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Identifying double peaked emission lines and AGN pairs in a sample of merging galaxies from the GOTHIC survey

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Abstract

In this project, we are working on detecting Dual Active Galactic Nuclei from a sample of 46000 galaxies taken from the Gothic Survey. Dual AGN (Active Galactic Nuclei) refers to a system in which two supermassive black holes are actively accreting matter and emitting high-energy radiation in a single galaxy. These dual AGN systems are believed to result from galaxy mergers or interactions, where two separate galaxies merge and bring their central supermassive black holes into proximity.Galaxy mergers are powerful drivers of galaxy evolution and galaxy growth. The individual galaxy nuclei can be either starburst (very large star formation rates), star forming or AGN in nature. If the nuclei are very close their emission lines will overlap and they will be double peaked. However double peaked emission lines are also due to outflows from star formation or AGN, or can be due to a rotating disk of hot ionized gas. Here we will examine the optical spectra from the GOTHIC survey, where both nuclei lie within a single fibre. After determining the sample of double nuclei galaxies we will investigate the origin of the double peaks.We will use their photometric data and MANGA data to make the color and BPT plots as well.

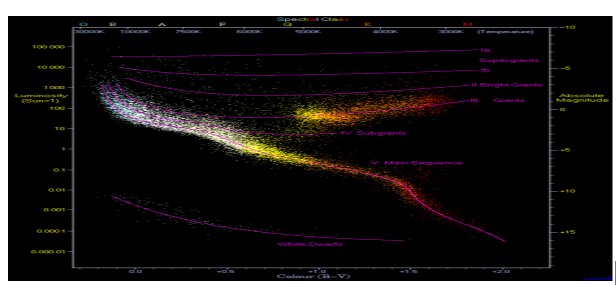
Keywords: SDSS, Galalxies , Dual AGNs , MANGA data, BPT Plots, Color Plots, outflows.

0.1 Introduction

In this project we are dealing with stars,galaxies, galaxies mergers,AGNs as well as dual AGNs ,thus we have to first start from the basic understanding of these celestial objects.In this section we will describe how the stars,galaxies as well as AGNs and Dual AGNs forms and behave in this cosmos.

0.1.1 Stars

Stars are self-gravitating gas masses that are protected from collapsing by pressure (both thermal and degeneracy). By examining a star's luminosities, which provide information on its motions,a surface temperature estimate (on the assumption of a blackbody energy distribution). Although certain stars are supported by degeneracy pressure, which does not require nuclear fusion to balance its gravity, most stars are powered by nuclear fusion processes that occur in the interior layers of the stars.
We must start with the Hertzsprung-Russell Diagram (HR Diagram)[2] in order to investigate a star's attributes because it depicts a star's absolute magnitude as a function of color for a specific stellar population. By displaying how many stars are in the main sequence and how many stars are in other branches, the HR diagram provides us an idea of the age of the stellar population. It also provides us with a sense of the population's metallicity, which may be determined by looking at the horizontal branch's pattern. Additional observables like absolute magnitude, apparent magnitude, distance modulus, hue, etc. can be used to measure the properties of stars in greater detail.



[3]

Stars can also be classified on the basis of their spectral classes, which is determined by the prominence of various absorption lines in their stellar spectra. In decreasing order of temperature the spectral classes are labelled as O,B,A,F,G,K, and M. The spectral classes are further subdivided into sublasses by the numbers 0,1,...,9.

0.1.2 Galaxies

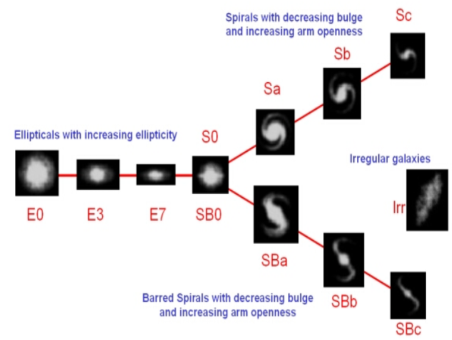
Galaxy, any of the systems of stars and interstellar matter that make up the universe. Many such assemblages are so enormous that they contain hundreds of billions of stars.Galaxies are classified by their morphologies:

Elliptical galaxies: These galaxies have an ellipsoidal shape, which gives them an elliptical appearance, regardless of the angle of view. They appear to have very little structure, and they usually have very little interstellar matter.Consequently, these galaxies also have a low portion of open clusters and a reduced rate of new star formation. Instead, they are dominated by generally older, more evolved stars orbiting the common center of gravity in random directions. The stars contain low abundances of heavy elements because star formation ceases after the initial burst. In this sense, they are similar to the much smaller globular clusters.

Spiral Galaxies: Spiral galaxies resemble spiraling pinwheels. Though the stars and other visible material in such a galaxy lie mainly on a plane, the majority of mass in spiral galaxies exists in a roughly spherical halo of dark matter which extends beyond the visible component, as demonstrated by the universal rotation curve concept.Some of the spiral galaxies have barred part in the central disk region alongwith the spiral arms. Spiral galaxies consist of a rotating disk of stars, interstellar medium, and a central bulge of generally older stars. Extending outward from the bulge are relatively bright arms.

Lenticular Galaxies:A lenticular galaxy is an intermediate form that has properties of both elliptical and spiral galaxies. These are categorized as Hubble type S0, and they possess ill-defined spiral arms with an elliptical halo of stars.

Irregular Galaxies: These type of galaxies fall under neither of the classications. They are very irregular in shape and are labelled as Irr in Hubble Classication System.



The Hubble Classification scheme for galaxies, often referred to as the "tuning fork" diagram. [1]

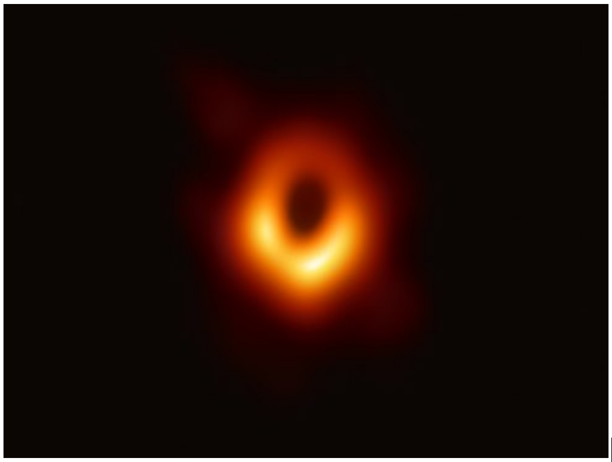
0.1.3 Super Massive Black Hole (SMBH)

A supermassive black hole (SMBH or sometimes SBH) is the largest type of black hole, with its mass being on the order of hundreds of thousands, or millions to billions of times the mass of the Sun. Black holes are a class of astronomical objects that have undergone gravitational collapse, leaving behind spheroidal regions of space from which nothing can escape, not even light. Observational evidence indicates that almost every large galaxy has a supermassive black hole at its center. For example, the Milky Way has a supermassive black hole in its Galactic Center, corresponding to the radio source Sagittarius A. Accretion of interstellar gas onto supermassive black holes is the process responsible for powering active galactic nuclei (AGNs) and quasars. **Schwarzschild radius:**The Schwarzschild radius or the gravitational radius is a physical parameter in the Schwarzschild solution to Einstein's field equations that corresponds to the radius defining the event horizon of a Schwarzschild black hole.

The Schwarzschild radius is given as

$$r_{\mathrm{s}} = \frac{2GM}{c^2}$$

where G is the gravitational constant, M is the object mass, and c is the speed of light.


[7]
The first direct image of a supermassive black hole, located at the galactic core of Messier 87.It shows radio-wave emission from a heated accretion ring orbiting the object at a mean separation of 350 AU, or ten times larger than the orbit of Neptune around the Sun. The dark center is the event horizon and its shadow.

0.1.4 Active Galactic Nuclei (AGN)

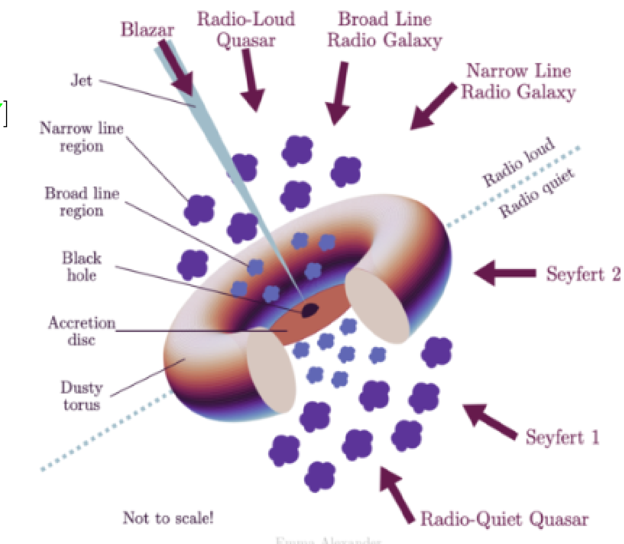
A compact central region from which we observe substantial radiation that is not the light of stars or emission from the gas heated by them. Active nuclei emit strongly over the whole electromagnetic spectrum, including the radio, X-ray, and gamma-ray regions where most galaxies hardly radiate at all. The most powerful of them, the quasars,easily outshine their host galaxies.
Gases swirl around the black hole, forming an accretion disk. In the inner circle of the accretion disk, mass is absorbed into the black hole, while a part of it is released as radiation and highly energetic matter. The radiation from the accretion from the closest stable orbit, gives us infomation about the near event horizon environment.[4]

There are different types of active galactic nuclies from their contribution to the emission from the jets and the lobes which the jets inflate

Radio-Loud Galaxies: Radio-loud objects have emission contributions from both the jet(s) and the lobes that the jets inflate. These emission contributions dominate the luminosity of the AGN at radio wavelengths and possibly at some or all other wavelengths.These include the Blazars like OVV Quasars and BL Lac objects,and also the Radio galaxies.

Radio-Quiet Galaxies: Radio-quiet objects are simpler since jet and any jet-related emission can be neglected at all wavelengths.These includes the Seyferts,LINERs,Radio-quiet quasars and Quasars 2s types of galaxies.

There is an another theory to classify AGNs according to Unified models which propose that different observational classes of AGN are a single type of physical object observed under different conditions.There are two types of unified models now,these are Radio-quiet unification and Rdio-Loud unification theory.



Unified AGN models [5]

The accretion luminosity (L_A), which is the luminosity corresponding to the radiation generated from accretion, can be stated as

$$L_A = \zeta \frac{GM(dm/dt)}{R_S}$$

where ζ is related to the efficiency of process of mass.

Depending on how we view them, the luminosity profile changes and these luminosity profile is often classified into several classes like the Seyfert 1, Seyfert 2, etc. The accretion rate $\dot{M}$ is scaled by the critical accretion rate which is given by to energy conversion.

$$M = \frac{L_{\text{Edd}}}{\eta c^2} \tag{1}$$

[6] Where, L_{Edd} is the Eddington limit in Luminosity.

0.1.5 Galaxy Mergers

Large galaxies like the Milky Way formed out of mergers with smaller galaxies and by stealing some of their stars. Astronomers discovered that as many as 25% of galaxies are currently merging with others. Probably even more are gravitationally interacting with their neighbors, with subsequent exchanges of stars and effects on the structures of both galaxies. For that reason, researchers study merging and interacting galaxies to understand how they form and evolve.[8]


[9]

Dry Mergers: Dry mergers refer to a type of galaxy merger that occurs without significant amounts of interstellar gas. In these mergers, two galaxies come together and combine their stellar populations without triggering a significant burst of star formation. As a result, the merger is "dry" in the sense that it lacks the presence of gas, as opposed to "wet" mergers where gas-rich galaxies merge and lead to substantial star formation.

Wet Mergers: Wet mergers refer to a type of galaxy merger that involves significant amounts of interstellar gas. In these mergers, two gas-rich galaxies come together and combine their gas reservoirs, leading to intense star formation activity. Unlike dry mergers, wet mergers have an abundant supply of gas, which fuels the formation of new stars during and after the merger process.

Dry mergers involve gas-poor galaxies combining their stellar content, transforming them into more massive and spheroidal shapes. They play a key role in the hierarchical growth of galaxies and stellar population mixing. Wet mergers, on the other hand, involve gas-rich galaxies merging with significant star formation and galaxy evolution implications.

0.1.6 Dual Active Galactic Nuclei (DAGN)

Dual AGN (Active Galactic Nuclei) refers to a system where two supermassive black holes are actively accreting gas and emitting intense radiation at the centers of two separate galaxies. These black holes are in close proximity to each other and are typically the result of a galaxy merger. The study of dual AGN provides valuable insights into galaxy interactions, black hole dynamics, and the co-evolution of galaxies.

As a result, the centers of double nuclei galaxies can contain AGN pairs, AGN-starburst pairings, or lone star forming nuclei.It is sometimes referred to as a dual AGN (DAGN) system when two or more AGN are discovered in a merger remnant and are separated by less than 10 kpc, while the definition varies in the literature and can encompass AGN at separations of up to 50 kpc. Multiple AGN systems may be more prevalent than we realize because triple AGN systems have also been found in small clusters of merging galaxies. Simulations have demonstrated that even small mergers can produce a large number of massive black holes (MBHs) that are spatially separated from the galaxy's nucleus; these MBHs are referred to as "wandering black holes" since they do not seem to be in merging with the nuclear SMBH.[10]

0.1.7 Gothic Survey

The GOTHIC algorithm gave the data that we utilised in this study. The automated search algorithm GOTHIC, also known as Graph-boosted Iterated Hill Climbing, was created to find dual or multiple nuclei in merging and interacting galaxies using optical imagery. In galaxies, it seeks to locate examples of dual or multiple active galactic nuclei (AGN). The Gothic method determines whether there are two or more closely spaced nuclei in a given picture of a galaxy. It is intended to conduct a comprehensive review of the available imaging data in search of dual nuclei galaxies and dual AGN. A large sample of galaxies from the Sloan Digital Sky Survey (SDSS) have been used to apply the technique on a known sample of galaxies in order to find dual AGNs. The algorithm has shown a high detection accuracy of over 95%.

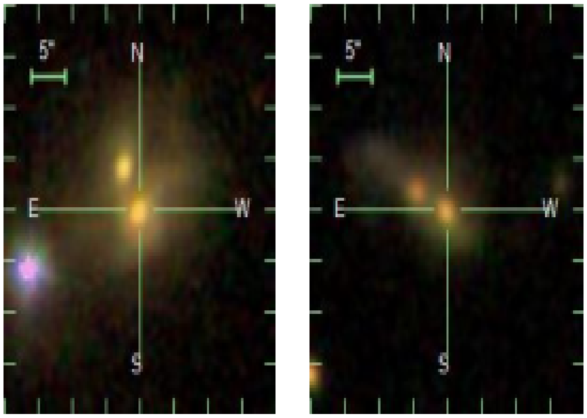


Figure 1: DAGN images sorted by GOTHIC from SDSS server.

[20]

0.2 Methodology

In this section we will describe how to select the sample data and how the sample of the galaxy are anlaysed to catagorize the falaxy according to their spectrums.

0.2.1 Data Collection from SDSS

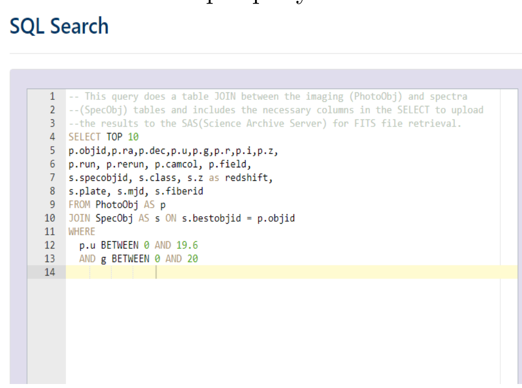
In SDSS, spectra for many objects are taken simultaneously. This is possible because the spectrographs are connected by fiber optic cables to an aluminum plate in the telescope's focal plane. With this arrangement in mind, any SDSS spectrum can be identified with three numbers. SDSS spectra were collected by a series of spectroscopic programs, described below. When analyzing spectral lines in SDSS data, remember that the SDSS wavelength scale is based on vacuum wavelengths.[11] We observe that the SDSS survey 18 as well as 16 gives the same spectrum so we use both to collect the spectrums of the galaxies.

The SDSS measures many spectra in a single observation: 640 at a time with the SDSS spectrograph (used in SDSS-I, -II and in the SEGUE surveys) and 1000 with the BOSS spectrograph (used in the SDSS-III BOSS survey). The SDSS does this by means of a plate, an aluminum disk placed in the focal plane of the telescope. Each plate corresponds to a specific patch of sky, and is pre-drilled with holes corresponding to the sky positions of objects in that area, meaning that each area requires its own unique plate.Some plates were observed in a single night; others were observed over multiple nights. Still others had intentionally repeated spectroscopic observations, with the same plate being re-observed several times. Thus, in addition to a plate number, identifying an SDSS spectrum requires knowing the MJD (modified Julian date) on which that spectrum was observed.

Each hole on each plate corresponds to one object on the sky. Optical fibers plugged into each hole bring the light from the focal plane to the pseudoslit of the spectrographs. Thus, each spectrum is also referenced by the number of the fiber (fiberID) with which it was collected. Plates used by the BOSS spectroscopic program had 1,000 fibers each; plates used by earlier SDSS spectroscopic programs had 640 fibers each. If a plate is observed on more than one MJD, the fibers will be replugged; thus a given fiberID on different MJDs will correspond to different objects on the sky.

In addition to the plate-MJD-fiberID system, SkyServer uses a unique number that encodes (64-bit hash) both plate-MJD-fiberID and the RUN2D reduction value of the spectroscopic redshift pipeline.[12]

We use the sql query to collect the data's



SQL Search

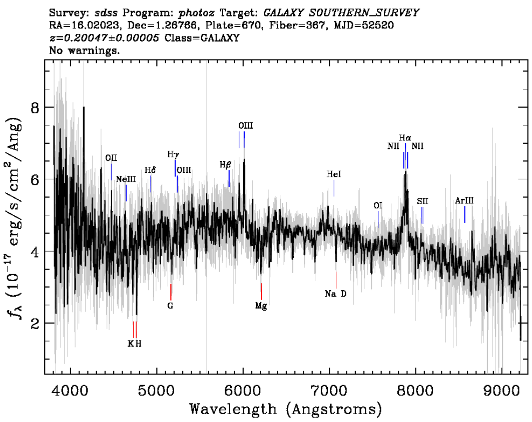
```sql
-- This query does a table JOIN between the imaging (PhotoObj) and spectra
--(SpecObj) tables and includes the necessary columns in the SELECT to upload
--the results to the SAS(Science Archive Server) for FITS file retrieval.
SELECT TOP 10
p.objid,p.ra,p.dec,p.u,p.g,p.r,p.i,p.z,
p.run, p.rerun, p.camcol, p.field,
s.specobjid, s.class, s.z as redshift,
s.plate, s.mjd, s.fiberid
FROM PhotoObj AS p
JOIN SpecObj AS s ON s.bestobjid = p.objid
WHERE
  p.u BETWEEN 0 AND 19.6
  AND g BETWEEN 0 AND 20
```

[13]

The SDSS SQL-16 search uis fine to collect all the datas,so we use the galaxies object IDs to collect all the spectrums images as well as the galaxy images. We have a total of 46000 galaxy sample data points which is taken from the Gothic survey and use the sdss to collect all the photometric data from the object ids of the galaxies.

0.2.2 Data Reduction

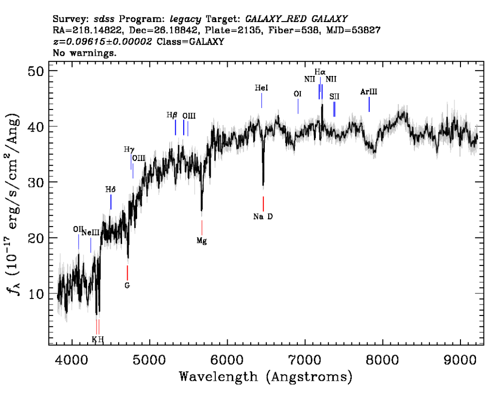
In this section we will show how the data is reduced according to the signal-to-noise ratio.First we take a 200 galaxies as a test data sample to understand what will be the threshold value to the Sn ratio.Manually we observe 200 galaxies from their spectrum as well as the images and then manage to use a Sn ratio threshold to reduce the data.



[14]

This above galaxy spectrum has the Sn ratio of approx 9 So we can see that it is combined with very much noisy part so we can discard this data.So the approch to discard one galaxy is taken from the manual observations.

In the peak detection method we have to analyse the emission likes like Hα,Hβ,OIII(4959Å),OIII(5008Å) and some nitrogen emission lines.We have to serach the dual peaks in these emission lines so we must need those galaxies which have a clear spectrum.So first we observe the spectrums according to their disguishable peak structure,if the emission peaks can be distinguished we take it as a good sepctrum and take a note of the Sn ratio.



[15]

Here is an example of the good spectrum having Sn ratio as approx 27.In this spectrum we can clearly distinguish the emission peaks of the elements given above. After analysing manually we got the Sn threshold as 25, means the galaxies having Sn ratio equal or greater than 25 are mostly clear,some outliers are their in this also but approx this is the threshold we use to reduce the data.

But most of the images of the galaxies in SDSS-18 as well as SDSS-16 are clear and we can visually distinguish the nucleus of the galaxy present mostly in the centers.

FinallyAfter reducing the 46000 samples of galaxies by using the SQL query we got 3400 galaxies approx which means that most of the galaxies or majority galaxies have the noisy spectrum which could change our results further. After this we use this galaxies and observe the emission lines as well as the image to separate these as Dual AGNs,outflows etc.

0.2.3 Spectrum Analysis

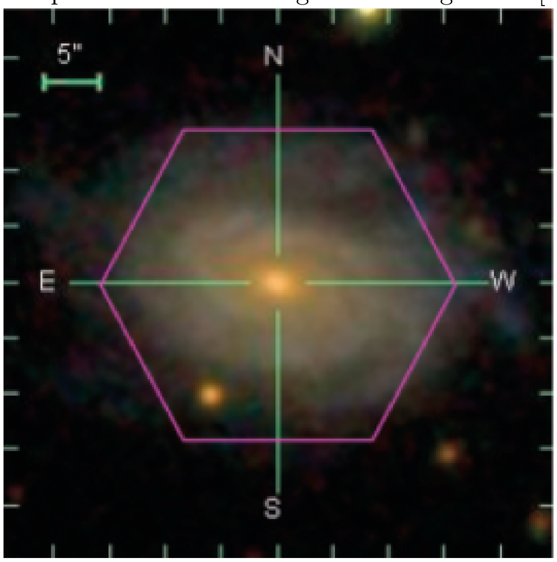
Here we will show how the spectrum is analysed,basically we analyse the spectrum as well as the image of the galaxies manually.First we serach the galaxies from their object ids and then use the interactive spectrum option of the sdss skyserver to get the spectrum.We observe some specific emission lines of the spectrum to understand whether the galaxy has the chances to be a Dual AGN,the dual AGN shows dual peaks in some specific emission lines due to their properties.When teo galaxies merge their emission lines oberlap thus create double emission peaks in certain wavelengths.

The specific emission lines are Hα , Hβ , OIII(4959Å) , OIII(5008Å) and sometimes Nitrogen peaks.If these emission lines shows double peak it will certainly due to DAGNs , outflows and due to the rotation curves sometimes.[16]

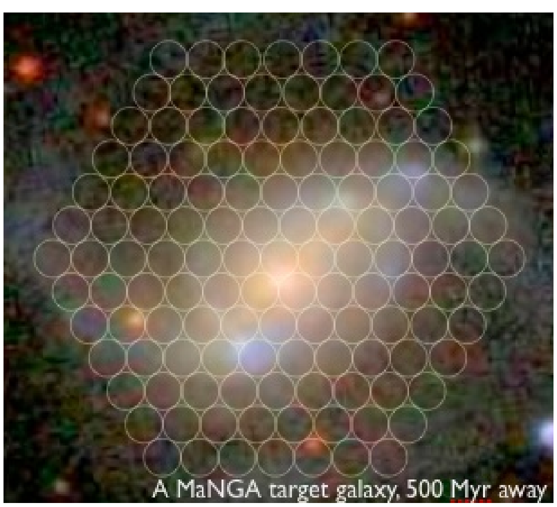
Genrally the Hα , Hβ emission lines come from the Broad Line Region (BLR) clouds and the OIII(4959Å) , OIII(5008Å) comes from the Narrow line Region (NLR) clouds. If we get double peaks in OIIIs and not getting in the Hα generraly it gives an insight that this is due to the outflows. If the Hα and Hβ both have double peaks it is due to AGN activity or feedback mechanisms as wells as the star formation taking place in that region.Mostly the double peaks in any of the OIII denotes a dual AGN but it is not true all the times.These DAGNs are fully confirmed by the analysis of the radio spectrum only.[17]
In the image analysis we visually observe the images of the galaxies and sorted it according to their double nuclies in the center part.We used the photometric data to do the color plot also.

0.2.4 MANGA Data

The MaNGA (Mapping Nearby Galaxies at Apache Point Observatory) survey is a project conducted by the Sloan Digital Sky Survey (SDSS). It aims to map the detailed internal structure and composition of nearby galaxies. The survey uses Integral Field Spectroscopy (IFS) to obtain spectra at multiple locations across each galaxy, allowing scientists to study the dynamics, star formation, and chemical composition in various regions of the galaxies.[18]



MaNGA data includes detailed information about each galaxy, such as its size, shape, brightness, spectra at different wavelengths, and kinematics. The data is publicly available and has been used by astronomers and researchers to study various aspects of galaxy evolution and structure.



MaNGA provides two-dimensional maps of stellar velocity and velocity dispersion, mean stellar age and star formation history, stellar metallicity, element abundance ratio, stellar mass surface density, ionized gas velocity, ionized gas metallicity, star formation rate and dust extinction for a statistically powerful sample. The galaxies are selected to span a stellar mass interval of nearly 3 orders of magnitude. No cuts are made on size, inclination, morphology or environment, so the sample is fully representative of the local galaxy population.[19]

We have used the manga data of the galaxies to do the BPT plots and then classify it accordingly. Certainly very few galaxies have the manga datas in the skyserver.

0.3 Results

We have analysed finally all the data points and thus depending upon this we got some statistics according to that analysis.All this results are taken from SDSS website.[24]

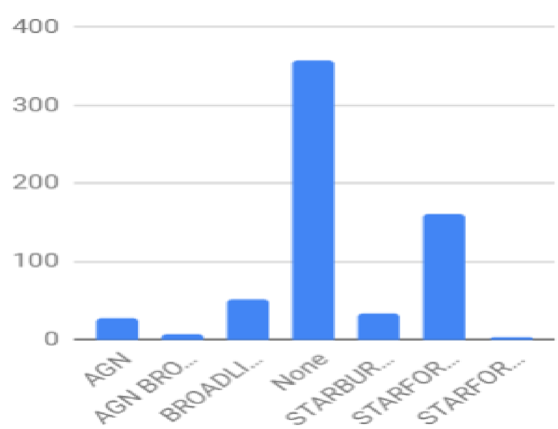


Figure 2: Distribution of galaxies according to their subclasses

Most of the galaxies here are None type of galaxies which shows neither AGN,Starforming,Starburst,Broadline and AGN Broadlines.

After that we got the we have most galaxies as starforming and Broadlines. Very few galaxies are AGN and AGN Broadlines. Least of them are starforming Broadlines here in the sample. After this we sorted out the galaxies according to their spectra analysis , image analysis as wells presence of manga data in the galaxies.

0.3.1 Observation from the spectra

In this from the sample data we got the total number of data's having dual peaks in any of the emission lines given is 425.Means the percent of dual peaks are about 12.4%.

From the spectra we analyse the Hα , Hβ , OIII(4959Å) , OIII(5008Å) to observe the double peaks in it, thus we get some stats accordingly.
The galaxies have double peaks in Hα are 66 galaxies.In this the most of the galaxies are starforming other than none subclass.

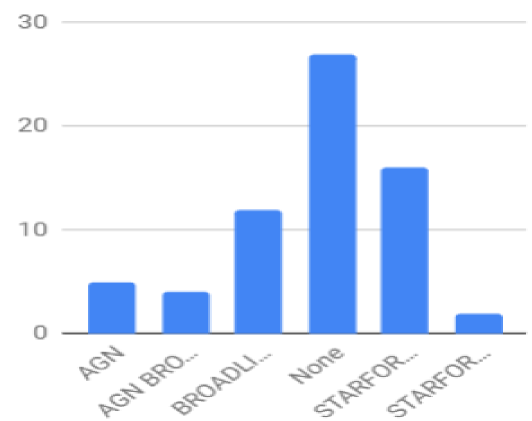


Figure 3: Distribution of galaxies according to their subclasses

In the peaks of Hβ we get 89 galaxies which has double peaks in its emission lines.Most of the galaxies have Starforming nature and few are AGNs.

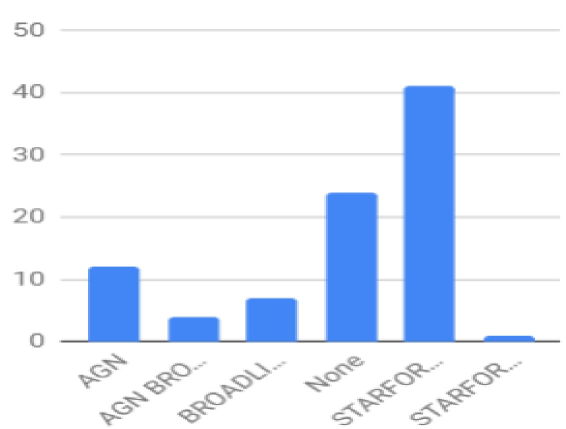


Figure 4: Distribution of galaxies according to their subclasses

And the galaxies which have double peaks in the OIII(4959Å) are 217 in number. In the OIII(4959Å) emission lines region we got starforming as 91 galaxies and some were Broadlines.

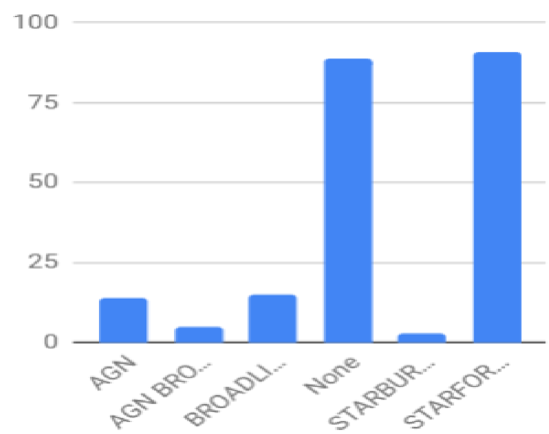


Figure 5: Distribution of galaxies according to their subclasses

In the OIII(5008Å) emission line we get double peaks in 255 galaxies.And most of the galaxies were starforming and Broadlines in subclasses.

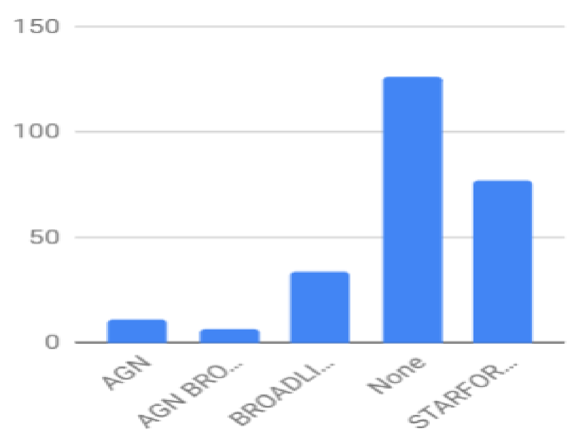


Figure 6: Distribution of galaxies according to their subclasses

And those galaxies which have double peaks in all these emission lines are only 16. Most of them are starforming and then some were Braodlines and few of them are AGNs and AGN Broadline.

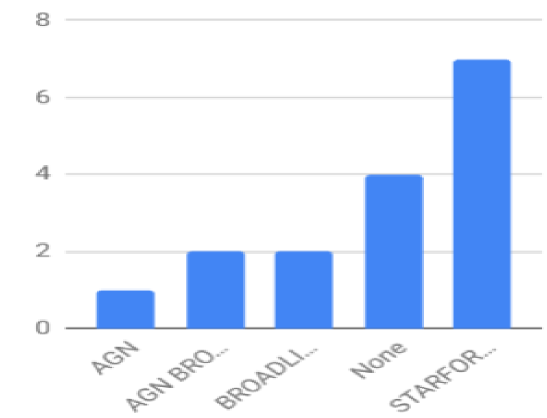


Figure 7: Distribution of galaxies according to their subclasses

These galaxies told us that they might be an dual AGN which have double peaks in all the given emission lines.
The galaxies having emission lines in Hα are mostly starforming.And those which in the Hβ they might be due to the outflows and Starforming regions of the galaxies. The galaxies having both double peaks in Hα and Hβ are 16 in number.These galaxies are mostly starforming as well as AGNs.

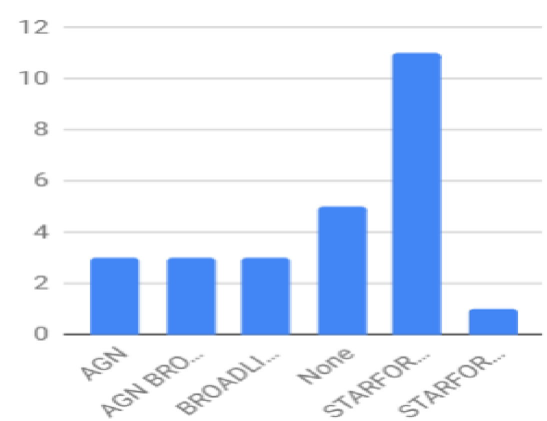


Figure 8: Distribution of galaxies according to their subclasses

The galaxies having double peaks in all the oxygen ions are 109.These are due to the outflows as well as Dual AGN activity.

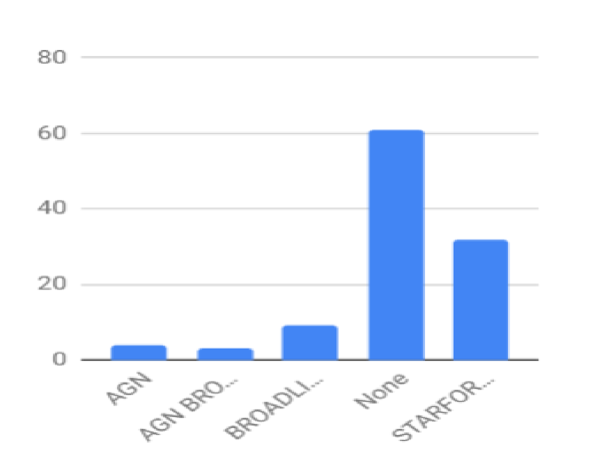


Figure 9: Distribution of galaxies according to their subclasses

The galaxies having double peaks in all of them are like this.

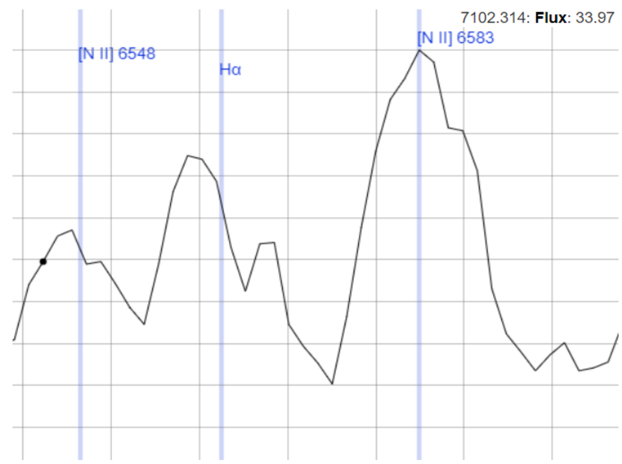


Figure 10: Galaxy double peak in Hα in it

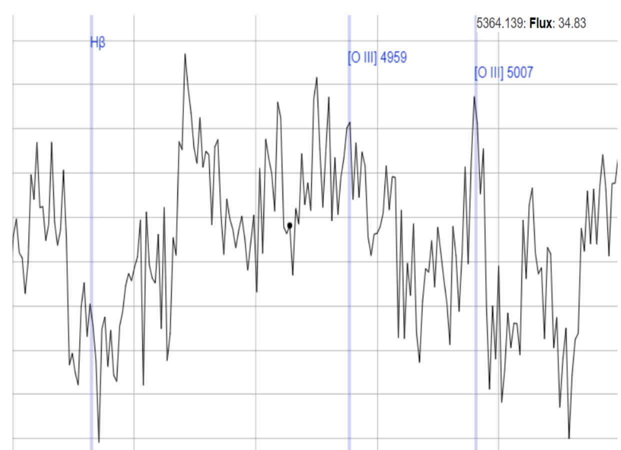


Figure 11: Galaxy double peaks in the other emission lines

After this all steps we make the color plot of the galaxies.

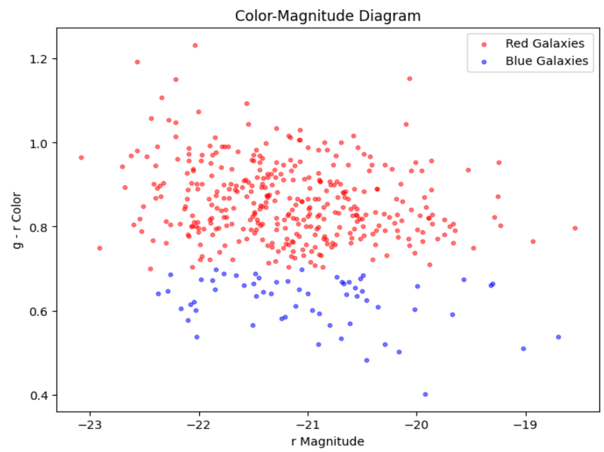


Figure 12: Color Plot

From this we can see that the red galaxies which means the galaxies are genenrally elliptical and old galaxies.The threshold selecting from the source in this plot.[21]

0.3.2 observation from the image

In this from the sample data we got the total number of data's having dual nucleus in any of the image is 218.Means the percent of dual nucleus are about 6.4%. The observations were made on the apperance of the galaxies whether they have double nucleus or not.We have sorted the galaxies accordinly whether they have double nucleus in them from the sample data we got after reducing.Some of them has manga data and we have plotted the BPT maps with them in the next section as well.

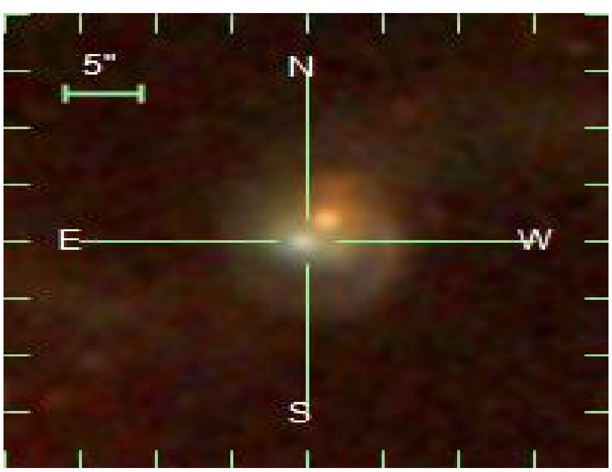


Figure 13: A dual nucleus galaxy

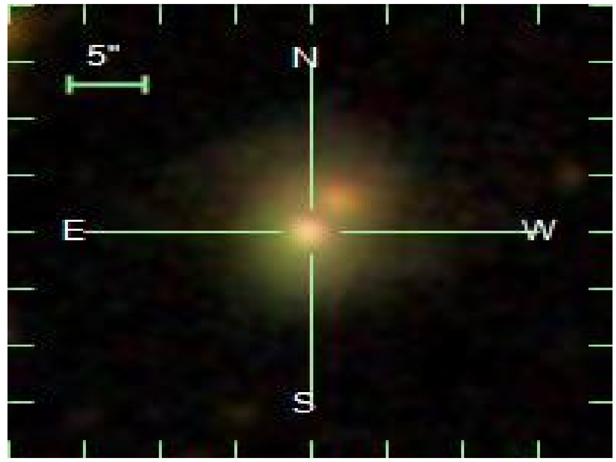


Figure 14: Another dual nuclei galaxy

These are some of the dual nucleus galaxies we observe which might be dual AGNs.These have nucleus whether merging or compact nucleus seen from the image got throught the sdss server. We might show some of the merger cases of the galaxies,

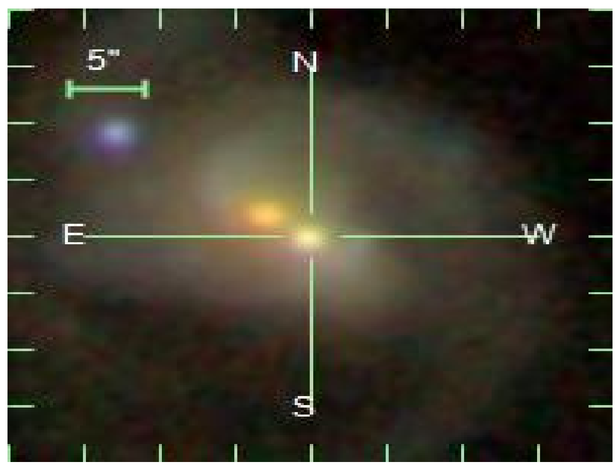


Figure 15: Galaxy mergers

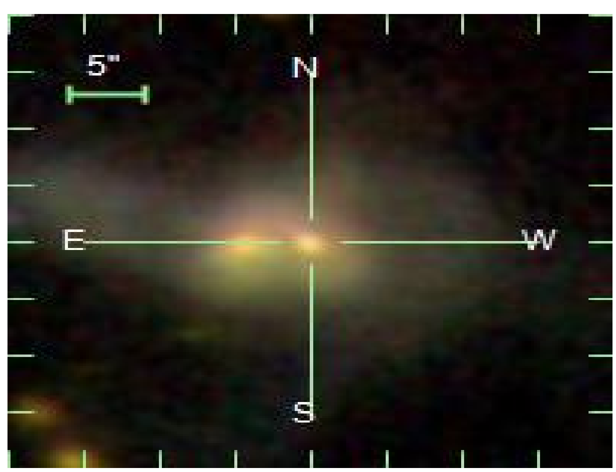


Figure 16: Another of galaxy mergers

These are one of the galaxies which are galaxy mergers clearly seen from the images taken from SDSS. In total we have 219 galaxies in the dataset which have double nucleus or looks like a merger.

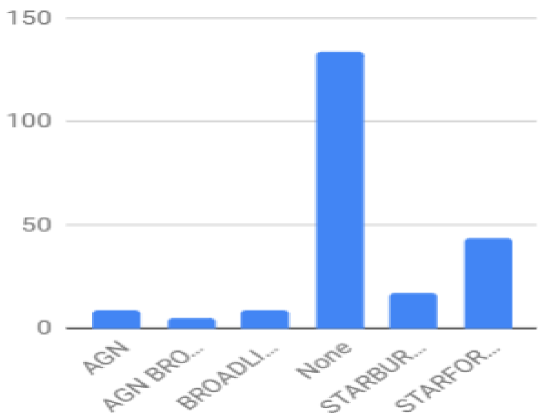


Figure 17: Subclasses of the galaxies which have double nucleus

Most of them are Star froming category other than the None ones,few of them are Starbursts and some of them are AGN and AGN broadlines.

After this we use to sort the data sample which are AGNs and AGN Broadline these were only 14 galaxies.Within these only one of the galaxies have double peaks in all the given emission lines.

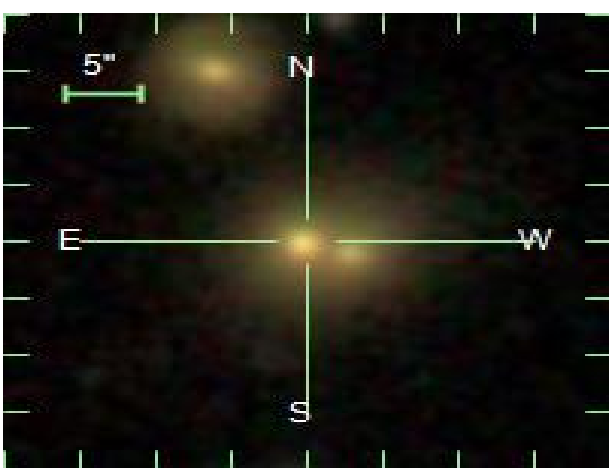


Figure 18: AGN BROADLINE as subclass

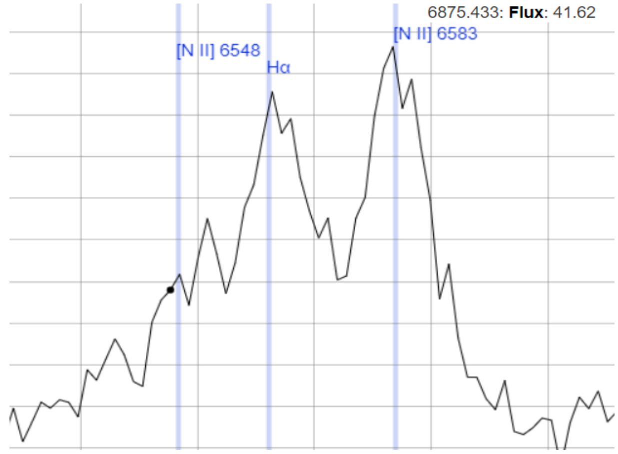


Figure 19: Spectrum of the above galaxy

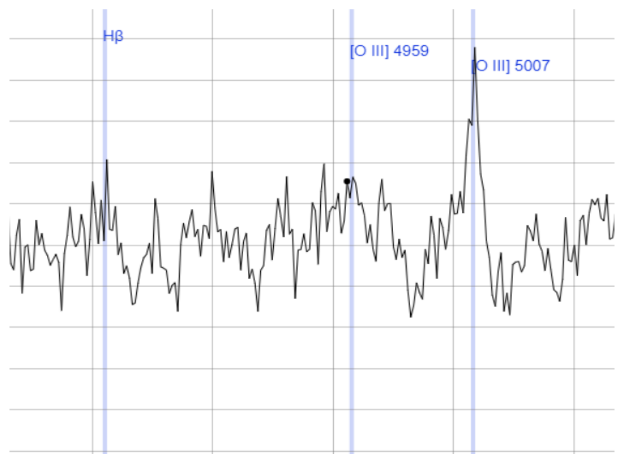


Figure 20: Spectrum of the above galaxy

We can see that all the emission lines have double peaks and some nitrogen lines have also double peaks in it.We can thus says that it might be an dual AGN.

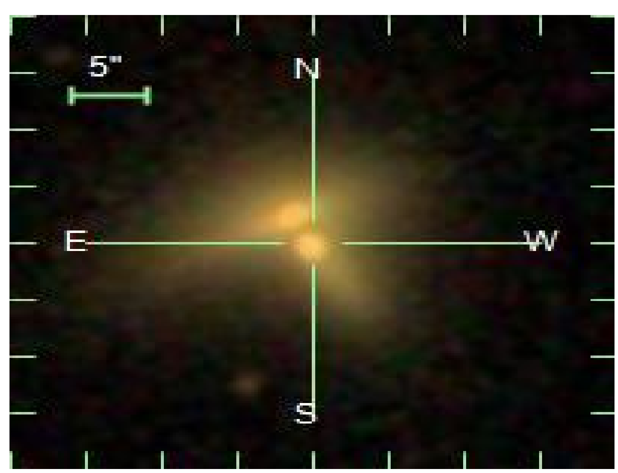


Figure 21: Another Dual Nucleus galaxy having subclass as AGN Broadline

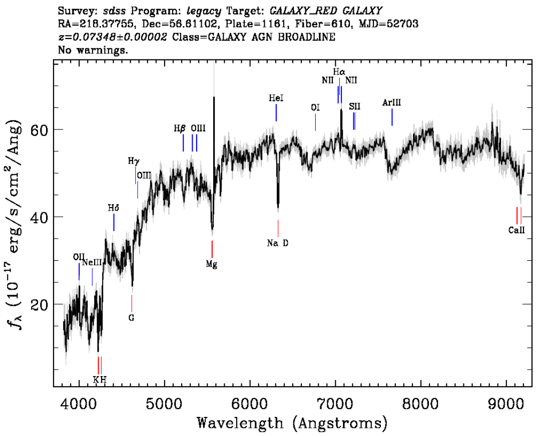


Figure 22: Spectrum of the above galaxy which have dual peaks in Hα and OIII(5008Åemission lines

We thus manage the image observations and find some cases which possibly be an dual AGNs.

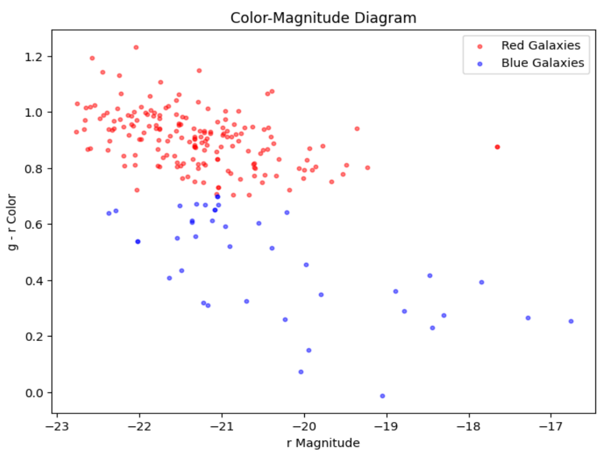


Figure 23: Color Plot

Here are the color plots of the galaxies and we can see that the red or old type galaxies are more in the data sets than the early type galaxies.

0.3.3 BPT Plots

Galaxies having Double nucleus

We have only two galaxies which have both manga data and the Double nucleus in it but most of them are starburst and starforming galaxies.

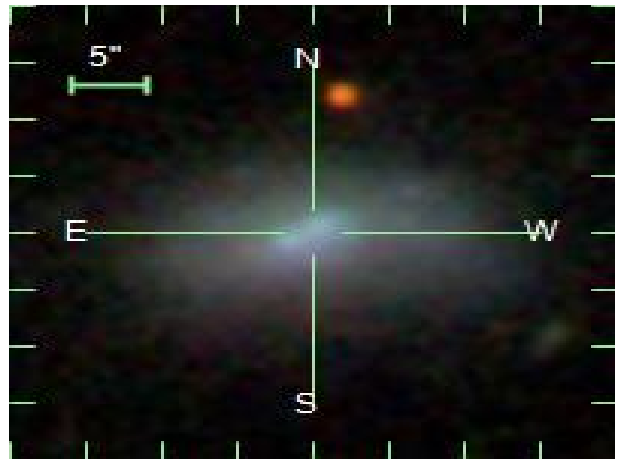


Figure 24: Galaxy image of the object id:1237657594072596746

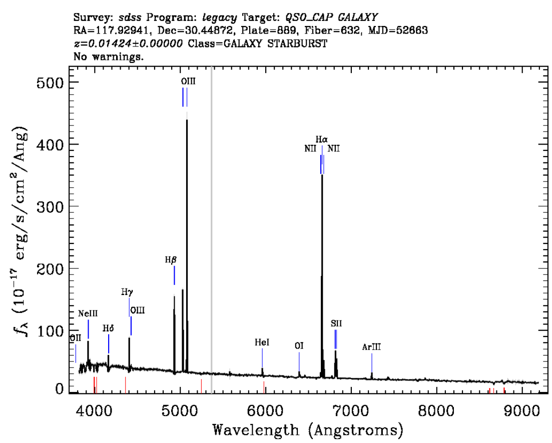


Figure 25: Spectrum of the galaxy

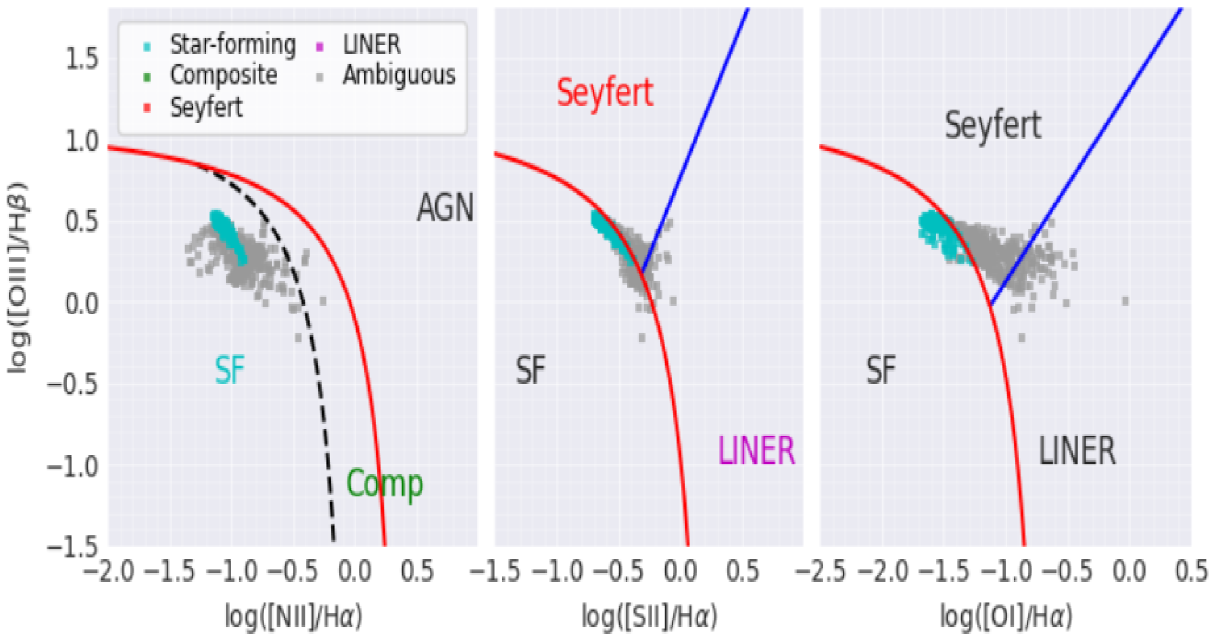


Figure 26: BPT Plot

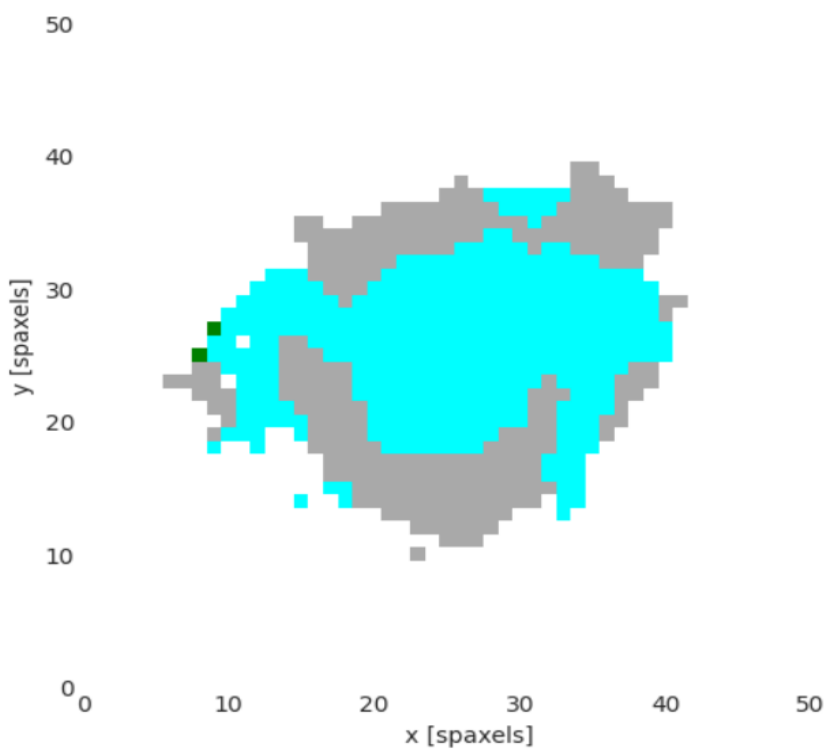
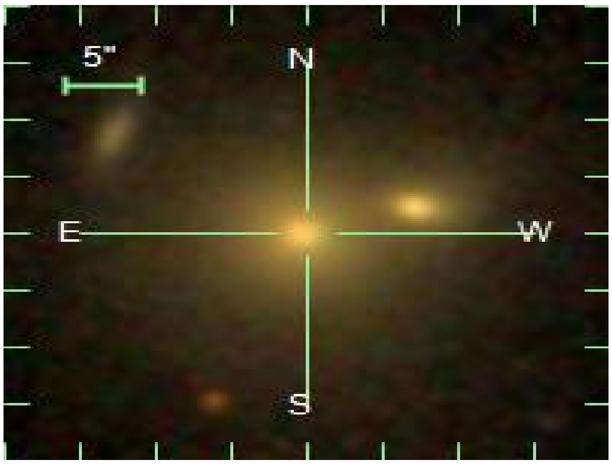


Figure 27: BPT Map,Thus we can see in the map that the starforming regions are very much than the other regions

Another galaxy which have both manga data as well as the double nucleus or a merger in it is,

Figure 28: Galaxy image of the object id:1237661086958420256



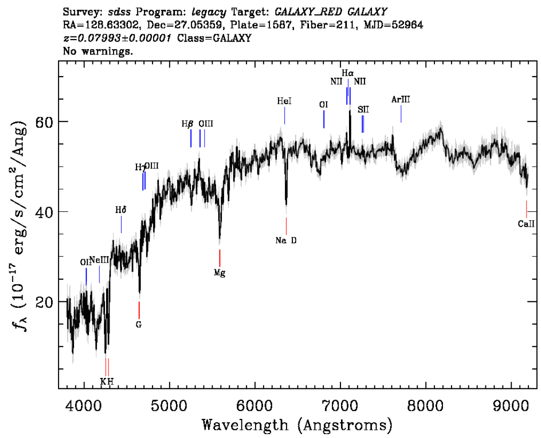


Figure 29: Spectrum image

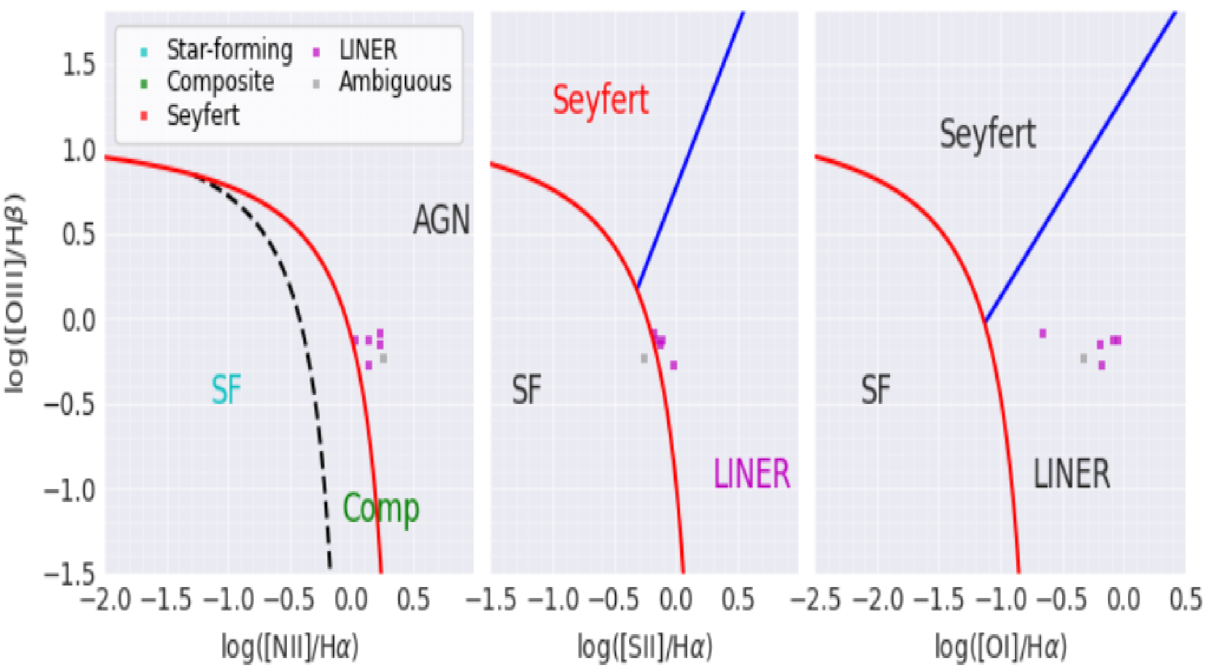


Figure 30: BPT Plot

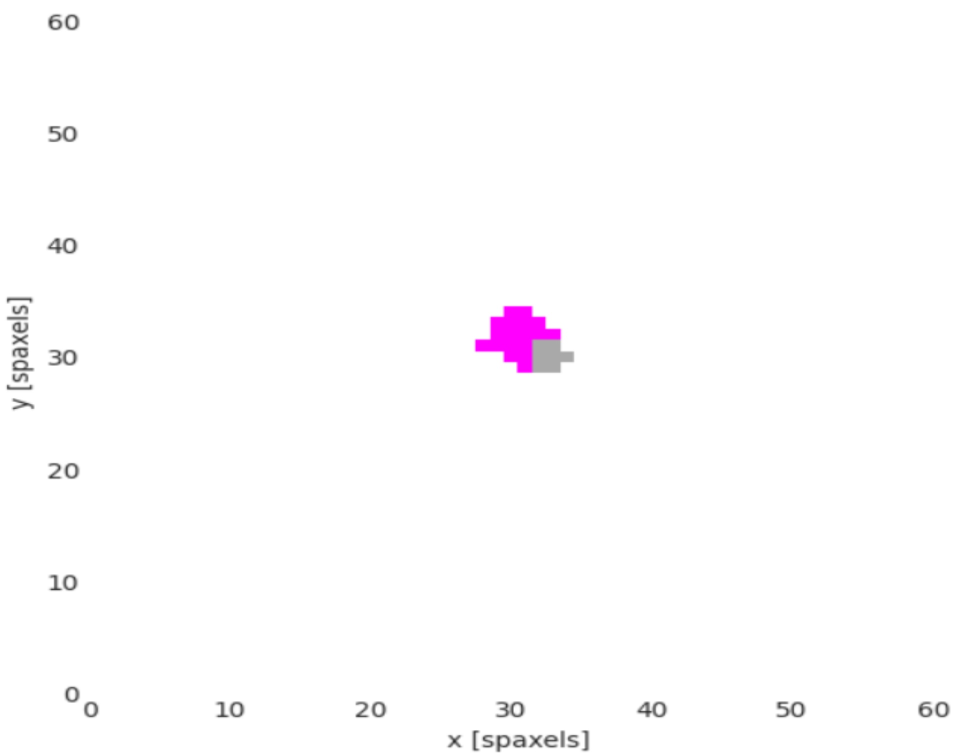


Figure 31: BPT Map,thus we observe that the LINER regions of the galaxies are more than the other parts

Galaxies having Double peaks

In this section we will show some galaxies BPT plots and maps which have double peaks in any of the given emission lines.

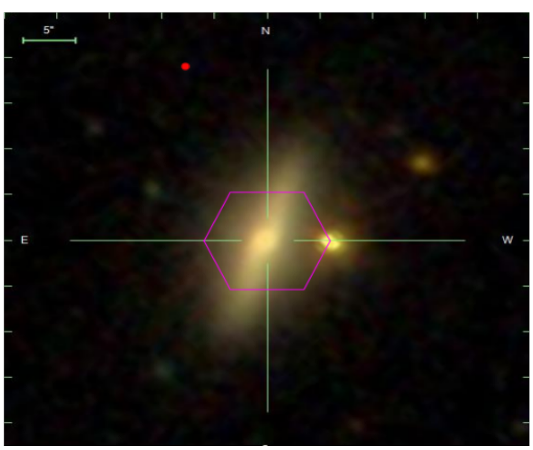


Figure 32: Galaxy image of the object id:1237657630579163311

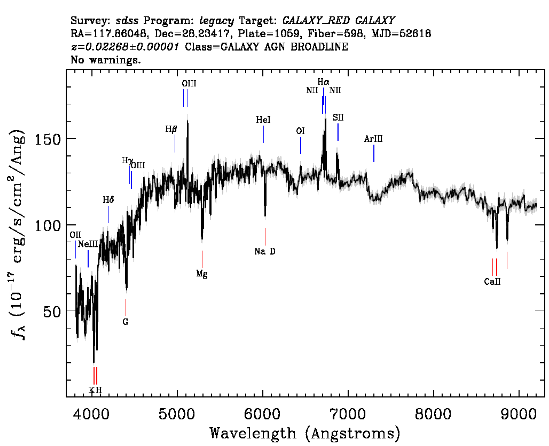


Figure 33: Galaxy spectrum,It has double peaks in the Oxygen emission lines

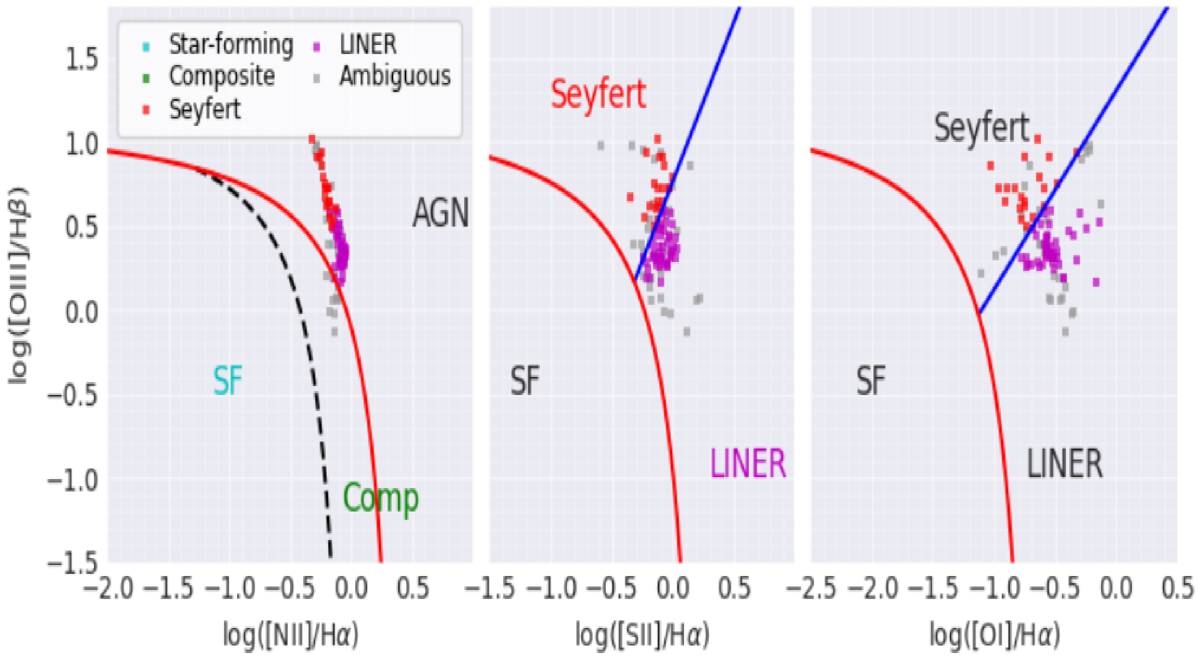


Figure 34: BPT Plots

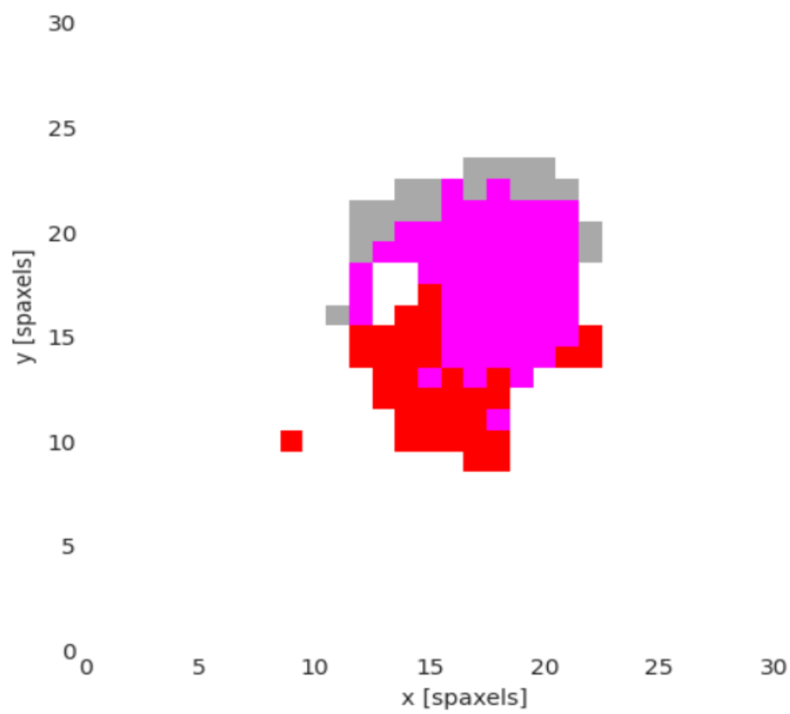


Figure 35: BPT Map,We here see that the seyfert and liner regions are maximum in the galaxies,as from the subclass it is an AGN Broadline

Another galaxy which has double peaks in the emission lines,

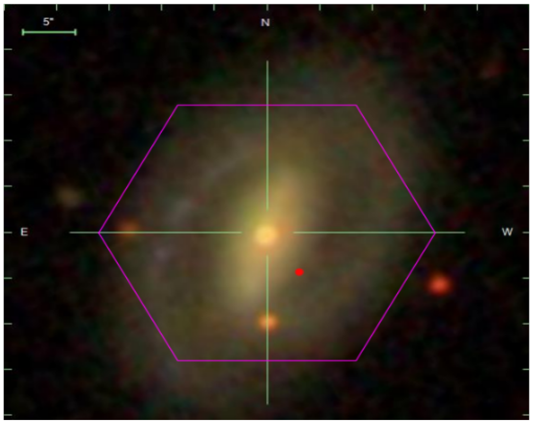


Figure 36: Galaxy image of the object id:1237661357538279499

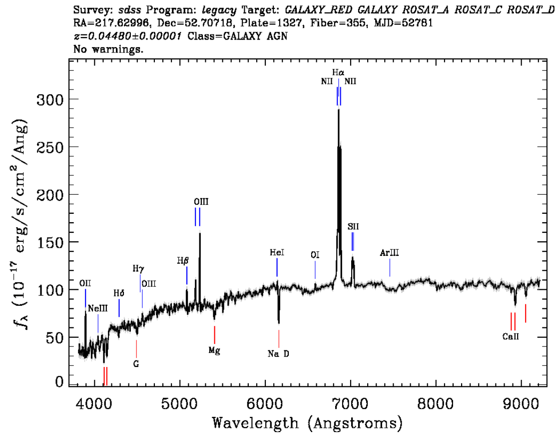


Figure 37: Spectrum image,It has double peaks in both Hα and Hβ emission lines

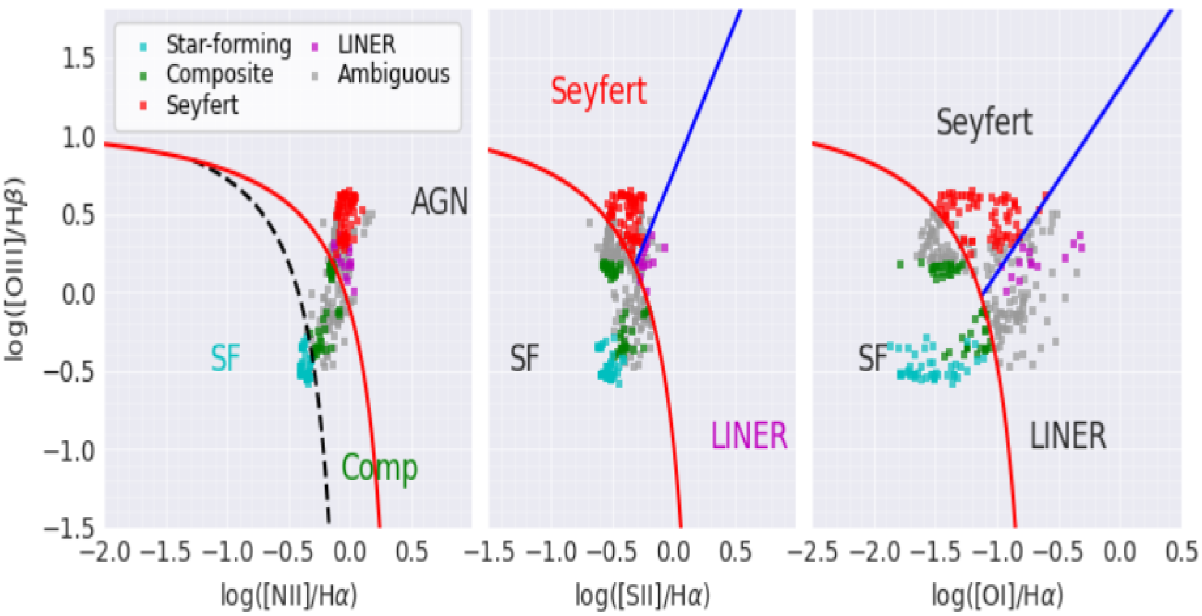


Figure 38: BPT Plots

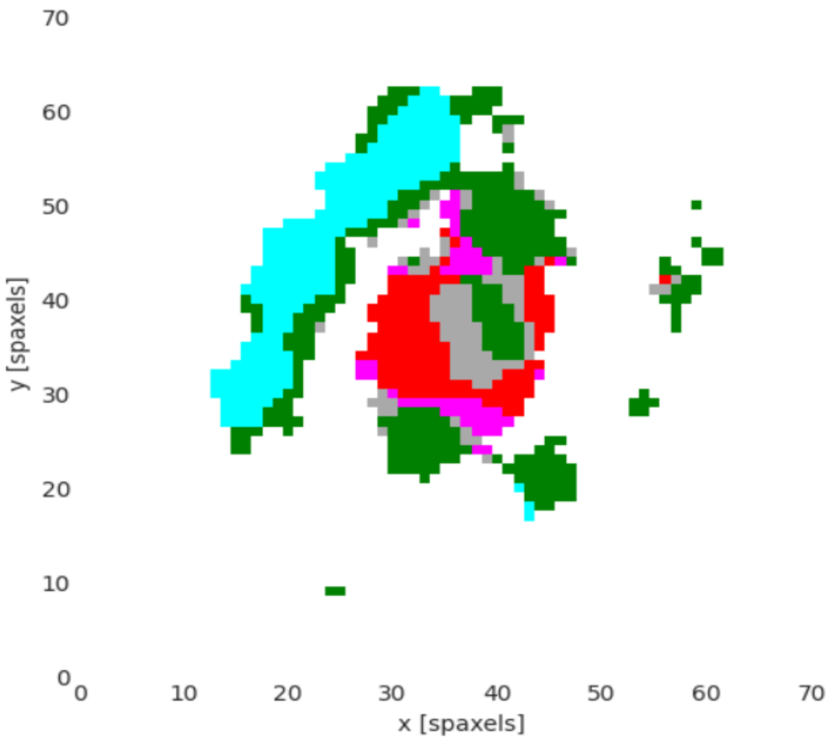


Figure 39: BPT Map,We here see that the seyfert and liner regions are maximum in the galaxies and some were star-forming and composite regions,as from the subclass it is an AGN

We now say that we could able to distinguish some galaxies accordingly and say that it is a dual AGN or not from the sample dataset.

0.3.4 DAGN Cases

In this section we will take into account some galaxies which might be an Dual AGN.

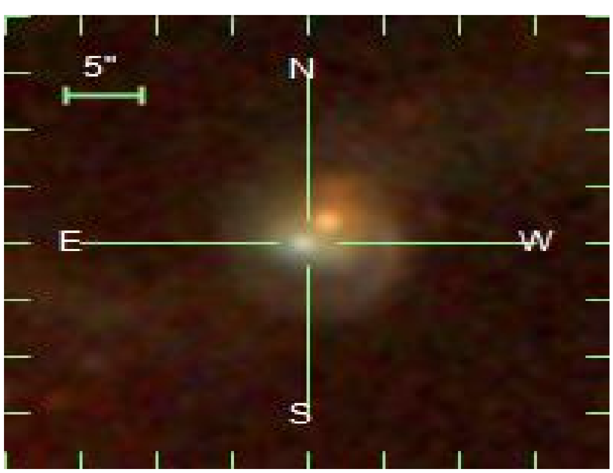


Figure 40: Galaxy image of object id:1237657627895791715

[22]

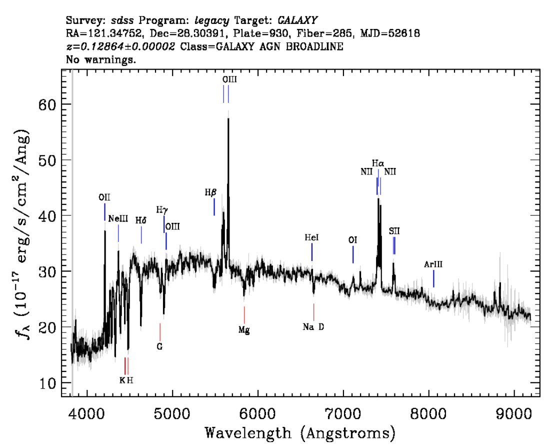


Figure 41: Spectrum image

In this galaxy we can say that it is an Dual AGN as we can observe it through the image and both the nucleus have different spectrum,thus the galaxy having two different spectrum of two nucleus have subclasses of AGN and AGN Broadline which confirms it as a Dual AGN.

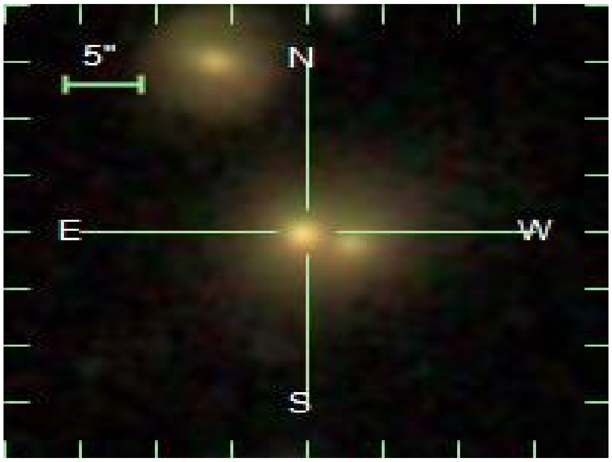


Figure 42: Galaxy image of the object id:1237655108374757514

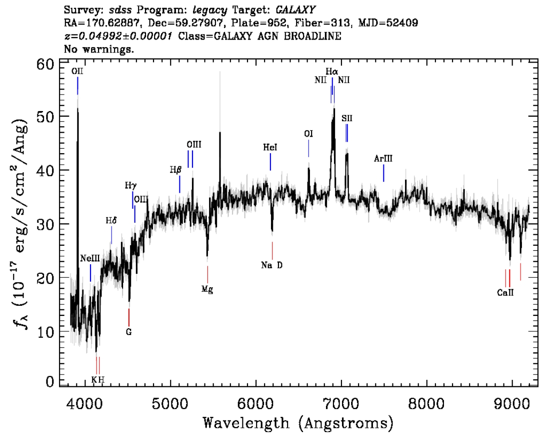


Figure 43: Spectrum image

This galaxy might be an dual AGN because it has double peaks in all emission lines and its subclass is AGN Broadlines. We have more cases like this which are possible outcomes of dual AGNs in the datasets of all the galaxies we get after the data reduction.

[23]

0.4 Conclusion and Future Prospects

Finally we got two of the galaxies confirmed as Dual AGN and there might be other Dual AGN also.In the dataset we are expecting the large number of double peaks galaxies we got so many but most of them have noisy spectrum,and we cann't distingusih between the emission lines clearly.

Very few galaxies are their which have both double nucleus as well as the dual peaks in the their spectrum which might be due to the some errors in the GOTHIC algorithms.The dual peaks we got mostly from the single nucleus galaxies which are mainly due to the outflows.

We have reduced the data by using the Sn ratio criteria but overall after the statistics we got we conclude that the Sn ratio criterio is not always be a good way to choose the galaxies for reduction.Sometimes there are some galaxies which have lower Sn ratio have good spectrums and higher Sn ratio as noisy spectrums,mathematically we can say the higher signal-to-noise ratio spectrums are very clear but after observation it is not the case.This happens due to the timings of observations or types of algirithms used to collect data's.

Out of 3400 galaxies approx we got about only 6.4 % of the galaxies have double nucleus in them observed from the image only.And the remainings have single nucleus.
In the dual peak case only 12.4% of the galaxies have dual peaks in any of the emission lines given above to consider.These stats are very less than the expected from the GOTHIC survey.
The GOTHIC survey took only known dual nucleus galaxies as their test data to check their efficiency of the algoritm but according to me if they take the mixture of sample with both single and double nucleus the efficiency value might be different and they could improve their algorithm accordingly.

Future Prospects After this sorted sample we got in this project,we can use this sample and collect radio spectrums of this galaxies to confirm which one is dual AGN or not because radio spectrums are more appropriate than the optical spectras to classify the galaxy subclasses. We have got some dual AGN cases as well so we can use their data to know more about their properties as well as their formations.

objid	Ab Mag(r)	Ab Mag (g-r)	Distance (MPC)	S/N	specobjid	class	Subclass	redshift	plate	mjd	fiberid	H (α)	H (β)	O (III) 4959	O (III) 5007	Manga?
1237655500274860158	-18.69732299	0.53757	48.43581346	30.89841	1025816351870052352	GALAXY	None	0.01195579	911	52426	442			✓	✓	
1237652899151413295	-21.06848604	1.03086	52.08602413	54.55061	751031624124098560	GALAXY	AGN BROADLINE	0.0128568	667	52163	205	✓	✓	✓	✓	
1237649961918005350	-20.49492377	0.80151	58.28069915	55.20855	517996727678987392	GALAXY	BROADLINE	0.01438588	460	51924	301				✓	
1237649964066406405	-22.07074777	0.90355	76.59414167	49.88491	518071769345583104	GALAXY	BROADLINE	0.01890633	460	51924	574				✓	
1237651495221657798	-19.86197557	0.95819	89.41268041	28.54161	493182948590249984	GALAXY	STARFORMING	0.02207043	438	51884	141			✓	✓	
1237655123930316917	-19.67610879	0.59157	89.84207168	25.41062	942434066567817216	GALAXY	STARFORMING	0.02217642	837	52642	203			✓	✓	
1237654605855850621	-20.10106407	1.04349	93.14055342	31.03108	640798713186379776	GALAXY	STARFORMING	0.02299061	569	52264	588			✓	✓	
1237652900755669126	-20.61694051	0.57026	96.10148557	30.69644	742120357862860800	GALAXY	STARFORMING	0.02372148	659	52199	554				✓	
1237655494909100195	-20.59129875	0.82586	99.19590618	42.17779	1030334520311703552	GALAXY	None	0.0244853	915	52443	495		✓		✓	
1237655504034201665	-20.01441937	0.60338	99.84811583	31.61871	923408938571950080	GALAXY	STARFORMING	0.02464629	820	52438	622				✓	
1237655108366762119	-20.61406095	0.78583	100.8691102	40.32088	863628763127113728	GALAXY	BROADLINE	0.02489831	767	52252	231	✓		✓	✓	
1237655744561676405	-20.43955248	0.93259	103.9605328	32.36042	3322645601098688512	GALAXY	STARFORMING	0.02568139	2951	54592	418			✓	✓	
1237648705127448802	-19.25532737	0.87215	104.0886737	25.04239	341287061967366144	GALAXY	None	0.02569302	303	51615	507			✓	✓	
1237653587944865864	-20.79095948	0.90021	106.5074279	39.04057	613749351713368064	GALAXY	BROADLINE	0.02629006	545	52202	487				✓	
1237656529456398718	-20.46930019	0.82752	112.4190831	34.56875	412128877767321600	GALAXY	None	0.02774928	366	52017	180				✓	
1237655373573062961	-19.74415904	0.78179	114.3799253	33.39256	918785216309389312	GALAXY	None	0.02823329	816	52379	185			✓	✓	
1237654879665455207	-20.13968185	0.81543	114.8582961	33.62569	659807615919876096	GALAXY	None	0.02835137	586	52023	110				✓	
1237655464320565483	-19.88984595	0.82142	115.1821525	26.74354	915409715192686592	GALAXY	STARFORMING	0.02843131	813	52354	193			✓	✓	
1237655743479480565	-20.45810737	0.62394	118.2250413	28.11306	2058192367495702528	GALAXY	STARFORMING	0.02918241	1828	53504	172				✓	
1237654604247662711	-21.1824607	0.82658	118.6058582	32.97917	644027704378681344	GALAXY	STARFORMING	0.02927641	572	52289	47				✓	
1237652600638210280	-20.36487066	0.88908	121.9804223	40.37226	719598510548118656	GALAXY	None	0.03010938	639	52146	540		✓	✓	✓	
1237653471443484716	-21.9909143	0.757	122.6684449	39.41287	514623975372908544	GALAXY	STARFORMING	0.03027921	457	51901	319	✓	✓	✓	✓	
1237654398619222037	-20.48168955	0.88462	124.7142012	32.83892	674445968908773376	GALAXY	STARFORMING	0.03078418	599	52317	116			✓	✓	
1237654605857358040	-20.38238129	0.83491	125.4244652	42.97638	643021651188934656	GALAXY	None	0.0309595	571	52286	483			✓	✓	
1237651273498558617	-20.88302581	0.90724	131.8157065	37.21352	502258867573385216	GALAXY	None	0.0325371	446	51899	391	✓		✓	✓	
1237655464304378007	-20.82497708	0.75927	132.6897623	25.18778	874852578964301824	GALAXY	STARFORMING	0.03275285	777	52320	103			✓	✓	
1237655502421360894	-19.9956598	0.65755	135.8964023	25.78307	709424452965787648	GALAXY	STARFORMING	0.03354437	630	52050	391				✓	
1237655370901422186	-20.51926068	0.77038	141.6563789	25.99038	881728649890392064	GALAXY	STARFORMING	0.03496615	783	52325	542				✓	
1237654954281337154	-20.99151281	0.842	143.7144915	25.03067	712702372492634112	GALAXY	None	0.03547417	633	52079	28			✓	✓	
1237654627863888202	-20.82343791	0.98347	143.8956226	25.58036	853553683220672512	GALAXY	None	0.03551888	758	52253	442		✓	✓	✓	✓
1237652901297061972	-21.78550824	0.99013	145.2953271	28.0484	748840297533827072	GALAXY	None	0.03586438	665	52168	425				✓	
1237648722841108622	-20.85275799	0.77033	146.6694278	31.57478	320980736754608128	GALAXY	STARFORMING	0.03620356	285	51930	361		✓		✓	
1237649920041484373	-20.25037987	0.82206	147.6426985	25.1987	476275482355066880	GALAXY	None	0.0364438	423	51821	72				✓	
1237652900774019233	-20.8297436	0.76977	151.4665455	27.54159	522454422425462784	GALAXY	None	0.03738767	464	51908	134				✓	
1237654880206782779	-21.47358117	0.79232	152.6990147	34.2295	666613592929383968	GALAXY	STARFORMING	0.03769189	592	52025	294				✓	
1237655692479037882	-20.81974368	0.85519	153.4661986	29.00013	1038219667665086464	GALAXY	None	0.03788126	922	52426	509				✓	
1237654653102391485	-20.70901187	0.79878	154.2000003	30.15858	858066608344557568	GALAXY	None	0.03806239	762	52232	476				✓	
1237648721224204454	-21.10370309	0.81905	154.5562666	32.09689	311993803217975296	GALAXY	BROADLINE	0.03815033	277	51908	434		✓	✓	✓	
1237651737390350675	-21.07988518	0.77678	155.2884073	25.70729	3324948252788287488	GALAXY	STARFORMING	0.03833105	2953	54560	603				✓	

Figure 44: Datasheet of sorted Dual peak galaxies

Link to whole sheet

objid	Ab Mag(r)	Ab Mag (g-r)	Distance (MPC)	S/N	specobjid	class	Subclass	redshift	plate	mjd	fiberid	H (α)	H (β)	O (III) 4959	O (III) 5007	N (6548)	N (6583)	Manga data?
1237655107301277785	-20.39059035	0.51475	40.47101252	58.12261	1924646573533	GALAXY	STARBURST	0.009989776	952	52409	247							
1237651539239895057	-18.44529037	0.22987	55.80255366	31.28889	81455994859294	GALAXY	STARBURST	0.01377418	485	51909	306							
1237654653642866786	-19.2349909	0.80369	67.66844255	35.80709	25262277584752	GALAXY	STARFORMING	0.01670313	766	52247	316							
1237648705134526835	-20.34152648	0.77124	116.1666046	28.97153	25152756832931	GALAXY	STARFORMING	0.02867431	313	51673	395							
1237655373573128355	-22.03705051	1.23284	116.8062554	34.91705	99638928079196	GALAXY	AGN	0.0288322	817	52381	377		✓	✓				
1237652942094729415	-19.35432024	0.94252	117.5265665	27.56779	43163330374144	GALAXY	STARFORMING	0.02901	741	52261	89							
1237652600638210280	-20.36487066	0.88908	121.9804223	40.37226	95985105461186	GALAXY	None	0.03010938	639	52146	540		✓	✓	✓			
1237651067886764056	-21.54699065	1.04378	132.5489005	35.45015	11367146762670	GALAXY	AGN	0.03271808	596	52370	365		✓	✓				
1237651274044538943	-19.046999	-0.01202	134.2096672	26.92775	18012127568465	GALAXY	STARBURST	0.03312802	490	51929	401							
1237654949988663521	-20.86184971	0.70361	134.8018779	35.2131	15874089776844	GALAXY	STARFORMING	0.0332742	623	52051	552			✓				
1237655742947066065	-19.48805805	0.8105	150.9015186	25.41506	4981044913793	GALAXY	STARFORMING	0.0372482	1834	54562	293							
1237654381977731176	-22.05106772	0.84817	155.0963379	41.09736	26861788181565	GALAXY	BROADLINE	0.03828364	553	51999	231							
1237651754563207315	-21.32539316	0.75192	159.5785929	31.87439	24491175531253	GALAXY	None	0.03939003	535	51999	337							
1237655124465484020	-21.99357722	0.90289	159.8517682	50.01706	01797875513692	GALAXY	None	0.03945746	835	52326	194							
1237651538723930199	-21.36381615	0.60658	160.6531446	31.61163	46811019180380	GALAXY	STARFORMING	0.03965527	617	52072	3							
1237656241167335496	-21.31694153	0.87219	162.0780884	39.13008	76937577122631	GALAXY	None	0.040007	744	52251	88							
1237651754001301546	-20.98692895	0.94333	162.8807613	38.83294	97991201521930	GALAXY	AGN	0.04020513	506	52022	341							✓
1237655744023691333	-22.1754382	0.80743	168.4246446	33.33155	7313384038098	GALAXY	STARFORMING	0.04157357	1836	54567	586			✓				
1237655108905664681	-19.52861922	0.77747	173.7928254	25.38484	59515196592885	GALAXY	None	0.04289864	769	54530	489							
1237651753997828236	-21.48249301	0.90861	183.3549344	49.05351	52982682133729	GALAXY	None	0.04525893	502	51957	351							✓
1237655108374757515	-19.96702917	0.82755	202.2217362	25.82588	1942788515391	GALAXY	AGN BROADLINE	0.04991597	952	52409	313	✓	✓	✓	✓			
1237651735771676782	-21.75685666	0.94177	214.9766704	35.62527	01574603590471	GALAXY	None	0.05306437	533	51994	192							
1237655745099071701	-19.90218905	0.79251	215.6779811	25.83943	8374394756950	GALAXY	None	0.05323748	1837	53494	350							
1237655745099071699	-21.75334922	0.93972	217.598473	41.65622	2700301802170	GALAXY	None	0.05371153	2951	54592	617							
1237651503806218249	-21.63798519	0.40769	219.7379346	27.5598	55907728060190	GALAXY	STARFORMING	0.05423963	298	51955	264							
1237648721246683363	-20.62569203	0.94661	221.5401301	29.27317	34456781370429	GALAXY	STARFORMING	0.05468448	305	51613	168		✓	✓	✓			
1237655691403001977	-21.16187013	1.0134	231.32684	30.25345	5861214971848	GALAXY	STARFORMING	0.05710021	920	52411	121		✓					
1237654952664760500	-21.22037362	0.81697	233.0036495	31.15913	7130316762015	GALAXY	STARFORMING	0.05751411	2884	54526	127	✓	✓		✓			
1237651250439782619	-19.77537408	0.87795	236.8322364	27.36549	04125808537374	GALAXY	None	0.05845915	622	52054	374							
1237648720685564031	-21.66388454	0.84815	245.6308481	42.00047	85037533953003	GALAXY	None	0.06063098	274	51913	26							
1237648720685564032	-21.54801935	0.99316	245.8033905	30.79954	96926002925015	GALAXY	BROADLINE	0.06067357	275	51910	255							
1237654382514536706	-21.97581083	0.90206	246.5756385	48.54988	16617087415357	GALAXY	AGN	0.06086419	552	51992	600	✓	✓	✓	✓			
1237655472361701927	-20.53111275	0.85356	248.9915164	26.66723	5576516361742	GALAXY	None	0.06146052	973	52426	276							
1237654399154520091	-21.33176367	0.9068	249.4748297	32.29161	21732740456386	GALAXY	None	0.06157982	597	52059	40							
1237651735747821794	-20.8212941	0.92026	258.3014354	27.26293	86242969271930	GALAXY	None	0.06375856	505	52317	163							
1237653613720567988	-22.23458164	0.97454	265.8718316	36.33493	27023966146662	GALAXY	None	0.06562722	553	51999	290							
1237653442449965173	-22.02958013	0.72365	295.6024473	25.22345	86290812512768	GALAXY	STARFORMING	0.07296586	647	52553	625							
1237665368508399679	-19.66927768	0.75269	137.5965471	27.10534	8314577756514	GALAXY	None	0.03396403	1979	53431	577							
1237665367972773964	-17.65938625	0.87554	36.66394986	34.22197	0870568003790	GALAXY	STARFORMING	0.009050049	2008	53473	231							
1237665369046777886	-16.7594888	0.25534	24.38022789	27.86625	0936538701457	GALAXY	STARBURST	0.006017962	2008	53473	471							
1237665429169569866	-20.4850814	0.93921	298.4174942	27.76427	0390294345443	GALAXY	None	0.07366072	2123	53793	381							

Figure 45: Datasheet of sorted Dual nucleus galaxies

Link to the whole sheet

objid	Ab Mag(r)	Ab Mag (g-r)	Distance (MPC)	S/N	specobjid	class	Subclass	redshift	plate	mjd	fiberid	H (α)	H (β)	O (III) 4959	O (III) 5007
1237655472357179447	-20.82117304	0.73572	136.5100441	30.32387	918809130687293440	GALAXY	Starforming	0.03369584	816	52379	272				
1237655130908655685	-21.10579486	0.82922	137.6115772	42.26059	698199269332510720	GALAXY	None	0.03396774	620	52375	514				
1237654600488714489	-21.04728519	0.73137	139.9236217	36.56835	642946059764525056	GALAXY	Starforming	0.03453844	571	52286	208				
1237654627863888202	-20.82343791	0.98347	143.8956226	25.58036	853553663220672512	GALAXY	None	0.03551888	758	52253	442		✓	✓	✓
1237656495107932306	-20.84238621	0.86525	143.9830079	28.02858	836809639431825408	GALAXY	Starforming	0.03554045	743	52262	240				
1237645943979311221	-20.54344874	0.98975	144.9858932	26.6209	1398480158033209344	GALAXY	None	0.035788	1242	52901	409		✓	✓	
1237649554404630592	-21.52953194	0.79794	148.5581174	33.17272	477558414609385472	GALAXY	Starforming	0.03666976	424	51893	638				
1237655130381090923	-20.83067275	0.29462	148.6231804	34.68856	1096778007709771776	GALAXY	StarBurst	0.03668582	974	52427	551				
1237649921115095146	-21.38802372	0.89561	152.5740743	37.94864	476412096674818048	GALAXY	None	0.03766105	423	51821	569				
1237655468062474420	-21.02221895	0.85296	157.0817712	46.54251	351406968230930432	GALAXY	Starforming	0.03877372	312	51689	459				
1237654604256247819	-20.91083828	0.46778	161.2566584	35.69786	941330152430790656	GALAXY	StarBurst	0.03980424	836	52376	283				
1237651754001301546	-20.98692895	0.94333	162.8807613	38.83294	569799120152193024	GALAXY	AGN	0.04020513	506	52022	341				
1237654652025176409	-21.7359323	0.91347	163.7383689	40.9374	853589397348575232	GALAXY	Broadline	0.04041682	758	52253	572				
1237652944245424346	-21.43963251	0.99011	166.9861696	34.12585	838963418881878016	GALAXY	None	0.0412185	745	52258	611				
1237652944784523441	-22.17613412	0.90487	168.7115536	29.77637	842329848188790784	GALAXY	Broadline	0.04164439	748	52233	570				
1237651753997828236	-21.48249301	0.90861	183.3549344	49.05351	565298268213372928	GALAXY	None	0.04525893	502	51957	351				
1237648721217716302	-21.7348213	0.95016	183.3733675	41.54018	301759894128715776	GALAXY	Broadline	0.04526348	268	51633	68				
1237648722828918975	-21.74435083	0.87327	184.1484919	42.42561	564092108621768704	GALAXY	None	0.04545481	501	52235	59				
1237654653635327883	-21.2769657	0.77057	184.5207201	27.55701	858039120553863168	GALAXY	Starforming	0.04554669	762	52232	378				
1237651753997828235	-21.99908397	0.86535	186.4536088	52.36866	564229822453147648	GALAXY	None	0.0460238	501	52235	560				
1237655374110589134	-21.36409338	0.7191	196.9820607	26.50919	919905343813740544	GALAXY	None	0.04862262	817	52381	164				
1237655130371063939	-20.48552969	0.7784	201.3074921	32.63439	695917777235503104	GALAXY	Starforming	0.0496903	618	52049	406			✓	
1237652936183709909	-21.10186248	0.78287	214.1738761	32.77234	1325274947441944576	GALAXY	None	0.05286621	1177	52824	330		✓	✓	
1237655502426075358	-22.54188221	0.81787	221.5707575	33.1342	1101239276374353920	GALAXY	Starforming	0.05469204	978	52441	397		✓	✓	✓
1237654952664629404	-21.90747835	0.85362	229.6284372	40.25142	3247131416273643520	GALAXY	None	0.05668098	2884	54526	131				
1237649919510184068	-21.0255824	0.99271	244.4254817	32.65427	481937968278300672	GALAXY	None	0.06033345	428	51883	192				
1237655129841860941	-22.0861412	0.78826	252.620296	28.6109	711659780457377792	GALAXY	None	0.06235624	632	52071	331				
1237655130370539648	-21.72211806	0.86538	269.2734985	25.20093	693719310329210880	GALAXY	Starforming	0.06646688	616	52442	600				
1237655106772008998	-21.64214199	0.72726	286.0305344	28.50696	1080886491242063872	GALAXY	StarBurst	0.07060315	960	52425	82				
1237653651846332538	-21.64333446	0.74004	288.8077832	27.63309	483144956110727168	GALAXY	AGN	0.07128868	429	51820	487				
1237654626789294436	-22.45884184	1.00114	291.6583189	42.80772	852452776951703552	GALAXY	Broadline	0.0719923	757	52238	533				
1237655374647197896	-21.96342551	0.75628	291.7420987	32.77312	919992754988148736	GALAXY	Starforming	0.07201298	817	52381	482				
1237651496834302236	-22.34646205	0.93527	295.3468949	29.32058	497743722788710400	GALAXY	None	0.07290278	442	51882	349				
1237656895066931656	-21.72050907	0.96736	56.76018653	56.6978	1105760468807199232	GALAXY	AGN broadline	0.01401056	982	52466	461				
1237656567575479198	-20.84391794	1.0008	220.4142086	25.2701	1106797582564222976	GALAXY	None	0.05440656	983	52443	138				✓
1237657190366904375	-22.34127328	0.61426	288.3664002	31.88632	433479740385421312	GALAXY	Starforming	0.07117973	385	51783	30				
1237657118404313514	-19.94903905	0.76467	95.12481185	37.46648	1192464934466775040	GALAXY	broadline	0.0234804	1059	52618	498				✓
1237657244045534749	-20.67251096	0.66499	104.4744736	29.30989	939122606953490432	GALAXY	starforming	0.02578825	834	52316	444				✓
1237657594072596746	-18.30131545	0.27426	57.68954173	25.35199	1001098784698034176	GALAXY	STARBURST	0.01423996	889	52663	632				
1237657594072465514	-21.69595903	0.95044	107.7044893	48.60102	1001087239825942528	GALAXY	NONE	0.02658554	889	52663	590				

Figure 46: Datasheet of sorted Manga data galaxies

Link to the whole sheet

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