On the origin of red spirals: Does assembly bias play a role?

Suman Sarkar [1] Biswajit Pandey [2] Apashanka Das [2]

[1]Indian Institute of Science Education and Research, Tirupati, India

[2]Visva Bharati University, Santiniketan, India

Introduction

- The distribution of optical colour shows bimodal character with two peaks. The peak corresponding to higher optical colour represents population of 'red sequence'.
- The blue cloud galaxies are actively star forming galaxies whereas the red sequence galaxies shows low star formation rate.
- Studies with Galaxy zoo data reveal that 20% of the galaxies in the red sequence have spiral morphology. (Bamford et al, MNRAS (2009), Skibba et al, MNRAS (2009)).

- Quenching of SFR in red spiral galaxies - environment, tidal interactions, minor mergers, galaxy harrasment and strangulation, mass quenching, bar quenching, internal reddening in colour.
- Studies with N-body simulation has shown that mass, angular momentum of dark matter haloes depend on their large scale geometric environment and relates 'assembly bias'.(Han et al, MNRAS (2007)).
- Galaxies with fixed stellar masses have different assembly histories known as galaxy assembly bias and can influence their different properties. Assembly histories of galaxies and their large scale geometric environment are correlated.
- In this work we measure mutual information between large scale geometric environment and optical colour of spiral galaxies. (Pandey & Sarkar, (MNRAS), (2017)).

Data

- We use the 16th data release of Sloan Digital Sky Survey (SDSS) to download the spectroscopic and photometric information of galaxies.
  - $r_p < 17.77, 135^\circ \leq ra \leq 225^\circ, 0^\circ \leq dec \leq 60^\circ$
- Morphological classification from Galaxy zoo (e.g elliptical, spiral and uncertain.)
- D4000 from MPA-JHU spectroscopic catalogue (Brinchmann et al, MNRAS, 2004)
- Volume limit our sample between $M_r \leq -21$ to remove the luminosity bias and redshift < 0.12.
- Extract a cubic region of side $181h^{-1}Mpc$ and $2x10^{10}M_{sun} \leq M_{stellar} \leq 2x10^{11}M_{sun}$.

Classification using fuzzy set theory

$$R = \{\, (u-r,\, \mu_R(u-r)) \mid (u-r) \in X \,\} \qquad (1)$$

$$\mu_R(u-r; a, c) = \frac{1}{1 + e^{-a[(u-r)-c]}} \qquad (2)$$

where a=5.2 and c=2.2 are const.

$$\mu_B(u-r) = 1 - \mu_R(u-r),\ \forall (u-r) \in X \qquad (3)$$

$$\mu_G(u-r) = 2\, min\{\, \mu_R(u-r),\, \mu_B(u-r) \,\},\ \forall (u-r) \in X \qquad (4)$$

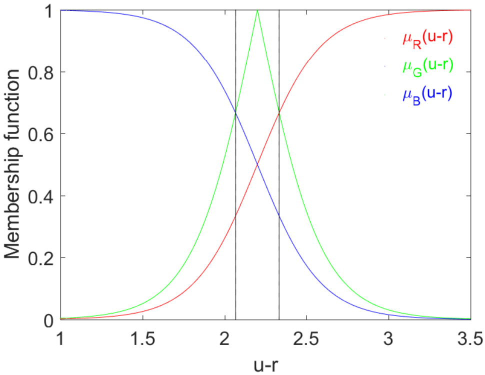


Figure: Red, blue and green galaxy classification using fuzzy set theory.

B.Pandey, MNRAS, 499, L31(2020)

Mututal information between colour and environment of spirals

- The Shannon entropy associated with the environment at scale d is

$$
\begin{aligned}
H(X) &= -\sum_{i=1}^{N_d} p(x_i) \log p(x_i) \\
&= \log N - \frac{N_i \log N_i}{N}
\end{aligned}
$$

- Similarly the information entropy associated with colour is given by,

$$
\begin{aligned}
H(Y) &= -\left(\frac{N_b}{N} \log \frac{N_b}{N} + \frac{N_r}{N} \log \frac{N_r}{N} \right) \\
&= \log N - \frac{N_b \log N_b + N_r \log N_r}{N}
\end{aligned}
$$

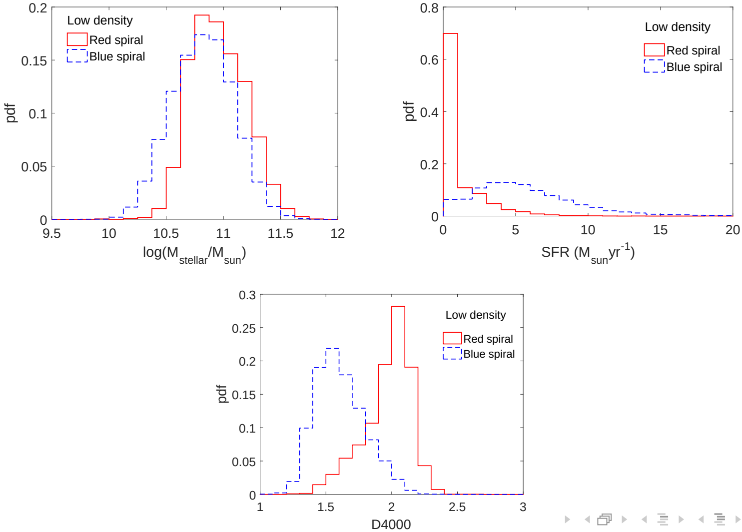
- The mutual information between environment X and their colour Y is defined as,

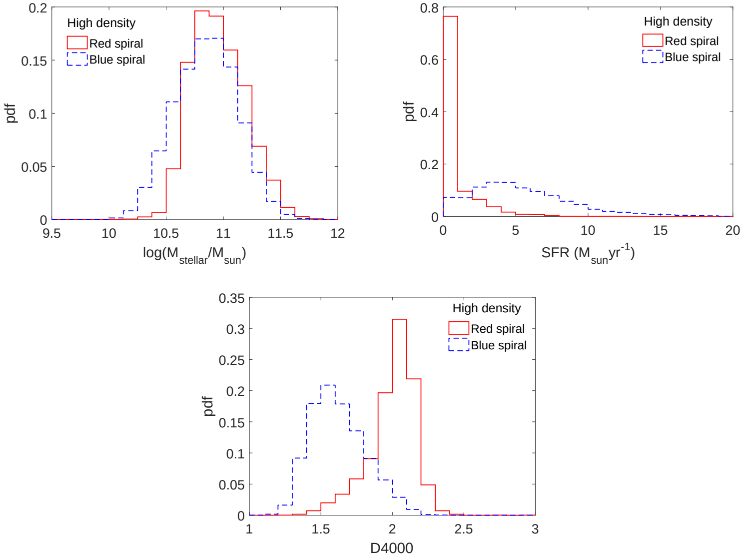
$$I(X;Y) = H(X) + H(Y) - H(X,Y)$$

H(X,Y) represents joint entropy and is given by,

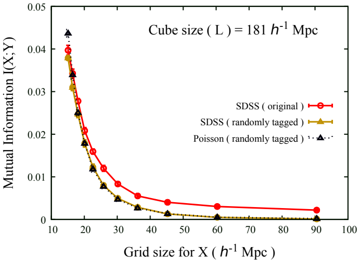
$$\begin{aligned} H(X,Y) &= -\sum_{i=1}^{N_d}\sum_{j=1}^{2} p(x_i,y_j)\log p(x_i,y_j) \\ &= \log N - \frac{1}{N}\sum_{i=1}^{N_d}\sum_{j=1}^{2} N_{ij}\log N_{ij} \end{aligned}$$

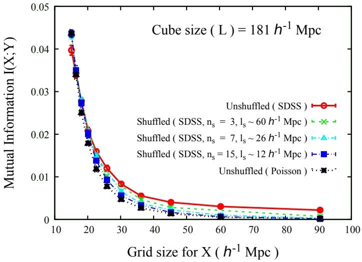
Comparing different properties of red and blue spirals




High density
Red spiral
Blue spiral
pdf
0.2
0.15
0.1
0.05
0
9.5
10
10.5
11
11.5
12
log(M_stellar/M_sun)
High density
Red spiral
Blue spiral
pdf
0.8
0.6
0.4
0.2
0
5
10
15
20
SFR (M_sun yr^-1)
High density
Red spiral
Blue spiral
pdf
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1
1.5
2
2.5
3
D4000

Mutual Information between large scale environment and colour of spirals





Conclusions.

- We compare the distributions of stellar mass, SFR, D4000 and local density of red and blue spirals and are statistically different at 99% confidence level.
- We also compare the stellar mass, SFR and D4000 of red and blue spirals in high density and low density regions and they also varies statistically at 99% confidence level.
- We test if the colour of the spirals are sensitive to their large scale environment by measuring mutual information between them.
- We get non zero mututal information and differences between original and randomised, original and shuffled data is statistically significant at 99% confidence level.

- Our analysis shows that the correlation between colour of spiral galaxies and their large scale environment are statistically significant.
- Colour of spiral exhibit an additional dependence on their large scale clustering due to assembly bias.
- Hydrodynamic simulations has shown that assembly bias may lead to wide variation of cold gas content within the haloes.
- Origin of red spirals have a combined role of local environment and assembly bias as well.

On the origin of red spirals: Does assembly bias play a role? (Sarkar S., Pandey B. and Das A., JCAP, 3, 24, (2022) . *arXiv:2111.11252*

Thank You