The evolution of the stellar mass-size relation of bulges and disks since $z = 1$.

Abdolhosein Hashemizadeh$^*$

Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT

We explore the evolution of the stellar mass-size relation of galaxies of different morphological types and specifically bulge and disk components. We use a sample of $\sim 35,000$ galaxies within a redshift range $0 < z < 1$, and stellar mass $\log_{10}(M_\star/M_\odot) \geq 9.5$ volume-limited sample drawn from the combined DEVILS and HST-COSMOS region for which we presented a morphological classification into subclasses of double-component (BD), pure-disk (pD), elliptical (E), and compact (C) in Paper-I and a structural decomposition into disk (D), diffuse bulge (dB), and compact bulge (cB) in Paper-II. We find that compared to disks, ellipticals and bulges follow steeper $M_\star - R_e$ relations, likely indicating distinct evolutionary mechanisms. Ellipticals and disk structures follow consistently unchanged slopes of $\sim 0.5$ and $\sim 0.3$, respectively, at all redshifts. We quantify that disks follow a redshift independent $M_\star - R_e$ slope regardless of the presence or absence of a bulge component (i.e., BD or pD) suggesting a similar origin and evolutionary pathway for all disks. Since $z = 1$ compact-bulges present a steepening relation which do not follow that of Es whilst diffuse-bulges experience a modest flattening. Overall, we find a close-to-no variation in the $M_\star - R_e$ relations over the last $\sim 8$ Gyr suggesting that despite ongoing although declining star-formation, mass evolution, morphological transitions and mergers, evolution moves galaxies along their $M_\star - R_e$ trails. This seems to be consistent with an inside-out growth and evolution picture in which galaxies grow in size as they do in stellar mass. Besides, minor mergers are likely to be responsible for the growth of Es, at least in $z < 1$.

Key words: galaxies: formation - galaxies: evolution - galaxies: bulges - galaxies: disk - galaxies: elliptical - galaxies: structure - galaxies: general
with each merger increasing the size of the galaxy. Lange et al. (2016) studied the \( M_* - R_e \) relation of \( z = 0 \) galaxies from the Galaxy And Mass Assembly (GAMA, Driver et al. 2011) survey. They further investigated the relation for galaxies of different morphological types as well as for disks and bulges using structural analysis based on GALFIT (Peng et al. 2002, 2010).

The evolution of the \( M_* - R_e \) relation has been of interest to both observers and simulators as a key meeting ground between easy observables (\( M_* - R_e \)) and parameters traced in numerical simulations (e.g., \( M_H \)). This has become more feasible with the development of deeper photometric and spectroscopic surveys such as Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (CANDELS, Grogin et al. 2011; Koekemoer et al. 2011) and the Cosmic Evolution Survey (COSMOS, Scoville et al. 2007). The state-of-the-art study of the evolution of the \( M_* - R_e \) with redshift is that performed by van der Wel et al. (2014) where they utilized the Hubble Space Telescope (HST) WFC3 imaging of CANDELS and explored the \( M_* - R_e \) relations of early- and late-type galaxies between \( 0 < z < 3 \) (also see van der Wel et al. 2012 for their single Sérsic fit measurements using GALFIT, Peng et al. 2002, 2010). They highlighted that ETGs evolve faster (\( R_{\text{eff}} \propto (1 + z)^{-1.48} \)) than LTGs (\( R_{\text{eff}} \propto (1 + z)^{-0.75} \)) while the late-type population is larger than the early-type population at all redshifts (van der Wel et al. 2014). More recently, Mowla et al. (2019) combined a sample of high-mass galaxies in the COSMOS-Drift And SHift (COSMOS-DASH) with the 3D-HST/CANDELS sample of van der Wel et al. (2014) and provided an updated version of the evolution of the \( M_* - R_e \) relation for early- and late-type galaxies.

The size evolution of disk and spheroid dominated galaxies with redshift is argued to have a direct link to their evolutionary history suggesting that disks that follow a flatter size evolution might have grown through gas infall (e.g., Cayon et al. 1996; Bouwens et al. 1997; Lilly et al. 1998; Ravindranath et al. 2004; Barden et al. 2005) while spheroid dominated galaxies following steeper size evolution (e.g., van der Wel et al. 2014 and Shen et al. 2003) are expected to grow through mostly major mergers (White & Frenk 1991).

As mentioned above, the evolution of the \( M_* - R_e \) relation has so far been studied for galaxies in two broad categories (e.g., ETG/LTG). Despite the importance of this fundamental plane the evolution of the \( M_* - R_e \) relation of galaxies of different morphological types, and more specifically for bulges and disks components, has not been thoroughly studied in the literature. In the present work, we make use of our morphological classifications (as described in Hashemizadeh et al. 2021; Paper-I) together with our bulge-disk decomposition analysis (as described in Hashemizadeh et al. 2022; Paper-II), to investigate the evolution of the \( M_* - R_e \) relation of galaxies of different morphological types as well as disks and bulges since \( z = 1 \).

2 THE EVOLUTION OF THE \( M_* - R_e \) RELATION

In this section, we aim to measure the evolution of the \( M_* - R_e \) relation of different morphological types together with that of disks and bulges, separately. Similar to Paper-I and II, we use our visual morphological classifications and separate our sample into pure-disk, elliptical+compact (E+C, following Paper-II) and double-component (BD) morphological types. We subdivide the BD systems into disk and bulge components using our bulge-disk de-compositions (as described in Paper-II) with bulges then divided into diffuse- and compact-bulges (dB and cB) according to their surface stellar mass distributions as described in Section 4 of Paper-II. Note that we use the same dB/cB separation method for both D10/ACS and the \( z \sim 0 \) GAMA samples.

Figure 1 shows the \( M_* - R_e \) relations of our D10/ACS sample together with \( z \sim 0 \) GAMA galaxies highlighted with yellow colour. Note that we use the \( R_e \) of GAMA galaxies contained within segments as recommended by Casura et al. (prep) and stellar masses as measured by Bellstedt et al. (2020). Likewise, we use the same B/T in r-band (within segments) to calculate the stellar mass of bulges and disks of BD systems, i.e., \( M_{\text{Bulge}}^\text{BD} = B/T \times M_{\text{Total}}^\text{BD} \) and \( M_{\text{Disk}}^\text{BD} = (1 - B/T) \times M_{\text{Total}}^\text{BD} \).

Following Lange et al. (2016) and Shen et al. (2003) we adopt a power law function to fit the \( M_* - R_e \) relations:

\[
\log(R_e/kpc) = a \log(M_*/M_\odot) - b, \tag{1}
\]

where \( R_e \) is the half-light radius or effective radius in unit of kpc and \( M_* \) represents the stellar mass of each component. We then use the HYPERFIT package (Robotham & Obreschkow 2015) to fit Equation 1 to the data, adopting a Markov Chain Monte Carlo (MCMC) minimisation method using a Componentwise Hit-And-Run Metropolis (CHARM) algorithm with 10,000 iterations. See Robotham & Obreschkow (2015) for more details about HYPERFIT.

Figure 1 shows both the distribution of the data in the \( M_* - R_e \) plane and the fit to data. The transparent region around the best fit lines represent the 1σ intrinsic scatter along the y-axis. The over-plotted dashed lines are \( M_* - R_e \) relations at \( z \sim 1 \) to highlight the evolution across time.

In general, the evolution of the \( M_* - R_e \) relation shows that disks are larger than all other structures at all epochs while at later times ellipticals start to become larger at the high-mass end. Further, while pure-disks and disk structures follow similar relations, at a given \( M_* \) disks located in bulge-i disk systems are relatively more massive than pure-disk systems. Figure 1 also highlights that at a given mass cBs are smaller and more massive than dBs at all redshifts, implying that cBs are denser structures, which is expected by our dB/cB definitions.

Investigating Figure 1, we find that the \( M_* - R_e \) relation of pure-disk systems (blue) and disk components (cyan) are consistent with modest discernible evolution from \( z = 1 \) to \( z \sim 0 \). This result is in agreement with other studies for example Ravindranath et al. (2004), Barden et al. (2005), Mosleh et al. (2017). We also show this trend in Figure 2 where we plot the evolution of the best fit slope (a), offset (b) and scatter of the \( M_* - R_e \) relations and highlight how pure-disk systems follow the same best fit parameters as disk components across all the redshift range suggesting that, as expected, they have similar origins.

The E+C population experience what is consistent with no evolution in their \( M_* - R_e \) relation from \( z = 1 \) to 0. According to Hashemizadeh et al. (in review), the stellar mass growth in E+C population is dominated by the growth
in their high-mass end, indicating that these systems move along their $M_* - R_e$ relation. This is consistent with other studies showing a significant growth of early-type galaxies in size (see e.g., Navarro & Steinmetz 2000; Trujillo et al. 2006; van der Wel et al. 2008; van der Wel et al. 2014).

Figure 2 further summarizes the above results and displays the evolution of the slope (a), offset (b) and intrinsic scatter, $\sigma$, of the $M_* - R_e$ relations (top and bottom panels, respectively). As shown in the top panel of Figure 2, dBs (green) have the steepest relation by $z \sim 0.45$ before cBs (gold) become the steepest relation. We note that dBs experience a flattening with cosmic time that is, interestingly, mapped to a significant steepening of cB relation. The top panel of this figure also shows that disks (both pure-disks; blue and disk components; cyan) have flattest relations with lowest offset (middle panel) while Es experience a somewhat unchanged slope ($a \sim 0.5$) and offset ($b \sim 5$). We note that, despite the evolution and transition between morphological types due for example to mergers, accretions, bulge formation, etc; see Hashemizadeh et al. 2021 and Hashemizadeh et al., in review the $M_* - R_e$ relations are relatively stable and hence well established at $z = 1$. 

Evolution of the Mass-Size Relation
Figure 1. The evolution of the $M_\ast - R_e$ relations at $0 < z < 1$. Contours represent quantiles showing the levels containing 50%, 68% and 95% of the data. Solid lines are fits to the data and dashed lines represent the fit to the data at $z \sim 1$. Transparent regions around lines show the intrinsic scatter along y-axis (1σ). Note that the stellar mass on the x-axis represents the component mass not the total mass of host galaxies. The first row highlighted with yellow transparent band shows the redshift range covered by GAMA data (i.e., $0 < z < 0.08$).
We calculate the scatter of the $M_e - R_e$ distributions along the y-axis, i.e., $\log(R_e)$ (bottom panel), and we find that the scatter of all structures are unchanged across redshift (with an average value of $\sim 0.2 - 0.25$; see Table 1 for exact values). At this stage we cannot entirely rule out whether the scatters of our dB/cB $M_e - R_e$ relations could be a by-product of our structural decomposition and/or dB/cB separation. However, the stability of the other component classes would suggest it is intrinsic. Figure 2 also shows that Es have a slightly broader $M_e - R_e$ distribution than other structures and its scatter decreases with time while dBs have the lowest scatter.

We report the best fit parameters of Equation 1 to each structure at different redshift bins in Table 1.

3 COMPARISON WITH THE LITERATURE

In this section, we compare our $M_e - R_e$ relations with key literature results at both low and high redshifts. Figure 3 shows the comparison of our D10/ACS low-z ($z < 0.25$) $M_e - R_e$ relations with our GAMA sample (Casura et al. prep) as well as with previous works by Lange et al. (2016) for GAMA galaxies and Shen et al. (2003) for SDSS galaxies.

As shown in the top panel of Figure 3, we find that despite the difference in redshift ranges ($z < 0.25$ for the D10/ACS versus $z < 0.08$ for GAMA) the $M_e - R_e$ relation of both pure-disk population and disk components of the D10/ACS are in good agreement with the GAMA relations. We find that at a given stellar mass the D10/ACS elliptical galaxies are larger in size than those of the GAMA sample, although they both follow relatively similar slope. The relation of our cB population is also consistent with GAMA while dB population is slightly more contracted in GAMA than in D10/ACS. We note again that we are comparing two very distinct types of data with significant difference in resolution, PSF etc. Moreover, the structural analysis of GAMA and D10/ACS have been done by different groups with different settings and pipelines. Therefore, one might naturally expect some mismatch between these two data-sets. These effects remain under investigation, and such work is outside the scope of this paper.

We can also compare our D10/ACS low-z $M_e - R_e$ relations with the earlier measurements of GAMA galaxies presented by Lange et al. (2016) (shown in the middle panel of Figure 3). The structural divisions of Lange et al. (2016) are not directly comparable with our classification, however, for completeness, we compare our pure-disk, disk component, dB, cB and E+C systems with their late-type disk, early-type disk, late-type bulge, early-type bulge and elliptical, respectively. We find that our $M_e - R_e$ relations of disk components and ellipticals are in good agreement with Lange et al. (2016). However, the relation for other structures are inconsistent likely due to our different classification techniques than that in Lange et al. (2016). This difference is more obvious in bulge structures where, as expected, morphological classification and structural analysis are important. This large difference in bulge relations (both central and dBs) are expected as with the HST high-resolution imaging we are able to resolve much smaller bulges at this low redshift range leading to steeper $M_e - R_e$ relations.

In the lower panel of Figure 3 we compare our low-z D10/ACS $M_e - R_e$ relations with the Shen et al. (2003) relation for early- and late-type galaxies (ETG and LTG, respectively) and based on SDSS data. Their ETG/LTG classification is based on Sérsic index ($n$) with $n < 2.5$ and $n > 2.5$ representing LTGs and ETGs, respectively. Again, their broad distinction is not comparable with our morphological classifications, but we find a relatively good agreement between their ETGs and our Es.

Finally, in Figure 4, we compare our D10/ACS $M_e - R_e$ relations with higher-z relations from Mowla et al. (2019) obtained from a combination of COSMOS-DASH data and previous van der Wel et al. (2014) data in CANDELS. Mowla et al. (2019) separate their sample into two classes of star-forming (SF) and quiescent (Q) galaxies which is not the same as our morphological categories but we show this comparison for completeness. Here, similar to Mowla et al. (2019), we split our sample into two broad redshift bins of $0.0 < z < 0.5$ and $0.5 < z < 1$ and highlight that their total $M_e - R_e$ relations in both redshift bins are flatter than our D10/ACS. The relation of our E+C population is in excellent agreement with their quiescent galaxies (orange dashed lines) in $0 < z < 0.5$ while offsets in $0.5 < z < 1$. We find that their relation for star-forming systems (purple dashed lines) are consistent with our disk populations.
Table 1. Best fit parameters of Equation 1 at different redshift bins.

| z-bins | 0.0 ≤ z < 0.08 | 0.0 ≤ z < 0.25 | 0.25 ≤ z < 0.45 | 0.45 ≤ z < 0.60 | 0.60 ≤ z < 0.70 | 0.70 ≤ z < 0.80 | 0.80 ≤ z < 0.90 | 0.90 ≤ z < 1.00 |
|--------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| a      | 0.364 ± 0.048  | 0.403 ± 0.086  | 0.432 ± 0.055  | 0.346 ± 0.039  | 0.318 ± 0.041  | 0.285 ± 0.024  | 0.261 ± 0.022  | 0.257 ± 0.026  |
| b      | 3.022 ± 0.475  | 3.391 ± 0.843  | 3.715 ± 0.541  | 2.889 ± 0.390  | 2.619 ± 0.405  | 2.285 ± 0.237  | 2.066 ± 0.224  | 2.034 ± 0.263  |
| scatter| 0.190 ± 0.006  | 0.207 ± 0.015  | 0.212 ± 0.006  | 0.224 ± 0.005  | 0.223 ± 0.004  | 0.222 ± 0.004  | 0.232 ± 0.003  | 0.225 ± 0.003  |

4 SIZE EVOLUTION OF STRUCTURES

With the mass-size measurements of our D10/ACS sample in place, we now explore the variation of the size of each of the above structures over time. Figure 5 shows this evolution with data points representing the median size of each structure per redshift bin per stellar mass bin. We bin our structures into three bins of component stellar mass, as: 9.5 ≤ log(M*/M⊙) < 10.0, 10.0 ≤ log(M*/M⊙) < 11.0 and 11.0 ≤ log(M*/M⊙).

Following the literature (see e.g., van der Wel et al. 2014; Mosleh et al. 2017; Paulino-Afonso et al. 2017; Marshall et al. 2019) we fit the size evolution as a function of z with the following function:

\[ R_*/kpc = a (1 + z)^β, \]  

where \( R_* \) is the effective radius in units of kpc and \( z \) is redshift. Table 2 summarizes the best fit parameters of Equation 2 to our data. We use a Levenberg-Marquardt nonlinear least-squares algorithm implemented in the minpack.lm package in R for fitting the above equation to our data.

Figure 5 shows that regardless of the type of structure, as expected, more massive components are larger in size than less massive ones throughout the redshift range. For example, the high-mass Es (red) are on average \( \sim 3 \) times larger than the low-mass ones while high-mass disk components (cyan) are on average \( \sim 2 \) times larger than low-mass ones. This dependence of mass and size of structures is obviously the direct reflection of the slope of the \( M_* - R_* \) relations that we discussed in Section 2, implying that the steeper the relation, the more mass dependent the size is.

Interestingly, as shown in Figure 5, we find a minimal size evolution since \( z = 1 \) for all structures. This unchanged trend is still valid for structures of different stellar mass. The best fit parameters reported in Table 2 show that although the growth in size is small, the slope of our parameterized fits, \( β \), seems to have some correlation with the stellar mass with more massive structures growing slightly faster than lower mass ones (Robotham et al. 2014). For example, the disk component (cyan) has \( β \sim -0.16 \pm 0.05 \) in their low stellar mass bin versus \( β \sim -0.55 \pm 0.07 \) in their high-mass range. We note that as expected we do not find any dB in the largest stellar mass bin (log(M*/M⊙) > 11) while we find only 14 cB systems in this mass regime. Due to this small number of objects we have large errors on data and hence not clear whether the trend is real. In spite of the large uncertainties, this trend is consistent with minimal size evolution. However, we do not rule out some effects of our dB/cB distinction procedure on this trend. We also show the size evolution of all bulges (magenta) showing that lower mass bulges, in general, grow by a factor of \( \sim 7 \) in size since \( z = 1 \).
Evolution of the Mass-Size Relation

5 SUMMARY AND CONCLUSION

In this work, using our structural analysis, we have investigated the evolution of the stellar mass-size relation since $z = 1$. We find close-to-no-variation in the $M_\ast - R_e$ relation for almost all structures indicating that in spite of ongoing although declining star-formation, mass evolution, morphological transitions and mergers the $M_\ast - R_e$ relations only modestly varies. This implies that in general evolution moves galaxies along their $M_\ast - R_e$ relations. Although the results of Paper-II shows a fairly moderate mass movement.

We find that in agreement with other studies (e.g., Trujillo et al. 2006; Lange et al. 2016) our E+C class and bulge components follow steeper $M_\ast - R_e$ relations than disk structures indicating that at a given stellar mass Es and bulges are smaller than disk structures but also that they likely build up via distinct evolutionary mechanisms. Note that this is valid until $M_\ast / M_\odot < 10^{11}$, while more massive ellip-
ticals are on average larger than disks and potentially the largest structures. These are likely cDs in clusters cores.

Our results show that the slope of the $M_* - R_e$ relations of pure disk systems at all redshift ranges is very consistent with that of disk components of bulge+disk systems (see Figures 1 and 2) suggesting the same origin and evolutionary pathway for all disks regardless of the presence or absence of a bulge component. In addition, in agreement with other studies (e.g., Ravindranath et al. 2004 and Barden et al. 2005), we find a redshift independent $M_* - R_e$ relation for disks with a slope of $\sim 0.3$. This is also in agreement with several studies that in a broader classification have shown that the $M_* - R_e$ of late-type galaxies evolves only very little in $z < 1$ (see e.g., Lilly et al. 1998; Dutton et al. 2011; van der Wel et al. 2014; Mosleh et al. 2017).

Exploring the variation of the $M_* - R_e$ relation of the E+C galaxies we find that this relation experience a what is consistent with no change while we have shown in Paper-II (Hashemizadeh et al. 2022) that the majority of the evolution in stellar mass happens at their high mass end (see Figures 1 and 2). Note, however, that Figure 5 shows that low-mass E+C systems seem to grow slightly faster in size than high-mass ones. This further confirms our results in Paper-I and II suggesting that, in agreement with Robotham et al. (2014), at $z < 1$ minor mergers are the dominant driver of the growth/formation of E systems. This interpretation is in agreement with other observational (e.g., Trujillo et al. 2011) and theoretical (e.g., Naab et al. 2009; Xie et al. 2015) studies identifying minor mergers to play the most important role in the growth of E galaxies.

In addition, compact bulges also present a steepening with time, whilst diffuse-bulges experience only a modest flattening (contraction). We find different $M_* - R_e$ relation for cBs than that of Es likely suggesting that they have different origins. This further highlights our argument that in-situ and secular star formation are the dominant processes in bulge formation in the $z < 1$ Universe given that we concluded in Paper-II that dBs have the largest growth rate in their stellar mass density.

We also investigated the size evolution of structures (Figure 5) and concluded that as expected more massive structures are larger in size, too, with only a modest varia-

![Figure 4. Comparison of our $M_* - R_e$ relations (solid lines) in two redshift ranges of $0.0 < z < 0.5$ and $0.5 < z < 1$ with that of COSMOS-DASH (dashed lines) from Mowla et al. (2019). COSMOS-DASH includes the $M_* - R_e$ relations for star-forming (purple) and quiescent (orange) galaxies.](image-url)
Evolution of the Mass-Size Relation

Figure 5. The size evolution of structures since $z = 1$ in three stellar mass bins shown as dotted ($9.5 \leq \log(M_*/M_\odot) < 10.0$), dashed ($10.0 \leq \log(M_*/M_\odot) < 11.0$) and solid ($11.0 \leq \log(M_*/M_\odot)$) lines. Note that the stellar mass here is the component stellar mass not the total. Data points represent median sizes in each $z$-bin while lines show the results of our parameterized fit of Equation 2 to data points. See Table 2 for best fit parameters.

We showed that although disk structures grow a little in size, bulges (of $\log(M_*/M_\odot) < 11$, in particular) grow slightly and eventually by a factor of $\sim 3$ at $z \sim 0$.

In summary, we find a surprisingly unchanged size and $M_* - R_e$ relation over the last $\sim 8$ Gyr. This lack of evolution particularly in disk structures is consistent with our previous results, suggesting that evolution is predominantly along the respective $M_* - R_e$ relations. In effect, the scaling relations lay down the trail along which galaxies have evolved. Each trail hence requiring a distinct path, i.e. an inside-out growth and evolution in which the size of galaxies grows as...
Table 2. Best fit parameters of Equation 2 for different bins of component stellar mass. Note the we don’t find any dB in the last mass bin.

| mass bins       | 9.0 ≤ log(M∗/M⊙) < 10.0 | 10.0 ≤ log(M∗/M⊙) < 11.0 | 11.0 ≤ log(M∗/M⊙) |
|-----------------|---------------------------|---------------------------|-------------------|
| Pure-Disk       |                           |                           |                   |
| α               | 3.342 ± 0.086             | 4.811 ± 0.126             | 17.753 ± 7.366    |
| β               | −0.093 ± 0.054            | −0.171 ± 0.056            | −1.684 ± 0.866    |
| Disk Component  |                           |                           |                   |
| α               | 3.318 ± 0.233             | 5.411 ± 0.123             | 9.783 ± 0.295     |
| β               | 0.157 ± 0.154             | −0.365 ± 0.054            | −0.547 ± 0.067    |
| Bulge (All)     |                           |                           |                   |
| α               | 1.259 ± 0.070             | 1.759 ± 0.128             | 3.802 ± 1.536     |
| β               | −1.211 ± 0.149            | −1.513 ± 0.219            | −0.276 ± 0.854    |
| Diffuse-Bulge   |                           |                           |                   |
| α               | 1.974 ± 0.178             | 3.272 ± 0.528             | −               |
| β               | −0.209 ± 0.204            | 0.056 ± 0.310             | −               |
| Compact-Bulge   |                           |                           |                   |
| α               | 0.517 ± 0.030             | 1.286 ± 0.095             | 3.685 ± 1.648    |
| β               | −0.188 ± 0.125            | −1.091 ± 0.198            | −0.219 ± 0.919   |
| Elliptical+Compact|                          |                           |                   |
| α               | 1.740 ± 0.097             | 2.864 ± 0.181             | 5.778 ± 0.638    |
| β               | −0.633 ± 0.121            | −0.440 ± 0.156            | −0.166 ± 0.266   |

they grow in stellar mass. In addition, minor mergers seem to be responsible for the growth of elliptical systems at least since z < 1. However, further investigations, numerical simulations in particular, is required to confirm these results and put them into a comprehensive physical picture.

ACKNOWLEDGEMENTS

DEVILS is an Australian project based around a spectroscopic campaign using the Anglo-Australian Telescope. The DEVILS input catalogue is generated from data taken as part of the ESO VISTA-VIDEO (Jarvis et al. 2013) and UltraVISTA (McCracken et al. 2012) surveys. DEVILS is part funded via Discovery Programs by the Australian Research Council and the participating institutions. The DEVILS website is https://devilsurvey.org. The DEVILS data is hosted and provided by AAO Data Central (https://datacentral.org.au). This work was supported by resources provided by The Pawsey Supercomputing Centre with funding from the Australian Government and the Government of Western Australia. We also gratefully acknowledge the contribution of the entire COSMOS collaboration consisting of more than 200 scientists. The HST COSMOS Treasury program was supported through NASA grant HST-GO-09822. SB and SPD acknowledge support by the Australian Research Council’s funding scheme DP180103740. MS has been supported by the European Union’s Horizon 2020 research and innovation programme under the Maria Sklodowska-Curie (grant agreement No 754510), the National Science Centre of Poland (grant UMO-2016/23/N/ST9/02963) and by the Spanish Ministry of Science and Innovation through Juan de la Cierva-formacion program (reference FJC2018-038792-I). ASGR and LJMD acknowledge support from the Australian Research Council’s Future Fellowship scheme (FT200100375, respectively).

This work was made possible by the free and open R software (R Core Team 2020). A number of figures in this paper were generated using the R magicaxis package (Robotham 2016b). This work also makes use of the celestial package (Robotham 2016a) and dttools (Obreschkow et al. 2018).
5.1 Data Availability

The catalogues used in this paper are D10VisualMoprhologyCat, described in Hashemizadeh et al. (2021), and DEVILS_BD_Decom and is held on the DEVILS database managed by AAO Data Central (https://datacentral.org.au). The catalogues are currently only available for the DEVILS team, but will be made publicly available in a future DEVILS data release. All imaging data are in the public domain and were downloaded from the NASA/IPAC Infrared Science Archive (IRSA) web-page: irsa.ipac.caltech.edu/data/COSMOS/images/acs_2.0/1/.

The main tools used in this study are ProFit (Robotham et al. 2017) version 1.3.3 (available at: https://github.com/ICRAR/ProFit) and ProFound (Robotham et al. 2018) version 1.3.4 (available at: https://github.com/asgr/ProFound). We used TINY TIM version 6.3 to generate the HST/ACS Point Spread Function (PSF). We further use LAPLACES-DEMON version 1.3.4 implemented in R available at: https://github.com/LaplacesDemonR/LaplacesDemon. Our structural decomposition pipeline, GRAFit, is available at: https://github.com/HoseinHashemi/GRAFit.

REFERENCES

Barden M., et al., 2005, ApJ, 635, 959
Bellstedt S., et al., 2020, arXiv e-prints, p. arXiv:2005.11917
Bouwens R. J., Cayón L., Silk J., 1997, ApJ, 489, L21
Casura S., et al., in-prep
Cayon L., Silk J., Charlot S., 1996, ApJ, 467, L53
Dalcanton J. J., Spergel D. N., Summers F. J., 1997, ApJ, 482, 659
Driver S. P., et al., 2011, MNRAS, 413, 971
Dutton A. A., et al., 2011, MNRAS, 410, 1660
Freeman K. C., 1970, ApJ, 160, 811
Grogin N. A., et al., 2011, ApJS, 197, 35
Hashemizadeh A., et al., 2021, MNRAS, 505, 136
Hashemizadeh A., et al., 2022, arXiv e-prints, p. arXiv:2203.00185
Jarvis M. J., et al., 2013, MNRAS, 428, 1281
Kauffmann G., et al., 2003, MNRAS, 341, 33
Koekemoer A. M., et al., 2011, ApJS, 197, 36
Kormendy J., Norman C. A., 1979, ApJ, 234, 539
Lange R., et al., 2016, MNRAS, 462, 1470
Lilly S., et al., 1998, ApJ, 500, 75
Marshall M. A., Mutch S. J., Qin Y., Poole G. B., Wyithe J. S. B., 2019, MNRAS, 488, 1941
McCracken H. J., et al., 2012, A&A, 544, A156
Mo H. J., Jing Y. P., White S. D. M., 1997, MNRAS, 284, 189
Mo H. J., Mao S., White S. D. M., 1998, MNRAS, 295, 319
Mosleh M., Tacchella S., Renzini A., Carollo C. M., Molaieinezhad A., Onodera M., Khorroshahi H. G., Lilly S., 2017, ApJ, 837, 2
Mowla L. A., et al., 2019, ApJ, 880, 57
Naab T., Johansson P. H., Ostriker J. P., 2009, ApJ, 699, L178
Navarro J. F., Steinmetz M., 2000, ApJ, 538, 477
Obreschkow D., Murray S. G., Robotham A. S. G., Westmeier T., 2018, MNRAS, 474, 5500
Paulino-Afonso A., Sobral D., Buitrago F., Afonso J., 2017, MNRAS, 465, 2717
Peng C. Y., Ho L. C., Impy C. D., Rix H.-W., 2002, AJ, 124, 266
Peng Y.-j., et al., 2010, ApJ, 721, 193

R Core Team 2020, R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, https://www.R-project.org/
Ravindranath S., et al., 2004, ApJ, 604, L9
Robotham A. S. G., 2016a, Celestial: Common astronomical conversion routines and functions (ascl:1602.011)
Robotham A. S. G., 2016b, magicaxis: Pretty scientific plotting with minor-tick and log minor-tick support (ascl:1604.004)
Robotham A. S. G., Obreschkow D., 2015, Publ. Astron. Soc. Australia, 32, 4033
Robotham A. S. G., et al., 2014, MNRAS, 444, 3986
Robotham A. S. G., Taranu D. S., Tobar R., Moffett A., Driver S. P., 2017, MNRAS, 466, 1513
Robotham A. S. G., Davies L. J. M., Driver S. P., Koushan S., Taranu D. S., Casura S., Liske J., 2018, MNRAS, 476, 3137
Scoville N., et al., 2007, ApJS, 172, 150
Shen S., Mo H. J., White S. D. M., Kauffmann G., Voges W., Brinkmann J., Csabai I., 2003, MNRAS, 343, 978
Trujillo I., et al., 2006, ApJ, 650, 18
Trujillo I., Conselice C. J., Bundy K., Cooper M. C., Eisenhardt P., Ellis R. S., 2007, MNRAS, 382, 109
Trujillo I., Ferreras I., de La Rosa I. G., 2011, MNRAS, 415, 3903
White S. D. M., Frenk C. S., 1991, ApJ, 379, 52
Xie L., Guo Q., Cooper A. P., Frenk C. S., Li R., Gao L., 2015, MNRAS, 447, 636
York D. G., et al., 2000, AJ, 120, 1579
van der Wel A., Holden B. P., Zirm A. W., Franx M., Rettura A., Illingworth G. D., Ford H. C., 2008, ApJ, 688, 48
van der Wel A., et al., 2012, ApJS, 203, 24
van der Wel A., et al., 2014, ApJ, 788, 28