473 | L            | 3.6±0.02                  | 0.554±0.003 | 117.3±0.19  |
| NGC 5638 | l            | 43.6±0.08                 | 0.755±0.002 | 151.7±0.21  |
| NGC 5701 | RL           | 6.3±0.03                  | 0.902±0.006 | 127.5±1.77  |
| NGC 5701 | R'           | 100.1±0.11                | 0.837±0.001 | 80.8±0.26   |
| NGC 5701 | rl           | 40.6±0.04                 | 0.866±0.001 | 171.8±0.29  |
| NGC 5701 | bl           | 21.1±0.09                 | 0.975±0.005 | 172.7±6.15  |
| NGC 5728 | R1           | 102.0±0.05                | 0.719±0.000 | 177.9±0.06  |
| NGC 5728 | nL           | 54.8±0.12                 | 0.522±0.001 | 32.4±0.07   |
| NGC 5750 | RL           | 4.7±0.01                  | 0.763±0.002 | 6.3±0.37    |
| NGC 5750 | l            | 82.5±0.14                 | 0.475±0.001 | 69.0±0.06   |
| NGC 5750 | r            | 55.5±0.09                 | 0.527±0.001 | 66.9±0.07   |
| NGC 5750 | bl           | 34.7±0.07                 | 0.499±0.001 | 63.1±0.07   |
| NGC 5750 | l            | 15.5±0.10                 | 0.487±0.003 | 57.9±0.18   |
| NGC 5838 | L            | 91.6±0.45                 | 0.347±0.002 | 40.5±0.05   |
| NGC 5838 | nL           | 3.8±0.02                  | 0.782±0.005 | 27.6±0.67   |
| NGC 5846 | nL           | 2.1±0.02                  | 0.943±0.012 | 25.1±6.44   |
| NGC 5846 | l            | 10.6±0.01                 | 0.975±0.001 | 85.9±1.44   |
| NGC 5846 | L            | 29.7±0.03                 | 0.978±0.001 | 66.6±1.98   |
| NGC 5898 | L            | 64.9±0.05                 | 0.939±0.001 | 55.5±0.51   |
| NGC 5898 | l            | 21.3±0.03                 | 0.990±0.002 | 37.2±5.69   |
| NGC 5898 | nL           | 6.8±0.02                  | 0.957±0.004 | 101.3±3.29  |
| NGC 5953 | rs           | 6.2±0.01                  | 0.980±0.001 | 69.5±2.24   |
| NGC 6012 | l            | 50.8±0.05                 | 0.686±0.001 | 165.4±0.10  |
| Galaxy   | feature type | major axis radius [arcsec] | q          [arcsec] | PA [degrees] |
|----------|--------------|---------------------------|-------------|--------------|
| NGC 6012 | x1r          | 21.9±0.50                 | 0.254±0.006 | 151.4±0.16   |
| NGC 6340 | nl           | 4.9±0.01                  | 0.924±0.001 | 101.1±0.63   |
| NGC 6340 | l            | 19.0±0.04                 | 0.940±0.003 | 105.0±1.61   |
| NGC 6340 | RL           | 32.2±0.05                 | 0.887±0.002 | 107.2±0.49   |
| NGC 6438 | l            | 15.7±0.05                 | 0.927±0.004 | 175.2±1.79   |
| NGC 6646 | R'           | 33.7±0.03                 | 0.734±0.001 | 86.8±0.12    |
| NGC 6646 | rs           | 19.4±0.04                 | 0.763±0.002 | 77.5±0.34    |
| NGC 6654 | R'           | 65.2±0.06                 | 0.647±0.001 | 178.6±0.09   |
| NGC 6684 | R' L         | 84.4±0.09                 | 0.634±0.001 | 32.7±0.06    |
| NGC 6684 | L            | 34.4±0.03                 | 0.814±0.001 | 19.8±0.14    |
| NGC 6703 | RL           | 40.0±0.04                 | 0.982±0.001 | 131.0±2.20   |
| NGC 6782 | R            | 52.1±0.04                 | 0.837±0.001 | 67.5±0.14    |
| NGC 6782 | rl           | 25.1±0.02                 | 0.687±0.001 | 1.7±0.11     |
| NGC 6782 | nr'          | 4.9±0.01                  | 0.920±0.002 | 14.3±0.72    |
| NGC 6782 | bl           | 13.1±0.03                 | 0.833±0.002 | 1.9±0.49     |
| NGC 6958 | l            | 29.7±0.04                 | 0.967±0.002 | 107.7±1.96   |
| NGC 7079 | RL           | 46.0±0.06                 | 0.565±0.001 | 80.7±0.09    |
| NGC 7079 | bl           | 11.8±0.02                 | 0.527±0.001 | 89.7±0.11    |
| NGC 7098 | R'           | 107.8±0.06                | 0.581±0.000 | 78.5±0.04    |
| NGC 7098 | l            | 67.5±0.07                 | 0.581±0.001 | 65.6±0.05    |
| NGC 7192 | l            | 12.0±0.02                 | 0.966±0.002 | 80.2±1.80    |
| NGC 7192 | L            | 40.9±0.03                 | 0.956±0.001 | 69.0±0.63    |
| NGC 7213 | r            | 25.4±0.02                 | 0.947±0.001 | 52.2±0.63    |
| NGC 7213 | rl           | 13.4±0.01                 | 0.966±0.001 | 75.2±0.54    |
| NGC 7217 | R'           | 86.4±0.06                 | 0.844±0.001 | 93.7±0.19    |
| NGC 7217 | l            | 35.9±0.03                 | 0.858±0.001 | 82.1±0.21    |
| NGC 7217 | nl           | 15.0±0.06                 | 0.858±0.005 | 84.6±1.17    |
| NGC 7377 | l            | 7.3±0.01                  | 0.789±0.002 | 101.3±0.33   |
| NGC 7727 | nr           | 9.2±0.03                  | 0.291±0.001 | 86.7±0.10    |
| NGC 7742 | L            | 23.0±0.02                 | 0.967±0.001 | 89.2±1.06    |
| NGC 7742 | r<sub>1</sub> | 10.3±0.01                | 0.981±0.001 | 91.4±1.49    |
| NGC 7742 | r<sub>2</sub> | 7.3±0.01                | 0.969±0.001 | 134.6±1.05   |
Table 6. Bar dimensions: major axis radius ($r_{\text{vis}}$, $r_{\text{ell}}$, $r_L$, explained in Section 6), orientations (PA) and minor-to-major axis ratios (q) of bars. STdev is the estimated standard deviation of $r_{\text{vis}}$ and $r_{\text{ell}}$.

| Galaxy | barytpe | PA [degrees] | $r_{\text{vis}}$ [arcsec] | $r_{\text{ell}}$ [arcsec] | $r_L$ [arcsec] | STdev [arcsec] | q |
|--------|---------|--------------|-------------------|-------------------|-------------|----------------|---|
| IC 4214 | nb | 89.3 | 4.1 | 3.9 | 4.3 | 0.1 | 0.750 |
| AB | 161.7 | 30.8 | 26.2 | 30.5 | 2.3 | 0.468 |
| IC 5240 | Bz | 93.4 | 34.1 | 38.6 | 22.2 | 0.269 |
| IC 5328 | ABa | 41.0 | 50.4 | 42.5 | 51.2 | 3.0 | 0.495 |
| NGC 474 | AB | 28.6 | 18.0 | 18.0 | 0.0 | 0.750 |
| NGC 484 | nb | 89.3 | 2.5 | 2.4 | 3.0 | 0.1 | 0.757 |
| NGC 507 | nb | 20.0 | 4.0 | 4.6 | 10.3 | 0.3 | 0.757 |
| AB | 58.9 | 20.7 | 17.5 | 19.3 | 1.6 | 0.624 |
| NGC 584 | AB | 58.3 | 17.6 | 2.0 | 0.625 |
| NGC 718 | AB | 155.5 | 20.0 | 25.8 | 1.3 | 0.572 |
| NGC 936 | B | 80.3 | 38.2 | 37.5 | 51.9 | 0.3 | 0.520 |
| NGC 1022 | nb | 45.0 | 1.2 | 116.2 | 17.8 | 17.5 | 25.8 | 0.1 | 0.565 |
| AB | 80.0 | 1.5 | 1.5 | 0.78 |
| NGC 1079 | ABa | 119.6 | 33.4 | 31.2 | 40.7 | 1.1 | 0.501 |
| NGC 1201 | nb | 3.0 | 5.0 | 5.0 | 0.0 | 0.65 |
| ABa | 15.0 | 25.0 | 0.556 |
| NGC 1302 | AB | 171.4 | 29.5 | 25.6 | 37.7 | 1.9 | 0.660 |
| NGC 1317 | nb | 56.2 | 6.4 | 6.3 | 8.7 | 0.1 | 0.533 |
| AB | 150.7 | 47.2 | 42.2 | 51.9 | 2.5 | 0.732 |
| NGC 1326 | nb | 87.2 | 5.4 | 3.9 | 7.0 | 0.7 | 0.646 |
| ABa | 24.5 | 35.7 | 34.9 | 0.4 | 0.590 |
| NGC 1350 | nb | 15.0 | 3.0 | 33.4 | 58.0 | 54.3 | 60.2 | 1.8 | 0.421 |
| ABa | 119.6 | 20.8 | 21.7 | 26.9 | 0.5 | 0.539 |
| NGC 1380 | AB | 5.8 | 78.1 | 70.0 | 95.0 | 4.0 | 0.457 |
| NGC 1387 | B | 109.3 | 21.5 | 23.8 | 33.0 | 1.1 | 0.676 |
| NGC 1389 | nb | 37.6 | 4.5 | 3.4 | 6.4 | 0.6 | 0.623 |
| AB | 0.0 | 2.0 | 0.547 |
| NGC 1415 | ABa | 132.7 | 27.4 | 35.0 | 4.0 | 0.427 |
| NGC 1440 | B | 52.1 | 20.8 | 19.3 | 25.1 | 0.8 | 0.541 |
| NGC 1452 | Ba | 34.1 | 28.1 | 25.6 | 31.6 | 1.2 | 0.516 |
| NGC 1512 | Ba | 45.9 | 62.5 | 76.4 | 87.0 | 0.9 | 0.350 |
| NGC 1533 | B | 165.8 | 20.2 | 21.2 | 29.3 | 0.5 | 0.603 |
| NGC 1537 | nb | 89.3 | 23.9 | 20.7 | 37.7 | 1.6 | 0.525 |
| NGC 1543 | nb | 35.1* | 10.3 | 8.2 | 10.1 | 1.0 | 0.717 |
| B | 92.1 | 76.6 | 66.8 | 85.2 | 4.9 | 0.510 |
| NGC 1553 | nb | 3.6* | 7.9 | 8.5 | 15.5 | 0.3 | 0.613 |
| NGC 1574 | B | 147.2 | 15.1 | 14.8 | 21.8 | 0.2 | 0.705 |
| NGC 1617 | ABa | 98.9 | 46.6 | 58.7 | 68.4 | 6.1 | 0.444 |
| NGC 2217 | nb | 138.9 | 7.7 | 7.5 | 9.6 | 0.1 | 0.818 |
| B | 111.4 | 41.6 | 39.5 | 46.3 | 1.0 | 0.548 |
| NGC 2273 | nb | 54.6* | 3.9 | 2.1 | 4.3 | 0.9 | 0.680 |
| AB | 115.5* | 16.1 | 17.4 | 20.4 | 0.7 | 0.592 |
| NGC 2293 | ABa | 134.4* | 25.3 | 25.4 | 0.1 | 0.446 |
| NGC 2460 | AB | 7.9 | 5.0 | 4.2 | 5.2 | 0.4 | 0.731 |
| NGC 2523 | B | 116.2 | 22.4 | 22.9 | 28.2 | 0.3 | 0.361 |
| NGC 2549 | Bz | 178.3 | 8.4 | 7.4 | 10.2 | 0.5 | 0.452 |
| NGC 2655 | AB | 86.5 | 43.0 | 50.0 | 0.0 | 0.659 |
| NGC 2681 | nb | 16.2 | 3.0 | 1.8 | 3.2 | 0.6 | 0.870 |
| AB | 70.0 | 17.5 | 17.5 | 21.6 | 0.0 | 0.696 |
| AB | 35.5 | 43.0 | 50.0 | 0.771 |
| NGC 2782 | nb | 97.6 | 5.9 | 2.3 | 4.8 | 1.8 | 0.668 |
| NGC 2787 | Ba | 155.4* | 28.3 | 28.2 | 0.1 | 0.638 |
| NGC 2859 | nb | 72.5* | 4.0 | 3.9 | 7.8 | 0.0 | 0.733 |
| ABa | 158.3 | 36.9 | 34.0 | 40.9 | 1.4 | 0.617 |
| NGC 2880 | B | 88.6* | 9.0 | 8.5 | 9.0 | 0.3 | 0.796 |
| NGC 2902 | nb | 119.9* | 4.5 | 4.9 | 6.8 | 2.0 | 0.939 |
| NGC 2950 | nb | 96.9 | 4.9 | 3.1 | 4.6 | 2.2 | 0.718 |
| Ba | 152.7 | 22.9 | 23.3 | 28.7 | 0.2 | 0.572 |
| Galaxy     | barytype | PA [degrees] | $r_{\text{vis}}$ [arcsec] | $r_{\text{ell}}$ [arcsec] | $r_{\text{L}}$ [arcsec] | STdev | q   |
|------------|----------|--------------|--------------------------|---------------------------|-------------------------|-------|-----|
| NGC 2983 B | a        | 41.0         | 19.3                     | 19.2                      | 21.3                    | 0.0   | 0.543 |
| NGC 3081 nb|          | 117.6        | 5.7                      | 5.6                       | 7.8                     | 0.0   | 0.511 |
|            | AB       | 75.5         | 30.7                     | 34.3                      | 40.0                    | 1.8   | 0.382 |
| NGC 3100 AB|          | 163.8        | 27.0                     | 31.7                      | 2.3                     | 0.651 |
| NGC 3166 nb|          | 86.5         | 2.3                      | 3.1                       | 6.8                     | 1.1   | 0.560 |
|            | AB       | 166.5        | 20.9                     | 18.8                      | 20.6                    | 1.0   | 0.832 |
| NGC 3169 nb|          | 49.3         | 7.7                      | 7.2                       | 11.4                    | 1.2   | 0.631 |
| NGC 3227 AB|          | 149.3        | 59.2                     | 53.9                      | 66.7                    | 7.6   | 0.391 |
| NGC 3245 AB|          | 175.5        |                          |                           |                         |       |      |
| NGC 3358 AB|          | 161.7        | 18.2                     | 20.0                      | 1.0                     | 0.579 |
| NGC 3384 nb|          | 47.2         | 3.5                      | 2.8                       | 9.1                     | 2.9   | 0.582 |
|            | B        | 135.0*       | 17.5                     |                           |                         |       |      |
| NGC 3412 B | a        | 113.4        | 16.2                     | 15.4                      | 17.0                    | 0.4   | 0.736 |
| NGC 3489 B |          | 20.8*        | 8.3                      | 6.6                       | 10.3                    | 1.3   | 0.666 |
| NGC 3516 B | a        | 168.6        | 11.8                     | 10.9                      | 14.2                    | 0.5   | 0.680 |
| NGC 3626 nb|          | 164.5        | 2.5                      | 2.3                       | 3.8                     | 1.0   | 0.602 |
|            | AB       | 170.7        | 20.4                     | 19.2                      | 28.4                    | 0.6   | 0.459 |
| NGC 3718 AB|          |              |                          |                           |                         |       |      |
| NGC 3729 B |          | 32.8*        | 20.8                     | 21.2                      | 24.7                    | 0.2   | 0.355 |
| NGC 3892 B |          | 99.6         | 29.4                     | 33.3                      | 42.4                    | 1.9   | 0.515 |
| NGC 3941 nb|          | 18.9         | 3.3                      | 3.1                       | 3.6                     | 0.6   | 0.809 |
|            | B        | 160.5*       | 20.8                     | 22.7                      | 1.0                     | 0.526 |
| NGC 3945 nb|          | 156.9        | 9.8                      | 9.6                       | 13.4                    | 0.1   | 0.642 |
|            | B        | 72.1         | 35.7                     | 33.3                      | 36.8                    | 1.2   | 0.700 |
| NGC 3998 nb|          | 129.3        | 6.9                      | 7.9                       | 9.3                     | 0.5   | 0.785 |
| NGC 4073 AB|          | 100.3        | 10.9                     | 9.5                       | 14.1                    | 0.7   | 0.639 |
| NGC 4106 nb|          | 20.0*        | 6.0                      | 5.0                       | 0.5                     | 0.625 |
|            | AB       | 170.0*       | 21.3                     | 23.7                      | 27.0                    | 1.2   | 0.787 |
| NGC 4143 nb|          | 135.0        | 2.0                      |                           |                         |       |      |
|            | AB       | 155.5        | 19.1                     | 20.5                      | 0.7                     | 0.578 |
| NGC 4203 AB| a        | 10.0         | 14.3                     | 12.8                      | 20.8                    | 1.2   | 0.753 |
| NGC 4220 AB|          | 133.4        | 31.6                     | 34.7                      | 39.5                    | 1.6   | 0.289 |
| NGC 4245 B |          | 136.2        | 34.9                     | 36.5                      | 47.6                    | 0.8   | 0.477 |
| NGC 4262 B | a        | 19.6         | 12.6                     | 12.8                      | 16.7                    | 0.1   | 0.647 |
| NGC 4267 AB|          | 27.9         | 16.7                     | 17.9                      | 22.8                    | 0.6   | 0.786 |
| NGC 4293 Bx|          | 76.2         | 74.2                     | 74.0                      | 0.0                     | 0.244 |
| NGC 4314 B |          | 145.8        | 67.3                     | 64.7                      | 95.5                    | 1.3   | 0.351 |
| NGC 4340 nb|          | 8.3*         | 4.2                      | 3.8                       | 4.2                     | 0.2   | 0.903 |
|            | B        | 37.6         | 37.9                     | 37.5                      | 43.9                    | 0.2   | 0.692 |
| NGC 4369 B |          | 156.2        | 5.6                      | 4.6                       | 11.0                    | 0.5   | 0.373 |
| NGC 4371 B | a        | 157.6        | 34.9                     | 33.8                      | 38.4                    | 0.5   | 0.736 |
| NGC 4424 B |          | 107.2        | 7.7                      | 7.2                       | 13.0                    | 2.2   | 0.211 |
| NGC 4429 Bx|          | 98.9         | 72.5                     | 78.3                      | 91.2                    | 3.0   | 0.338 |
| NGC 4457 nb|          | 72.7         | 4.0                      | 3.4                       | 6.1                     | 0.6   | 0.813 |
|            | AB       | 69.3         | 40.5                     | 30.2                      | 37.2                    | 5.1   | 0.625 |
| NGC 4477 B |          | 8.4*         | 29.4                     | 29.0                      | 0.2                     | 0.621 |
| NGC 4503 AB|          | 25.0         |                          |                           |                         |       |      |
| NGC 4546 AB|          | 20.9*        | 5.0                      |                           |                         |       |      |
| NGC 4596 B |          | 74.1         | 53.8                     | 53.5                      | 65.9                    | 0.2   | 0.463 |
| NGC 4608 B |          | 25.8         | 43.8                     | 43.8                      | 52.8                    | 0.0   | 0.493 |
| NGC 4612 AB| a        | 101.7        | 17.5                     | 17.9                      | 22.2                    | 0.2   | 0.757 |
| NGC 4643 B |          | 131.4        | 48.1                     | 45.2                      | 59.2                    | 1.5   | 0.527 |
| NGC 4665 B |          | 1.9*         | 48.3                     | 43.8                      | 69.0                    | 1.6   | 0.486 |
| Galaxy     | bartype | PA  | $r_{\text{vis}}$ | $r_{\text{ell}}$ | $r_{L}$ | STdev | q  |
|------------|---------|-----|-----------------|-----------------|--------|-------|----|
|            | (1)     | (2) | (3)            | (4)          | (5)    | (6)   | (7) |
| NGC 4691 B | 98.3    | 17.9 | 14.0            | 21.0          | 1.9    | 0.289 |
| NGC 4694 nb| 145.2   | 3.2  | 2.5             | 3.4           | 0.9    | 0.455 |
| NGC 4754 nb| 18.9    | 8.1  | 6.7             | 9.6           | 0.7    | 0.754 |
|            | B_a     | 131.5* | 25.0      | 22.7         | 25.1   | 1.2   | 0.765 |
| NGC 4880 AB| 168.6   | 8.4  | 8.1             | 16.6          | 0.1    | 0.571 |
| NGC 4984 nb| 61.7    | 4.0  | 4.2             | 8.7           | 0.4    | 0.817 |
|            | AB_a    | 90.7  | 30.5          | 28.2         | 44.3   | 1.2   | 0.697 |
| NGC 5026 B | 170.5*  | 22.2 | 24.8           | 31.7          | 1.3    | 0.617 |
| NGC 5101 B | 118.9   | 51.0 | 48.3           | 59.4          | 1.4    | 0.474 |
| NGC 5206 B | 24.5    | 95.1 | 95.0           | 0.0           |        |       |
| NGC 5333 nb| 156.5*  | 2.6  | 2.0             | 0.3           | 0.698  |
| NGC 5353 B | 144.5   | 20.8 | 18.0           | 1.4           | 0.426  |
| NGC 5365 nb| 45.9*   | 4.8  | 5.7             | 10.9          | 0.5    | 0.685 |
|            | B_a     | 112.0 | 29.1        | 26.2         | 30.5   | 1.5   | 0.740 |
| NGC 5377 AB| 45.2    | 65.9 | 57.7           | 67.5          | 6.1    | 0.341 |
| NGC 5448 AB| 94.8    | 40.2 | 36.5           | 42.9          | 1.8    | 0.311 |
| NGC 5473 B | 83.1    | 15.6 | 13.9           | 14.5          | 0.8    | 0.767 |
| NGC 5701 B | 176.9   | 38.7 | 39.9           | 46.6          | 0.6    | 0.571 |
| NGC 5728 nb| 85.2    | 4.0  | 3.2             | 3.7           | 0.4    | 0.597 |
|            | B       | 31.4  | 52.9          | 56.0         | 73.1   | 1.6   | 0.323 |
| NGC 5750 AB| 112.1   | 20.0 | 21.6           | 23.8          | 1.9    | 0.589 |
| NGC 5838 nb| 39.6    | 3.5  | 3.0             | 0.2           | 0.75   |
|            | AB      | 50.7  | 12.1          | 12.8         | 13.4   | 0.9   | 0.714 |
| NGC 6012 B | 154.8   | 18.2 | 22.9           | 41.3          | 2.2    | 0.386 |
| NGC 6438 AB| 171.4   | 4.4  | 3.2             | 7.4           | 0.6    | 0.711 |
| NGC 6646 AB| 51.4    | 14.5 | 16.5           | 22.8          | 1.4    | 0.675 |
| NGC 6654 nb| 135.0*  | 4.4  | 2.6             | 3.6           | 0.9    | 0.860 |
|            | B_a     | 12.7  | 25.9          | 25.6         | 33.4   | 0.1   | 0.465 |
| NGC 6684 nb| 60.3    | 3.5  | 2.9             | 4.9           | 0.3    | 0.689 |
|            | AB      | 151.4 | 24.5        | 28.8         | 31.8   | 2.1   | 0.693 |
| NGC 6782 nb| 149.3   | 4.3  | 3.5             | 4.1           | 0.4    | 0.577 |
|            | AB      | 178.9 | 25.11        | 26.2         | 26.2   | 0.5   | 0.483 |
| NGC 7079 nb| 131.7*  | 4.5  | 2.4             | 3.3           | 1.0    | 0.827 |
|            | B_a     | 53.4  | 14.9          | 14.8         | 18.2   | 0.0   | 0.588 |
| NGC 7098 nb| 79.0*   | 7.8  | 9.2             | 10.7          | 0.7    | 0.684 |
|            | AB_a    | 50.0  | 43.2          | 42.0         | 51.8   | 0.6   | 0.454 |
| NGC 7332 B | 32.4    | 30.1 | 35.2           | 1.2           | 0.324  |
| NGC 7371 AB| 163.1   | 9.5  | 9.2             | 10.7          | 0.2    | 0.729 |
| NGC 7743 AB| 94.8    | 19.0 | 21.4           | 22.3          | 1.2    | 0.640 |

*Visually estimated.
Figure 1. Example of zeropoint calibration based on 2MASS 14'' circular aperture magnitude $m_{14}$. In the upper row, circular and elliptical isophote cumulative magnitudes are shown, while the lower row displays the original image (right) and the cleaned image convolved to FWHM=2.5'' (left). The circular aperture growth curve is adjusted to go through $m_{14}$ at $r=7''$. The dotted lines indicate the effect of adjusting the sky background by $\pm 0.5$ times the sky rms-variation, being completely negligible on the derived $\mu_0$. The two crosses at the elliptical aperture growth mark the 2MASS $k_0$ and $k_{ext}$, and their differences from the measured curve are indicated. The black and red elliptical curve corresponds to cleaned and original images, illustrating the maximum possible effect of star removal. The 2MASS 14 arcsec aperture (white) and the used elliptical isophotes (black) are displayed on top of images. (for all galaxies [http://www.oulu.fi/astronomy/NIRSOSPub/Kcalibration.html])
Figure 2. The zeropoints derived based on 2MASS 14” aperture calibration are displayed vs. airmass, for the 14 different observing campaigns. The rms scatter for each campaign is indicated. Boxes mark galaxies for which the zeropoint was adopted based on fitted campaign values, instead of using 2MASS aperture measurement.
Figure 3. Comparison of 2MASS and standard star calibration based zeropoints ($\mu_0 = -(\mathcal{K}_s - k_s)$). The three curves with different colors indicate linear fits for zeropoint versus airmass, obtained by observing 10 standard stars per night. The symbols indicate zeropoints derived for the galaxies observed during the same nights, based on 2MASS calibrations. In the left, applying 2MASS calibration to original images (with typical FWHM $\sim 1-2''$), there is about 0.04 mag shift between the calibration methods. However, after allowing for the poorer seeing of 2MASS images (FWHM = 2.5'') the systematic shift is about 0.02 mag.
Figure 4. Example of NIRS0S surface brightness profile for NGC 584. The large figure shows the brightness profile vs isophotal radius, obtained with IRAF ellipse routine. Fixed orientation and ellipticity are used: \( PA = 73.6^\circ \) and \( q = 0.675 \) correspond to estimated outer disk orientation. Error bars indicate the uncertainties \( \delta \mu \) returned by ellipse-routine. Before calculating the profile, the NIRS0S image was rebinned by a factor of 3, to pixel size 0.86". For comparison, also the profile derived from 2MASS Atlas image (pixel size 1"), and Spitzer SINGS survey (pixel size 0.75", 3.6 micron IRAC1 band) are shown: allowing for the \( \approx 3 \) mag shift between the \( K_s \) band and the 3.6\( \mu \) AB-system magnitudes, all profiles agree well, except for extending to different depths. The inserted figure shows the \( \Delta \mu \) vs \( \mu \) (taking into account the aforementioned difference between 2MASS/NIRS0S and SINGS magnitude systems), illustrating the \( \approx 2-3 \) mag differences in depth between the images.
Figure 5. An example of the atlas images, explained in more detail in the text (for all galaxies: [http://www.oulu.fi/astronomy/NIRS0S_pub/atlas.html](http://www.oulu.fi/astronomy/NIRS0S_pub/atlas.html))
Figure 6. Examples of stage (S0−, S0+, S0+) and family (A, SA, B) in the classification are shown. In this and in the following figures the images are sky subtracted and they are shown in a magnitude scale.

Figure 7. Examples of bars and rings. The left upper panel (NGC 2681) shows an example of a galaxy having three bars. The largest bar is manifested as two weak ansae in the direction of 45 degrees counter-clockwise from the North, whereas the main bar appears nearly horizontally. The nuclear bar is visible only in the atlas image shown in Fig. 5.
Figure 8. An illustration of barlens (bl) in NGC 2983. The left panel shows the original image, and the right panel the residual image after subtracting bar+bulge decomposition model taken from Laurikainen et al. 2010). Barlens is the nearly spherical lens inside the bar. The two blobs (=ansae) at the two ends of the bar are real, but the ring-like structure surrounding the bar is an artifact due to the fact that the bar model is only an approximation of the true surface brightness distribution of the bar.
Figure 9. An illustration of barlens (bl) in an Sa-type spiral, NGC 4314: barlens is the large component inside the bar, having a nuclear ring inside the barlens. The small panels are the same as in Figure 5.
Figure 10. The scatter plot of the optical and the NIR classifications, taken from RC3 and this study, respectively. The size of the symbol indicates the number of galaxies represented by the symbol. The dashed line corresponds to $T(\text{RC3})=T(2.2 \, \mu m)$. 
Figure 11. Examples of different type of lenses. Left panels show the images and right panels the 2D multi-component decompositions from Laurikainen et al. (2010), explained in more detail in the text. In the decomposition plots the white dots show the data points of the 2-dimensional surface brightness distribution (brightness of each pixel as a function of sky-plane radius from the galaxy center), and the black and grey colors show the model components. The uppermost black dots show the total model.
Figure 12. Two examples in which photometric classification moves an elliptical galaxy to an S0 stage. Both galaxies have an exponential outer surface brightness profiles, and also evidence of lenses, manifested as exponential sub-sections in the brightness profile. In the decomposition plots the meaning of the dots and lines are the same as in Fig. 10.
Figure 13. An illustration of our strategy for measuring the dimensions of the structures: the fitted ellipsoids of the identified structures are shown for NGC 1543. From outside towards inside the ellipsoids are for: the outer ring (R), the lens and the bar (L,B), and the nuclear lens (nL). Also the nuclear bar (nb) is fitted, though it has the same dimension as the nuclear lens (for all galaxies: http://www.oulu.fi/astronomy/NIRSOs_pub/nirso_dimensions.html).
Figure 14. Examples of possible formative sequences of lenses. In Fig. (a) the two lower panels show the inner parts of the galaxies NGC 3998 and NGC 4203: in these figures the bulge models obtained from the decompositions are subtracted from the original images.
Figure 15. Examples of multiple lenses. (a) Three barred galaxies are shown: the upper row illustrates the lenses surrounding the primary bars, and the lower panels those surrounding the nuclear bars (only the central regions of the galaxies are shown). For NGC 1543 and NGC 6782 the lenses are clear. However, for NGC 3081 the nuclear and inner ring are very prominent and the two bars extremely weak, so that no lenses are coded to the classification. (b) Typical examples of multiple lenses in non-barred galaxies.
Figure 16. Candidates of S0c type galaxies, showing no spiral arms and bulge-to-total flux ratios as small as typically found for Sc-type spirals. For each galaxy are shown the flux-calibrated cleaned image, and the azimuthally averaged surface brightness profile. The radial scale is in arcsec.