A Catalogue of Two-Dimensional Photometric Decompositions in the SDSS-DR7 Spectroscopic Main Galaxy Sample: Extension to $g$- and $i$-Bands

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ABSTRACT

We extend the catalogue of two-dimensional, PSF-corrected de Vaucouleurs, Sérsic, de Vaucouleurs+Exponential, and Sérsic+Exponential fits of $\sim 7 \times 10^5$ galaxies presented in Meert, Vikram & Bernardi (2015) to include the $g$- and $i$-bands. Fits are analysed using the physically motivated flagging system presented in the original text, making adjustments for the differing signal-to-noise when necessary. We compare the fits in each of the $g$-, $r$-, and $i$-bands. Fixed aperture magnitudes and colours are also provided for all galaxies. The catalogues are available in electronic format.

Key words: galaxies: structure – galaxies: fundamental parameters – galaxies: evolution

1 INTRODUCTION

The study of the structural components of galaxies has contributed substantially to the understanding of the formation and evolution of galaxies. The structural components of galaxies in the local Universe trace morphological galaxy type and many other galaxy parameters related to both assembly and evolution of galaxies: colour, metallicity, gas fraction, etc. Properties may also trace halo size and galaxy environment and place constraints on ACDM cosmology. However, careful estimation of structural parameters for large numbers of galaxies is required to test different formation and evolution models.

This paper extends the original r-band fits presented in Meert, Vikram & Bernardi (2015) (hereafter M15) to the $g$- and $i$-band so that colour comparisons can be made and colour-dependent galaxy properties can be measured. M15 presented a catalogue of two-dimensional, PSF-corrected de Vaucouleurs, Sérsic, de Vaucouleurs+Exponential, and Sérsic+Exponential fits of $\sim 7 \times 10^5$ spectroscopically selected galaxies drawn from the Sloan Digital Sky Survey DR7 (SDSS DR7: York et al. 2000; Abazajian et al. 2009). Fits are presented for the SDSS $g$- and $i$-bands utilizing the fitting routine GALFIT (Peng et al. 2002) and analysis pipeline PYMORPH (Vikram et al. 2010).

There has been much recent work on improving photometric decomposition of galaxies (e.g. Gadotti 2009; Simard et al. 2009; Kelyn et al. 2012; Lackner & Gunn 2012; Häußler et al. 2013). These papers take different approaches to fitting multi-band imaging, Simard et al. (2011) (hereafter S11) fits the $g$- and $r$-bands jointly, producing a single set of fitted galaxy parameters that are band-independent (with the exception of magnitude, which is allowed to differ across the bands). Lackner & Gunn (2012) fit to the $r$-band data only, then refit to the $g$- and $i$-bands, holding all fitting parameters fixed, except for magnitude. Häußler et al. (2013) instead fits all available bands simultaneously allowing fitted parameters to vary smoothly across the bands. Here, we fit all bands independently of each other, using no information from neighbouring bands to inform our fits.

While using multi-wavelength data to constrain fitting provides a more stable fit, especially in bands with lower signal-to-noise, it is not without downsides. Requiring the same fitting parameters across multiple bands ignores the intrinsic wavelength dependence of galaxies, their subcomponents, and the populations of stars contained within the components. This bias can be partially mitigated by allowing the relative magnitudes of the components (or the B/T) to have a wavelength dependent behavior. However, other parameters such as bulge radius or Sérsic can have wavelength dependence as well. Fitting using the methods of
2 THE DATA

The data used in this analysis are the same 670,722 galaxies fit in M15. The M15 sample was drawn from the spectroscopic sample of the Legacy area of the Sloan Digital Sky Survey Data Release 7 (hereafter SDSS DR7; Abazajian et al. 2009). The spectroscopic sample provides a well-established sample with well-defined and tested selection criteria. The criteria are presented in Strauss et al. (2002). The primary selection criteria for these galaxies is that the extinction-corrected $r$ band Petrosian magnitude between magnitude 14 and 17.77. Thus the sample is magnitude limited and requires corrections in order to make robust conclusions about the population of galaxies.

Figure 4 shows the distributions in the $g$, $r$, and $i$-bands using SDSS values of mean surface brightness within the Petrosian half-light-radius, redshift, extinction-corrected apparent Petrosian magnitude, Petrosian half-light radius, $V_{\text{max}}$-weighted absolute Petrosian magnitude, and signal-to-noise for the sample used in this paper.

The definition of the surface brightness and S/N used here is the same as in the previous paper, M15. The mean surface brightness within the Petrosian half-light radius is defined as

$$\mu_{50, r} = m_{\text{petro}, r} + 2.5 \log \left( 2\pi r_{50, \text{petro}}^2, 50 \right).$$

We also define the S/N as the mean pixel flux within the half-light radius divided by the noise associated with that pixel, or

$$\left( \frac{S}{N} \right) = \frac{I_{\mu_{50}}}{N_{\text{avg}}}$$

$$N_{\text{avg}} \equiv \sqrt{I_{\text{pho}} + I_{\text{sky}} + \text{dark variance}}$$

$$I_{\mu_{50}} = 10^{-0.4 \times (\mu_{50} - zp) + \text{platescale}^{-2}}$$

where $I_{\mu_{50}}$ is the source DN (‘data numbers’ or, equivalently, counts) of the average surface brightness defined in Equation 1. The zero-point, $zp$, is calculated from the SDSS zeropoint, extinction, and airmass terms associated with each image. The platescale is used to convert the surface brightness from counts per square arcsecond to counts per pixel. $N_{\text{avg}}$ is the noise in a pixel using the SDSS background measurement as an estimate of the background flux and the average flux per pixel inside the Petrosian half-light radius as the galaxy flux.

The surface brightness (top left panel) is brightest in the $i$-band and dimmest in the $g$-band. The sizes of galaxies in each band (bottom row, left panel) are similar, although the $g$-band is slightly larger than the $r$-band on average. The $i$-band is slightly smaller than the $r$-band. The large difference in surface brightness is due to substantial differences in the total magnitudes of the objects (top row, right panel). However, the S/N is most relevant to fitting. The S/N (bottom row, right) shows that the $i$-band has S/N similar to, and perhaps slightly higher than, the $r$-band. Although the $i$-band galaxy images are brighter and roughly the same size as the $r$-band galaxy images, which would imply a higher S/N, the sky brightness is also $\approx 50\%$ brighter in the $i$-band. The $g$-band has comparably lower average S/N relative to the $r$-band. The average $g$-band sky is dimmer by 1 magnitude relative to the $r$-band, but the galaxy brightness is also dimmer on average. Since the original simulations used to test the accuracy of the fitting algorithm were based on $r$-band measurements, the true accuracy of fitting in the $g$-band may be substantially lower. This is most concerning in the case of the Ser-Exp and dev-Exp fits where two components are being simultaneously fit, further lowering the S/N of each component (because the total flux is now divided between the two fitted components). We will return to this issue in Sections 4 and 6.

In addition to the data provided by CasJobs, M15 also used data from the Morphology catalogue of Huertas-Company et al. (2013) (hereafter referred to as...
3 THE FITTING PROCESS

The fitting process is the same as in M15 with only minor modifications. FpC images and psField files are the primary data used in the fitting procedure. Postage stamp images of each source were extracted from the FpC image such that the stamp was 40 Petrosian half-light radii on a side (20 petroR50_r from the centre of the image to the edge) and centered on the target source. In addition, a minimum size of 80 pixels on each side was set to ensure that enough pixels were retained to properly determine the background. We continue to set the cutout size based on the $r$-band sizes since the $r$-band data is used throughout SDSS to set consistent measures across all bands.

The band-specific PSF is extracted from the PsField files using the readAtlasImages-v5_4_11 program distributed on the SDSS site. The PSF provided by SDSS using the readAtlasImages-v5_4_11 program has a standard image size of 51 pixels on each side. The average PSF width for the bands is 1.47″, 1.35″, and 1.28″ for the $g$, $r$, and $i$-bands, respectively.

Prior to fitting, the soft-bias is removed from the images and PSF, we create sigma images from the SDSS images, and we normalize the postage stamp and sigma images to a 1-second.

We again fit the dev, Ser, dev-Exp, and Ser-Exp models as in M15 to the sample described in Section 2 using PyMorph (Vikram et al. 2010). PyMorph is a Python based automated software pipeline built on SExtractor (Bertin & Arnouts 1996) and the two-dimensional fitting routine Galfit (Peng et al. 2002). The two-step neighbor identification process described in Section 3.4 of M15 is also applied to the $g$- and $i$-band fits.

3.1 Measuring colours of fitted galaxies

Galaxy colour is the ratio of light in two bands. Differences in the fitted parameters (e.g. Sérsic index, radius) across the bands imply colour gradients. Analytical profiles integrated to infinitely large radius can have large portions of their total integrated light well beyond the apparent extent of the galaxies. For instance, a Ser galaxy with $n=4$ has approximately 85 per cent of its total light within 4 half-light radii. For a Ser galaxy with $n=8$, the total light contained

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**Figure 1.** (a) The distribution of mean surface brightness within the half-light radius. (b) Redshift distribution. (c) Extinction-corrected apparent Petrosian magnitude. (d) Petrosian half-light radius. (e) $V_{max}$-weighted absolute Petrosian magnitude, and (f) Signal-to-Noise distribution.
within 4 half-light radii drops to approximately 76 per cent of the total galaxy light. Therefore, colour differences can be due to low levels of light at large radii. In order to mitigate this effect and make comparisons similar to common SDSS colours, we measure several aperture magnitudes that can be used for colour calculations.

First, the fibre magnitude is measured for the 2 and 3′′ circular apertures representing the fibers used in BOSS (Dawson et al. 2013) and SDSS, respectively. These are measured using the PSF-convolved fitted model (e.g., dev, Ser, dev-Exp, or Ser-Exp). The magnitudes can be used for comparison to the fibre magnitudes and fibre colours available in the SDSS database. In addition, magnitudes using the Petrosian aperture and our fitted models are measured. The Petrosian aperture is a circular aperture that is twice the r-band Petrosian radius. This can be compared directly to the Petrosian magnitude and related colours.

We also provide an aperture magnitude intended for comparison to the SDSS CModel and Model magnitude for each model and band. SDSS dev and Exp galaxy profiles fit by the Photo pipeline are truncated at 8σdev and 4σexp, respectively. Therefore, we define the aperture radius as either 8σdev,SDSS or 4σexp,SDSS in the r-band depending on whether the SDSS Model magnitude uses the dev or Exp fits. This radius is used to define an elliptical aperture, from which we measure the aperture magnitude of each fitted model in all of the bands. In Section 5 we compare the aperture colours calculated using these aperture magnitudes to the SDSS Model and CModel magnitudes.

4 S/N CONCERNS

4.1 General effects of lower S/N

Figure 1 in Section 2 showed that the S/N of the i-band is similar to that of the r-band originally studied in M15. Therefore, we expect the performance of the flagging in the i-band to be similar to that of the r-band. However, the g-band fits were found to be lower in S/N with the peak of the distribution approximately a factor of 2 smaller than the peak in the r-band.

The simulations of M13 were primarily based on assuming the S/N of the r-band data, so further investigation may be necessary prior to accepting the g-band fits. M13 also tested fitting the SDSS using different S/N and resolution, focusing on cases of increased S/N and resolution that might be expected in other surveys, and showing that increasing resolution by a factor of 2 more strongly influenced the accuracy of the fitting than increasing S/N by a factor of 4 (see M13, Sections 3.3 and 3.4).

According to M13, when the appropriate profile (i.e., one vs. two-component) is chosen, magnitude and half-light radius are expected to be accurate at the 5% level (using 1-σ errorbars). However, these tests presumed the average S/N of an r-band image. This is not a concern for the i-band, which has both better seeing and brighter galaxies. In the i-band the sky is also brighter offsetting any gains in S/N and making the distribution S/N very similar to the r-band, if not skewed slightly higher. In the g-band, the sky is dimmer, but the galaxies are also dimmer and the PSF wider such that the average S/N is substantially lower.

We expect this to affect our measurements in a few ways. First, the fitting parameters, particularly in the case of the dev-Exp and Ser-Exp fits may be biased or have very large uncertainty. Second, (and partially as a result of the first issue) the choice of bulge/two-component/disk based on the flagging may be biased.

Since our resolution is only moderately different between bands (less than 10 per cent) we expect the effects to be somewhat smaller than those reported in M13. However, prior to fitting the g-band, we simulated the M13 mock galaxies with S/N reduced by a factor of 2 to explore the effects of reduced S/N in the g-band. Figure 2 shows the behaviour of total magnitude (left-hand column), total half-light radius (centre column), and B/T (right-hand column) for the original fiducial simulations of Ser-Exp fits published in M13 (top row) and the results of lowering the S/N by a factor of 2 (bottom row), similar to what we observe in the g-band images. There is growth in the scatter of these estimated parameters by as much as a factor of two, but no additional bias is introduced beyond what was previously reported in M13. We expect the g-band estimates of magnitude and half-light radius to be accurate at the 15 per cent level (using 1-σ errorbars) compared to 10 per cent accuracy in the r- and i-bands with biases similar to those reported in M13. The scatter grows most strongly at the dimmer magnitudes where S/N is already lowest.

While they are not shown here, the sub-components of the Ser-Exp model are differently affected by the reduction in S/N. Disk components behave similar to the total magnitude and half-light radius with similar increases in scatter. Bulge components are more strongly affected by the change in S/N with a larger increase in the scatter, but no significant bias arising from the lower S/N. The difference between the bulge and disk components is likely due to the smaller number of free parameters in the disk versus the bulge (i.e., the bulge Sérsic index adds a substantial amount of freedom to the bulge model that the disk does not possess).

4.2 Flagging adjustments as a result of S/N

The flagging procedure presented in Section 4 of M15 is intended (among other goals) to reliably distinguish between one- and two-component fits, reducing any fitting bias resulting from fitting a one-component profile to a two-component galaxy (see M13 for more information on the simulations and results). The majority of the flags are constructed using relative measurements that should not require adjustment to accommodate measurements in bands other than the r-band. For instance, determining that a galaxy has a contaminated bulge or disk component (flag bits 22 and 23) requires comparing the size of the bulge and disk components to the Petrosian radius in the corresponding band. Since the comparison is a relative one and does not have an absolute physical scale set, we expect the comparison to be valid across all the bands.

However, the bounds for determining when a bulge or disk component is not present (i.e., flag bits 1 and 4) are partially determined by a cut on magnitude calibrated to the r-band fits using a training set of visually classified galaxies. Since the magnitudes and S/N are different in the g- and i-bands, it is possible that these cuts need to be adjusted to work in the neighbouring bands.
Comparison of the original fiducial simulations of Figure 2. We expect the estimated parameters by as much as a factor of two, but no additional bias is introduced beyond what was previously reported in per cent CI errorbars shown. The 68 percent scatter of the data is shown as the dashed contours. There is growth in the scatter of (left-hand column), total half-light radius (centre column), and B/T (right-hand column). The median value is plotted in red with 95 percent CI errorbars calculated using these values. The i-band requires no such adjustment.

We use these magnitudes as the basis for the flag bits 1 and 2, which means that more second fit components (either bulge or disc) will have little or no light to fit, and can be used by the fitting algorithm to reduce fit residuals by trying to fit light from neighbour galaxies.

In particular, the no bulge condition set in M15 was

$$1000(B/T - 0.8)^5 + (m_{\text{disc}} - 19) > 0.5$$

and the no disc condition was

$$1000(0.2 - B/T)^3 + (m_{\text{bulge}} - 19) > 0.5$$

These cuts were set based on visual classification of fitted galaxies by the authors and the fact that scatter in the bulge or disc components grows substantially when the component was dimmer than 19. This cut of 19 was based on the assumption of S/N present in the r-band images. In particular, the average sky brightness and noise properties in the g-, r-, and i-bands differ as well as the average magnitudes.

We computed the equivalent magnitude in the g- and i-bands of a component with the same S/N as an r-band 19.0 object while assuming median sky brightness, median bulge (or disc) half-light radius, and median noise properties. Table I summarizes the median values used in each band and the equivalent magnitude for the g- and i-bands calculated using these values. The g-band requires no adjustment. The i-band requires more adjustment due to the increasing sky brightness and dark variance in the band.

We use these magnitudes as the basis for the flag bits 1 and 4 (i.e., “no bulge” or “no disk”) flags. These flags are the only flags that use an absolute cut on magnitude, so we expect that the remaining flags require no such adjustment.

5 RESULTS OF FITTING AND FLAGGING

We again use the series of physically motivated flags analysed in detail in M15. We use these flags to determine the reliability of the various fits and the individual subcomponents. We also use the flags to mark poorly fitted galaxies. Table 2 shows the flagging categories, the final percentage of Ser-Exp galaxies in each flagging category for the g-, r-, and i-bands (left, centre, and right columns, respectively).

M15 used a tiered structure to describe the fits. The most general description is the accuracy of the total magnitude and radius. M15 showed that about 94% of the r-band Ser-Exp sample is classified as having an accurate measurement of the total magnitude and half-light radius. This percentage is reduced in the g- and i-bands to approximately 92 percent. The increase in failed fits can be mostly attributed to increasing neighbour contamination, which is reflected in the flagging as an increase of the “Ser component contamination by Neighbours or Sky” and the “Exp component contamination by Neighbours or Sky” flags which contain an additional $\pm 1.5$ percent of the total sample compared to the original r-band fits of M15. This increase in neighbour contamination and failed fits is not due to the increase in number of neighbours (as these are the same set of galaxies in each band), but instead due to the decrease in the number of two-component galaxies. Fewer two component galaxies means that more second fit components (either bulge or disc) will have little or no light to fit, and can be used by the fitting algorithm to reduce fit residuals by trying to fit light from neighbour galaxies.

In addition to the increase of failed galaxies, there is a decrease in the percentage of two-component fits from $\approx 39$ percent in the r-band to 33 percent in the g-band and 37 percent in the i-band.

The number of pure bulge galaxies drops in the bluer filters from 20 percent in the i-band to 17 percent in the g-band and the number of disks increases substantially from 24 percent in the i-band to 31 percent in the g-band. These observations agree with a simple bulge+disk model of galaxies where the disk tends to be bluer and the bulge is redder. It may also partially explain the increase in failed cases due to contamination or sky since the g- (i-) band will feature the disk (bulge) more...
Table 1. Median values of radius, zeropoint, sky brightness, gain, and dark variance for the $g$, $r$, and $i$ bands. The S/N and magnitude are also shown. The $r$-band flags in M15 used a cut of 19 magnitudes as the basis for determining that a bulge or disk component is not reliable. Here, we show the median S/N of an object in the $r$-band, then using median values for the $g$- and $i$-bands, we calculate the equivalent magnitude of an object with the same S/N (within 1 per cent) as the $r$-band value. This band-dependent magnitude is used for bulge and disk flagging in the two-component $g$- and $i$-band fits and accounts for differences in the sky brightness and zeropoints between the bands.

| Band | $r_{arcsec}$ | zeropoint | $\mu_{sky}$ [mag arcsec$^{-2}$] | Gain | Dark Variance | S/N | m |
|------|--------------|-----------|-------------------------------|------|---------------|-----|---|
| g    | 1.20         | 24.2      | 22.0                          | 3.85 | 1.44          | 1.34 | 19.0 |
| r    | 1.12         | 23.9      | 21.0                          | 4.70 | 1.00          | 1.34 | 19.0 |
| i    | 1.00         | 23.6      | 20.3                          | 4.86 | 5.75          | 1.34 | 18.2 |

Table 2. A breakdown of the M15 flags now shown for the $g$, $r$, and $i$-band fits. The prevalence of galaxies with two-component fits decreases toward the bluer end from $\approx$ 39 per cent in the $i$-band to 33 per cent in the $g$-band. The prevalence of pure bulge galaxies also decreases toward bluer bands while the prevalence of disk galaxies increases. This is as expected using a simple bulge+disk model with a bluer disk and redder bulge.
prominently and the second component will be dimmer or not present due to the different colour. With dim or low S/N component, there is a more likely possibility that the fitting routine will settle into a local minima that improperly uses this second component since it is not well constrained by the observations. A poorly constrained component may be used to fit stray light from neighbouring galaxies, increasing the failure rate as observed here.

5.1 Flagging versus basic fitting parameters

Figure 3 shows the absolute magnitude distribution (left-hand side) and the physical half-light radius distribution (right-hand side) of the $g$- (top row), $r$- (middle row), and $i$-band (bottom row) for galaxies in the catalogue. The figure shows the bin-by-bin percent of galaxies of each type; Disk (blue points, labelled as “disks”), Bulge (red points, labelled as “bulges”), Two-Component (green points, labeled as “2com”), Problematic Two-Component (yellow points, labelled as “bad 2com”), Failed Galaxies (black points, labelled as “bad”), according to our categorical flags. We have also separated the good two-component models into those with Sérsic indices below 8 and those galaxies with acceptable fits but the Sérsic index of the bulge hits the $n = 8$ boundary of the parameter space (cyan points, labeled as “n8”) to check for any bias resulting from the restriction on the fitted Sérsic index. The background shows the total distribution of galaxies with respect to the parameter used to bin the data.

The fits of this work contain almost no bulges (only a few percent) and a mixture of disk and two-component galaxies at low magnitudes (below about -19.5). Two-component fits are the dominant model between -20 and -22 and bulges dominate at magnitudes brighter than -22. In the $g$-band, the failure rate is substantially higher at the brightest magnitudes (above -24 in the $g$-band). It is reasonable to expect that the majority of these bright $g$-band galaxies be incorrectly fit, dimmer galaxies farther than true bright $g$-band galaxies. The $g$-band sample is dimmer than the $r$-band and galaxies as bright as -24 in the $g$-band are extremely rare due to the surface-brightness, flux, and size limits of this sample, making it more likely that galaxies as bright as -24 are indeed incorrectly fit galaxies. The $r$- and $i$-bands appear similar in behaviour, while the $g$-band shows increased contributions from pure disk galaxies in the absolute magnitude distribution. In the $g$-band magnitude distribution (top left) the range of magnitudes with majority pure disk population is substantially larger compared to the $r$- and $i$-bands (middle and lower rows). The physical half-light radii are also similar in behaviour across the bands. This shows that the fitting is quite similar in distribution across the bands with a smooth transition from having more disks in the $g$-band to fewer disks in the $i$-band. However, in addition to stability across the entire sample, single galaxies should show strong correlation across the three fits.

In Figure 4 we show the breakdown of the fitting categories across two bands at a time. Each cell of the matrix shows the fraction of the entire catalogue that is classified in the combination of bands and fitting categories denoted by the axes of the matrix (e.g. the top left cell of the first matrix shows that 12 percent of the sample is classified as “pure bulge” in both the $g$- and $r$-band fits). The majority of galaxies ($\approx 65 - 70$ per cent are in the top left $3 \times 3$ quadrant of each matrix, indicating that the majority of galaxies are similarly identified across the bands. Also, the bulge-disk and disk-bulge cells are below 0.5 per cent (indicated by the 0.00 value) showing that few or no galaxies switch directly from bulge to disk categories, which would be unexpected. Additionally, the cells along the diagonal contain between 50 and 60 percent of the sample, indicating that the majority of galaxies receive the same broad classification in neighbouring bands. This demonstrates that there is stability in the flagging classification used in this work.

5.2 Examining the colour

As discussed in Section 5.1 we provide aperture magnitudes as part of this data release to allow colour measurements. In this section, we make some simple comparisons of colours to commonly used colours obtained from the SDSS database.

M15 assigned a T-type to each galaxy in the catalogue using the type probabilities (Ell, S0, Sab, Scd) provided by the BAC (Huertas-Company et al. 2011) (see M15 for additional details). The BAC of Huertas-Company et al. (2011) used a Bayesian approach to assign probabilities of being one of four broad galaxy types (Elliptical, S0, Sab, or Scd) to each galaxy using colour, total axis ratio, and concentration as measured by the SDSS. An SVM algorithm was used to produce the probabilities, using the Fukugita et al. (2007) sample as the training set.

Figure 5 compares the PyMorph Ser-Exp, SDSS Model, and SDSS CModel colours as a function of absolute Petrosian magnitude for the full sample, Ell, and Scd galaxies in the left-hand, centre, and right-hand columns, respectively. The $g-r$ and $r-i$ colours are shown in separate rows.

When comparing the PyMorph Ser-Exp and SDSS Model colours, the $g-r$ colour shows a slight negative bias ($\approx 0.025 - 0.05$) indicating that PyMorph Ser-Exp models are slightly bluer compared to SDSS Model colours for the total sample. When looking at only Elliptical galaxies, the bias is reduced. This is not the case for the Scd galaxies. The scatter is also broader in colours based on the $g$-band ($\approx 0.075$ vs $\approx 0.05$ in the $r-i$ colour). When comparing PyMorph Ser-Exp and SDSS CModel colours, the bias disappears but the scatter remains relatively broad. The SDSS Model fixes the fit type to be pure Exp or pure deV for the galaxies. This static choice of model may play a role in the differences observed here. Fixing the model across the bands will certainly reduce the scatter in the colours, as the only way to adjust the model is an overall normalization (changing the total magnitude). However, as previously stated, this ignores the changing profile of the galaxy across the bands as well as the associated colour gradients, which may contain interesting information about the galaxy.

Figure 6 shows colours calculated from the light profiles of this work versus the absolute Petrosian magnitudes of the galaxies. The PyMorph aperture colours derived from the Ser-Exp fits of this work are shown for the classes Elliptical (Ell) and Scd identified in M15 (rows 1 and 2, respectively). There appears to be little change in the total colours across the types. In addition, the scatter is broad enough to make conclusions using the colours difficult. The typical colour-magnitude relationship is visible for Elliptical galaxies (red sequence) and Scd galaxies (blue cloud). Including S0 and Sab galaxies increase the scatter in these relations as...
the dominant contribution to the light transitions from the redder Ellipticals to the bluer Scd galaxies.

While we discuss the total colours here, bulge and disc colours can be calculated from our data. Component colours contain even more uncertainty than what is presented here, and the reader is cautioned to check that the colours are not biased in respect to the particular science being conducted.

6 DISCUSSION AND USE OF THE CATALOGUE

When using the catalogue, we recommend using the same selection criteria described in Section 8 of M15. The format of the data is similar to the format used in M15. We provide our fits and flags for each of the four models (deV, Ser, deV-Exp, and Ser-Exp) and in each of the three bands. The r-band data is included in this new data release for completeness and has the aperture magnitudes added into the data. In addition, we provide a preferred catalogue for public use. This preferred catalogue has Ser fits for galaxies flagged as pure bulge or pure disc. The remaining galaxies have Ser-Exp fits.

When using the catalogue, we recommend removing galaxies flagged as bad (flag 20) as these galaxies have catastrophically bad estimates of total magnitude and radius. Additional galaxies may be removed depending on how conservative the user seeks to be. The problematic two-component fits (flag 14) or the two-component fits with bulge Sérsic index n = 8 may be used for total magnitude and radius measurements, but the sub-components are not reliable.

The user should also be aware that we have swapped the bulge and disc components of galaxies with bit 6, 7, or 13 set (which were flagged as inverted profiles in the Ser-Exp fit). These galaxies have B/T inverted and the components
reversed relative to the Ser-Exp fit. Therefore, no additional alterations must be made to account for the inverted nature of the profile. However, using the “raw” fit produced prior to flagging requires swapping bulge and disc parameters and inverting the B/T. This alteration has been done in all catalogues.

We suggest one of these composite samples drawn from the preferred fit catalogue described in the previous paragraph:

The conservative catalogue Select all galaxies with final flag bits 11, 12, or 13 set and bulge Sérsic index < 8. In addition, the user should select galaxies with Ser-Exp final flag bits 1 or 4 set. These galaxies will have B/T of 1 (for bulges; final flag bit 1 set) or a B/T of 0 (for discs; final flag bit 4 set) and the relevant Ser parameters are reported in the catalogue.

The intermediate catalogue Use the catalogue above plus all galaxies with final flag bit 10 set and bulge Sérsic index = 8.

The full catalogue Use the catalogue above plus all galaxies with final flag bit 14 set. This is the least restrictive version of the catalogue but may include galaxies with strange, difficult-to-interpret fit parameters.

When using the multi-band data, the selection criteria should be applied across all 3 bands.

While the dev and dev-Exp models are not a focus of this work, we recognize that there may be cases in which these models are preferred for analysis, especially when comparing to previous work. The breakdown of flags for these models is shown in the online Appendix A. If the dev-Exp model is desired for two-component galaxies rather than the Ser-Exp used here, the same criteria used to draw the composite samples described in this section may be applied to the dev-Exp fits. This may be done at the user’s discretion. We point out here that all flagging is carried out in the same manner for the Ser-Exp and dev-Exp models, except where the fits do not allow such treatment (e.g. there can be no cases of bulges appearing disc-like in the dev-Exp sample since the Sérsic index is fixed at 4 in all dev-Exp fits). The single-component dev and Ser fits also receive the same treatment during flagging.

The data files for this catalogue are available online at http://www.physics.upenn.edu/~ameert/SDSS_PhotDec/

Tables 3 and 4 describe the format of the data tables released as part of this work. We distribute the data as a binary table using the FITS standard. The first binary extension contains the model independent measurements for each galaxy (e.g. SExtractor measurements, the number of fitted neighbours, etc.). The following extensions contain the “best model” (the combination of Ser and Ser-Exp fits), the dev model, the Ser model, the dev-Exp model, and the Ser-Exp model in that order. These extensions include the fitted values for magnitude, radius, and other parameters as well as the flags described in M15 (labelled as finalflag, in column 34). A separate table containing ra/dec/z information and other identifying information is also available to allow matching between this catalogue and external work. There are separate files for each of the three bands and the bands are denoted in the name of the file as either “gband,” “rband,” or “iband.”

7 CONCLUSIONS

The r-band catalogue of dev, Ser, dev-Exp, and Ser-Exp galaxies presented in M15 constructed for the SDSS DR7 Spectroscopic sample was extended to the g- and r-bands. We used the PyMorph pipeline, including the SExtractor and Galfit programs, to perform 2D decompositions (see Sections 2 and 3). We used the original flagging system of M15 where appropriate and applied the flagging system to the Ser-Exp fits.

Depending on the band chosen, we identified 92 to 94 percent of our fitted sample as having reliable total magnitude and half-light measurements. About 33-39 percent of the sample are two-component galaxies with well-behaved components. An additional ≈ 11% may be two-component
fits, but with difficult-to-interpret components. The remaining 44% are pure bulge and disk galaxies. We compared the fits across the bands and found fitting to be stable and to exhibit trends with increasing disk contributions toward the $g$-band and increasing bulge contributions toward the $i$-band. While adjustments for differences in the S/N were considered, simulations at S/N values approximating the ADP/NNX09AD02G and NSF/0908242. Clampitt for many helpful discussions.

We would like to thank our referee for many helpful comments and suggestions. These have greatly improved the paper.

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This work was supported in part by NASA grant ADP/NNX09AD02G and NSF/0908242.

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ACKNOWLEDGEMENTS

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Figure 5. PyMorph Ser-Exp minus SDSS Model colours (top two rows) and PyMorph Ser-Exp minus SDSS CModel colours (bottom two rows) as a function of absolute Petrosian magnitude for the $g-r$ and $r-i$ colors. The colours are shown for all galaxies, Ell, and Scd galaxies in the left-hand, centre, and right-hand columns, respectively. Median values are plotted in as red symbols with 95 per cent CI as error bars. The 68 per cent contours are shown as blue dashed lines. PyMorph colours appear similar to the SDSS CModel colours with some scatter, but little or no apparent trend with respect to magnitude.

Examination of the Ser-Exp fits and the flagged categories show that the morphological classes assigned in this catalogue using the flags (i.e., bulge, disk, or two component) also correlate well across the bands and with absolute magnitude. Aperture colours calculated from these fits show a larger scatter compared to SDSS and have a blueward bias of approximately 0.05 magnitudes relative to SDSS, which appears to be correlated with $g$-band measurements. This bias occurs more strongly at the bright end of the later types (probably due to a larger uncertainty in the $g$-band since brighter galaxies are bulge dominated and therefore redder). The fits also show the usual color magnitude relations when divided into different morphological types (red sequence and blue cloud).
Figure 6. PyMorph Ser-Exp colours of this work versus the absolute Petrosian magnitudes of the galaxies. The PyMorph aperture colours derived from the Ser-Exp fits of this work are shown for the classes, Elliptical (Ell) and Scd identified in M15 (rows 1 and 2, respectively). The three combinations of bands \(g-r\), \(g-i\), and \(r-i\) in the left-hand, centre, and right-hand columns. Median values are plotted in as red symbols with 95 per cent CI as error bars. The 68 per cent contours are shown as blue dashed lines.

| Column Number | Column Name              | Explanation                          | Data Type |
|---------------|--------------------------|--------------------------------------|-----------|
| 0             | SExMag                   | the SExtractor magnitude (mag)       | float     |
| 1             | SExMagErr                | the SExtractor magnitude error (mag) | float     |
| 2             | SExHrad                  | the SExtractor half-light radii (arcsec) | float |
| 3             | SExSky                   | the SExtractor sky brightness (mag/arcsec^2) | float |
| 4             | num_targets              | the number of targets                | int       |
| 5             | num_neighborfit          | the number neighbour sources fitted with Ser profiles | int |
| 6             | AperRad                  | the aperture radius (arcsec) used for colour measurements | float |
| 7             | C                        | the Concentration                    | float     |
| 8             | C_err                    | the Concentration error              | float     |
| 9             | A                        | the Asymmetry                        | float     |
| 10            | A_err                    | the Asymmetry error                  | float     |
| 11            | S                        | the Smoothness                       | float     |
| 12            | S_err                    | the Smoothness error                 | float     |
| 13            | G                        | the Gini coefficient                 | float     |
| 14            | M20                      | the M20 value                        | float     |
| 15            | extinction               | The SDSS-provided galactic extinction (magnitude) | float |
| 16            | dismod                   | the calculated distance modulus      | float     |
| 17            | kpc_per_arcsec           | the angular scale (kpc/arcsec)       | float     |
| 18            | Vmax                     | the Volume used for Vmax corrections (Mpc^3) | float |
| 19            | SN                       | the average S/N per pixel inside the half-light radius | float |
| 20            | kcorr                    | k-correction calculated using the SDSS model magnitudes | float |

Table 3. Description of columns in the electronic table UPenn_PhotDec_nonParam_g(r)(i)band for the \(g\), \(r\), and \(i\)-band data, respectively. The data are model-independent measurements fitted by PyMorph. Problematic data or parameters are replaced with -999.
| Column Number | Column Name       | Explanation                                      | Data Type |
|---------------|-------------------|--------------------------------------------------|-----------|
| 0             | m_tot             | total fitted apparent magnitude                  | float     |
| 1             | m_aper            | the aperture magnitude used measured within the AperRad | float     |
| 2             | BT               | the B/T (bulge-to-total light ratio) of the fit  | float     |
| 3             | r_tot             | the half-light radius (arcsec) of the total fit  | float     |
| 4             | ba_tot            | the axis ratio (semi-minor/semi-major of the total fit | float     |
| 5             | BT_aper           | the B/T (bulge-to-total light ratio) of the fit inside the fixed aperture | float     |
| 6             | xctr_bulge        | the bulge x centre (pixels)                      | float     |
| 7             | xctr_bulge_err    | the bulge x centre error (pixels)                | float     |
| 8             | yctr_bulge        | the bulge y centre (pixels)                      | float     |
| 9             | yctr_bulge_err    | the bulge y centre error (pixels)                | float     |
| 10            | m_bulge           | the bulge magnitude                              | float     |
| 11            | m_bulge_err       | the bulge magnitude error                        | float     |
| 12            | r_bulge           | the bulge halflight radius (arcsec)              | float     |
| 13            | r_bulge_err       | the bulge radius error (arcsec)                  | float     |
| 14            | n_bulge           | the bulge Sérsic index                           | float     |
| 15            | n_bulge_err       | the bulge Sérsic index error                     | float     |
| 16            | ba_bulge          | the bulge b/a                                    | float     |
| 17            | ba_bulge_err      | the bulge b/a error                              | float     |
| 18            | pa_bulge          | the bulge position angle (degrees)               | float     |
| 19            | pa_bulge_err      | the bulge position angle error (degrees)         | float     |
| 20            | xctr_disc         | the disc x centre (pixels)                       | float     |
| 21            | xctr_disc_err     | the disc x centre error (pixels)                 | float     |
| 22            | yctr_disc         | the disc y centre (pixels)                       | float     |
| 23            | yctr_disc_err     | the disc y centre error (pixels)                 | float     |
| 24            | m_disc            | the disc magnitude                               | float     |
| 25            | m_disc_err        | the disc magnitude error                         | float     |
| 26            | r_disc            | the disc halflight radius (arcsec)               | float     |
| 27            | r_disc_err        | the disc radius error (arcsec)                   | float     |
| 28            | n_disc            | the disc Sérsic index                            | float     |
| 29            | n_disc_err        | the disc Sérsic index error                      | float     |
| 30            | ba_disc           | the disc b/a                                     | float     |
| 31            | ba_disc_err       | the disc b/a error                               | float     |
| 32            | pa_disc           | the disc position angle (degrees)                | float     |
| 33            | pa_disc_err       | the disc position angle error (degrees)          | float     |
| 34            | GaSky             | the PyMorph sky brightness (mag/arcsec²)         | float     |
| 35            | GaSky_err         | the PyMorph sky brightness (mag/arcsec²)         | float     |
| 36            | chi2nu            | the \(\chi^2/\text{DOF}\)                       | float     |
| 37            | finalflag         | the primary quality flag described in this work   | float     |
| 38            | autoflag          | the intermediate, visually calibrated, automated flag described in this work | float     |
| 39            | pyflag            | the PyMorph run flag                             | float     |
| 40            | pyfitflag         | the PyMorph fit flag                             | float     |

Table 4. Description of columns in the electronic table UPenn_PhotDec_Models_g(r)(i)band for the $g$, $r$, and $i$-band data, respectively. The data are the “best model”, dev, Ser, dev-Exp, and Ser-Exp model fit parameters fitted by PyMorph. Unfit parameters or missing data are replaced with values of -999.

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### Table A1. deV model table showing flagging breakdown for the g, r, and i bands.

| Descriptive Category | % dev,$g$ | % dev,$r$ | % dev,$i$ |
|----------------------|-----------|-----------|-----------|
| Trust Total and Component Magnitudes and Sizes | – | – | – |
| Two-Component Galaxies | – | – | – |
| No Flags | – | – | – |
| Good Ser, Good Exp (Some Flags) | – | – | – |
| Flip Components, n_{Ser} <2 | – | – | – |
| Trust Total Magnitudes and Sizes Only | 96.623 | 97.653 | 96.958 |
| Bulge Galaxies | 96.623 | 97.653 | 96.958 |
| No Exp Component, n_{Ser} >2 | 96.623 | 97.653 | 96.958 |
| Ser Dominates Always | – | – | – |
| Disk Galaxies | – | – | – |
| No Ser Component | – | – | – |
| No Exp, n_{Ser} <2, Flip Components | – | – | – |
| Ser Dominates Always, n_{Ser} <2 | – | – | – |
| Exp Dominates Always | – | – | – |
| Parallel Components | – | – | – |
| Problematic Two-Component Galaxies | – | – | – |
| Ser Outer Only | – | – | – |
| Exp Inner Only | – | – | – |
| Good Ser, Bad Exp, B/T$\geq$0.5 | – | – | – |
| Bad Ser, Good Exp, B/T<0.5 | – | – | – |
| Tiny Bulge, otherwise good | – | – | – |
| Bad Total Magnitudes and Sizes | 3.377 | 2.347 | 3.042 |
| Centering Problems | 0.292 | 0.338 | 0.311 |
| Ser Component Contamination by Neighbors or Sky | 1.865 | 1.302 | 1.651 |
| Exp Component Contamination by Neighbors or Sky | – | – | – |
| Bad Ser and Bad Exp Components | – | – | – |
| Galfit Failure | 0.386 | 0.187 | 0.286 |
| Polluted or Fractured | 1.041 | 0.679 | 0.947 |

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### Appendices

**APPENDIX A: FLAG TABLES FOR deV, Ser, AND deV-Exp MODELS**

In this appendix, we provide the breakdown of the flags as a percent of the total sample for the deV, Ser, and deV-Exp galaxy fits in each of the three bands. These tables are similar in format to Table 2. The appendix includes 3 tables.
| Descriptive Category                                      | % ser, g | % ser, r | % ser, i |
|----------------------------------------------------------|----------|----------|----------|
| Trust Total and Component Magnitudes and Sizes           | –        | –        | –        |
| **Two-Component Galaxies**                               |          |          |          |
| No Flags                                                 |          |          |          |
| Good Ser, Good Exp (Some Flags)                          |          |          |          |
| Flip Components, $n_{\text{Ser}} < 2$                   |          |          |          |
| Trust Total Magnitudes and Sizes Only                    | 95.502   | 97.380   | 96.612   |
| **Bulge Galaxies**                                       |          |          |          |
| No Exp Component, $n_{\text{Ser}} > 2$                   | 52.177   | 58.378   | 60.972   |
| Ser Dominates Always                                    |          |          |          |
| **Disk Galaxies**                                        |          |          |          |
| No Ser Component                                         |          |          |          |
| No Exp, $n_{\text{Ser}} < 2$, Flip Components           | 43.325   | 39.001   | 35.640   |
| Ser Dominates Always, $n_{\text{Ser}} < 2$              |          |          |          |
| Exp Dominates Always                                    |          |          |          |
| Parallel Components                                     |          |          |          |
| **Problematic Two-Component Galaxies**                   |          |          |          |
| Ser Outer Only                                           |          |          |          |
| Exp Inner Only                                           |          |          |          |
| Good Ser, Bad Exp, B/T $\geq 0.5$                       |          |          |          |
| Bad Ser, Good Exp, B/T $< 0.5$                           |          |          |          |
| Tiny Bulge, otherwise good                              |          |          |          |
| **Bad Total Magnitudes and Sizes**                       |          |          |          |
| Centering Problems                                      | 4.498    | 2.620    | 3.388    |
| Ser Component Contamination by Neighbors or Sky          | 0.320    | 0.357    | 0.322    |
| Exp Component Contamination by Neighbors or Sky          | 3.012    | 1.618    | 2.036    |
| Bad Ser and Bad Exp Components                           |          |          |          |
| Galfit Failure                                           | 0.327    | 0.124    | 0.239    |
| Polluted or Fractured                                    | 1.046    | 0.681    | 0.948    |

Table A2. Ser model table showing flagging breakdown for the $g$, $r$, and $i$ bands.
| Descriptive Category                        | % devexp,$g$ | % devexp,$r$ | % devexp,$i$ |
|--------------------------------------------|--------------|--------------|--------------|
| **Trust Total and Component Magnitudes and Sizes** | 33.077       | 42.223       | 44.524       |
| Two-Component Galaxies                     |              |              |              |
| No Flags                                   | 22.918       | 30.152       | 31.952       |
| Good Ser, Good Exp (Some Flags)            | 8.526        | 10.701       | 11.180       |
| Flip Components, $n_{ser} <2$              | 1.633        | 1.369        | 1.391        |
| **Trust Total Magnitudes and Sizes Only**   | 59.362       | 52.444       | 48.390       |
| Bulge Galaxies                             |              |              |              |
| No Exp Component, $n_{ser} >2$             | 15.043       | 14.636       | 14.211       |
| Ser Dominates Always                       | 9.610        | 4.646        | 3.398        |
| Disk Galaxies                              |              |              |              |
| No Ser Component                           | 5.433        | 9.898        | 10.813       |
| No Exp, $n_{ser} <2$, Flip Components      | –            | –            | –            |
| Ser Dominates Always, $n_{ser} <2$         | –            | –            | –            |
| Exp Dominates Always                       | 1.789        | 3.421        | 4.156        |
| Parallel Components                        | –            | –            | –            |
| Problematic Two-Component Galaxies         |              |              |              |
| Ser Outer Only                             | 8.029        | 9.346        | 9.954        |
| Exp Inner Only                             | 4.906        | 5.289        | 5.494        |
| Good Ser, Bad Exp, B/T$>$=0.5              | 0.003        | 0.011        | 0.010        |
| Bad Ser, Good Exp, B/T$<$0.5               | 0.620        | 0.884        | 1.042        |
| Tiny Bulge, otherwise good                 | 1.868        | 2.648        | 2.874        |
| **Bad Total Magnitudes and Sizes**         | 7.560        | 5.334        | 7.086        |
| Centering Problems                         | 0.762        | 0.599        | 0.769        |
| Ser Component Contamination by Neighbors or Sky | 1.816   | 1.251        | 1.608        |
| Exp Component Contamination by Neighbors or Sky | 3.887   | 2.788        | 3.868        |
| Bad Ser and Bad Exp Components             | 0.634        | 0.177        | 0.148        |
| Galfit Failure                             | 0.389        | 0.249        | 0.290        |
| Polluted or Fractured                      | 1.038        | 0.677        | 0.945        |

Table A3. deV-Exp model table showing flagging breakdown for the $g$, $r$, and $i$ bands.
Table B1. Sample of the model-independent measurements described in Table 3. The full table has 21 columns and is available in machine-readable format on-line.

| SEXMag | SEXMagErr | SEXHrad | SEXSky | kpc_per_arcsec | Vmax | SN | kcorr |
|--------|-----------|---------|--------|----------------|------|----|-------|
| 17.67  | 0.03      | 2.15    | 20.79  | ...            | 0.61 |    | 2800960 |
| 17.43  | 0.03      | 2.58    | 20.79  | ...            | 1.47 |    | 58645700 |
| 17.11  | 0.02      | 3.96    | 20.79  | ...            | 2.76 |    | 699989000 |
| 16.93  | 0.02      | 2.75    | 20.79  | ...            | 1.36 |    | 94692800 |
| 16.70  | 0.02      | 3.29    | 20.79  | ...            | 1.37 |    | 123920000 |

Table B2. Sample of the model-dependent measurements for the Ser-Exp fit described in Table 4. The full table has 41 columns and is available in machine-readable format on-line. Similar tables are also available for the deV, Ser, and deV-Exp fits.

APPENDIX B: EXAMPLE CATALOGUE DATA TABLE

This appendix includes sample tables of the data released as part of this work. The meaning of the table columns are described in Table 3 and Table 4. The full tables are available on-line in machine-readable format.