

# The relation between stars and gas in distant galaxies

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Observing any galaxy in the universe will yield the fact that it contains stars and also gas. The dynamics of both can be explored by observing galaxies and collecting spectroscopic data.

## Contents

## 1. INTRODUCTION

## 1. Introduction

- a. Galactic classification
  - b. Galactic stellar formation
  - c. Galactic data
    - 1. HUDF
    - 2. MUSE
  - d. Project Aims

## 2. Analysis

- a. Cube extraction
  - b. Line fittings and pPXF
    - 1. Gaussian doublet fitting
    - 2. Voigt fitting

### 3 Discussion

- ### a. Implications of results

## 4 Conclusions

### Acknowledgments

## References

1 Amongst the different types of cosmic  
2 structure within our universe, galaxies can  
3 be described as the most unique and diverse.  
4 With each containing countless numbers of  
4 stars and vast amounts of gas, dust, and  
4 dark matter [1], it would certainly be sur-  
4 prising if these various objects were found  
1 to not be connected in any way.

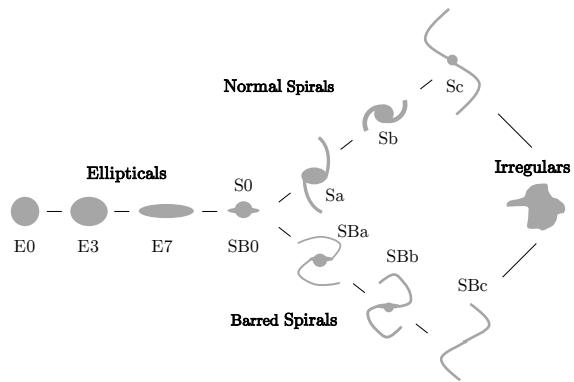
Through observational astronomy the internal structure of galaxies and the motions of their inner objects can be studied and understood. With approximately  $(2.0^{+0.7}_{-0.6}) \times 10^{12}$  galaxies in the universe up to  $z = 8$ , which in principle could be observed [2], there is definitely not a lack of choice. What is important is how these objects are observed and how the collected data is later analysed.

6 It is additionally significant to understand what a galaxy generally is and how they can be defined and placed into different categories. Once an appreciation is built for the galactic classification, the intricacies of motions and inter-relationships can be explored further.

### a. Galactic classification

As stated previously, a galaxy can be quite broadly defined as a collection of gas, dust, stars and dark matter. But if a large enough sample was observed then one would begin to see that they can be grouped and classified together.

The most general categorisation is called the *Hubble Sequence* or the *Hubble Tuning Fork* [1]. Developed by Edwin Hubble in 1926, galaxies can be roughly divided into ellipticals, spirals and irregulars (Fig. 1). With early Hubble type ellipticals along the horizontal handle, then the two prongs contain normal and barred spirals (later Hubble types), and irregulars as the third category. What can be seen from the Tuning Fork is a summarised view of the main galaxy types, however in reality there are more than the 11 named.



**Figure 1:** The Hubble Sequence displays the different morphologies of galaxies, they can be classified into three general groups: ellipticals, spirals, and irregulars. The former two can be broken up further, and from the diagram one can see an example pictogram and the respective classification name.

(This diagram has been adapted from *An Introduction to Modern Astrophysics* [1].)

The sequence itself does not show the evolution of the galaxies, rather it provides a way to view the different potential morphologies. So then, what does each grouping from the sequence actually represent?

Starting with the most broad, irregulars are objects which do not fall into the two main galaxy types (ellipticals and spirals).

In fact they themselves can be split into two sub-categories depending on if a particular galaxy could be seen to have structure, such as spiral arms [1]. If they did then they would be Irr I galaxies, and if they appeared to be extremely disorganised then Irr II. Generally, irregulars are not particularly large, their diameters typically range from 1 to 10 kpc, and they have an absolute B-band magnitude of  $-13$  to  $-20$  mag.

This classification by appearance can easily be extended to ellipticals and spirals, and their individual component composition can be studied and explored as well.

With ellipticals, they span from being virtually spherical (E0) to highly flattened (E7) collections of objects and material [3]. Through observations of their stars, it can be seen that the majority of them are old and red types. This may be attributed to the amount of gas used in the initial stages of galactic stellar formation. If a larger proportion was used up initially then current observations would show the stellar-birthrate in ellipticals to be low [1]. This could additionally explain the lack of disks which can otherwise be seen in spiral galaxies, if there is not enough surrounding material then the disk and arms features would not be able to form.

Exploring spirals, they can be described as being composed of a central nucleus with a surrounding disk of material. This disk contains denser regions which forces material to collapse and coalesce to form additional features. One of the characteristics leads to a supplemental classification, and that is whether the nucleus has a “bar” running through it. Observing and comparing the two different types, one finds that barred spirals appear to be more elongated along the bar axis than their non-barred counterparts.

The other main attribute for spiral galaxies are the protruding arms surrounding the main bulge [1]. In the later type spirals (Sc and SBc) they have arms which are more loosely wound than the earlier types (Sa and SBa) [3]. It can be seen implied that with more available “raw” gas and dust [1], spir-

als in their various forms could be assumed to have an overall younger stellar population.

It is within the arms of spiral galaxies that new stars are found to be created, however stellar birth is definitely not limited to just these regions. Inside the spiral structure the gravitational field allows for angular momentum to be transported outwards. Older and less massive stars in the galaxy produce a gravitational field which eventually leads to the shocking of interstellar gas [4]. As a result the density of the gas in the arms increase and certain regions then collapse to form new, young, blue, and massive stars.

There is therefore a range in the stellar population age of spiral galaxies. The spiral arms contain young stars whilst the central nucleus is akin to that of elliptical galaxies, where they have an older population of stars and fewer new stars are being created [1, 4].

These then are the general characteristics of galaxies, and whilst they can be classified based on their appearance, it is through studying their stellar populations that our understanding of them will improve.

### b. Galactic stellar formation

One could argue that the main backbone in any galaxy lies with the gas and dust, as without them there would be no stars and galaxies would simply not exist. There are many models which aim to provide an explanation for galactic evolution, from an initial proto-nebulae to potential structure. It would be difficult to explain them all, but it would be beneficial to address some issues which would have to be answered by a comprehensive theory.

One such problem is deciding if an initial nebula collapses in free-fall or whether it goes through a slow and dissipative collapse [1]. If the time taken to cool the nebula significantly (cooling timescale) is much less than the time taken for free-fall, then the cloud would not be pressure supported and the collapse would be a rapid free-fall. On

the other hand, if the cooling time exceeds the free-fall time then a rapid collapse cannot occur as the gas cannot radiate its energy away fast enough, so the gravitational potential energy released from collapse will heat the nebula adiabatically.

This is important to understand as from the heated and collapsed gas, the first stars can then be produced. It is not surprising then that a theory for galactic evolution should also be able to explain the rate of star formation. This rate can be described as a stellar birthrate function,  $B(M, t)$ , and be expressed as,

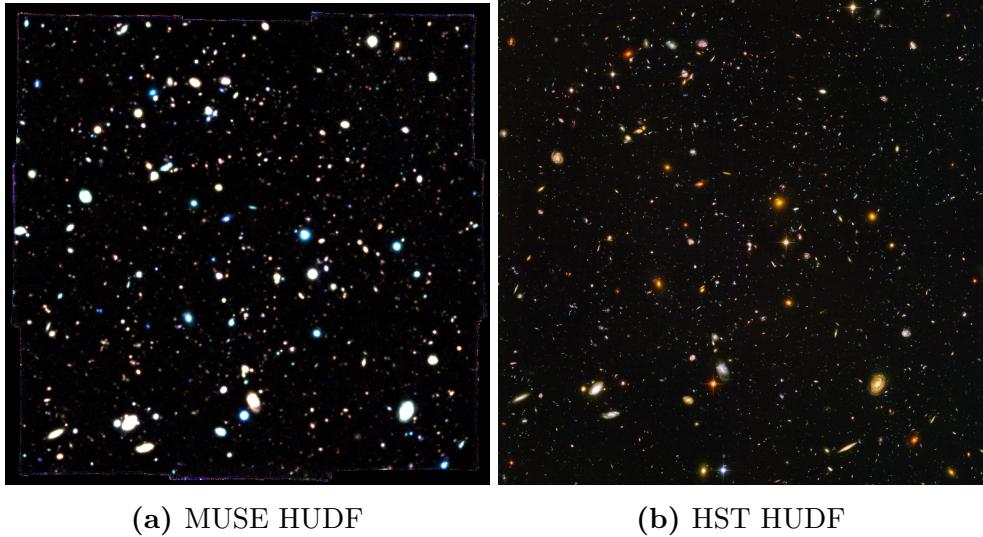
$$B(M, t)dMdt = \psi(t)\xi(M)dMdt, \quad (1)$$

where  $\psi(t)$  is the star formation rate (SFR),  $\xi(M)$  is the initial mass function (IMF),  $M$  is the stellar mass, and  $t$  is the time [1].

Describing what each term physically represents,  $B(M, t)$  is the number of stars per unit volume with masses between  $M$  and  $M + dM$  which are formed out of the interstellar medium (ISM) between time  $t$  and  $t + dt$ ,  $\psi(t)$  is the rate per unit volume at which mass in the ISM is converted into stars, and  $\xi(M)$  is the relative number of stars which form in each mass interval [1].

Various problems arise when several researchers provide different assumptions for the different terms in the equation [1]. Some say that the SFR is time-independent, whilst others describe it as exponentially decreasing with time, and a few even argue that the SFR is proportional to a power of the surface mass density of the galactic disk. Then take the IMF, there is disagreement on the exact form it takes, some model it to be a power-law as a function of mass, but it is not clear if it also varies with time or location.

Through contentious debate and research, astronomers can continue to build these different models and theories which attempt to explain galactic evolution. Whilst on the other hand, the evolution of the stars themselves are known and understood to a greater degree.



**Figure 2:** (a) A colour image created from the MUSE spectroscopic data of the HUDF. The wavelength range was split into three equal regions and then collapsed to create three bands (R, G, B). A final colour image was produced by combining these separate frames together. (b) The optical HUDF as captured by the Advanced Camera for Surveys instrument on the Hubble Space Telescope [6].

In a brief overview: stars are born from an interstellar medium where the gas and dust coalesce, collapse and heat-up until a protostar is created. Depending on the initial mass of material used, the star can then take various paths which will affect its subsequent future [5]. To view the different stages of stellar evolution, Hayashi tracks and the Hertzsprung-Russell diagram can be paired together [1]. In doing so, one would find that the majority of stars lie on the main-sequence, including our own Sun.

The classification of stars can be performed by using the *Harvard Spectral Classification*

However, to prove or disprove any amount of them, observational data of stars and galaxies will definitely be required.

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#### d. Project Aims

This paper discusses the study undertaken to understand the dynamics between the gas and stars in galaxies, data extraction is performed on the MUSE data cube, the sample is reduced, doublet fitting performed, applied the data set to a processing

### c. Galactic data

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#### 1. HUDF

To obtain spectroscopic information on the Hubble UDF objects, the Multi-Unit Spectroscopic Explorer or MUSE was employed. This instrument is

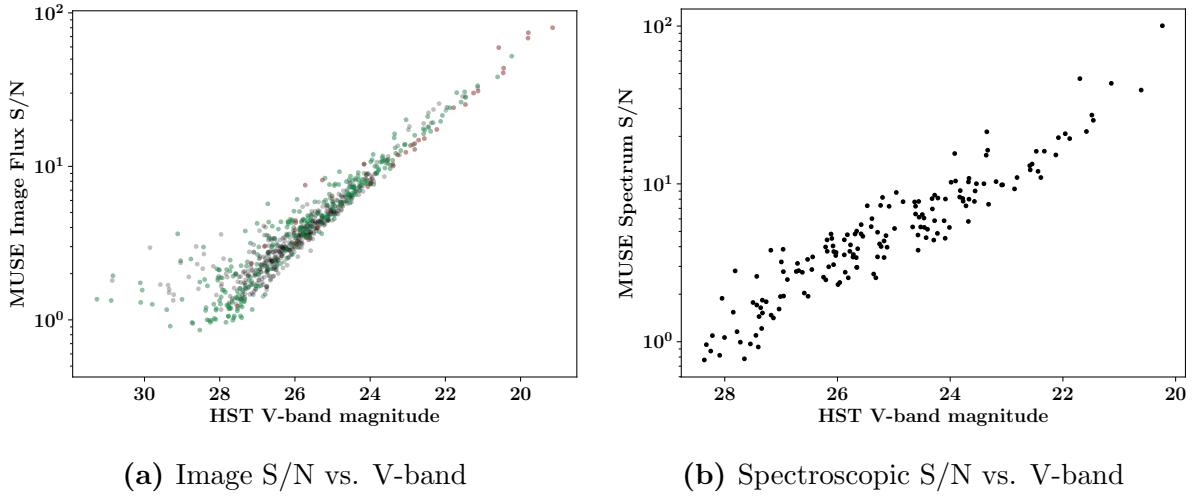
#### 2. MUSE

package pPXF.

In section 2, the experimental methods behind the data extraction and analysis are discussed.

## 2. ANALYSIS

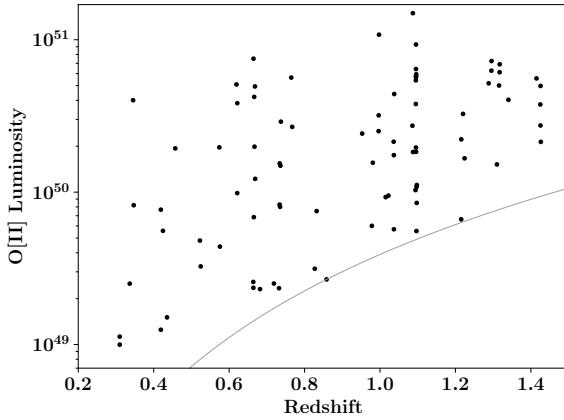
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**Figure 3:** (a) The signal-to-noise of the image flux for every object in the MUSE collapsed image plotted against their respective V-band magnitudes from the HST catalogue. The red points represent those with redshifts  $z < 0.3$ , and the green points are a chosen sample of 300 points as defined by the sextractor probability that they are not stars. (b)

### a. Cube extraction

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**Figure 4:** Graph showing the calculated luminosity for the O[II] doublet plotted against redshift. Data points are plotted as well as a model line representing the lower-limit of the flux from the sample. [???]a

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### b. Line fittings and pPXF

After extracting the individual galactic objects from the main MUSE cube, the data

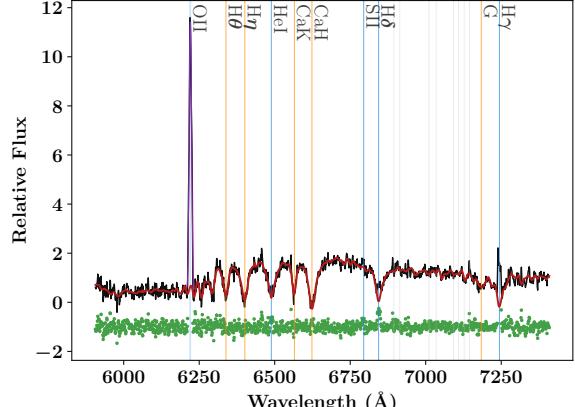
had to be verified and then fitted using two different routines: (i) O[II] doublet fitting, and (ii) pPXF absorption line fitting.

#### 1. Gaussian doublet fitting

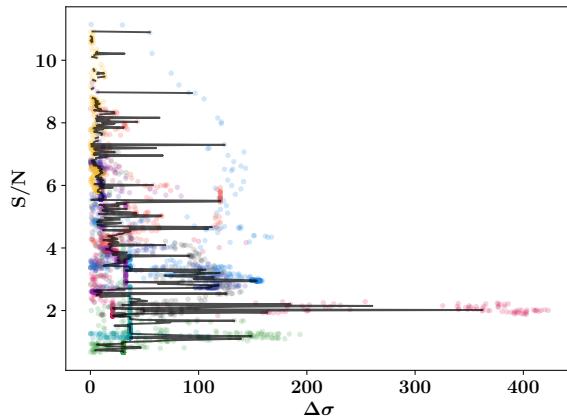
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#### 2. Voigt fitting

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**Figure 5:** Fitting of a galaxy spectrum with pPXF.



**Figure 6:** The signal-to-noise versus the fractional error of the  $\sigma$  line width of the pPXF curve fittings.

### 3. DISCUSSION

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#### a. Implications of results

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### 4. CONCLUSIONS

In conclusion, through extensive data and statistical analysis it can be said that the dynamics of stars and gas in galaxies are ... (?)

### Acknowledgments

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