Green valley galaxies in the cosmic web: Internal vs Environmental quenching.

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Introduction

- The distribution of optical color show two distinct peaks corresponding to two galaxy population which are called 'red sequence' and the 'blue cloud'. The two population show significant overlap and the relatively shallow and flat region between the two peaks is termed as 'green valley'.
- The red sequence galaxies are primarily the quiescent galaxies with dominant bulge component, older stellar population and higher stellar mass whereas the blue cloud galaxies are star forming galaxies with disk like morphology, younger stellar population and lower stellar mass.
- The steady increase in the number of red galaxies and their stellar mass since $z \sim 1$ (Bell et.all,2004,APJ) indicates that blue cloud migrate to the red sequence via quenching of star formation. Although mergers of less massive already quenched galaxies increases the red population also.

- Internal mechanism's responsible for quenching star formation are mass quenching (Kauffmann et. all 2003,MNRAS), morphological quenching and bar quenching.
- External quenching mechanism responsible include the geometrical environment (e.g cosmic web) in which the galaxies are residing.
- The cold gas reservior destruction caused by AGN feedback also supports quenching of star formation.
- The blue galaxies evolve to red galaxies via quenching of star formation. The galaxies having intermediate properties between red and blue galaxies are the green valley galaxies undergoing such a transition. In this work we study the mechanisms responsible for quenching in green valley galaxies.

Data

- We use the 16th data release of Sloan Digital Sky Survey (SDSS) to download the spectroscopic and photometric information of galaxies.
  - $13.5 \leq r_p < 17.77, 135^\circ \leq ra \leq 225^\circ, 0^\circ \leq dec \leq 60^\circ$
- Morphological classification from Galaxy zoo (e.g elliptical, spiral and uncertain.)
- Detailed morphological properties from Galaxy zoo 2.
- AGN galaxies classification from MPA-JHU catalogue.
- Volume limit our sample between $-23 \leq M_r \leq -21$ to remove the luminosity bias which gives redshift between 0.041 and 0.12.

Classification using fuzzy set theory

$$A = \{ (x, \mu_A(x)) \mid x \in X \} \tag{1}$$

where $\mu_A(x)$ is the membership function.

$$R = \{ (u - r, \mu_R(u - r)) \mid (u - r) \in X \} \tag{2}$$

$$\mu_R(u - r; a, c) = \frac{1}{1 + e^{-a[(u-r)-c]}} \tag{3}$$

where a=5.2 and c=2.2 are const.

$$\mu_B(u - r) = 1 - \mu_R(u - r), \forall (u - r) \in X \tag{4}$$

$$\mu_G(u - r) = 2\, min\{ \mu_R(u - r), \mu_B(u - r) \}, \forall (u - r) \in X \tag{5}$$

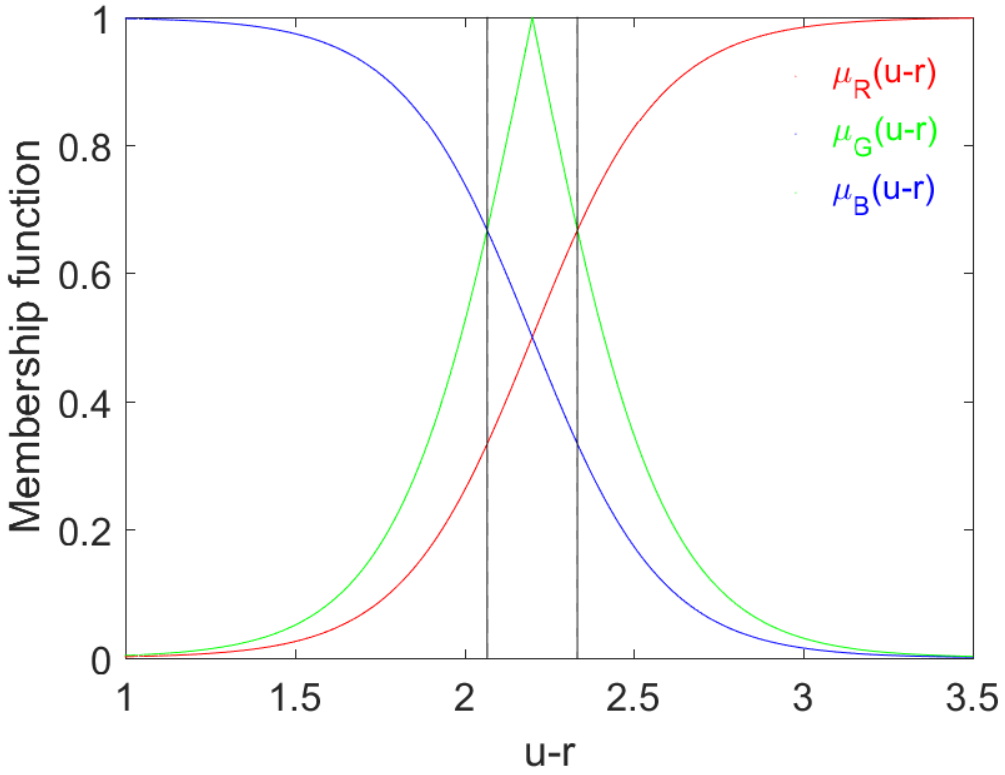

Figure: Red, blue and green galaxy classification using fuzzy set theory.

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Geometric environment using local dimension

- Galaxies reside in different types of geometric environments of the cosmic web e.g filaments, sheets and three dimensional volume.
- We calculate the local dimension of each galaxy using $N(< R) = AR^D$. (P. Sarkar & S. Bharadwaj, MNRAS 2009).
- Galaxies with D=1 are located at the centre of straight filaments, D=2 are lying within a sheet like structure and D=3 are distributed homogeneously in 3 dimensional volume.

Local dimension	Geometric environment
$0.75 \leq D < 1.25$	$D1$
$1.25 \leq D < 1.75$	$D1.5$
$1.75 \leq D < 2.25$	$D2$
$2.25 \leq D < 2.75$	$D2.5$
$D \geq 2.75$	$D3$

Table: This table lists the different geometric environments and local dimension.

Fraction of Red, Blue and Green galaxies.

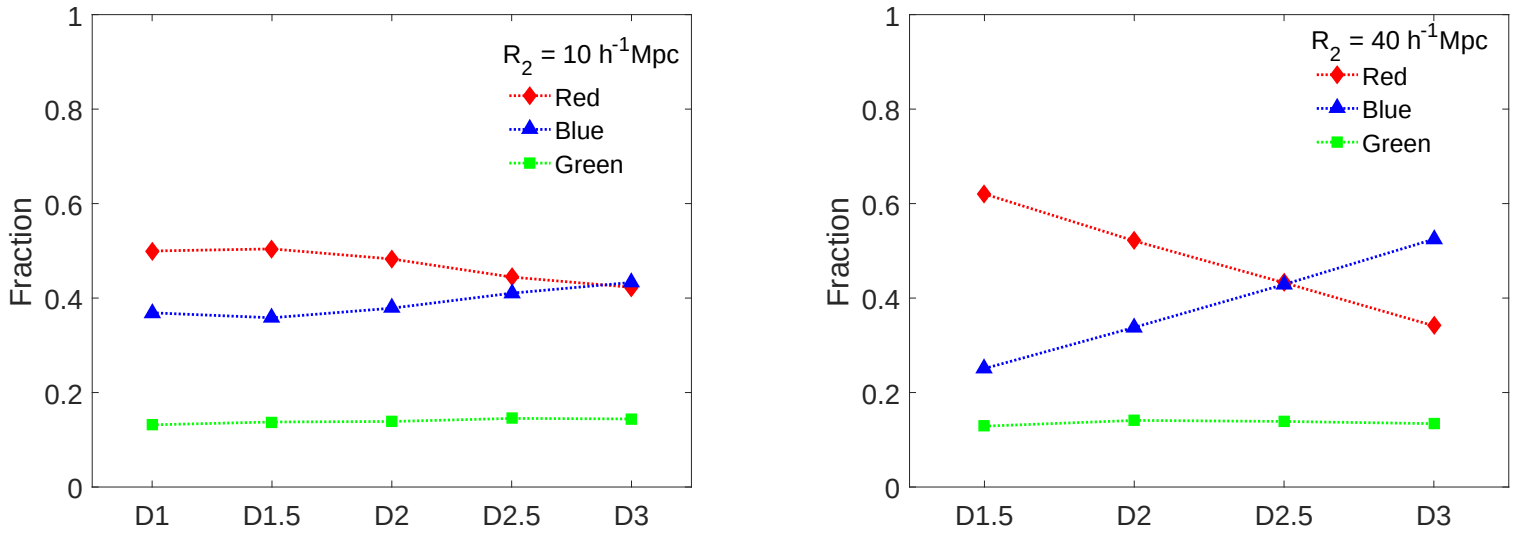
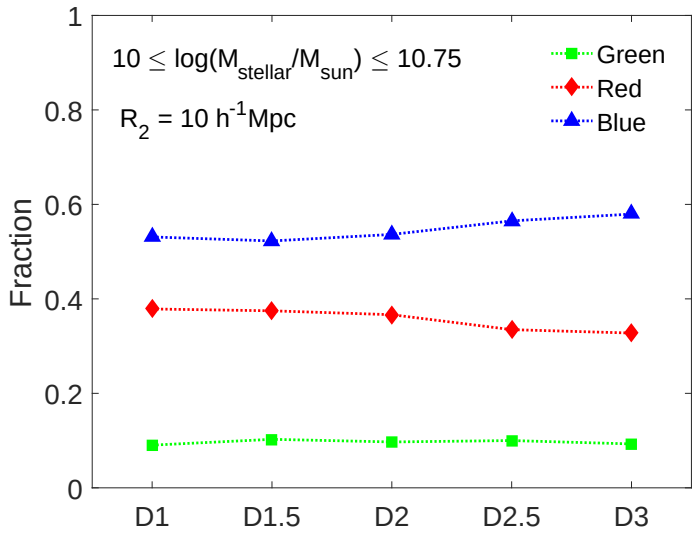
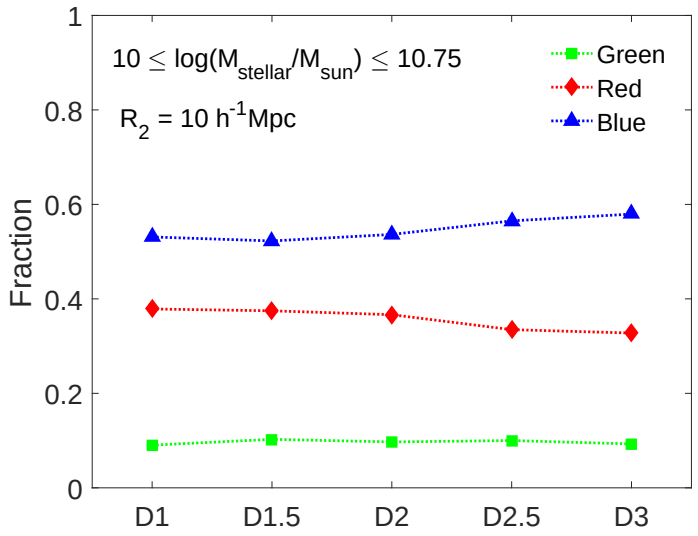


Figure: Fraction of red, blue and green galaxies in different environments.


$10 \leq \log(M_{stellar}/M_{sun}) \leq 10.75$
R_2 = 10 h^{-1}Mpc
Green
Red
Blue
Fraction
1
0.8
0.6
0.4
0.2
0
D1
D1.5
D2
D2.5
D3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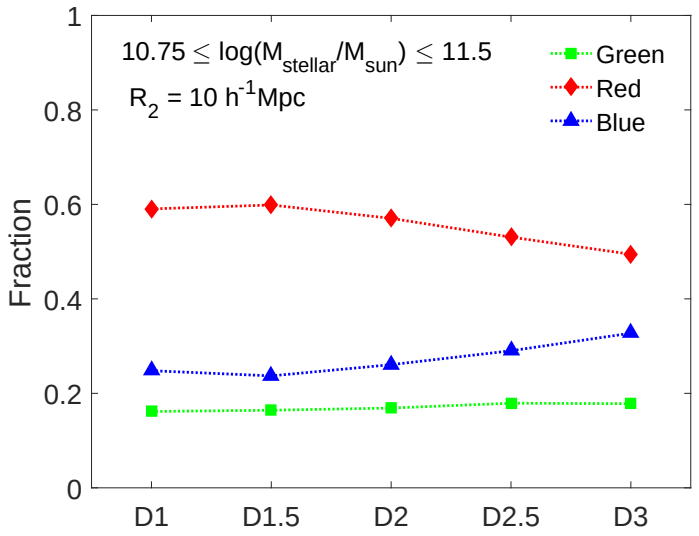
$10.75 \leq \log(M_{stellar}/M_{sun}) \leq 11.5$
R_2 = 10 h^{-1}Mpc
Green
Red
Blue
Fraction
1
0.8
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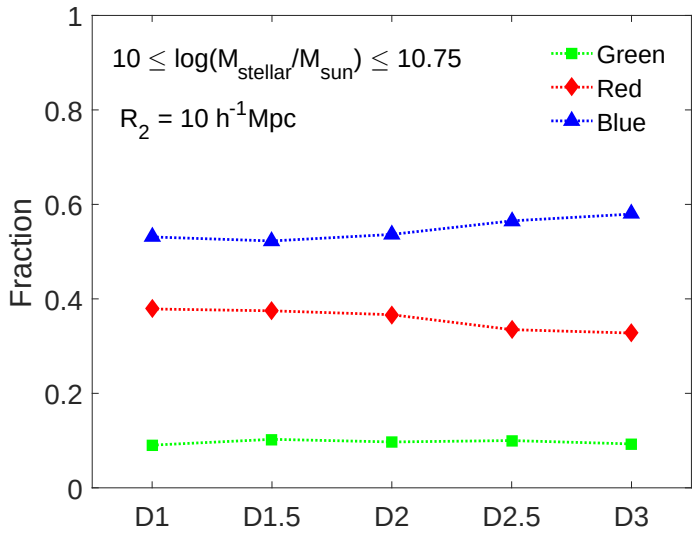
0.4
0.2
0
D1
D1.5
D2
D2.5
D3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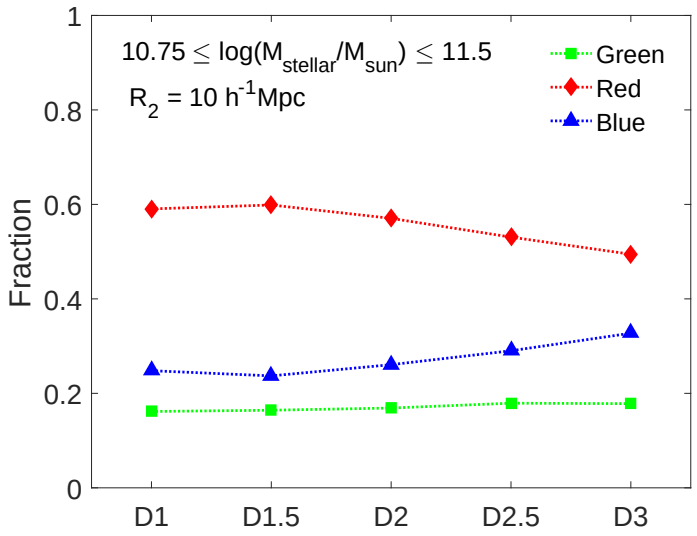
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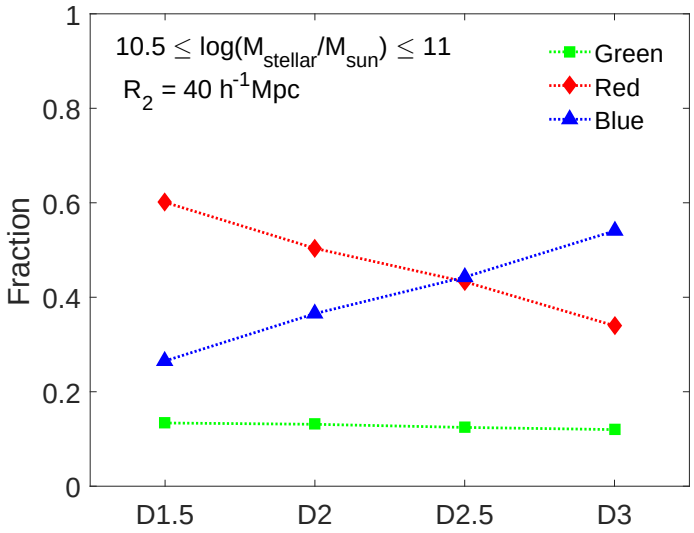
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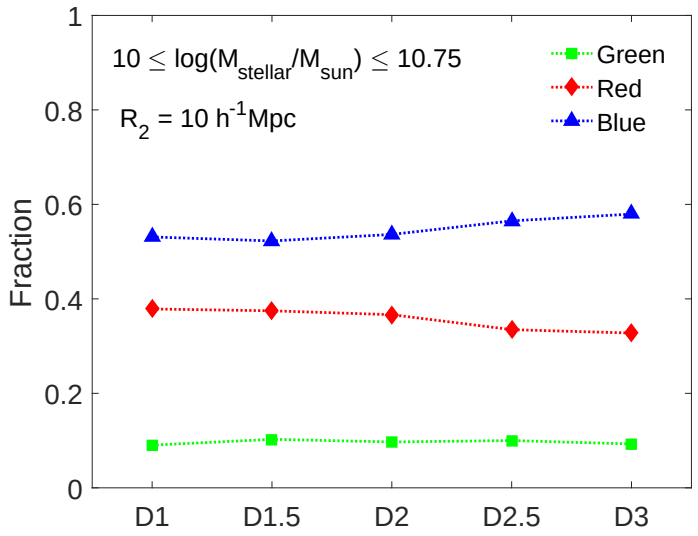
R_2 = 40 h^-1Mpc
Green
Red
Blue
Fraction
1
0.8
0.6
0.4
0.2
0
D1.5
D2
D2.5
D3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Red
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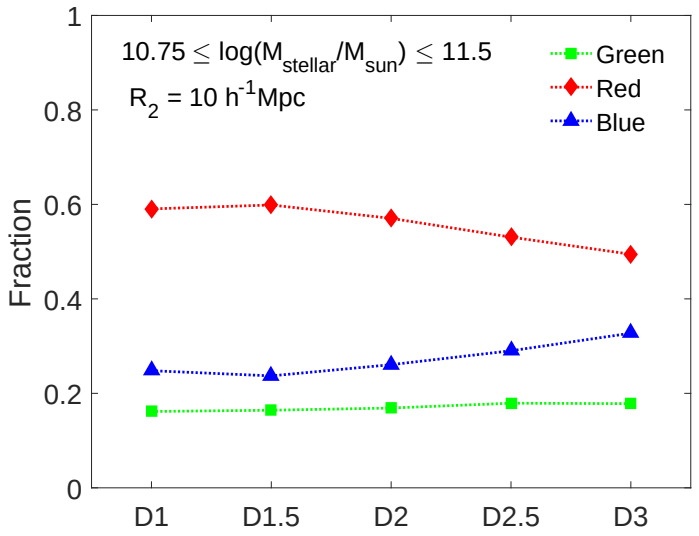
D3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D1
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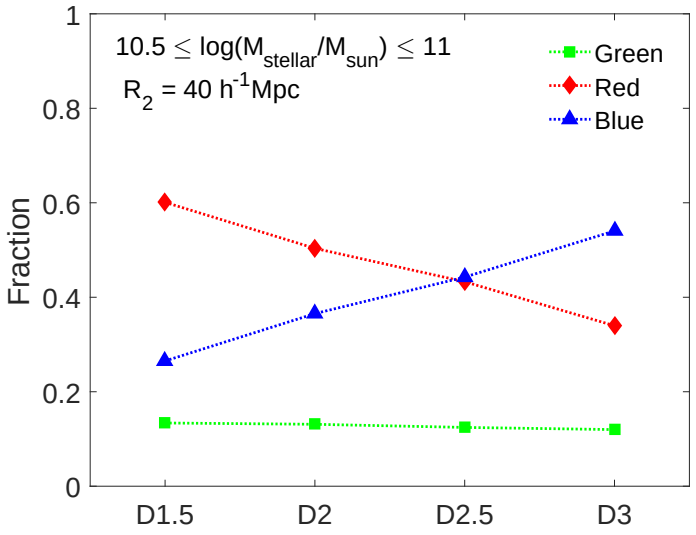
D3


10.5 ≤ log(M_stellar/M_sun) ≤ 11
R_2 = 40 h^-1Mpc
Green
Red
Blue
Fraction
0
0.2
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0.8
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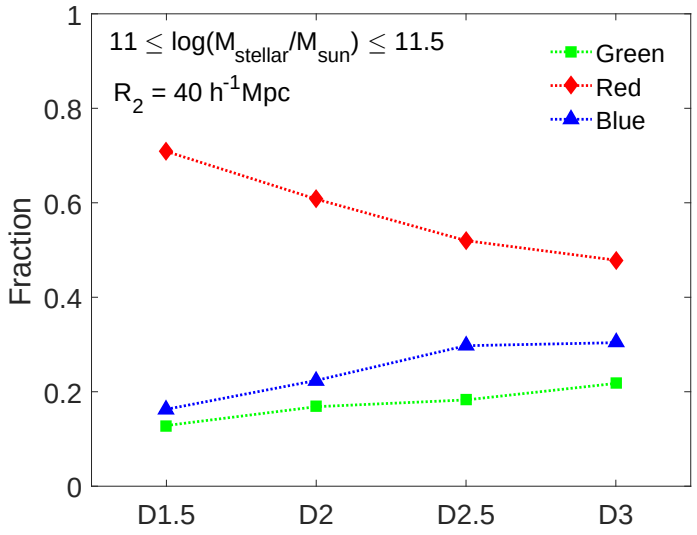
D1.5
D2
D2.5
D3


11 ≤ log(M_stellar/M_sun) ≤ 11.5
R_2 = 40 h^-1Mpc
Green
Red
Blue
Fraction
0
0.2
0.4
0.6
0.8
1
D1.5
D2
D2.5
D3

AGN fraction in green valley galaxies.

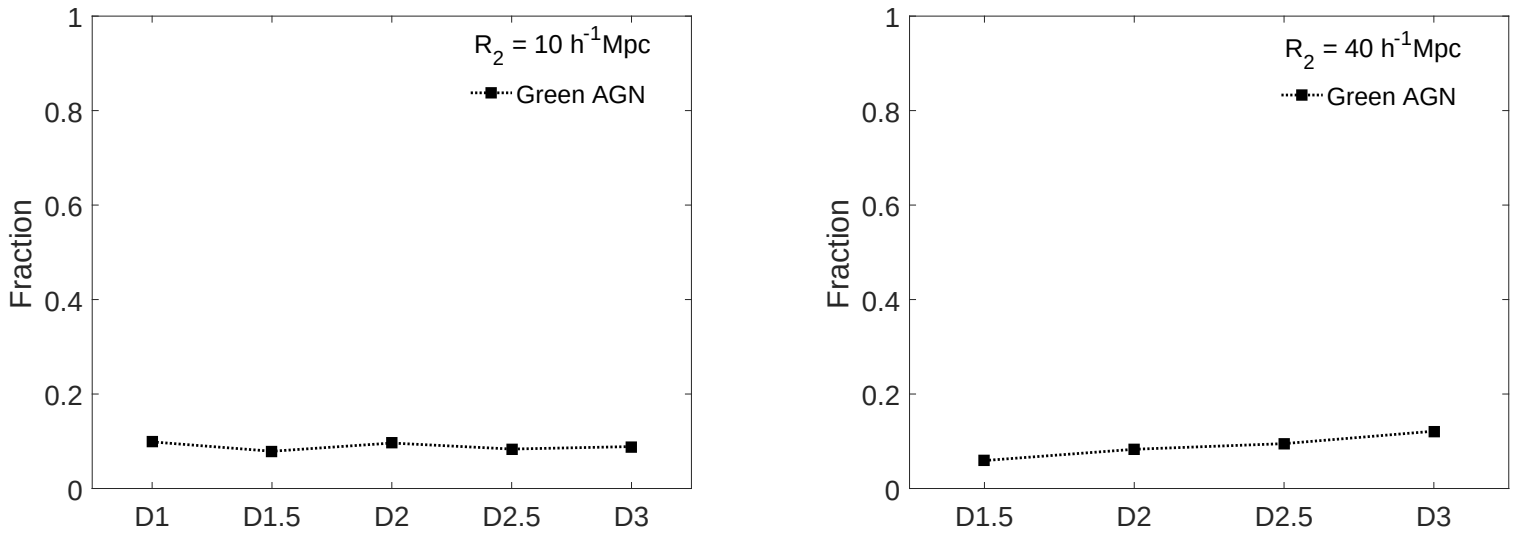


Figure: AGN fraction in green valley galaxies.

Morphology of green valley galaxies.

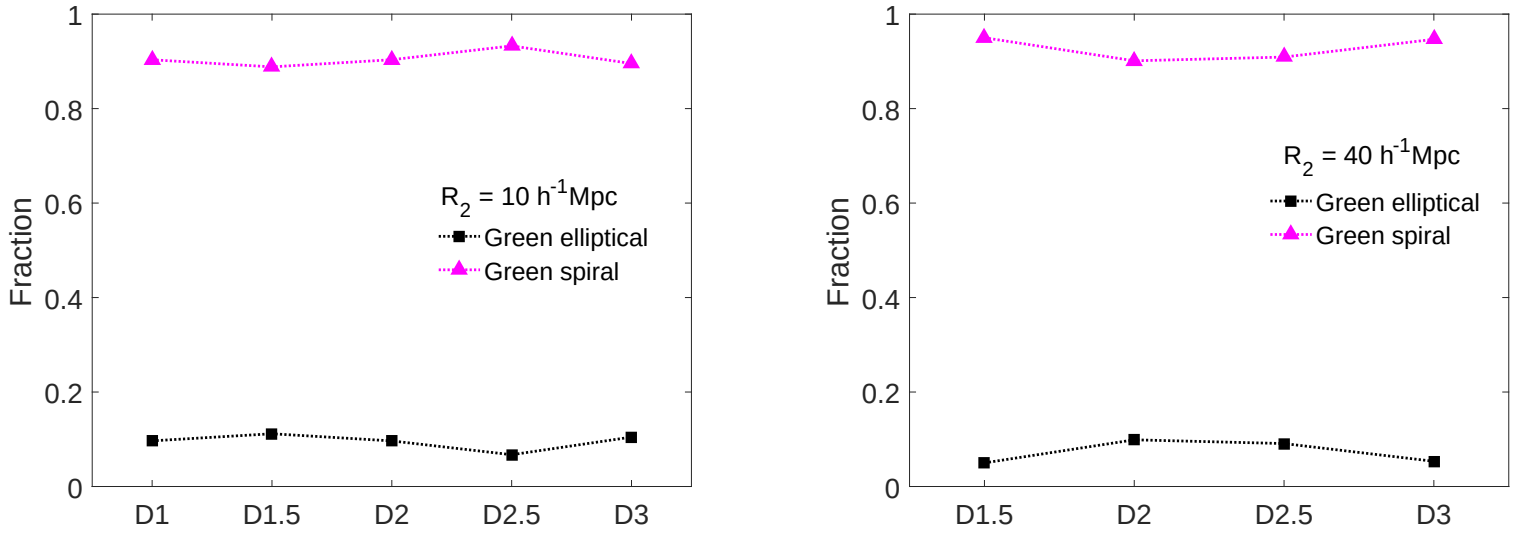


Figure: Elliptical and spiral fraction in green valley galaxies.

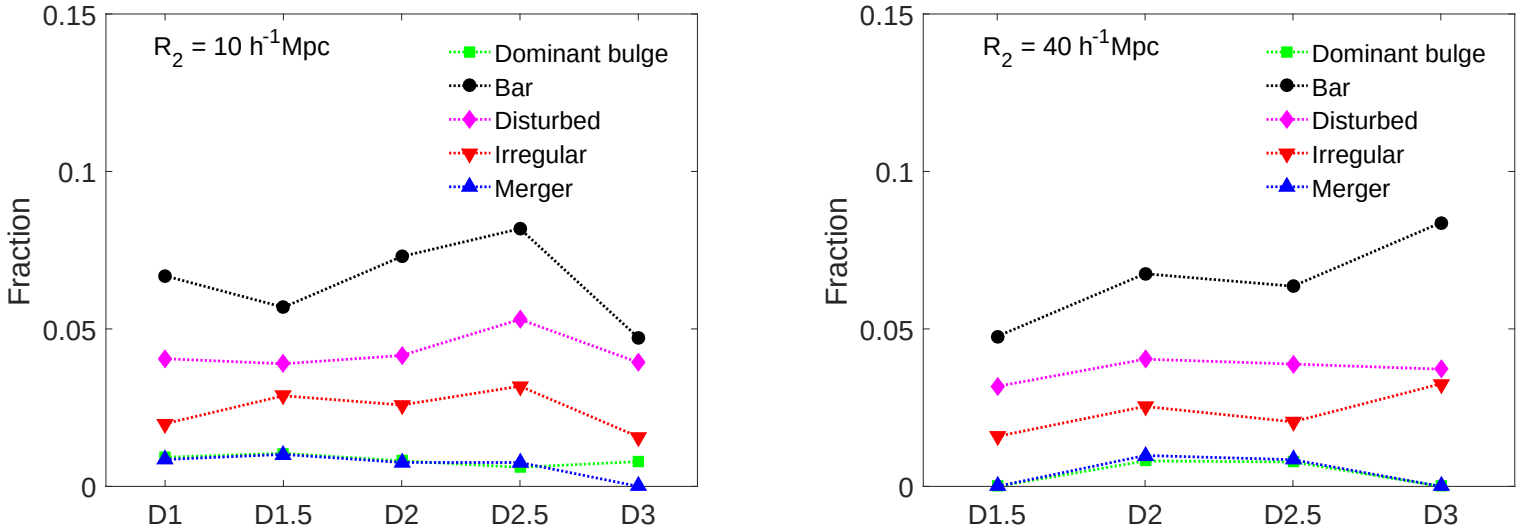


Figure: Dominant bulge, bar and irregular feature's fraction in green valley galaxies.

Conclusions.

- Environmental factors play a minor role and mass quenching plays the dominant role in quenching star formation. The green valley galaxies are massive galaxies.
- Green valley galaxies are mainly spiral galaxies with disk like morphology with no bulge component.
- AGN feedback in green valley galaxies doesn't contribute much in quenching star formation in green valley galaxies.
- Presence of bulge and bar in disk dominated spiral green galaxies are also not responsible much.

- Green valley galaxies quench their star formation through mass accretion and other internal process other than AGN feedback are responsible for truncating cold gas supply for maintaining the hot halo.
- As a whole environmental influences plays minor role and internal processes plays the dominant role in quenching star formation in green valley galaxies.

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Thank You