Ultra-diffuse galaxies are smaller than Milky Way-like galaxies and more like dwarfs

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The effective or half-light radius has become a very popular choice for characterising galaxy size, but it measures the concentration of light within galaxies and thus does not capture our intuitive definition of size which is related to the edge or boundary of objects. We define a new physically motivated measurement of size for galaxies, R_1, based on the expected location of the gas density threshold for star formation, for which we use the stellar mass density contour at 1 $M_\odot$ pc^{-2} as a proxy. With this new size measure, the intrinsic scatter of the global stellar mass ($M\star$)–size relation (explored over five orders of magnitude in stellar mass) decreases to ∼0.06 dex: 2.5 times smaller than the scatter measured using the effective radius (∼0.15 dex). Galaxies with $M_\star > 10^{11}$ $M_\odot$ show a different slope with stellar mass than less massive galaxies, which is suggestive of a larger gas density threshold for star formation at the epoch when their star formation peaks. We go on to investigate the nature of faint ultra-diffuse galaxies (UDGs) when compared to dwarfs and Milky Way-like galaxies. Using our new R_1 measure instead of the effective radius and considering the sizes and stellar mass density profiles of UDGs and regular dwarfs, we find that the UDGs have sizes that are within the size range of dwarfs and, on average, UDGs are ten times smaller than Milky Way-like galaxies. These results show that the use of size estimators sensitive to the concentration of light can lead to misleading results.

Based on these two papers: Trujillo, I., Chamba, N., Knapen, J.H., A physically motivated definition for the size of galaxies in an era of ultradeep imaging, 2020, [MNRAS, 493, 87]
And Chamba, N., Trujillo, I., Knapen, J.H., Are ultra-diffuse galaxies Milky Way-sized?, [2020, A&A Letters, 633, L3]

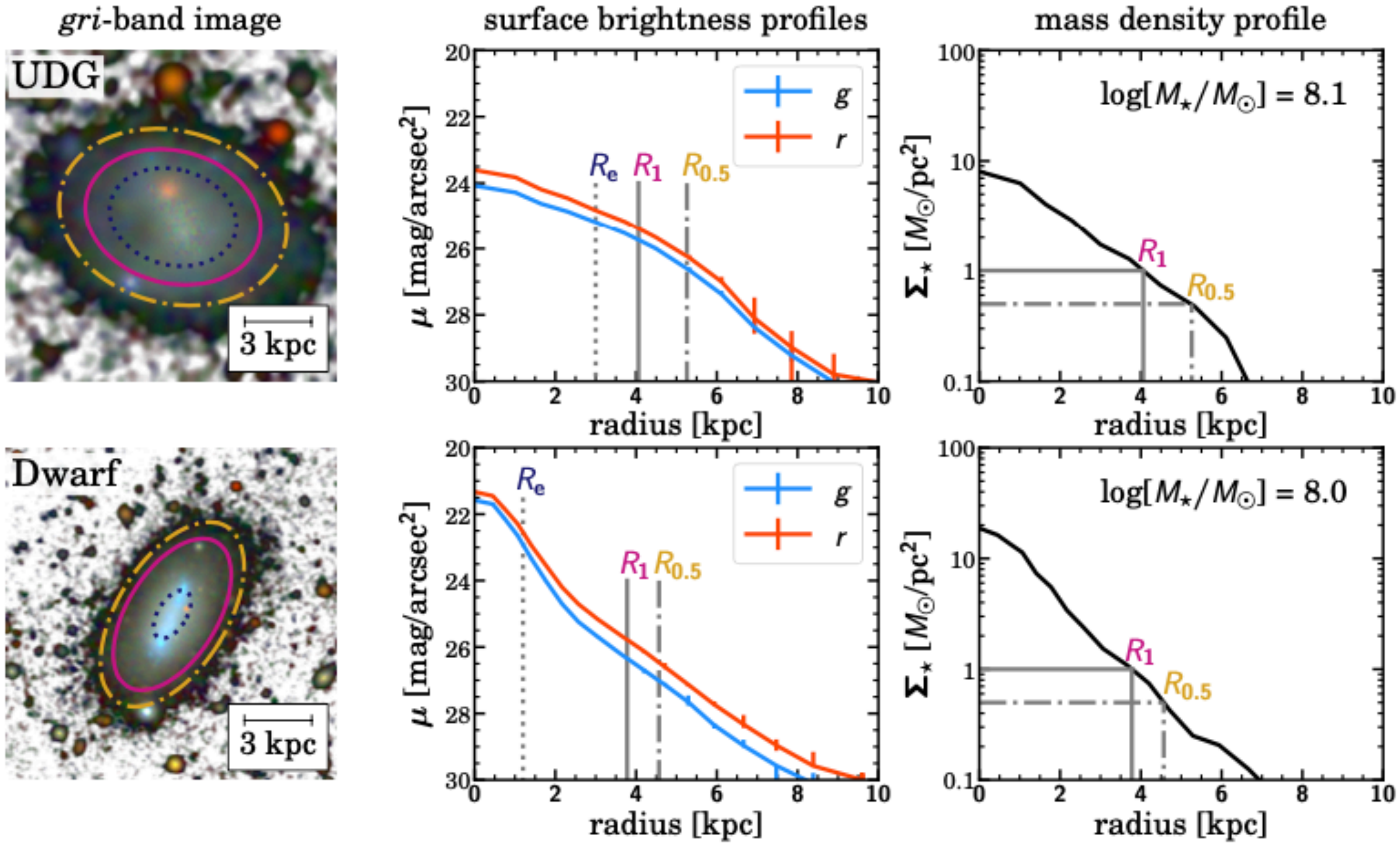


Fig. 1. Illustration of the consequence of using R_e as galaxy size for UDGs and dwarf galaxies. Here we show two galaxies of similar stellar mass at the same physical scale: UDG-B5 (*top*) and a representative dwarf galaxy (SDSS J224114.12−003715.0, *bottom*). The colour image is the *gri*-band composite with a grey-scaled background for contrast and contours showing R_e (dotted), R_1, (solid) and $R_{0.5}$ (dot-dashed). The surface brightness and stellar mass density profiles derived for both galaxies are also shown.

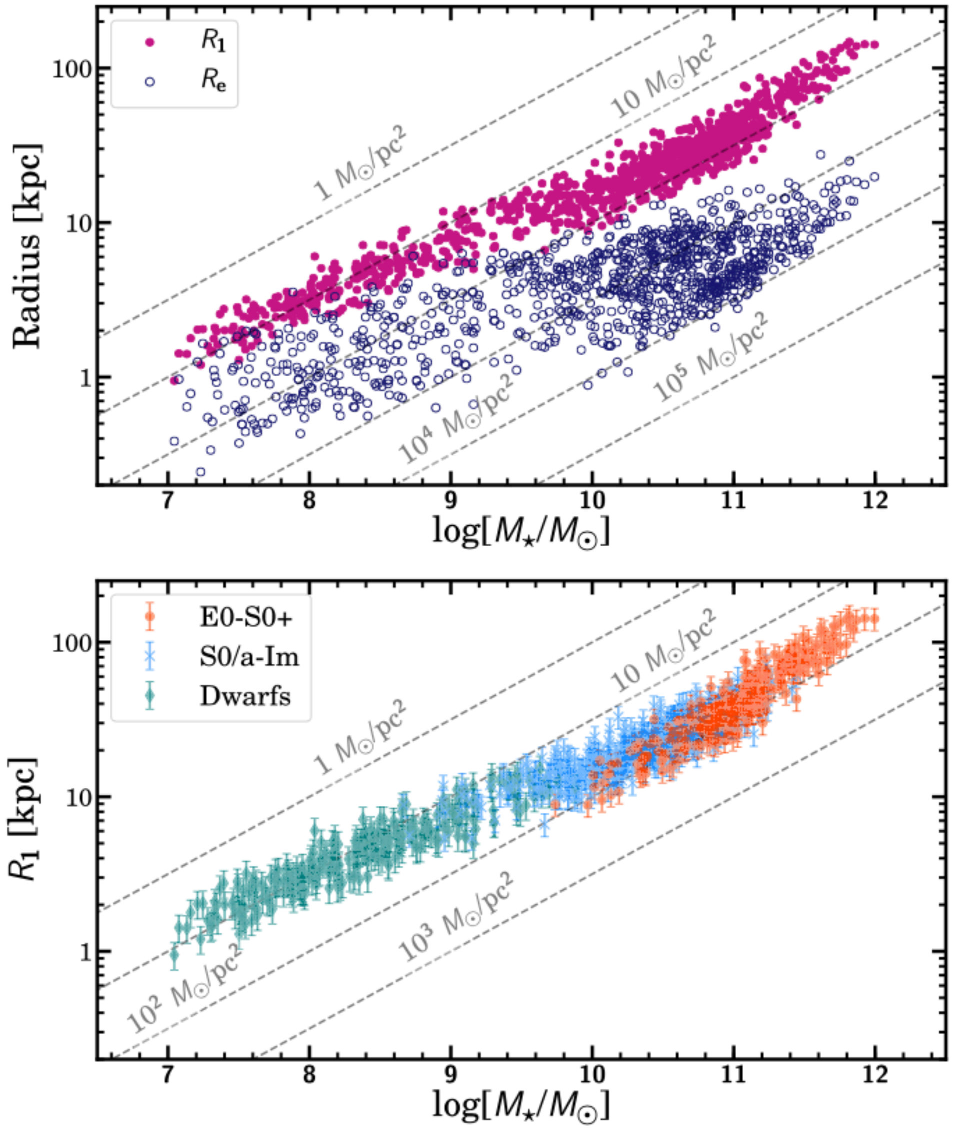


Fig. 2 Stellar mass–size relation for the galaxies in our sample of 1005 galaxies from the SDSS Stripe 82 survey with morphological classifications from the literature.

Upper panel: The observed R_1–mass and R_e–mass relations, where R_e has been measured using the *g*-band. The scatter of the relation using R_1 is significantly smaller compared to that with R_e.

Lower panel: The same R_1–mass relation after splitting our sample into three categories: ellipticals (E0-S0+), spirals (S0/a-Im), and dwarfs as labelled in the legend. Spiral and dwarf galaxies follow the same trend, while massive ellipticals with $M_\star$>10^{11} $M_\odot$ show a tilt with respect to less massive galaxies. The grey dashed lines correspond to locations in the plane with constant (projected) stellar mass density.

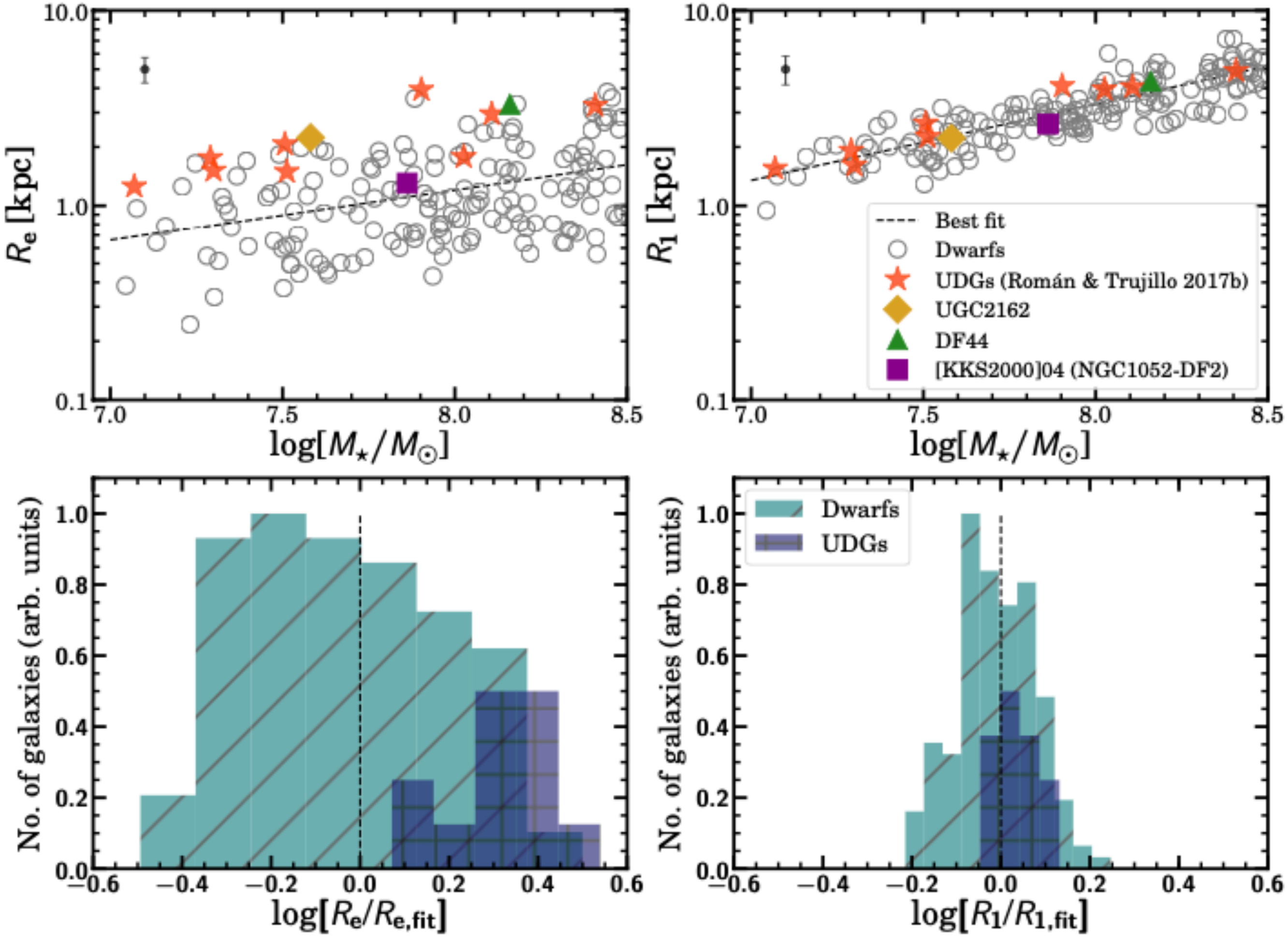


Fig. 3. Comparison between R_e and the physically motivated size parameter for UDGs and dwarfs. *Top*: R_e–stellar mass relation (*left*) and the R_1–stellar mass relation (*right*) for dwarfs (grey) and UDGs (colours). The best-fit line of each relation for the dwarf sample is also over-plotted. The upper left corner of each plot shows the typical uncertainty in our measurements (see TCK20). *Bottom*: histograms showing the distribution of $R_e/R_{e,\mathrm{fit}}$ (*left*) and $R_1/R_{1,\mathrm{fit}}$ (*right*) where "fit" refers to the best-fit line of each relation for the dwarf sample.

Using R_e (left), ultra-diffuse galaxies (UDGs) appear 'larger' than dwarf galaxies. Using R_1 (right) the size distributions are very similar.

When comparing the UDGs (blue) with both dwarf galaxies (green) and Milky Way-like galaxies (pink), we see that when we use R_1 for their sizes the UDGs are like dwarfs but unlike MW-like galaxies, where using R_e gives the erroneous impression that the UDGs are very large dwarfs, or perhaps even 'failed spirals'. In fact, they are as large as dwarfs but with less concentrated light distributions.

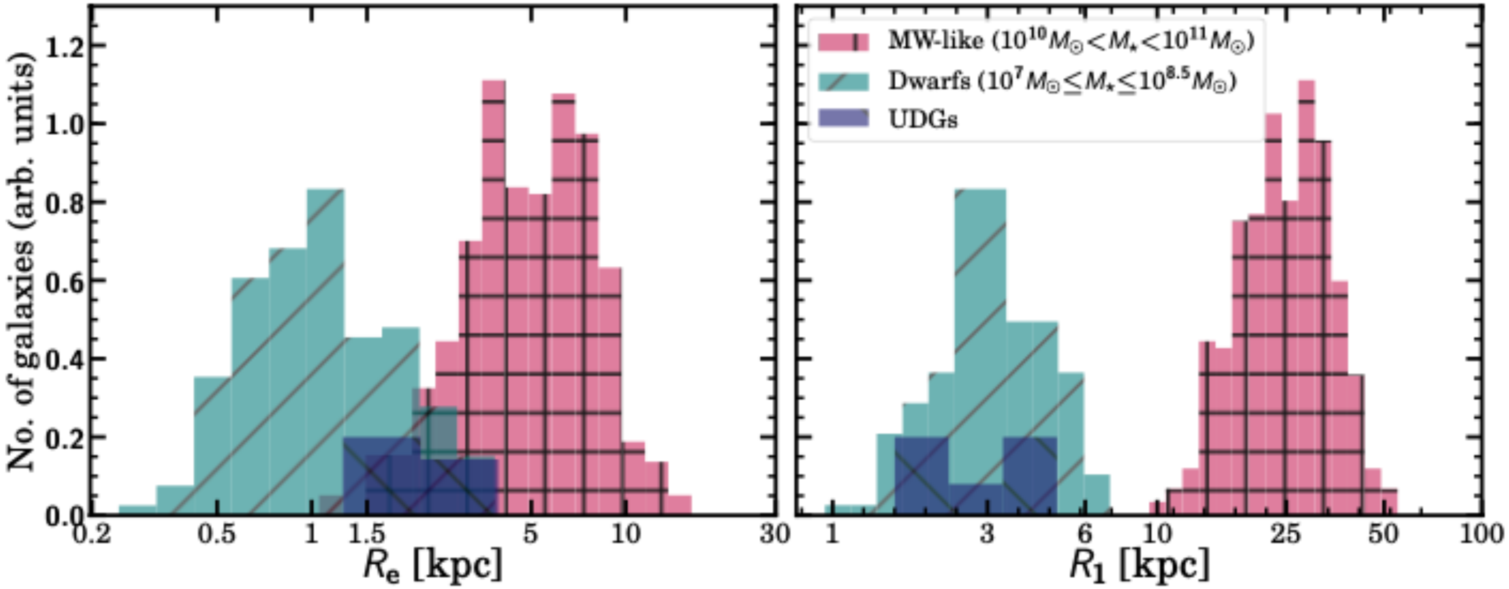
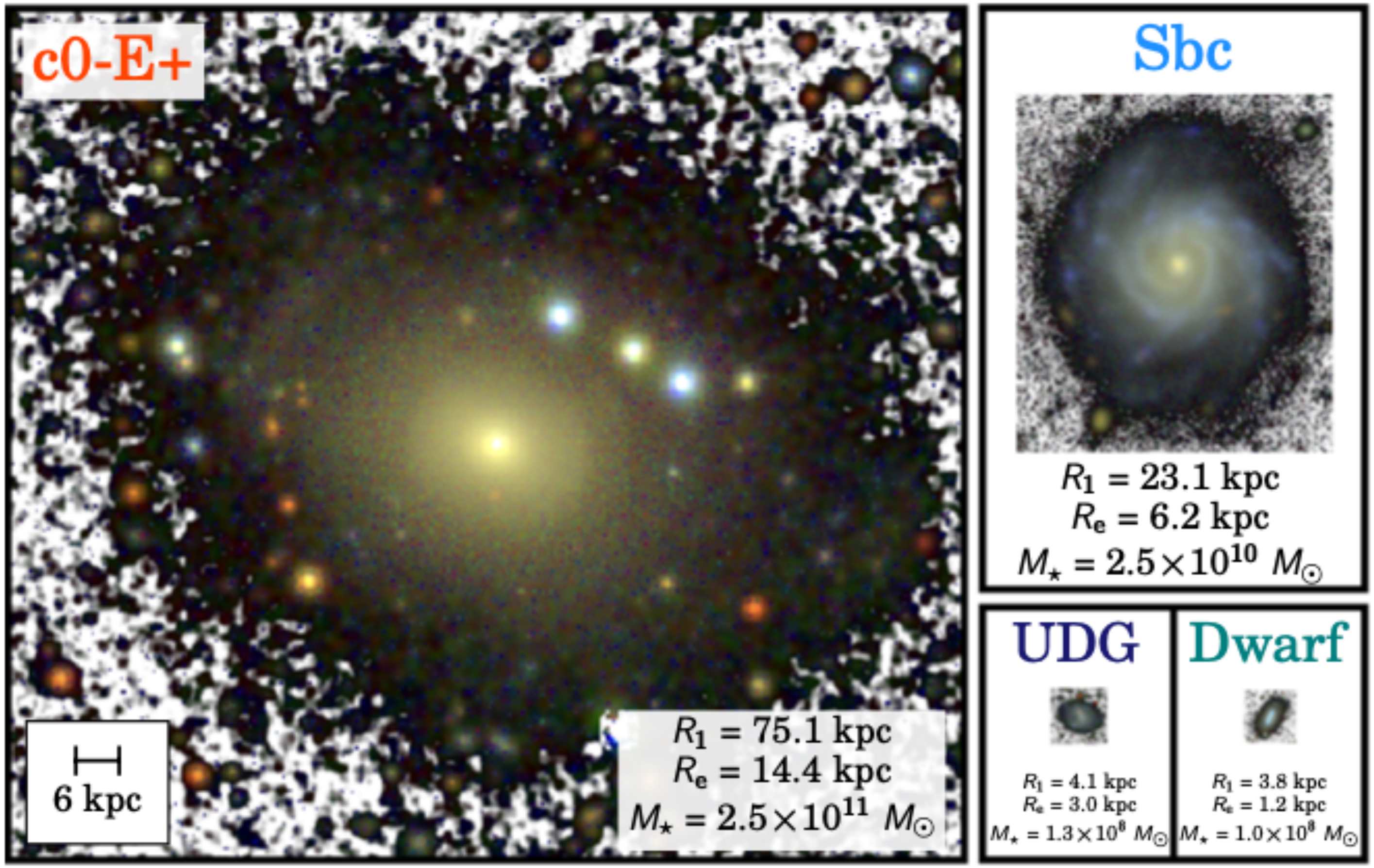


Fig. 4. Histograms showing the size distribution of UDGs, dwarfs, and MW-like galaxies. In R_e (*left*), UDGs overlap with the dwarfs and MW-like systems in our sample and in R_1 (*right*), the UDGs clearly separate from the MW-like galaxies and overlap with the dwarfs. These results show that UDGs have the extensions of dwarfs.



We conclude that using our new physically motivated size indicator R1 for galaxies helps to understand the true nature of galaxies such as UDGs. This is illustrated above, where galaxies typical or their class are depicted scaled to their correct physical size.