

# Properties of green valley galaxies in relation to their selection criteria

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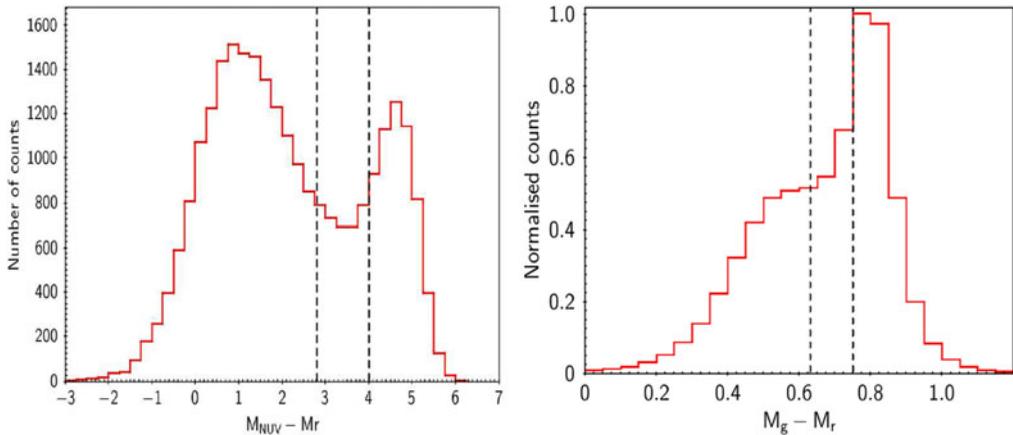
**Abstract.** The distribution of galaxies has been studied to show the difference between the blue cloud and red sequence and to define the green valley region. However, there are still many open questions regarding the importance of the green valley for understanding the morphological transformation and evolution of galaxies, how galaxies change from late-type to early-type and the role of AGN in galaxy formation and evolution scenario. The work focused on studying in more details the properties of green valley galaxies by testing the six most used selection criteria, differences between them, and how they may affect the main results and conclusions. The main findings are that, by selecting the green valley galaxies using different criteria, we are selecting different types of galaxies in terms of their stellar masses, sSFR, SFR, spectroscopic classification and morphological properties, where the difference was more significant for colour criteria than for sSFR and SFR vs.  $M_*$  criteria.

**Keywords.** galaxies: active, galaxies: star formation, galaxies: fundamental parameters, galaxies: evolution, ultraviolet: galaxies, methods: statistical

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## 1. Introduction

The bi-modality in the distribution of galaxies usually obtained in colour-mass, colour-magnitude (CMD) or colour-star formation rate diagrams has been studied to show the difference between the blue cloud and red sequence galaxies and to define the intermediate green valley region. In general, blue cloud galaxies are activity star-forming sources that are rich in gas, while red sequence galaxies are mainly abundant quiescent sources and a small fraction of dusty star-forming galaxies and edge-on systems (Blanton & Moustakas 2009). Between the red sequence and the blue cloud there is a sparsely populated green valley region that has been viewed as the crossroads of galaxy evolution where the galaxies in it are thought to represent the transition population between the blue cloud of star-forming galaxies and the red sequence of quenched and passively evolving galaxies (Schiminovich *et al.* 2007; Pović *et al.* 2012; Salim 2014; Lin *et al.* 2017; Coenda *et al.* 2018; Bryukhareva & Moiseev 2019; Phillipps *et al.* 2019).



**Figure 1.** Distributions of  $M_{\text{NUV}} - M_r$  colour for UV sample (left panel) and  $M_{\text{NUV}} - M_r$  colour for optical sample (right panel). Green valley region is represented in between the two black dashed lines.

Several selection criteria have been used to define green valley in order to study the properties of the green galaxy population, using colours such as  $U - V$  (Brammer *et al.* 2009),  $U - B$  (Mendez *et al.* 2011; Mahoro *et al.* 2017, 2019),  $\text{NUV} - r$  (Wyder *et al.* 2007; Lee *et al.* 2015; Coenda *et al.* 2018),  $g - r$  (Trayford *et al.* 2015, 2017; Walker *et al.* 2013, Eales *et al.* 2018),  $u - r$  (Bremer *et al.* 2018; Eales *et al.* 2018; Kelvin *et al.* 2018; Ge *et al.* 2019; Phillipps *et al.* 2019), specific SFR (sSFR) (Schiminovich *et al.* 2007; Salim *et al.* 2009; Salim 2014; Phillipps *et al.* 2019; Starkenburg *et al.* 2019), and the SFR-stellar mass ( $M_*$ ) diagram (Noeske *et al.* 2007; Chang *et al.* 2015). Therefore, the study of green valley galaxies provides us crucial clues to connect the red sequence and blue cloud galaxies in terms of their star formation quenching and evolution.

## 2. Data and sample selection

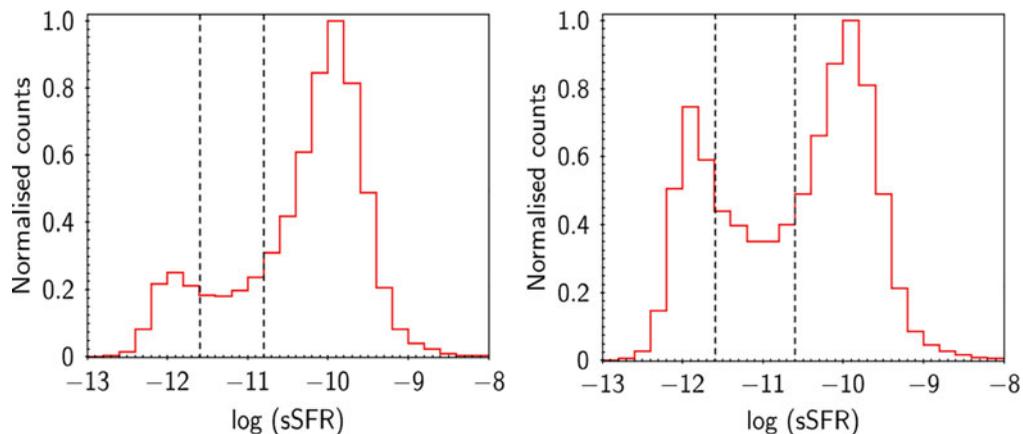
We used optical and ultraviolet (UV) data in this study. The optical data are from the Sloan Digital Sky Survey (SDSS) Data Release 7 (DR7) with photometric system of five filters named  $u$ ,  $g$ ,  $r$ ,  $i$  and  $z$  with limiting magnitudes of 22.0, 22.2, 22.2, 21.3 and 20.3 respectively (York *et al.* 2003). For SFR,  $M_*$  and sSFR we used MPA-JHU catalogue (Kauffmann *et al.* 2003; Brinchmann *et al.* 2004; Tremonti *et al.* 2004). The ultraviolet data are from the GALEX-MIS (GR5) survey with limiting magnitudes of 22.6 and 22.7 in far-UV (FUV) and near-UV (NUV) respectively (Martin *et al.* 2005).

Six criteria commonly used in previous studies were tested to select the green valley samples.

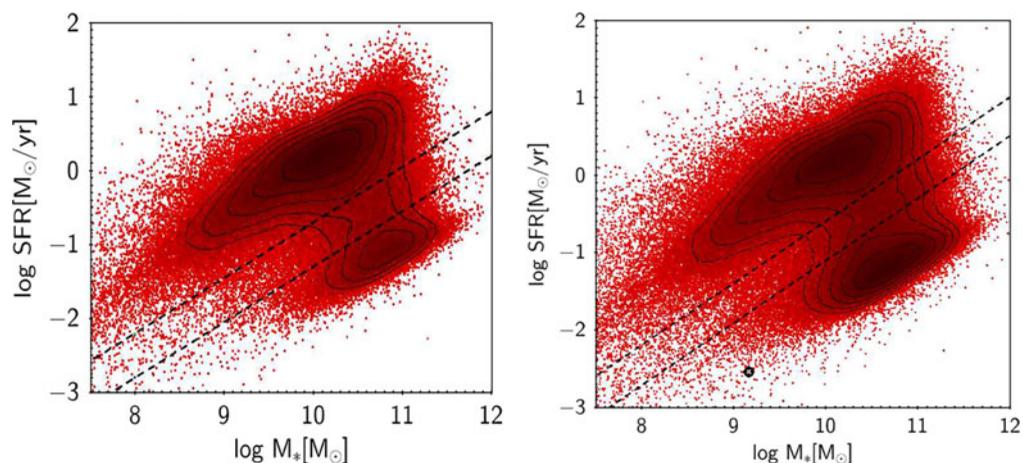
(a) The NUV absolute magnitude minus the  $r$  absolute magnitude ( $M_{\text{NUV}} - M_r$ ) and the  $g$  absolute magnitude minus  $r$  absolute magnitude ( $M_g - M_r$ ). The range of green valley galaxies is defined in between  $2.8 < M_{\text{NUV}} - M_r < 4$  and  $0.63 < M_g - M_r < 0.75$ , as shown in Figure 1 which is in line with previous studies (Belfiore *et al.* 2017; Taylor *et al.* 2017; Eales *et al.* 2018).

(b) sSFR in UV and in optical. The green valley sample is defined in the range of  $-11.6 < \text{sSFR} < -10.8$  for both criteria as shown in Figure 2 which is in line with Salim *et al.* 2009 and Salim 2014.

(c) SFR vs.  $M_*$  in UV and in optical. The green valley sample is defined as shown in Figure 3 (in line with Noeske *et al.* 2007; Chang *et al.* 2015).



**Figure 2.** Distributions of sSFR for UV (left panel) and optical (right panel) samples. Green valley region is represented in between the two black dashed lines.

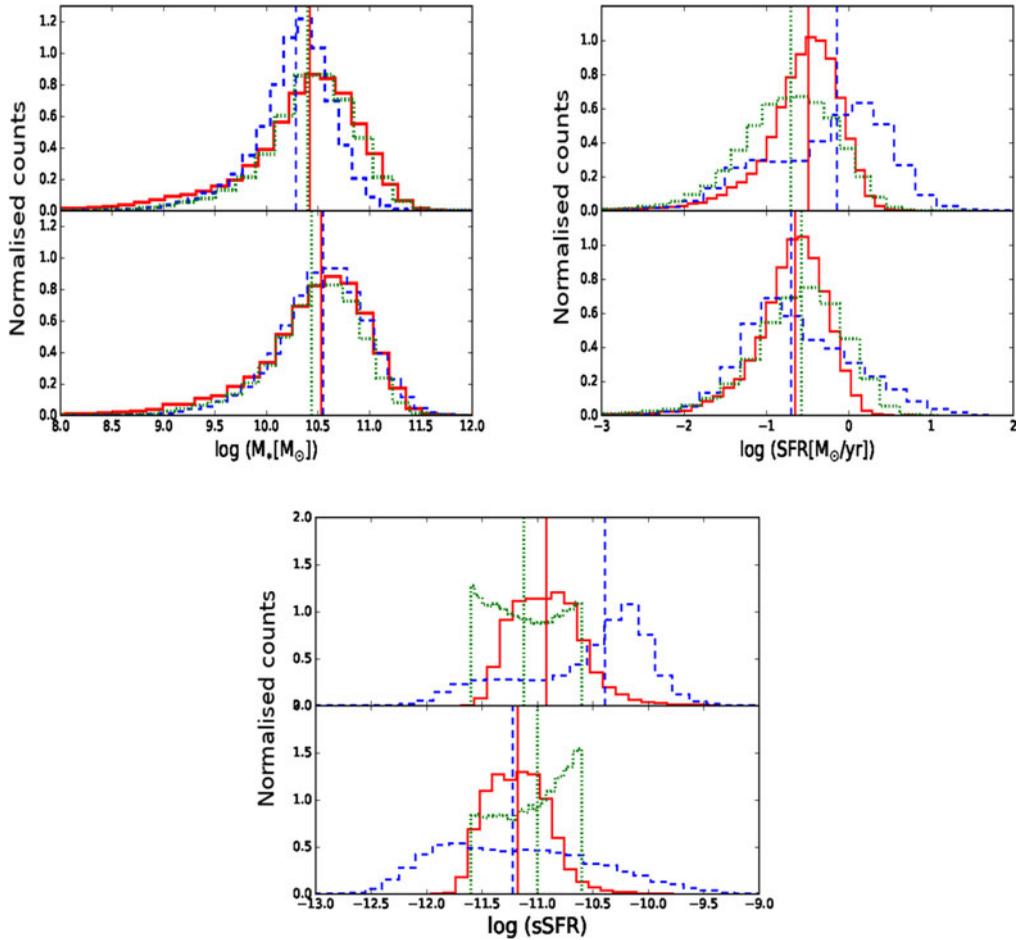


**Figure 3.** SFR versus stellar mass for UV sample (left panel) and optical sample (right panel). Green valley region is represented in between the two black dashed lines.

### 3. Analysis and results

We analysed the distributions of stellar mass, SFR and sSFR in different green valley samples. Figure 4 represents distributions of these parameters, respectively, in optical (top panels) and UV (bottom panels). In each panel, three samples are compared using: SFR-SM criteria (red solid line), colour criteria (blue dashed line), and sSFR criteria (green dotted line). It can be seen that when using different criteria we are selecting different galaxies in terms of their stellar mass, where more massive galaxies are selected when using UV data. When observing the total samples, in general SFR and sSFR are higher in optically selected green valley galaxies than in UV, however this difference is more significant when using colour and/or SFR vs. stellar mass criteria.

Using BPT-NII diagram (Baldwin *et al.* 1981), we classified green valley samples into star forming, composites, Seyfert 2 and LINERs galaxies. Most of the galaxies in the green valley are classified as star forming and Composites where the main difference is when using colour criteria. We found higher fraction of star forming and composite



**Figure 4.** Comparison of stellar mass, SFR, and sSFR in optical (top panels) and UV (bottom panels). The blue dashed, green dotted, and red solid histograms in all figures represent the green valley sample selected using colours ( $M_{\text{NUV}}-M_r$  and  $M_g-M_r$ ), sSFR, SFR vs. stellar mass criterion. The vertical dashed lines in all figures represent the median for each histogram, where each median has the same colour as the one of the corresponding histogram.

galaxies being selected in optical and UV colour criterion, respectively, while in general higher fraction of Seyfert 2 and LINER galaxies have been selected in UV.

We used the visual morphological classification from the Galaxy Zoo survey (Lintott *et al.* 2011), where galaxies have been classified as elliptical, spiral, and uncertain. When comparing the fraction of elliptical and spiral galaxies selected by different green valley criteria, the only significant difference was found between the two colour criteria where we are detecting more spiral and less elliptical galaxies in optical in comparison to UV (41% vs. 24% for spirals, and 3% vs. 14% for ellipticals, respectively).

#### 4. Conclusions

This work conducted a study on properties of galaxies in different green valley samples selected based on different criteria and analysed the differences and similarities from one criterion to another. Our main findings are:

- By selecting the green valley galaxies based on UV and optical data, we are selecting different types of galaxies in terms of their stellar masses, SFRs, sSFRs, morphological classification, spectroscopic types etc.

- With colour criteria, there is a difference in terms that with optical colour we are selecting much more spirals than ellipticals but for UV colour criteria, we have more ellipticals. For sSFR and SFR-M, the difference is not more pronounced.
- With spectroscopic types, more star forming galaxies were selected in optical sample while composites and AGNs were selected more in UV sample. This is very pronounced for colour criteria.

## Acknowledgements

Financial support from the Swedish International Development Cooperation Agency (SIDA) through the International Science Programme (ISP) to the East African Astrophysics Research Network (EAARN) is gratefully acknowledged. MP acknowledges financial support from the Ethiopian Space Science and Technology Institute (ESSTI) under the Ethiopian Ministry of Innovation and Technology (MInT), and support from the Spanish Ministry of Science, Innovation and Universities (MCIU) through project AYA2016-76682C3-1-P and the State Agency for Research of the Spanish MCIU through the Center of Excellence Severo Ochoa award to the IAA-CSIC (SEV-2017-0709). AM acknowledges support from the National Research Foundation of South Africa (Grant Numbers 110816)

## References

- Baldry, I. K., Glazebrook, K., Brinkmann, J., Ivezić, Ž., Lupton, R. H., Nichol, R. C., Szalay, A. S., *et al.* 2004, *ApJ*, 600, 681
- Baldwin, J. A., Phillips, M. M., Terlevich, R., *et al.* 1981, *PASP*, 93, 5
- Belfiore, F. *et al.* 2017, preprint, ([arXiv:1710.05034](https://arxiv.org/abs/1710.05034))
- Blanton, M. R. & Moustakas, J. 2009, *ARA&A*, 47, 159
- Brammer, G. B. *et al.* 2009, *ApJ*, 706, L173
- Bremer, M. N. *et al.* 2018, *MNRAS*, 476, 12
- Brinchmann, J., Charlot, S., White, S. D. M., Tremonti, C., Kauffmann, G., Heckman, T., Brinkmann, J., *et al.* 2004, *MNRAS*, 351, 1151
- Bryukhareva, T. S. & Moiseev, A. V. 2019, *MNRAS*, 489, 3174
- Chang, Y.-Y., van der Wel, A., da Cunha, E., Rix, H.-W., *et al.* 2015, *ApJS*, 219, 8
- Coenda, V., Martínez, H. J., Muriel, H., *et al.* 2018, *PASP*, 473, 5617
- Eales, S. A. *et al.* 2018, *MNRAS*, 481, 1183
- Ge, X., Gu, Q.-S., Chen, Y.-Y., Ding, N., *et al.* 2019, *Research in Astronomy and Astrophysics*, 19, 027
- Kauffmann, G. *et al.* 2003, *MNRAS*, 341, 33
- Kelvin, L. S. *et al.* 2018, *MNRAS*, 477, 4116
- Kewley, L. J., Dopita, M. A., Sutherland, R. S., Heisler, C. A., Trevena, J., *et al.* 2001, *ApJ*, 556, 121
- Lee, G.-H., Hwang, H. S., Lee, M. G., Ko, J., Sohn, J., Shim, H., Diaferio, A., *et al.* 2015, *ApJ*, 800, 80
- Lin, L. *et al.* 2017, *ApJ*, 851, 18
- Lintott, C. *et al.* 2011, *MNRAS*, 410, 166
- Mahoro, A., Pović, M., Nkundabakura, P., *et al.* 2017, *MNRAS*, 471, 3226
- Mahoro, A., Pović, M., Nkundabakura, P., Nyiransengiyumva, B., Väisänen, P., *et al.* 2019, *MNRAS*, 485, 452
- Martin, D. C. *et al.* 2005, *ApJ*, 619, L1
- Mendez, A. J., Coil, A. L., Lotz, J., Salim, S., Moustakas, J., Simard, L., *et al.* 2011, *ApJ*, 736, 110
- Noeske, K. G. *et al.* 2007, *ApJ*, 660, L43
- Phillipps, S. *et al.* 2019, *MNRAS*, 485, 5559
- Pović, M. *et al.* 2012, *A&A*, 541, A118
- Salim, S. 2014, 1995, *Serbian Astronomical Journal*, 181, 1
- Salim, S. *et al.* 2009, *ApJ*, 700, 161

- Schawinski, K., Thomas, D., Sarzi, M., Maraston, C., Kaviraj, S., Joo, S.-J., Yi, S. K., Silk, J.,  
*et al.* 2007, *MNRAS*, 382, 1415
- Schiminovich, D. *et al.* 2007, *ApJS*, 173, 315
- Starkeburg, T. K., Tonnesen, S., Koppenhafer, C., *et al.* 2019, *ApJ*, 874, L17
- Taylor, M. 2017, [arXiv:1707.02160](https://arxiv.org/abs/1707.02160)
- Trayford, J. W. *et al.* 2017, preprint ([arXiv:1705.02331](https://arxiv.org/abs/1705.02331))
- Trayford, J. W. *et al.* 2015, *MNRAS*, 452, 2879
- Tremonti, C. A. *et al.* 2004, *ApJ*, 613, 898
- Walker, L. M. *et al.* 2013, *ApJ*, 775, 129
- Wyder, T. K. *et al.* 2007, *ApJS*, 173, 293
- York, D. G. *et al.* 2000, *AJ*, 120, 1579