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Star formation rates and galaxy morhology at different redshifts

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1 GOALS

The main theme of this project is the evolution of the star formation. There are two relevant quantities that are given in the provided data: stellar mass (SM) and star formation rate (SFR). Stellar mass is the mass of stars for each galaxy at a given redshift z. The star formation rate is an instantenious increase in the stellar mass. We can also measure the ratio of the two (SFR/SM) – the quantity that measures how fast is the formation of stars in each galaxy. We call the quantity the Specific Star Formation Rate (sSFR). It is closely related with galaxy morphology. Large values of sSFR mean that the galaxy quickly increases its stellar mass. Thus, many stars have been formed recently. The color of the galaxy is relatively blue and it is likely to be a spiral galaxy. Low values of sSFR indicate old stellar population. Galaxy is red and likely is either E or S0.

(1) *Evolution of star formation in the whole Universe.* How efficient is the Universe in producing new stars? For each redshift find the total star formation rate $\sum_{i=1}^{N}$ SFR(i). Divide it by the total volume of the sample. This is the total star formation rate of the Universe at redshift z (in units of $M_\odot$/yr/Mpc^3). Find it for different z and make a plot. Describe it. Does it have maxima and minima? How star formation rate at $z = 0$ compares with that at $z = 1$ and $z = 5$? What fraction of global star formation rate is due to large galaxies with masses $M_* > 5 \times 10^{10} M_\odot$? What fraction is due to satellite galaxies? On the same plot of the global SFR draw curves for those two components.

(2) *Evolution of color bimodality.* We know that at low redshifts there are two distinct populations of galaxies: star-forming blue galaxies and no-star-formation red galaxies. You are going to study those at different redshifts. For a given redshift select galaxies in a stellar mass range $(M*, M_* + dM)$. Bin them according to their specific star formation rate sSFR. Make a plot of the number of galaxies dN/d(sSFR) as a function of sSFR. Note that values of sSFR are small (1.e-13–1.e-8). Do it for different stellar masses $M_* \approx 5 \times 10^9, 3 \times 10^{10}, 10^{11}$ and for $z = 0, 1, 2, 5$. Describe what you see.

(3) *Are satellites redder or bluer as compared with the central galaxies?* We classify galaxy as "quenched" (thus red), if its sSFR$< 10^{-11}$. What is the fraction of quenched central galaxies $f_{\rm c,quenched}$ as a function of stellar mass M_* at a given redshift? Fix redshift and plot $f_{\rm c,quenched}(M_*)$. On the same diagram plot quenched fraction of satellites. Do it for $z = 0, 1, 2, 5$. Are satellites more or less "quenched"? How quenched fractions evolve with time?

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2 DATA

Data for all projects are on cosmology6 server. There are 12 directories named SampleXX (XX =01, 02,...12) that have the data. Each student must use only one directory. Names of files code sample number and redshift. For example file Sample.01.Redshift.0.000.h5 is for sample 1 and redshift $z = 0$. Each directory has data for 5 redshifts ranging from 0 to 5. At redshit $z = 0$ there are about 44 million galaxies and about 1 million at redshift 5.

There are 10 quantities that are given for each galaxy:

x, y, z – coordinates in comoving h^{-1}Mpc units
vx, vy, vz – peculiar velocites in km/sec units
SM – stellar mass in $M_\odot$ units
SFR – star formation rate in $M_\odot/yr$ units
$M_{\rm vir}$ – virial mass in $h^{-1}M_\odot$ units
ID – index that tells whether object is central or satellite

Index ID is used to identify which galaxy is a central object and which is a satellite. "Central" galaxy is the largest galaxy in a halo. For that galaxy one can define the virial mass. An example is our Milky Way (MW) and satellites around it. Virial mass of MW is about $M_{\rm vir} \approx 10^{12} M_\odot$ and virial radius $R_{\rm vir} \approx 300$kpc. The stellar component is mostly confined to the much smaller inner ~ 20kpc region where its mass is $M_{\rm star} \approx 6 \times 10^{10} M_\odot$. Satellites by definition are galaxies within virial radius of the central galaxy. Satellites are typically heavily affected by the central galaxy and by dark matter halo. One normally does not use virial masses of satellites because satellites are stripped by tidal forces of the central galaxy, which drastically reduce masses bound to satellites.

Index ID of central galaxies is set to be ID=-1, and it is a positive number for satellites.

3 READING DATA

Data a written in hdf5 data format. Below are snippets of python how to read the data. One needs to import a library to read hdf5 files. This is done by routines in h5py:

```
import numpy as np
import math
import h5py
```

Open file Sample.01.Redshift.0.000.h5 and read some information:

```
h = h5py.File('Sample.01.Redshift.0.000.h5', 'r')
```

```
print("Keys: Box = h.attrs["Box"]
Ngalaxies = h.attrs["Ngalaxies"]
Redshift = h.attrs["Redshift"]
```

Here parameter Box is the size of the sample: $\text{Volume}_{\text{sample}} = Box^3$. For samples provided for the project $Box = 750h^{-1}$Mpc though that can be changed. So, read it from the files. Parameter Ngalaxies is the number of objects in the sample. "Redshift" is the redshift. Now read all the rest of the data:

```
x = np.real(h.get('x'))
y = np.real(h.get('y'))
z = np.real(h.get('z'))
M = np.real(h.get('Mvir'))
SM = np.real(h.get('StellarMass'))
SFR = np.real(h.get('StarFormationRate'))
ID = np.int_(h.get('CentralObject'))
```