

Available from: http://dx.doi.org/10.1111/j.1365-2966.2006.10586.x


This is the author’s version of the work. It is posted here in accordance with the copyright policy of the publisher for your personal use. No further distribution is permitted.
The Millennium Galaxy Catalogue: Bulge/Disc Decomposition of 10095 Nearby Galaxies

Paul D. Allen\textsuperscript{1,*}, Simon P. Driver\textsuperscript{1,2}, Alister W. Graham\textsuperscript{1}, Ewan Cameron\textsuperscript{1}, Jochen Liske\textsuperscript{3}, & Roberto De Propris\textsuperscript{4}

\textsuperscript{1}Research School of Astronomy and Astrophysics, The Australian National University, Mount Stromlo Observatory, Cotter Rd, Weston, ACT 2611, Australia.
\textsuperscript{2}School of Physics and Astronomy, North Haugh, St Andrews, Fife, KY16 9SS, UK.
\textsuperscript{3}European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748, Garching bei München, Germany.
\textsuperscript{4}Cerro Tololo Inter-American Observatory, Casilla 603, La Serena, Chile.

\textsuperscript{*}paul@mso.anu.edu.au

\texttt{ABSTRACT}

We have modelled the light distribution in 10095 galaxies from the Millennium Galaxy Catalogue (MGC), providing publically available structural catalogues for a large, representative sample of galaxies in the local Universe. Three different models were used: (1) a single Sérsic function for the whole galaxy, (2) a bulge-disc decomposition model using a de Vaucouleurs ($R_1^{1/4}$) bulge plus exponential disc, (3) a bulge-disc decomposition model using a Sérsic ($R_1^{1/n}$) bulge plus exponential disc. Repeat observations for \approx 700 galaxies demonstrate that stable measurements can be obtained for object components with a half-light radius comparable to, or larger than, the seeing half-width at half maximum. We show that with careful quality control, robust measurements can be obtained for large samples such as the MGC. We use the catalogues to show that the galaxy colour bimodality is due to the two-component nature of galaxies (i.e. bulges and discs) and not to two distinct galaxy populations. We conclude that understanding galaxy evolution demands the routine bulge-disc decomposition of the giant galaxy population at all redshifts.

Key words: astronomical data bases: catalogues - galaxies: general - galaxies: fundamental parameters - galaxies: structure - galaxies: statistics.

\texttt{1 INTRODUCTION}

To understand the origins of the diverse galaxy population observed today it is essential to quantify the properties of different structures which may be associated with separate formation processes. Recent work (e.g. Baldry et al. 2004) reported that the local galaxy population consists of two distinct classes (red and blue). Driver et al. (2006) demonstrate that the galaxy bimodality is particularly distinct in the colour-log($n$) plane, where $n$ is the Sérsic index for the best-fitting $R_1^{1/n}$ model to the 2D galaxy light distribution. Furthermore, they suggest that the bimodality may be better interpreted as a representation of the two-component nature of galaxies (i.e. red bulges and blue discs). They arrive at this conclusion by noting that E/S0's and Sd/Irr's lie in the two distinct peaks, whereas the Sabc's (i.e. bulge+disc systems) straddle the two peaks. The colour bimodality may reflect the end-result of two different processes associated with bulge and disc formation.

It has long been known that although galaxies can cover an expanse of quite different morphologies, they have many prevalent features in common, most notably spheroids (or bulges) and discs. The prominence of these features is often used to classify galaxies and place them into an evolutionary scenario (e.g. Hubble 1926; de Vaucouleurs 1959; van den Bergh 1976). Early classification of galaxy morphology was based on the visual inspection of images, and although this can be useful, significant differences between individual classifiers have been observed (e.g. Lahav et al. 1993; Naim et al. 1995a), and less subjective techniques are clearly desirable.

In order to provide a more quantitative assessment of galaxy morphology, a number of different methods have been proposed and employed. For example, the concentration of the stellar distribution (e.g. Morgan 1958, 1959, 1962; Fraser 1972; de Vaucouleurs 1977; Graham et al. 2001), along with...
its asymmetry in a $C - A$ system (Burbidge et al. 1962; Elmegreen et al. 1992; Doi et al. 1993; Schade et al. 1993; Abraham et al. 1996), can be used to quantify galaxy morphology in a way that is not dependent on an assumed model. Extended classification systems also include a measure of the ‘clumpiness’ of the galaxy light ($C - A - S$; Conselice 2003). Other methods employ artificial neural networks (e.g. Naim et al. 1995b; Lahav et al. 1996; Odewahn et al. 1996) to classify galaxies according to a Hubble sequence scheme.

Bulge-disc decomposition is another popular and useful method for quantifying the morphologies of galaxies by fitting model surface brightness profiles to data. Galaxies are described in terms of the two most easily recognised stellar components: bulges and discs. Such an approach has some clear disadvantages; the fitting process is model-dependent and does not account for secondary features such as spiral arms, rings, bars, star forming knots, tidal tails, and other asymmetries. However, even at $z \sim 1$, bulges and discs are clearly in place and appear to be the dominant structural features in the majority of luminous ($M_B < -17$ mag) galaxies (e.g. Simard et al. 1999; Ravindranath et al. 2002; Barden et al. 2003; Peng et al. 2002; Trujillo et al. 2005). In addition, software is now available which makes it fairly straightforward to perform bulge-disc decompositions on many thousands of galaxies (e.g. Simard et al. 2002; Peng et al. 2002; Trujillo & Aguerri 2004; de Souza et al. 2004).

A bulge-disc model is also convenient because the surface brightness profiles of bulges are known to be well modelled by $R^{1/4}$ (de Vaucouleurs 1948), $R^{-n}$ (Sérsic 1968), or exponential laws (Andredakis & Sanders 1994; de Jong 1996a) and discs are observed to follow a pure exponential profile (de Vaucouleurs 1959; Freeman 1970). Bulges and discs are also often observed to have different average colours, metallicities, and kinematics, justifying their treatment as distinct entities. Most models of galaxy formation and evolution also involve separate formation scenarios for bulges and discs (e.g. Cole et al. 2000).

Using HST imaging, several statistically significant samples of high redshift galaxies with measured structural parameters have been constructed (e.g. Simard et al. 2002; Ravindranath et al. 2004; Barden et al. 2005). However, for the local Universe there only exist samples of hundreds of galaxies, that have had a bulge-disc decomposition, and these are often preselected to be only late-type (e.g. de Jong 1996a; Graham & de Blok 2001; MacArthur et al. 2003), or early-type (e.g. Caon et al. 1993; Graham & Guzmán 2003; de Jong et al. 2004), or in high-density environments (e.g. Gutiérrez et al. 2004; Christlein & Zabludoff 2005). In order to obtain a representative low redshift sample it is necessary to draw on a survey that is both deep and wide. Blanton et al. 2003 fit a single Sérsic function to over 180,000 SDSS galaxies, and recently Tasca & White 2004 have performed bulge-disc decomposition on a smaller sample of 1588 SDSS galaxies.

In this paper we use a publically available bulge-disc decomposition code (GIM2D; Simard et al. 2002) to provide a quantitative measure of the surface brightness profiles of 10095 galaxies with $B_{\text{MGC}} < 20$ mag in the Millennium Galaxy Catalogue (MGC). In Section 2 we briefly describe the MGC dataset analysed in this paper. Section 2 outlines the GIM2D fitting process. The resulting structural catalogues are introduced in Section 3 and in Sections 4 and 5 we address the validity and repeatability of the structural measurements. Finally, in Section 6 we recover the fundamental empirical results describing bulges and discs (the Kormendy relation and the $\mu_0 - \log(h)$ relation), and show that galaxy bimodality can be explained as a manifestation of distinct bulge and disc properties. In future papers we use the structural catalogues presented in this paper to consider the bulge and disc luminosity functions (Allen et al. in prep 2006), the bulge-disc bivariate brightness and size distribution (Liske et al. in prep 2006), and the supermassive black hole mass function (Graham et al. in prep 2006). Throughout this paper we assume a cosmology with $\Omega_m = 0.3$, $\Omega_{\Lambda} = 0.7$, and adopt $h = H_0/(100 \text{ km s}^{-1} \text{ Mpc}^{-1})$ for ease of comparison with other results.

2 THE MILLENNIUM GALAXY CATALOGUE

The Millennium Galaxy Catalogue (MGC; Liske et al. 2003) is a deep ($\mu_{\text{lim}} = 26$ B mag arcsec$^{-2}$), wide area ($\sim 37.5 \text{ deg}^2$) imaging and redshift survey covering a 0.5 deg wide strip along the equatorial sky from 10h to 14h 50'. The survey region overlaps both the Two-degree Field Galaxy Redshift Survey (2dFGRS; Colless et al. 2001) and the Sloan Digital Sky Survey data release 1 (SDSS-DR1; Abazajian et al. 2003). Comparison between these surveys shows that the MGC (which contains 10095 galaxies with $B < 20$ mag) is deeper, more complete, more precise, and of higher resolution than either the 2dFGRS or SDSS-DR1 data sets (Cross et al. 2004; Driver et al. 2005). In Driver et al. (2005), their Figure 1 compares MGC imaging to DSS and SDSS imaging, and their Figure 3 demonstrates the extremely high redshift completeness of the MGC as a function of apparent magnitude, effective surface brightness, and colour.

Although the input MGC imaging is in the $B$-band, a full match to the SDSS photometric catalogues provides additional colour information in the $ugriz$ bands. Full details of the MGC, including observations, data reduction, image detection and classification, are given in Liske et al. (2003). The MGC redshift survey is discussed in detail in Driver et al. (2003). With photometric precision of $\pm 0.03$ mag, astrometric accuracy of $\pm 0.08$ arcsec (Liske et al. 2003), and 96% redshift completeness to $B_{\text{MGC}} = 20$ mag (increasing to 99.8% for $B_{\text{MGC}} < 19$ mag), the MGC represents an extremely high quality and high completeness census of the local galaxy population. It is therefore the ideal data set to use for a detailed analysis of the structural composition of galaxies in the local Universe, and to provide a low redshift anchor for higher redshift studies.

Figure 1 shows the seeing corrected half-light radii (as measured in Liske et al. 2003) for MGC galaxies as a function of apparent $B$-band magnitude. Most galaxies are intrinsically larger than the PSF HWHM and are therefore useful for structural analysis (n.b. those galaxies that are much smaller than the typical PSF size are eventually removed from the final analysis - see Section 5.1).
are available (e.g. MacArthur et al. 2003), this approximation is
a fixed feature of the GIM2D code.

\[ I_d(R) = I_0 \exp(-R/h), \]

where \( I_0 \) is the central intensity and \( h \) is the scale length
(identical to a Sérsic profile with \( n = 1 \)). Although GIM2D
permits the application of a simple opacity model for discs, we
choose at this stage to treat discs as transparent and
infinitely thin. We explore the effects of dust on disc opacity
in a future paper (Allen et al., in prep).

The ellipticity of the bulge component and the inclina-
tion of the disc component are permitted to vary indepen-
dently. Flattening of bulges is described by an ellipticity,
\( \epsilon = 1 - b/a \), where \( a \) and \( b \) are the semi-major and semi-
minor axes of the ellipse respectively. The bulge effective
radius, and disc scale-lengths computed by GIM2D corre-
spend to the semi-major axes of the bulge and disc respec-
tively. Discs can have an inclination, \( i \), from face-on \((i = 0)\)
to edge-on \((i = 90)\), measured under the assumption that
face-on discs are circular. Bulges and discs are also permitted
to have independent position angles, \( \theta_b \) and \( \theta_d \). Finally,
the GIM2D code allows us to recalculate the background
levels for each galaxy before the surface brightness models
are fitted to the galaxies.

3 DECOMPOSITION OF GALAXY PROFILES

To perform 2D bulge-disc decomposition on the MGC sam-
ple we elected to use the GIM2D package (Simard et al.
2002). GIM2D allows galaxies to be modelled using a single-
component model, or a two-component bulge plus disc
model. Where a two component model is used, the com-
ponents are required to have a common spatial centre, but
their luminosities are independent, allowing the calculation
of a bulge-to-total \((B/T)\) luminosity ratio for each galaxy.

The intensity profile of the spheroidal (bulge) components,
\( I_b(R) \), can be described using a Sérsic function (Sérsic 1968;
Graham & Driver 2005):

\[ I_b(R) = I_e \exp(-b_n((R/R_e)^{1/n} - 1)), \]

where the effective radius, \( R_e \), encloses half the total bulge
luminosity, and \( I_e \) is the intensity at the effective radius.
The Sérsic parameter, \( n \), determines the shape of the pro-
file. A profile with \( n = 4 \) corresponds to the \( R^{1/4} \) model
(de Vaucouleurs 1948) that was traditionally used to de-
scribe bright elliptical galaxies. The term, \( b_n \), is defined such
that \( \Gamma(2n) = 2\Gamma(2n, b_n) \), where \( \Gamma \) is the complete gamma
function and \( \gamma \) is the incomplete gamma function, ensuring
that \( R_e \) encloses half the light for all values of \( n \). The term
\( b_n \) can be approximated by \( 1.9992n - 0.3271 \) (Capaccioli
1984).²

For discs, the intensity profile, \( I_d(R) \), can be modelled
using an exponential function:

\[ I_d(R) = I_0 \exp(-R/h), \]

where \( I_0 \) is the central intensity and \( h \) is the scale length
(identical to a Sérsic profile with \( n = 1 \)). Although GIM2D
permits the application of a simple opacity model for discs, we
choose at this stage to treat discs as transparent and
infinitely thin. We explore the effects of dust on disc opacity
in a future paper (Allen et al., in prep).

The ellipticity of the bulge component and the inclina-
tion of the disc component are permitted to vary indepen-
dently. Flattening of bulges is described by an ellipticity,
\( \epsilon = 1 - b/a \), where \( a \) and \( b \) are the semi-major and semi-
minor axes of the ellipse respectively. The bulge effective
radius, and disc scale-lengths computed by GIM2D corre-
spend to the semi-major axes of the bulge and disc respec-
tively. Discs can have an inclination, \( i \), from face-on \((i = 0)\)
to edge-on \((i = 90)\), measured under the assumption that
face-on discs are circular. Bulges and discs are also permitted
to have independent position angles, \( \theta_b \) and \( \theta_d \). Finally,
the GIM2D code allows us to recalculate the background
levels for each galaxy before the surface brightness models
are fitted to the galaxies.

3.1 Galaxy Input Images and Masks

Initially, GIM2D uses the SExtractor (Bertin & Arnouts
1996) output catalogue to prepare galaxies for analysis. In
particular, the galaxy \( x-y \) position, sky background, and
isophotal area as determined by SExtractor are required by
GIM2D. Postage stamp images were created for each galaxy,
centred on the input \( x-y \) positions, with the height and
width set to contain 10 times the SExtractor determined
isophotal area of the galaxy.

For each original image, SExtractor was set to produce
a segmentation image, or mask. This consists of a pixel map
defining background pixels to have a value of 0, and pixels
that are considered part of objects are assigned values of 1
to \( N \). A mask postage stamp image with the same dimen-
sions as the input image was then produced for each galaxy.
Figure 2 shows example input MGC galaxies and their as-
associated masks. In some cases the masks did not distinguish
between nearby objects (in most cases two or more nearby
objects were given the same pixel value in the mask). As we
discuss later, this results in an erroneous output. When this
occurred, SExtractor deblend and/or threshold parameters
were changed to produce a correct mask (see Section 4.4 for
full details) and the input masks remade.

3.2 Point Spread Functions

Before accurate profile measurements can be made, it is im-
portant to disentangle the intrinsic morphologies of galaxies
from distortions that arise from the combined optical system
of telescope, instrument, and atmosphere. These distortions
vary both as a function of position and time, so their com-
bined effects must be modelled using a point spread function
(PSF), which is unique to each galaxy. In the fitting process,
GIM2D convolves the model profiles with a model PSF before
comparing the model to the data.

Initially the IRAF/DAOPHOT package was used to create
either PSF model for each CCD frame. This was achieved using
a minimum of 20 stars (often more), selected on the basis

Figure 1. Seeing corrected half-light radii (pixels) for MGC
galaxies (as measured in Liske et al. 2003) versus apparent
B-band magnitude. The dashed line shows the typical seeing
HWMM. The pixel scale is 0.333′′.
Figure 2. GIM2D input and output for three representative example galaxies: MGC27301, MGC61361 (both shown with Sérsic+exponential fits), and MGC55593 (single-component Sérsic fit). For each galaxy the top row contains images of the galaxy (left), GIM2D model image (centre), and a residual image showing the difference (right). The bottom row shows the input PSF (left, note the expanded scale), the SExtractor segmentation image or mask (centre), and a plot of the best-fitting profile found by GIM2D (right).
of their SExtractor stellarity parameter being \( > 0.8 \), and their magnitude lying in the range \( 17 < B_{\text{MGC}} < 19.5 \) mag. The stars were chosen to provide good spatial coverage of the CCD, to not be blended, to have no bright neighbours or saturated pixels, and to be away from CCD defects. The DAOPHOT routine PSF was then used to fit a model PSF for each CCD, based on the surface brightness profiles of the stars.

The PSF for each image was modelled using an analytic function, and a lookup table of residuals to account for the variation of the PSF across the CCD frame. The PENNY2 function, which consists of an elliptical Gaussian core with Lorentzian wings (both of which have independent position angles) was used to model the PSF, with the fitting radius of the function (i.e. the radius which encloses the region of pixels used in fitting the analytic function) defined to be equal to the median seeing for the frame. Where the median seeing is the median FWHM of simple Gaussian fits to the profiles of stars. The diameter of the region used for fitting the PENNY2 function is therefore twice the estimated median seeing.

To check the quality of the PSF, the ALLSTAR routine was used to reconstruct and subtract the PSF from the stellar images. When the PSF is good, the stars are cleanly removed from images leaving only sky noise. In most cases the PSF provided a good model for the stars (\( \chi^2_{\text{red}} \approx 1 \), where \( \chi^2_{\text{red}} \) is the reduced \( \chi^2 \) for the fit), although for a small number of frames the \( \chi^2_{\text{red}} \) values were poor and additional stars were rejected, and the PSF regenerated until an acceptable \( \chi^2_{\text{red}} \) was obtained.

Using the model PSFs made for each CCD image, with the associated look-up tables, the DAOPHOT routine SEEPSF was employed to create an image of an artificial star corresponding to the exact location of every MGC galaxy. GIM2D then convolves this image with the model fits before comparison with the input data. Example PSF stars are shown in Figure 2 (note the expanded scale for the PSFs).

### 3.3 The GIM2D Models

Three different models were fit to each MGC galaxy.

- One component: fitted with a Sérsic function.
- Two components: de Vaucouleurs bulge + exponential disc.
- Two components: Sérsic bulge + exponential disc.

A full description of the GIM2D fitting algorithm is given in Simard et al. (2002), but a brief outline follows. The first stage in the fit is to further refine the background subtraction. GIM2D uses those pixels flagged in the SExtractor segmentation image as ‘background’ to estimate the mean value of the background. A 5 pixel buffer is placed around each object in the segmentation image to exclude possible object pixels from isophotes lower than the threshold that could potentially bias the background estimation. The new background value is then fixed, and 2D surface brightness fits are applied to the galaxies.

Table 1 shows the 8-12 parameters that are fit by GIM2D and the the upper and lower limits permitted for each of the fits, most of which are based on GIM2D defaults. Since some galaxies are known to have \( n > 4.0 \) (e.g. Caon et al. 1993; Graham et al. 1996), we permit the Sérsic index to be as high as 12 (c.f. Tasca & White 2002, who fix \( n_{\text{upper}} = 4 \)). Since we have assumed an infinitely thin disc, inclinations are given an upper limit of 85 degrees. Bulge ellipticities are permitted to have a maximum value of 0.7. However, in the Sérsic-only catalogue the fit may best correspond to either a bulge or a disc. Therefore, in this catalogue, those objects with a GIM2D upper error limit of 0.7 for the ellipticity were refit using a revised upper limit of 0.92 (corresponding to an inclination of 85 degrees), and both versions of the fit stored.

GIM2D uses the pixels flagged by the segmentation image as ‘object’ to measure image moments in order to produce initial estimates of the total flux, size, and position angle for each galaxy. Maximum values for these parameters are then set at twice the best estimates from the image moments. Using the limits applied in Table 1 and the maxima derived from the image moments, \( N \) models are created coarsely sampling the permitted parameter space. For this analysis we set \( N = 400 \). An ‘initial condition filter’ is then used to search through these models to find the best fit. The values associated with this model are then used as the starting point for the final fit. GIM2D then uses the Metropolis algorithm to search for the maximum likelihood model (essentially a pixel-to-pixel \( \chi^2 \) minimisation) that best describes each galaxy. GIM2D also explores the parameter space around the best fit to compute 68% confidence intervals for each parameter.

### 3.4 MGC Structural Catalogues

Publically available MGC catalogues have already been released containing non-GIM2D parameters, such as photometry, imaging, estimates of galaxy half-light radii, mean effective surface brightnesses, and a match to SDSS-DR1 (Liske et al. 2003). These were supplemented with redshifts and rest-frame colours in (Driver et al. 2005). The best-fitting values for the twelve parameters computed by GIM2D (see Table 1) have been combined with the MGC-BRIGHT catalogue (i.e. 10095 galaxies with \( B < 20 \) mag) to produce three structural catalogues: one for each of the three models fitted here. For each fit, GIM2D also measures the reduced \( \chi^2 \) (as computed between the PSF-convolved best-fitting model and the input data) as a measure of goodness-of-fit. Furthermore, using the topology of parameter space explored during the fitting process, GIM2D computes 68% confidence limits for each of the parameters (see Simard et al.)
Figure 3. Residual offsets in the location of the object centre as determined by SExtractor and GIM2D (in x-y pixels), are shown for the de Vaucouleurs + exponential catalogue (left), the Sérsic + exponential catalogue (centre), and the single-component Sérsic catalogue (right). The dashed lines correspond to a difference of 3 pixels (= 1 arcsec) in either x or y.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Flux</td>
<td>F (counts)</td>
<td>0.0</td>
</tr>
<tr>
<td>Bulge/Total Flux Ratio</td>
<td>B/T</td>
<td>0.0</td>
</tr>
<tr>
<td>Bulge Effective Radius</td>
<td>R_e   (pixels)</td>
<td>0.0</td>
</tr>
<tr>
<td>Sérsic Index</td>
<td>n</td>
<td>0.2</td>
</tr>
<tr>
<td>Bulge Ellipticity</td>
<td>e</td>
<td>0.0</td>
</tr>
<tr>
<td>Bulge Position Angle</td>
<td>(\theta_b) (degrees)</td>
<td>-360.0</td>
</tr>
<tr>
<td>Disc Scale Length</td>
<td>h     (pixels)</td>
<td>0.0</td>
</tr>
<tr>
<td>Disc Inclination</td>
<td>i (degrees)</td>
<td>0.0</td>
</tr>
<tr>
<td>Disc Position Angle</td>
<td>(\theta_d) (degrees)</td>
<td>-360.0</td>
</tr>
<tr>
<td>x –Position</td>
<td>(\Delta x) (pixels)</td>
<td>–</td>
</tr>
<tr>
<td>y –Position</td>
<td>(\Delta y) (pixels)</td>
<td>–</td>
</tr>
<tr>
<td>Background level</td>
<td>(\Delta b) (counts)</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 1. The 12 parameters that can be fitted by GIM2D, and the upper and lower limits permitted in the fits. No entry indicates that no hard limits are applied. For the Sérsic-only (one component) fit, the \(B/T\) lower limit is constrained to 1.0, so only the Sérsic component is fit. When a de Vaucouleurs \((R^{1/4})\) fit is applied, the upper and lower limits of the Sérsic index are held fixed at \(n = 4.0\).

3.4.1 Other Parameters

After profile fitting has taken place and output and residual images made, GIM2D also computes several measures of concentration and asymmetry which are described in detail in Simard et al. (2002). These include the \(C - A\) system (based on Abraham et al. 1996) and, using residual images, \(R_T\) and \(R_A\) (Schade et al. 1995). Two other measures, \(A_z\) and \(D_z\), are also defined by Simard et al. (2002), as part of the GIM2D package. Although these parameters are not discussed further in this paper, the \(C - A\) parameters are made available in the final MGC structural catalogues, and the other asymmetry measures are available on request.

4 QUALITY CONTROL

4.1 Comparison with Independent Measurements

As an initial test on the accuracy of the GIM2D output, simple global observables such as magnitudes, half-light radii, and \(x - y\) centroid positions can be compared to their values measured using other means in the Liske et al. (2003) MGC catalogues. In most cases the agreement is excellent, although there are a number of outliers, which can be a useful part of the quality control process as we discuss in Section 4.2.

Figure 3 shows the residuals between the SExtractor and GIM2D centroids. The majority of objects (88.0%) lie within 1 pixel of the SExtractor central position, and 99.1% have GIM2D central positions within 1 arcsec (3 pixels) of the SExtractor position for the Sérsic+exponential catalogues, and similar accuracy is found for the other two models used in this paper. In most cases an outlying object is simply a sign of an irregular galaxy with an offset or ill-defined core, although it can, as we discuss in the next section, indicate problems with the masks (SExtractor segmentation images), or the GIM2D output.

Figure 4 shows the difference between the Liske et al. (2003) and GIM2D magnitudes as a function of MGC magnitude, and the best-fitting relations between these parameters along with residual histograms, and the mean and standard deviation (with iterative 3\(\sigma\) clipping). For all three structural catalogues the GIM2D magnitudes are brighter.

Structural catalogues and images are made available at the MGC website http://www.eso.org/~jliske/mgc

© 0000 RAS, MNRAS 000, 000–000
The mean and standard deviation (with 3σ clipping) of residuals. The panels on the right show histograms of the residuals. The mean and standard deviation (with 3σ clipping) of MGC magnitude. The solid line shows the least squares fit to the data, and the dashed lines define the 1σ envelope. There is no apparent trend with magnitude. The GIM2D magnitudes are slightly brighter in all three catalogues: de Vaucouleurs+exponential (top), Sérsic+exponential (middle), and Sérsic (bottom). The panels on the right show histograms of the residuals. The mean and standard deviation (with 3σ clipping) of these distributions are shown in each case.

by 0.07 − 0.09 mag, with a 0.05 − 0.07 mag standard deviation. There appears to be no significant trend with magnitude. Systematically brighter GIM2D magnitudes are not unexpected since profiles are integrated to R = ∞, and it is known that flux can be missed when using aperture or Kron magnitudes (see Graham & Driver 2005). There are a small percentage of objects with large residuals that we discuss in the next section.

Finally, GIM2D also computes an approximate measure of the total galaxy half-light radius, which assumes that the bulge and disc have the same position angle (although the position angles are independent in the fits). In Figure 4 the GIM2D galaxy half-light radii are compared to the seeing corrected half-light radii measured in Liske et al. (2003). Again, there is good agreement but with some scatter. It is also notable that at small radii (<1.2″) the GIM2D radii are smaller than the Liske et al. (2003) radii. This is unsurprising as it is in the regime where the PSF is of comparable angular size to the galaxies. GIM2D measurements will be dominated by errors due to the PSF correction and the original MGC measurements will be subject to the assumptions of the seeing correction applied by Liske et al. (2003). For larger, well resolved galaxies the GIM2D half-light radii are slightly larger, as expected, given their brighter magnitudes.

4.2 Reanalysis of Outliers

Analysis of the input and GIM2D output images of outlying objects in Figures 3 and 4 reveals that the difference in parameters between Liske et al. (2003) and GIM2D measurements can have a number of sources. In some cases galaxies are irregular, with more than one possible ‘centre’, or have a very asymmetric surface brightness distribution. The GIM2D models can be a poor fit to such objects, and position and magnitudes consequently have significant differences. In addition, many objects have nearby neighbours, in which case SExtractor has applied a deblending algorithm to attempt to separate the flux from the two objects. SExtractor creates a mask image with overlap pixels simply designated to one object or the other. However, when SExtractor computes the magnitudes for these objects, the flux in the pixels lying in overlap regions is shared between the two objects. No such deblending is performed by GIM2D, which simply uses the mask, and all the flux is assumed to belong to one object or the other. Therefore some GIM2D inputs can be contaminated by light from nearby neighbours, and the derived magnitudes will differ from those determined by SExtractor.

Another cause of large parameter differences are erroneous masks or segmentation images. SExtractor, like most automated detection algorithms, is typically set to run with ‘optimal’ tuning (i.e. the detection parameters are set so that reasonable output is produced for as many objects as possible). Nevertheless, a fraction of objects at the extremes will still be incorrectly recovered. Perhaps the best examples are the SExtractor deblending parameters DEBELND_NTHRESH and DEBELND_MINCONT which govern the number of deblending thresholds, and the minimum contrast used when SExtractor decides whether two nearby local maxima in surface brightness are significant enough to be considered separate objects, or just structure within a single object. At one extreme, if the deblending is too strong, objects such as spiral discs or irregular galaxies can be broken up into several smaller objects. At the other extreme, two nearby, but clearly distinct objects are considered one, and assigned the same arbitrary pixel value in the mask (this is especially common when a small object lies close to a much larger one). To confuse matters further, in a small number of cases, SExtractor has failed to assign different pixel values to two nearby objects in the mask, even if two objects appear correctly deblended in the catalogue. These errors can be fixed by changing the deblend parameters to be more or less sensitive depending on the problem, and rerunning SExtractor. However it is not possible, even using the most optimal setup, to produce output that is satisfactory in every case. This is a problem when trying to automate measurements for increasingly large data sets as it becomes more and more difficult to check all objects by eye (and defeats the purpose of trying to automate the process!). Either some fraction of wrong detections has to be tolerated, or a way needs to be found where the failures can be flagged and corrected.

For the MGC, all 10095 objects were checked by eye in Liske et al. (2003), and therefore, as already discussed, differences between the Liske et al. (2003) catalogues and GIM2D output can be indicative of bad masks. If a galaxy has been over-deblended, then the GIM2D magnitude will be an underestimate. When two galaxies are treated as one, the centroids will be grossly different, and the GIM2D magnitudes will be over-estimated. All objects with Δx or Δy greater than 3 pixels (1 arcsec) or a magnitude difference |ΔB| > 0.2 mag, were selected and inputs, outputs, and masks examined.
by eye. It was found that 222 masks needed to be corrected by hand.

An example is shown in the top row of Figure 5 with the original input image, bad mask (which assigns the same pixel value to two distinct objects), and the clearly erroneous GIM2D fit on the right. A corrected mask, which is produced by making small adjustments to SExtractor deblending and threshold parameters, is shown in the bottom panel, along with the (now corrected) GIM2D output.

5 INTERPRETING GIM2D OUTPUT

One of the problems with automatic bulge-disc decomposition routines is that in addition to perfectly good fits, they automatically generate a lot of rubbish. In this Section we describe our best efforts to clean up this situation.

As a starting point we first trim the catalogue and examine only those systems within the redshift range $0.013 < z < 0.18$, and impose the galaxy size and surface brightness limits introduced in Driver et al. (2005). This results in a trimmed catalogue of 7750 galaxies (see Driver et al. 2005).

The interpretation of single-component Sérsic fits is fairly trivial, with the resulting light profile assumed to be the best-fit to the light from the entire galaxy. However, when two components are modelled, the two functions are typically taken to correspond to a bulge and a disc. It is necessary to verify whether or not this is the case, ensuring that the two-component model really does correspond to two distinct structural components within a galaxy. This is especially important in the case where a Sérsic+exponential model is used because this fit has the most degrees of freedom.

No restrictions on the relative sizes of the ‘bulge’ and ‘disc’ components were applied when using GIM2D. The two components can sometimes be inverted or used to fit other structural features, especially in irregular galaxies. The component light profiles may also cross once, twice or not at all. To ensure the correct interpretation of the GIM2D fits (and whether components should be interpreted as bulges, discs, something else) we classify all profiles into one of eight different types: six are composed of two components, and two have only single-component profiles. The two-component profile types are plotted in Figure 4 for six example galaxies from the Sérsic + exponential catalogue. The profile types can be summarised as follows:

- **Type 1** ‘Classic’ profile. The Sérsic profile dominates at the centre, while the exponential profile dominates the flux at large radii. At a surface brightness brighter than 26 B mag arcsec$^{-2}$ the profiles cross only once (i.e. they have the same surface brightness at only one radius).
- **Type 2** Disc dominated system. The exponential profile dominates at all radii, with a small, central Sérsic profile. The profiles never cross, and $B/T$ is always $< 0.5$.
- **Type 3** Sérsic profile dominates at small and large radii, but an exponential profile dominates at intermediate radii. The profiles cross twice. $B/T$ is always $> 0.5$, and the Sérsic index, $n$, is typically $> 1.5$. Objects fitted by these profiles are typically single-component Elliptical galaxies.
- **Type 4** Inverted profile. The exponential profile dominates at the centre, and the Sérsic profile dominates at large radii. The profiles cross once only, and $n$ is always small. The correct interpretation of the profile is problematic, and could be a signature of possible disc truncation, poor background subtraction, or the profile could correspond to irregular or dwarf systems.
- **Type 5** Bulge or disc dominated. The Sérsic profile dominates at all radii, with a weak underlying exponential component. The profiles never cross, and $B/T > 0.5$. There is a bimodal distribution in $n$ for this type (see Section 5.1).
- **Type 6** Disc with perturbation. The exponential profile dominates at small and large radii, and the Sérsic profile briefly dominates at intermediate to large radii. The Profiles cross twice. The Sérsic component models either a disc perturbation (such as a spiral arm), or features in an Irregular galaxy.
- **Type 7** Pure disc: an exponential-only profile with $B/T = 0$.
- **Type 8** Pure bulge, disc, or other: Sérsic profile only with $B/T = 1$. A bimodal distribution in $n$ reveals discs with $n \sim 1$, and bulges with $n \sim 4$ for our sample.

All 8 profile types occur in the Sérsic+exponential catalogue, types 1, 2, 3, 5, 7 and 8 occur in the de Vaucouleurs+exponential catalogue, and the Sérsic-only catalogue only contains type 8 profiles by definition. In both
Figure 6. An example of bad and corrected mask images. The top left panel shows the input image for MGC64481 (the central object), and the original mask (top centre). The top right image is the original GIM2D output image, which can be initially identified due to its large centroid offset, and magnitude difference between the GIM2D output and Liske et al. (2003). The bottom panels show the corrected mask and output images.

Table 2. The fraction of galaxies corresponding to each profile type (see Figure 7).

<table>
<thead>
<tr>
<th>Type</th>
<th>$R^{1/n}$+Exp (%)</th>
<th>$R^{1/4}$+Exp (%)</th>
<th>$R^{1/n}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50.8</td>
<td>52.5</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>9.5</td>
<td>0.4</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1.9</td>
<td>4.1</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>5.9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>14.1</td>
<td>7.1</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>4.8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>12.1</td>
<td>35.3</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>0.8</td>
<td>0.5</td>
<td>100</td>
</tr>
</tbody>
</table>

5.1 The Logical Filter

The use of raw GIM2D profiles from the two-component models would clearly be inappropriate given the distinct and often physically meaningless profiles that are fitted in some cases (e.g., types 4 or 6). Moreover, many systems do not actually exhibit two components, and in these cases it is not surprising that a two-component fit produces erroneous output. A non-negligible fraction of incorrect output is typical for most automated algorithms. A quick inspection of the bulge-disc decompositions from BUDDA (de Souza et al. 2004), and Aguerri et al. (2005) reveals that the majority of galaxies are of type 1. In the de Vaucouleurs+exponential catalogue the majority of galaxies are of type 1. In the de Vaucouleurs+exponential catalogue ~ 1/3 of galaxies are best modelled by an exponential-only fit (type 7), three times as many as in the Sérsic+exponential catalogue. Table 2 summarises the fraction of each type that is found in the three different catalogues.

However, it is possible to ask whether one can identify a suitable set of ‘rules’ to apply to the GIM2D catalogues to produce a meaningful, final ‘filtered’ catalogue. This catalogue would consist of bulge-disc decompositions where appropriate (using the Sérsic+exponential fits), and single-component Sérsic fits otherwise. The interpretation of the single-component Sérsic fits (as a bulge or a disc) would depend on colour and/or Sérsic index. This same approach could be followed using the de Vaucouleurs catalogue for bulge-disc decomposition but we choose to consider only the more meaningful Sérsic+exponential catalogues here.

For each fit GIM2D computes the reduced-$\chi^2$ as a measure of the goodness-of-fit for the output model. In most cases both the Sérsic+exponential fits and the single-component Sérsic catalogues have reasonable reduced-$\chi^2$ values (~ 1), although the Sérsic+exponential reduced-$\chi^2$ values are generally smaller. Although the Sérsic+exponential fits may have a reasonable reduced-$\chi^2$,
Figure 7. Examples surface brightness profiles for the 6 distinct types of GIM2D fit that we use to classify galaxies from the Sérsic + exponential catalogue (see text). In each panel the bold solid line represents the total profile, the Sérsic component is represented by a dotted curve, and the dashed straight line represents the exponential component. The locations of the half-light radii for each component: $R_e$, and $1.678h$, are also shown. Table 2 summarises the frequency with which each type occurs.

this doesn’t indicate whether or not the fit is appropriate (i.e. whether the Sérsic function is really corresponding to a bulge and the exponential function to a disc). Therefore the approach followed here involves analysis of the global properties of each type (including colours, Sérsic indices, and the sizes of components), along with visual examination of examples of each of the eight types.

Objects have a range of $B/T$ values (Figure 8 shows the $B/T$ distribution for our type 1 galaxies), although we note that the frequency of high $B/T$ values is small (indeed, only 62/7750 objects are type 8 with $B/T = 1$). This perhaps reflects the fact that the addition of a weak exponential model to a light profile dominated by a Sérsic model can make little difference to the overall total profile (see e.g. Saglia et al. 1997). The exponential component may represent a weak disc, an isophotal twist, a PSF error, or some perturbation in the profile. This degeneracy means that kinematic measurements are required to test for the presence of a low-luminosity, rotationally supported disc.

Figure 9 shows the distribution of disc inclinations for spheroid dominated systems (type 1 and type 5 galaxies with $n > 1.5$) for $B/T < 0.8$ and $B/T >= 0.8$. For objects with $B/T < 0.8$, the distribution is relatively flat, as expected for a random sample of discs with random orientations in space. However, for $B/T >= 0.8$, ‘discs’ with inclinations towards face-on dominate, especially for those objects that have been
Figure 9. Distribution in $\cos(i)$ for the ‘disc’ component of galaxies with types 1 and 5 with a bulge component having $n > 1.5$. The top panel shows a roughly flat distribution for those galaxies with $B/T < 0.8$, whereas the lower panel, for galaxies with $B/T > 0.8$, indicates a suspicious preference for face-on exponential profiles.

The majority of the two-component fits correspond to visually classified as E/S0. It is therefore highly improbable that these faint discs are all real. Therefore, we choose to replace the S{\`e}rsic + exponential fits for type 1 & 5 objects with $B/T > 0.8$ with single S{\`e}rsic profiles (c.f. Trujillo & Aguerri 2004, Guti{\`e}rrez et al. 2004, who replace objects with $B/T > 0.6$ with single S{\`e}rsic profiles). Driver et al. (2006) have demonstrated the existence of a bimodality in the colour-log($n$) plane for luminous galaxies (when modelled with a single S{\`e}rsic function); one can clearly identify a high-$n$ red peak, and a low-$n$ blue peak. The colours referred to here are the $(u-r)_{\text{core}}$ PSF colours from SDSS photometry (see Driver et al. 2006 for more detail of our use of PSF colours). Furthermore, they suggest that the two peaks can be identified with bulges and discs, respectively. This differs in a subtle but important way from the usual interpretation of the colour bimodality, which is credited to early- and late-type galaxies rather than bulge and disc stellar systems. Figure 11 shows the colour-log($n$) plane for the S{\`e}rsic (which one might initially interpret as a ‘bulge’) component for each of the six two-component types we identify (see Figure 7). The top-left panel of Figure 11 shows the same cumulative raw distribution for all types together. This differs from Driver et al. (2004) in that we have now separated the bulge and disc components, as Driver et al. argued should be done. It is clear from Figure 11 that most galaxies are ‘classical’ type 1 profiles, and of these, the majority of the ‘bulges’ are associated with a high-$n$ red peak. However, for most galaxies of types 2-6, and for a small but significant fraction of type 1 galaxies, the bulges do not correspond to the high-$n$ red peak. To investigate this situation further we now consider each of the profile types in turn.

The top-left panel of Figure 12 shows that most objects lie in a clear peak around $n \sim 3$, and PSF colour $(u-r)_{\text{core}} \sim 2.5$. These bulges appear to belong to plausible bulge-disc systems, and are accepted by us as correct decompositions, and therefore progress unchanged to the final filtered catalogue. Additionally, there is a tail of objects and a possible second peak around $n \sim 0.5$, with a wider range in colours, albeit generally blue $(u-r)_{\text{core}} < 2.0$. This could be indicative of a population of pseudo-bulges or bars. Such a population might be expected in disc dominated systems ($B/T < 0.5$), and these objects are accepted as having good decompositions and genuine bulges. An additional separation into bulges and pseudo-bulges/bars can be made at a later stage if required. However, pseudo-bulges are unlikely to be found in the high $B/T$ regime. Figure 12 shows the distribution in S{\`e}rsic index for S{\`e}rsic dominated ($B/T > 0.5$) type 1 galaxies. Based on this distribution we accept objects with $n > 1.5$ as having a good bulge-disc decomposition and they are included as such in the filtered catalogue, whilst type 1 objects with $n < 1.5$ are replaced with single-component S{\`e}rsic fits. These objects appear to be either pure disc systems or dwarf ellipticals.

Type 2 galaxies are clearly disc-dominated objects (they all have $B/T < 0.5$), with a possible small bulge. The addition of a weak S{\`e}rsic function to an exponential function can be enough to perturb the total profile significantly (see the type 2 example in Figure 14). However, the modelled perturbation to the total profile is not always at the centre, and is sometimes at much larger radii (analogous to the type 6 profile shown in Figure 14 but without the profiles crossing). In these cases it would be incorrect to interpret the S{\`e}rsic function as a bulge, and we therefore impose the additional restriction for type 2 objects that $R_e < 0.5 \times h$.

Figure 12. The distribution of bulge S{\`e}rsic index, $n$, for type 1 galaxies that are bulge dominated (i.e. $B/T > 0.5$).
ensuring that only Sérsic functions modelling a central feature are considered as bulge-disc systems. We allow these objects to pass through to the filtered catalogue. Based on the colour-log(n) distribution in Figure 10, the bulges of the majority of these galaxies do not correspond to the classical red, high-n peak, and may be better interpreted as pseudo-bulges. A small fraction of these objects are red, but they are all highly inclined systems, and thus likely red due to dust. Those objects with $R_e > 0.5 \times h$ (i.e. the Sérsic function does not correspond to a central perturbation) are replaced with single-component Sérsic fits, and are interpreted as disc-only systems.

Only a small fraction of galaxies are classified as type 3. These fits are erroneous and are sometimes caused by nearby neighbours (which GIM2D would be unaware of) contributing extra flux at large radii. They are generally red, bulge-dominated systems, with high-n and we choose to replace them with a Sérsic-only fit, which will typically be later interpreted as a bulge-only system. This class does contain a fraction (<1%) of genuine bulge-disc systems that will be missed.

Many type 4 profiles can be considered true inversions, with the exponential function fitting a central feature, and the Sérsic function fitting the outer disc. This can occur for a number of reasons. A PSF error can mean that the exponential is used to fit a sharp ‘spike’ at the centre of the profile. Such spikes are always much smaller than the HWHM of the PSF. In other cases, the galaxy appears to be an irregular disc with active star formation. The size and shape of the two components can be comparable, especially for the redder galaxies, when the modelled galaxy is often a dwarf. In all cases the bulge-disc interpretation would be erroneous and a single Sérsic fit is preferred in the filtered catalogue. However a fraction of these galaxies appear to be genuine bulge-disc systems with severe disc truncation. This seems to be a real phenomenon, and is likely to be an increasing problem with future, deeper data sets. Similarly, at higher redshifts, discs are seen to be described with a Sérsic function requiring $n < 1$ (Tamm & Tornjes 2006). Unfortunately, modelling disc truncation is beyond the scope of GIM2D, and it is not possible to fit the 2D images accurately. Therefore, we choose to replace these fits with single-component

Figure 10. The distribution of galaxy bulges (pre-filtering) in the $(u-r)_{core} - \log(n)$ plane for each of the six profile types we identify in Section 5.
Sérsic functions, and accept that a small fraction (<5%) of bulge-disc systems may be missed, or rather, not decomposed.

The type 5 galaxies all have $B/T > 0.6$, and are therefore dominated by the Sérsic component. The addition of an exponential function (that does not cross) makes little difference to the total profile. The distribution in Sérsic index and colour is clearly bimodal (figure 10), and there is a correlation between (two-component) Sérsic-'bulge' parameters, and the Sérsic-only parameters. These galaxies tend to be blue, low-$n$ disc-only systems, or red, high-$n$ bulge-only systems (i.e. spheroids). They are best fitted by a single Sérsic component, and these fits are therefore used in the filtered catalogue.

The fits to type 6 galaxies are clearly incorrect if interpreted as bulge-disc decompositions. From Figure 10, the ‘bulge’ components have very low $n$, and blue $(u-r)$ colours. These galaxies also have low Sérsic index ($n < 1$) from the Sérsic-only fits. They appear to be either dwarf galaxies or very flat ($n < 1$) discs with active star formation and/or other irregularities. In all cases a single Sérsic fit is adopted as more appropriate.

Finally, those objects that only have one component from the Sérsic + exponential model fits (type 7 and type 8) are replaced with single-component Sérsic-only fits.

In summary, all profiles were replaced with Sérsic-only fits except for types 1 and 2, which generally keep the two-component bulge-disc decomposition. The exceptions are when (i) $B/T > 0.8$, or (ii) a low-$n$ ($< 1.5$) Sérsic component dominates ($B/T > 0.5$) for the type 1 galaxies, and (iii) when $R_e > 0.5 \times h$ (i.e. the Sérsic function models a non-central perturbation) for the type 2 galaxies. The logical filter is summarised in Figure 14. After the filtering process, the full catalogue contains 3454 two-component objects where the Sérsic component is treated as a bulge, and the exponential component is treated as a disc. The remaining
galaxies in the catalogue (4296 objects) are fitted with a single Sérsic component. The distribution of these Sérsic-only objects in the colour-n plane is shown in Figure 13, where the bimodal nature is evident. Based on this distribution we choose $n = 1.5$ as the division between the two populations. We classify 825 galaxies with $n > 1.5$ as bulge-only objects, and 3471 galaxies with $n < 1.5$ as discs. As already discussed, these replacements will include a small fraction (<6%) of type 3 or type 4 galaxies that are genuine bulge-disc systems, that are misinterpreted here as bulge-only or disc-only.

As a useful verification of this bulge- or disc-only interpretation we also looked at the above Sérsic-only replacements in the $R^{1/4}$ + exponential catalogue. For the replacement ‘disc-only’ objects 80.1% of galaxies had a best-fitting $R^{1/4}$ + exponential model with $B/T = 0$ (i.e. GIM2D found a single exponential disc the most optimal model). The remainder of the replacement discs were all in disc-dominated systems with $B/T < 0.5$ (half of them with $B/T < 0.1$). For the replacement ‘bulge-only’ objects, the $R^{1/4}$ + exponential model produced mostly high $B/T$ output, with a median of $B/T \sim 0.8$, suggesting that this population is indeed dominated by E/S0 galaxies.

6 REPEAT OBSERVATIONS AND PARAMETER ACCURACY

The geometry of the MGC is such that each pointing of the INT Wide Field Camera overlaps by approximately 0.027 deg$^2$, with the previous one (see Figure 2 in Liske et al. 2004), building up a mosaic strip across the sky. Objects that lie in these overlap regions are therefore observed twice. Although the MGC catalogues only utilise one of these observations, the imaging data exists and SExtractor catalogues, and GIM2D input images were prepared for all 702 duplicate galaxies. Here we remove those objects with incorrect masks (see Section 4.2), reducing the number of twice-observed comparison objects to 682.

In each case, repeat observations lie on a different CCD of the WFC, with different PSFs, airmasses, sky brightnesses, noise, and seeing conditions. Often, the observations were carried out on a different night or even as part of different observing runs several months or years apart. They therefore provide an excellent test of the repeatability of GIM2D fits for a diverse and representative sample of galaxies under different conditions.

In all three catalogues acceptable repeatability (most measurements agree better that 20%) is obtained if a bulge/disc component size limit is imposed such that the half-light radius is larger than the half-width half maximum of the seeing disc (half-light radius > 0.5×seeing). Bulges are compared when $R_e > 0.5\Gamma$, and discs are compared when $1.678h > 0.5\Gamma$, where $\Gamma$ is the average seeing for the image the galaxy lies in. Below this threshold the differences between repeat measurements begin to increase. In addition we also find that the repeatability is poor for less luminous components, and we therefore impose a $M = -17$ B mag limit on the component magnitudes. Note that the uncertainties discussed here are not included in the final structural catalogues which only contain the 68% confidence intervals computed by GIM2D (see Section 5.3).

Profiles from the repeat observations have been interpreted according to the rules described in Section 5.1 and replacements made where necessary. In most cases the profile type is the same for each pair of observations of an object, but where the profile types differ, components interpreted as bulges or discs are directly compared (e.g. even if a galaxy has a type 2 profile in one measurement and a type 1 profile in the other, the bulge and disc components are still compared). When one measurement of an object has resulted in a single-component Sérsic profile and the other measurement uses a two-component profile (e.g. type 1), the Sérsic-only profile is interpreted as either a bulge or a disc (see Section 5.1), and compared with the corresponding component in the other fit. Type discrepancies such as this occur about 12% of the time. For each parameter we compute the mean residual and the $3$–$\sigma$ clipped standard deviation. In all cases the size of residuals correlates with the apparent half-light radii of the components.

Figure 15 shows a comparison between bulge and disc parameters from repeat observations for the filtered catalogue using two-component Sérsic + exponential fits (or Sérsic replacements). In all cases the mean is close to zero. We find bulge $R_e$ differences have a standard deviation of 12.2%, the Sérsic index, $n$, has a standard deviation of $\Delta \log(n) = 13.2\%$. Ellipticity differences have a standard deviation of 4.1%, and the bulge magnitudes, $M_{\text{bulge}}$, have a standard deviation of 0.10 B mag. For discs a larger sample can be used, as more discs are larger than the 0.5$\Gamma$ cut. Scale lengths, $h$, have a standard deviation of 6.6%, and disc inclinations, $\cos(i)$, have a standard deviation of 4.7%. Finally, disc magnitudes have a standard deviation of 0.15 B mag. The largest residuals are mostly due to those objects that have different types between repeat observations (e.g. one observation results in a high $B/T$ type 1 bulge-disc classification, and the other observation results in a type 5 bulge
Figure 14. A summary of the steps involved in the logical filter for the Sérsic+exponential catalogue.

only classification in which cases only the bulge parameters are compared).

Figure 14 shows histograms of the distribution in differences between parameters from repeat observations using the de Vaucouleurs + exponential catalogue. Once again, the catalogues have been filtered according to the rules described in Section 4. These measurements also show an acceptable level of repeatability, although the scatter in the bulge differences is larger than that found using the Sérsic + exponential catalogue. Bulge standard deviations are: $\Delta R_e/R_e = 32.7\%$, $\Delta e/e = 9.5\%$, and $\Delta M_{\text{bulge}} = 0.29$ mag. For discs, measurements are comparable to the Sérsic + exponential catalogue, with standard deviations of $\Delta h/h = 6.7\%$, $\Delta \cos(i) = 4.9\%$ and $\Delta M_{\text{disc}} = 0.11$ mag.

Residuals for measured parameters for single-component Sérsic fits are shown in Figure 17. As would be expected this much simpler model produces much more repeatable results. In this case the standard deviations are $\Delta R_e/R_e = 3.7\%$, $\Delta e/e = 2.0\%$, $\Delta M = 0.04$ mags, and $\Delta \log(n) = 4.2\%$.

7 FUNDAMENTAL BULGE AND DISC PROPERTIES

To demonstrate the consistency and suitability of the separation into bulge and disc populations we recover two fundamental statistical results: the Kormendy relation (Kormendy 1977) and the relation between disc central surface brightness and disc scale-length (de Jong 1996). In Figure 18 the size-surface brightness relation is shown for all bulges with $R_e > 0.5h$ and $M_{\text{bulge}} < -17$ mag, along with the relation of Kormendy (1977). The majority of red bulges follow the Kormendy relation well (especially for large values of $B/T$), however the smaller population of blue bulges do not. For reasons explained in Graham & Guzmán (2003), faint spheroids do not follow the Kormendy relation, having smaller $R_e$, and fainter $\langle \mu_e \rangle$.

Figure 19 shows the distribution in scale-length, $h$, and central surface brightness, $\mu_0$, for discs from the Sérsic+exponential catalogue after filtering (see Section 5.1). Only galaxies with $1.678h > 0.5h$, and $M_{\text{disc}} < -17$ mag (see Section 6) are shown. The dashed line shows the $M_{\text{bulge}} = -17B$ mag limit. It is clear that larger discs have larger (i.e. fainter) values for their central surface brightness as shown by other authors (de Jong 1996; Graham 2001).

The right panel of Figure 11 shows the distribution of bulges in the colour-log($n$) plane from the Sérsic+exponential catalogue (post-filtering). This distribution can be compared with that presented in Driver et al. (2003) who consider total rather than component properties, and identify two distinct peaks. In Figure 11 the bulges clearly form a single red, high-$n$ peak, although there is a small shoulder of bluer, low-$n$ objects. That the majority
of bulges identify with the red, high-$n$ peak supports the conclusions of [Driver et al. (2006)] that the colour bimodality reported in the galaxy population is best explained by two fundamental components: bulges and discs, rather than two different galaxy populations. Furthermore, this probably reflects two dominant formation processes and epochs. The small number of blue, low-$n$ bulges may also be evidence of a third population of pseudo-bulges resulting from secular evolution. The bimodal nature of the different components is again evident in Figure 20, which shows the relationship between the model $\mu_0$, and $M_B$ for bulge, disc, and pseudo-bulge components. It is clear that there are two distinct groupings with the high surface brightness bulges and the low surface brightness discs. The small number of blue, pseudo-bulges appear to have intermediate surface brightnesses.

8 CONCLUSIONS

We have used GIM2D to perform 2D model fits (including bulge-disc decomposition) for 1095 galaxies with $B_{\text{MGC}} < 20$ mag from the Millennium Galaxy Catalogue. We initially produced three catalogues using: (1) a single-component Sérsic model, (2) a Sérsic+exponential bulge-disc model, and (3) an $R^{1/4}$+exponential bulge-disc model. We find that there is good agreement between GIM2D centroids, magnitudes, and half-light radii, with those in the [Liske et al. (2003)] MGC catalogues. However, there are a significant number of objects that have incorrect mask images from SExtractor which had to be corrected manually.

When a two-component model is used, we find that a significant fraction of galaxies have mathematically ‘good’ fits, which may not be the most appropriate or meaningful. The components may be inverted, cross each other once,
twice, or not at all. In addition, it is also important to stress that many galaxies are not two component systems, and simply interpreting one component as ‘bulge’ and the other as ‘disc’ would clearly be wrong. We identify eight distinct profile types based on which of the two components dominate at the galaxy centre, at $\mu = 26$ mag arcsec$^{-2}$, and whether the components cross.

The majority ($\sim 50\%$) of objects are ‘classical’ type 1 galaxies where the Sérsic function dominates at the centre (modelling a bulge), and the exponential function dominates the outer regions (modelling a disc). The remaining objects often require more careful interpretation. The different types are sometimes due to phenomena such as disc truncation, multiple nuclei, or strong irregularities, all of which lie beyond the scope of the simple GIM2D model. Using the ‘type’ scheme we implement a strategy to ensure only genuine bulge-disc systems are fitted with a Sérsic+exponential model, and replace all other objects with single-component Sérsic fits. In most cases only single component systems end up with Sérsic-only fits. A small number ($< 6\%$) of genuine bulge+disc systems are classified as type 3 or type 4 (especially those with disc truncation), and will therefore be mis-classified as single-component systems. This ‘logical filtering’ process results in a fourth catalogue, where each galaxy is treated as either bulge+disc, bulge-only, or disc-only, and it is this catalogue that we suggest contains the most appropriate, physically meaningful modelling of the galaxy population. All five structural catalogues are made publically available with this paper (see Appendix A).

To test the repeatability and accuracy of our measurements, we applied GIM2D twice to the objects that lie in the overlap regions between the individual pointings that make up the MGC strip. We find that if size and absolute magnitude cuts are imposed, parameter measurements are

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure16}
\caption{Comparison between repeat observations of galaxies for bulge (top panel) and disc (lower panel) parameters derived from $R^{1/4}$ bulge + exponential disc filtered catalogues. The solid lines correspond to the mean difference between repeat measurements and the dashed lines show the standard deviation. In each panel the mean and standard deviation is noted.}
\end{figure}
repeatable at less than the 15% level. Although the catalogues contain entries for all objects, we recommend imposing cuts in size (half-light radius > 0.5Γ) and component absolute magnitude (M < −17 B mag) in order to obtain reliable measurements. To demonstrate the accuracy of the final, logically filtered catalogue we recover the fundamental Kormendy and μ0 − log(h) relations for bulges and discs respectively. In a series of future papers, the catalogues presented here will be used in detail to measure bulge and disc luminosity functions, bivariate brightness distributions, and size distributions. We are also using the catalogues to measure the supermassive black hole mass function and to study the effects of disc opacity.

Finally, we have used the catalogues to show that the galaxy colour-log(n) bimodality is due to the two-component...
The distribution of galaxy component properties in the $M_B - \mu_0$ plane is shown by the dots. Red contours outline the distribution of bulge components, and blue contours outline the distribution of disc components. Two clear populations are evident. The magenta contours outline the blue ($(u-r)_{core} < 2.35$) bulge components, which appear to lie in an intermediate position. The right panel shows histograms of the number of each type of component. The number of discs is boosted because they are more likely to meet the size criteria than bulges (or pseudo-bulges).

nature of galaxies, rather than two distinct galaxy populations. Luminous bulges generally occupy the red, high-$n$ peak, and discs occupy the blue, low-$n$ peak. There is also some evidence for a third population of blue, pseudo-bulges. The observed bimodality may be the end-result of two distinct processes and timescales associated with bulge and disc formation. We conclude that routine bulge-disc decomposition is essential at all redshifts to fully understand the evolution of the luminous ($M_B < -17$ mag) galaxy population. Three major steps forward are now required: (1) high-resolution, deep near-IR survey data, (2) the expansion of bulge-disc decomposition software to accommodate real phenomena such as nuclei and disc truncation, and (3) deeper studies to characterise the dwarf ($M_B > -17$ mag) population.

ACKNOWLEDGEMENTS

We thank Luc Simard for making his GIM2D code publicly available. The Millennium Galaxy Catalogue consists of imaging data from the Isaac Newton Telescope obtained through the ING Wide field Camera Survey Programme. The Isaac Newton Telescope is operated on the island of La Palma by the Isaac Newton Group in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias. Spectroscopic data comes from the Anglo-Australian Telescope, The ANU 2.3-m, the ESO New Technology Telescope, the Telescopio Nazionale Galileo, and the Gemini North Telescope. The survey has been supported through grants from the Particle Physics and Astronomy Research Council (UK), and the Australian Research Council (AUS). The data and data products are publically available from http://www.eso.org/~jliske/mgc/ or on request from J. Liske.

REFERENCES

de Vaucouleurs G., 1948, Annales d’Astrophysique, 11, 247
—, 1959, Handbuch der Physik, 53, 275
—, 1977, in Evolution of Galaxies and Stellar Populations, pp. 43–+
Fraser C. W., 1972, The Observatory, 92, 51
Graham A. W., Driver S. P., 2005, PASA, 22, 118

© 0000 RAS, MNRAS 000, 000–000
Lahav O., et al., 1995, Science, 267, 859
Morgan W. W., 1958, PASP, 70, 364
—, 1959, PASP, 71, 394
APPENDIX A: CATALOGUES AND CATALOGUE PARAMETERS

We provide five structural catalogues each containing 118 parameters for the 10 095 galaxies assembled from MGC-BRIGHT. The catalogues are available from the MGC website at [http://www.eso.org/~jliske/mgc](http://www.eso.org/~jliske/mgc) as:

- `master.bsersic.cat` – Catalogue containing Sérsic-only profile fits with $e < 0.7$.
- `master.dsercic.cat` – Catalogue containing Sérsic-only profile fits with $i < 85.0$.
- `master.dve.cat` – Catalogue containing de Vaucouleurs plus exponential profile fits.
- `master.logic.cat` – Bulge and disc catalogue after processing through the logical filter, containing Sérsic+exponential bulge+disc profiles.
- `master.dsersic.cat` – Catalogue containing Sérsic-only profile fits with $e < 0.7$.

The parameter file relevant for all five data files is:

- `master.par` – List of parameters included in the above five files.

Full details for each column entry are given below.

| Column 1: (ID) MGC unique identification number as listed in NED numbers 00000–69999 | Column 2: $B_{\text{MGC}}$ The SExtractor BEST magnitude corrected for Galactic extinction via the Schlegel et al. (1998) dust maps, the photometric system is defined in Liske et al. (2003) and conversions to various filters are listed in the appendix of Liske et al. (2003) and Cross et al. (2004). |
| Column 3: $\langle \mu_e \rangle$ The apparent effective $B_{\text{MGC}}$ surface brightness inside the empirically measured seeing corrected half-light radius: $\mu_e = B_{\text{MGC}} + 2.5 \log_{10} (2 \pi R_e^2)$ (mag arcsec$^{-2}$). |
| Column 4 & 5: (RA & DEC) Right ascension and declination in J2000.0 (deg). |
| Column 6: (CLASS) Classification parameter: 1=galaxy, 8=star. |
| Column 7: ($R_e$) The empirically measured half-light radius using the positional angle and ellipticity provided by SExtractor. The magnitudes are assumed total (arcsec). |
| Column 8: $\langle R_e \rangle$ Seeing corrected half-light radius, i.e., $R_e = \sqrt{R_e^2 - 0.32 \Gamma^2}$ (see Driver et al. 2005). (arcsec). |
| Column 9: (I') Full width at half maximum of the seeing (arcsec). |
| Column 11: ($K_z(B)$) $B_{\text{MGC}}$ K-correction (mag). |
| Column 12: (z) Best redshift for this galaxy. |
| Column 13: ($Q_z$) Redshift quality flag: 1=targeted but no redshift, 2= tentative redshift measurement, 3= reliable redshift, 4= definite redshift, 5= unequivocal redshift 9 = not targeted. |
| Column 14: ($u_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian apparent magnitude (AB mag). |
| Column 15: ($g_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian apparent magnitude (AB mag). |
| Column 16: ($r_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian apparent magnitude (AB mag). |
| Column 17: ($i_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian apparent magnitude (AB mag). |
| Column 18: ($z_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian apparent magnitude (AB mag). |
| Column 19: (ID) Duplicate of column 1. |
| Column 20: ($M_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian Absolute$^1$ magnitude (AB mag). |
| Column 21: ($M_{\text{BGC}}$[Kron]) MGC extinction corrected Kron Absolute$^1$ magnitude ($B_{\text{MGC}}$ mag). |
| Column 22: ($M_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian Absolute$^1$ magnitude (AB mag). |
| Column 23: ($M_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian Absolute$^1$ magnitude (AB mag). |
| Column 24: ($M_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian Absolute$^1$ magnitude (AB mag). |
| Column 25: ($M_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian Absolute$^1$ magnitude (AB mag). |
| Column 26: ($u_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian Absolute$^1$ effective surface brightness (AB mag arcsec$^{-2}$). |
| Column 27: ($g_{\text{BGC}}$[Kron]) MGC extinction corrected Kron Absolute$^1$ effective surface brightness ($B_{\text{MGC}}$ mag arcsec$^{-2}$). |
| Column 28: ($g_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian Absolute$^1$ effective surface brightness (AB mag arcsec$^{-2}$). |
| Column 29: ($r_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian Absolute$^1$ effective surface brightness (AB mag arcsec$^{-2}$). |
| Column 30: ($i_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian Absolute$^1$ effective surface brightness (AB mag arcsec$^{-2}$). |
| Column 31: ($z_{\text{SDSS}}$[Pet]) SDSS-DR1 extinction corrected Petrosian Absolute$^1$ effective surface brightness (AB mag arcsec$^{-2}$). |
| Column 32: ($M_{\text{SDSS}}$[PSF]) SDSS-DR1 extinction corrected PSF Absolute$^1$ magnitude (AB mag). |
| Column 33: ($M_{\text{SDSS}}$[PSF]) SDSS-DR1 extinction corrected PSF Absolute$^1$ magnitude (AB mag). |
| Column 34: ($M_{\text{SDSS}}$[PSF]) SDSS-DR1 extinction corrected PSF Absolute$^1$ magnitude (AB mag). |
| Column 35: ($M_{\text{SDSS}}$[PSF]) SDSS-DR1 extinction corrected PSF Absolute$^1$ magnitude (AB mag). |
| Column 36: ($M_{\text{SDSS}}$[PSF]) SDSS-DR1 extinction corrected PSF Absolute$^1$ magnitude (AB mag). |
| Column 37: ($\theta_1$) Angular size of 1h$^{-1}$pc at object redshift: $\theta_1 = 3600 \tan^{-1}(1+z)/c$ (arcsec), a value of 0.0 implies no redshift (arcsec). |
| Column 38: ($d_\text{p}$) Proper (co-moving) distance to the object (h$^{-1}$ Mpc). |
| Column 39: (c type) Continuum type: 1=El 15 Gyr, 2= Sa 7.4 Gyr, 3= Sc 2.2 Gyr (see Driver et al. 2003). |
| Column 40: (m type) Eyeball morphological type: 0 = not classified, 1 = E/S0, 2 = Sabc, 3=Sd/Irr (all $B_{\text{MGC}} < 19$ mag have been classified). |

© 0000 RAS, MNRAS 000, 000–000
<table>
<thead>
<tr>
<th>Column 41</th>
<th>(ID) Duplicate of column 1.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column 42</td>
<td>(2dFGRS No.) Matched 2dFGRS serial number for this object (000000 if no match).</td>
</tr>
<tr>
<td>Column 43</td>
<td>(η) 2dFGRS η parameter if matched (see Madgwick et al. 2002 -99.9 if no match).</td>
</tr>
<tr>
<td>Column 44</td>
<td>(ID) Duplicate of column 1.</td>
</tr>
<tr>
<td>Column 45</td>
<td>(L\text{TOT}) Total flux (digital units).</td>
</tr>
<tr>
<td>Column 46</td>
<td>(L\text{TOT}^-) Total flux error (-).</td>
</tr>
<tr>
<td>Column 47</td>
<td>(L\text{TOT}^+) Total flux error (+).</td>
</tr>
<tr>
<td>Column 48</td>
<td>(BULGE\text{FRAC}) Bulge fraction (0=pure disc).</td>
</tr>
<tr>
<td>Column 49</td>
<td>(BULGE\text{FRAC}^-) Bulge fraction error (-).</td>
</tr>
<tr>
<td>Column 50</td>
<td>(BULGE\text{FRAC}^+) Bulge fraction error (+).</td>
</tr>
<tr>
<td>Column 51</td>
<td>(BULGE\text{RE}) Bulge effective radius (pixels).</td>
</tr>
<tr>
<td>Column 52</td>
<td>(BULGE\text{RE}^-) Bulge effective radius error (-).</td>
</tr>
<tr>
<td>Column 53</td>
<td>(BULGE\text{RE}^+) Bulge effective radius error (+).</td>
</tr>
<tr>
<td>Column 54</td>
<td>(BULGE\text{E}) Bulge ellipticity.</td>
</tr>
<tr>
<td>Column 55</td>
<td>(BULGE\text{E}^-) Bulge ellipticity error (-).</td>
</tr>
<tr>
<td>Column 56</td>
<td>(BULGE\text{E}^+) Bulge ellipticity error (+).</td>
</tr>
<tr>
<td>Column 57</td>
<td>(BULGE\text{PA}) Bulge position angle.</td>
</tr>
<tr>
<td>Column 58</td>
<td>(BULGE\text{PA}^-) Bulge position angle error (-).</td>
</tr>
<tr>
<td>Column 59</td>
<td>(BULGE\text{PA}^+) Bulge position angle error (+).</td>
</tr>
<tr>
<td>Column 60</td>
<td>(R_D) Exponential disc scale length (pixels).</td>
</tr>
<tr>
<td>Column 61</td>
<td>(R_D^-) Exponential disc scale length error (-).</td>
</tr>
<tr>
<td>Column 62</td>
<td>(R_D^+) Exponential disc scale length error (+).</td>
</tr>
<tr>
<td>Column 63</td>
<td>(DISC\text{I}) Disc inclination (0=face-on).</td>
</tr>
<tr>
<td>Column 64</td>
<td>(DISC\text{I}^-) Disc inclination error (-).</td>
</tr>
<tr>
<td>Column 65</td>
<td>(DISC\text{I}^+) Disc inclination error (+).</td>
</tr>
<tr>
<td>Column 66</td>
<td>(DISC\text{PA}) Disc position angle.</td>
</tr>
<tr>
<td>Column 67</td>
<td>(DISC\text{PA}^-) Disc position angle error (-).</td>
</tr>
<tr>
<td>Column 68</td>
<td>(DISC\text{PA}^+) Disc position angle error (+).</td>
</tr>
<tr>
<td>Column 69</td>
<td>(X\text{OFF}) X offset of galaxy centre (pixels).</td>
</tr>
<tr>
<td>Column 70</td>
<td>(X\text{OFF}^-) X offset error (-).</td>
</tr>
<tr>
<td>Column 71</td>
<td>(X\text{OFF}^+) X offset error (+).</td>
</tr>
<tr>
<td>Column 72</td>
<td>(Y\text{OFF}) Y offset of galaxy centre (pixels).</td>
</tr>
<tr>
<td>Column 73</td>
<td>(Y\text{OFF}^-) Y offset error (-).</td>
</tr>
<tr>
<td>Column 74</td>
<td>(Y\text{OFF}^+) Y offset error (+).</td>
</tr>
<tr>
<td>Column 75</td>
<td>(BACK) Background level (digital units).</td>
</tr>
<tr>
<td>Column 76</td>
<td>(BACK^-) Background level error (-).</td>
</tr>
<tr>
<td>Column 77</td>
<td>(BACK^+) Background level error (+).</td>
</tr>
<tr>
<td>Column 78</td>
<td>(n) Sersic index (=4 for de Vaucouleurs profile).</td>
</tr>
<tr>
<td>Column 79</td>
<td>(n^-) Sersic index error (-).</td>
</tr>
<tr>
<td>Column 80</td>
<td>(n^+) Sersic index error (+).</td>
</tr>
<tr>
<td>Column 81</td>
<td>(CHI) \chi^2 of GIM2D fit.</td>
</tr>
<tr>
<td>Column 82</td>
<td>(RHALF) GIM2D HLR (pixels).</td>
</tr>
<tr>
<td>Column 83</td>
<td>(C1) Concentration index alpha=1.</td>
</tr>
<tr>
<td>Column 84</td>
<td>(A1) Asymmetry index (background corrected) alpha=1.</td>
</tr>
<tr>
<td>Column 85</td>
<td>(B1) Background correction applied to A1.</td>
</tr>
<tr>
<td>Column 86</td>
<td>(C2) Concentration index alpha=2.</td>
</tr>
<tr>
<td>Column 87</td>
<td>(A2) Asymmetry index (background corrected) alpha=2.</td>
</tr>
<tr>
<td>Column 88</td>
<td>(B2) Background correction applied to A2.</td>
</tr>
<tr>
<td>Column 89</td>
<td>(C3) Concentration index alpha=3.</td>
</tr>
<tr>
<td>Column 90</td>
<td>(A3) Asymmetry index (background corrected) alpha=3.</td>
</tr>
<tr>
<td>Column 91</td>
<td>(B3) Background correction applied to A3.</td>
</tr>
<tr>
<td>Column 92</td>
<td>(C4) Concentration index alpha=3.</td>
</tr>
<tr>
<td>Column 93</td>
<td>(A4) Asymmetry index (background corrected) alpha=3.</td>
</tr>
<tr>
<td>Column 94</td>
<td>(B4) Background correction applied to A3.</td>
</tr>
<tr>
<td>Column 95</td>
<td>(M_{MBGC} (GIM2D)) Total extinction corrected absolute$^2$ magnitude derived from L\text{TOT} (mag).</td>
</tr>
<tr>
<td>Column 96</td>
<td>(M_{MBGC} (Bulge) GIM2D)) Total extinction corrected absolute$^2$ magnitude derived from BULGE\text{FRAC}*L\text{TOT} (mag).</td>
</tr>
<tr>
<td>Column 97</td>
<td>(M_{MBGC} (Disc) GIM2D)) Total extinction corrected absolute$^2$ magnitude derived from (1-BULGE\text{FRAC})*L\text{TOT} (mag).</td>
</tr>
<tr>
<td>Column 98</td>
<td>(R_e (Bulge) GIM2D)) Half-light radius of bulge component: (R_e = 0.333\text{BULGE}\text{E}/\theta (h^{-1} \text{kpc}).</td>
</tr>
<tr>
<td>Column 99</td>
<td>(\alpha_D (Disc) GIM2D)) Scale-length of disc component: (\alpha_D = 0.333\text{R}_D/\theta (h^{-1} \text{kpc}).</td>
</tr>
</tbody>
</table>

© 0000 RAS, MNRAS 000, 000–000
Column 100: \( (\mu_0 \text{ (Bulge)}) \) Absolute central surface brightness: \( \mu_0(\text{Bulge}) = \mu_e(\text{Bulge}) - 1.0857b \) (see Graham & Driver 2005 eqn. 7) (mag arcsec\(^{-2}\)).

Column 101: \( (\mu_e \text{ (Bulge)}) \) Absolute effective surface brightness at \( R_e \) (Bulge): \( \mu_e(\text{Bulge}) = \langle \mu_e \rangle(\text{Bulge}) + 2.5 \log_{10} \left[ \frac{\Omega}{\Omega_{\text{MGC}}} \Gamma(2n) \right] \) (see Graham & Driver 2005 eqn. 9) (mag/arcsec\(^{-2}\)).

Column 102: \( (\langle \mu_e \rangle \text{ (Bulge)}) \) Absolute effective surface brightness of bulge component: \( \langle \mu_e \rangle(\text{Bulge}) = M_{\text{Bulge}}(\text{Bulge}) + 2.5 \log_{10} \left( 2\pi R_e^2 \right) + 36.57 \) (see Graham & Driver 2003 eqn. 12) (mag arcsec\(^{-2}\)).

Column 103: \( (\mu_o \text{ (Disc)}) \) Absolute central surface brightness: \( \mu_o(\text{Disc}) = \mu_e(\text{Disc}) - 1.0857b \) (see Graham & Driver 2005 eqn. 7) (mag arcsec\(^{-2}\)).

Column 104: \( (\mu_e \text{ (Disc)}) \) Absolute effective surface brightness at \( 1.678\alpha_D \): \( \mu_e(\text{Disc}) = \langle \mu_e \rangle(\text{Disc}) + 2.5 \log_{10} \left[ \frac{\Omega}{\Omega_{\text{MGC}}} \Gamma(2n) \right] \) (see Graham & Driver 2005 eqn. 9) (mag arcsec\(^{-2}\)).

Column 105: \( (\langle \mu_e \rangle \text{ (Disc)}) \) Absolute effective surface brightness of disc component: \( \langle \mu_e \rangle(\text{Disc}) = M_{\text{Bulge}}(\text{Disc}) + 2.5 \log_{10} \left( 2\pi (1.678\alpha_D)^2 \right) + 36.57 \) (see Graham & Driver 2003 eqn. 12) (mag arcsec\(^{-2}\)).

Column 106: \( (R_e) \) Radius at which the surface brightness of the disc equals the surface brightness of the bulge, i.e., \( \langle \mu_e \rangle(\text{Bulge}) + 1.0857b \left( \frac{b}{R_e(\text{Bulge})} \right)^2 = \langle \mu_e \rangle(\text{Disc}) + 1.0857 \langle \frac{\Omega}{\Omega_{\text{Bulge}}} \rangle \) (see Graham & Driver 2002 eqn. 17) (arcsec).

Column 107: \( (\mu_s) \) Surface brightness at \( R_s \) (mag arcsec\(^{-2}\)).

Column 108: \( (p \text{ type}) \) Profile type as defined in Section 3.

Column 109: \( (b) \) the value which satisfies \( \Gamma(2n) = 2\gamma(2n, b) \) (see Graham & Driver 2005).

Column 110: \( (\text{ID}) \) Duplicate of column 1.

Column 111: \( ((u - r)_d) \) Rest frame global colour: \( M_g(\text{Pet}) - M_r(\text{Pet}) \) (AB mag).

Column 112: \( ((u - r)_c) \) Rest frame core/bulge colour: \( M_u(\text{PSF}) - M_r(\text{PSF}) \) (AB mag).

Column 113: \( ((u - r)_d) \) Rest frame outer/disc colour: \( (u - r)_d = -2.5 \log_{10} \left( \frac{M_{Bulge}(\text{Bulge})}{1 + \frac{M_{Bulge}(\text{Bulge})}{M_{Disc}(\text{Disc}) + 2.5 \log_{10} \left( 2\pi R_e^2 \right) + 36.57}} \right) \) (AB mag).

Column 114: \( (\text{ID}) \) Duplicate of column 1.

Column 115: \( (\text{FLAGS}) \) SExtractor flags from original detection.

Column 116: \( (\text{ID}) \) Duplicate of column 1.

Column 117: \( (S) \) Galaxy significance: i.e., \( \frac{M(\langle \mu_e \rangle)}{\sigma(M(\langle \mu_e \rangle))} \) (see Driver et al. 2005, 2006).

Column 118: \( (\Delta S) \) Error in \( S \) (see Driver et al. 2002, 2003).

Notes:

1 Absolute magnitudes are derived using \( \Omega_M = 0.3, \Omega_\Lambda = 0.7, H_0 = 100 \text{ km s}^{-1} \text{ Mpc}^{-1} \), the appropriate k-correction derived for each filter and an evolutionary correction of the form \( L_z = L_z(1 + z)^{-\beta} \), where \( \beta = 1.5, 0.75, 0.5, 0.375, 0.3, 0.2 \) for u, B, g, r, i, z respectively. Galaxies without redshifts have values of -99.9 in these columns.

2 MGC absolute magnitudes are derived using: \( M_{T, B, D} = Z_p - 2.5 \log_{10} \left( X_{T, B, D} \tilde{V} \right) - (B - M_B) - A_B \) where \( X = 1 \), BULGE, FRAC or (1-BULGE, FRAC) for Total (T), Bulge (B) or Disc (D) respectively (null values are set to 99.99).