

# 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.

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## 1. INTRODUCTION

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

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

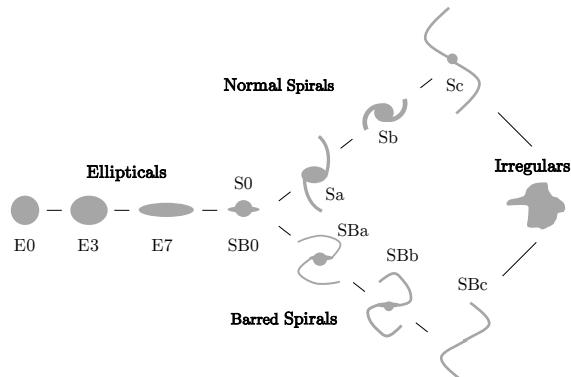
5 It is additionally significant to under-  
stand what a galaxy generally is and how  
5 they can be defined and placed into differ-  
ent categories. Once an appreciation is built  
for the galactic classification, the intricacies  
of motions and inter-relationships can be ex-  
plored further.

### 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], spirals 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 age for the stellar population 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

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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 package pPXF.

In section 2, the experimental methods  
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comprehensive theory.

One such problem is deciding between 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.

We introduced the concept that through optical measurements of the stars

### 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

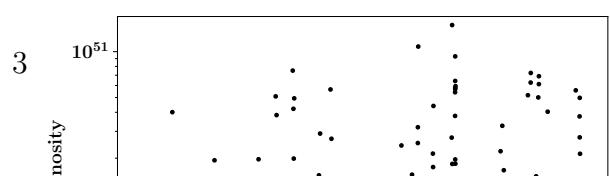
behind the data extraction and analysis are discussed.

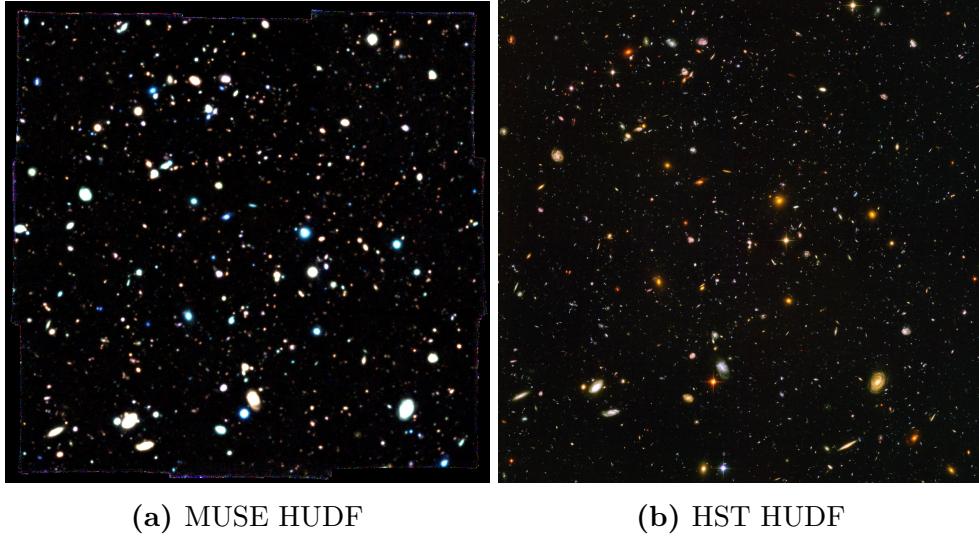
## 2. ANALYSIS

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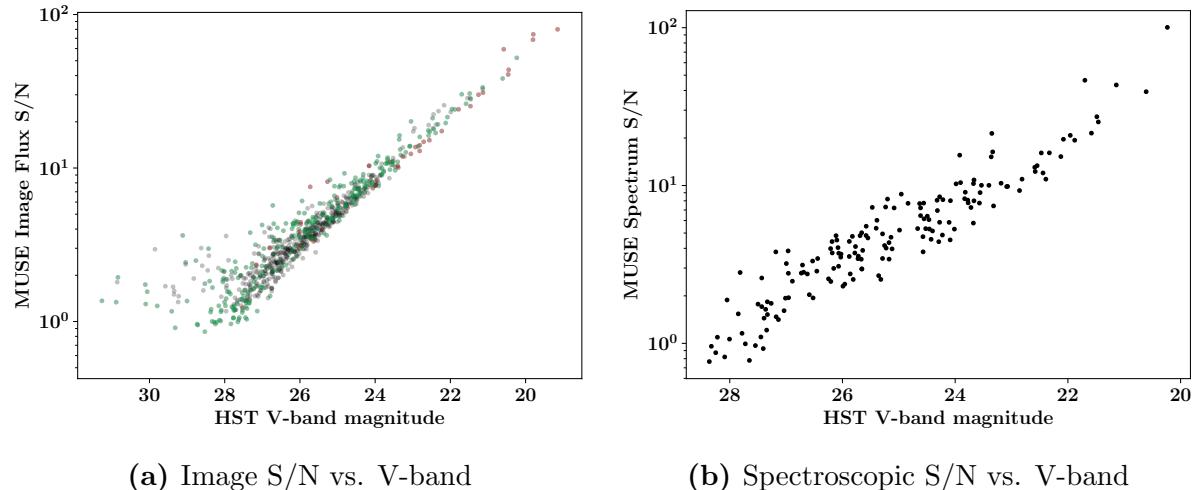
### a. Cube extraction

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**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 [5].



**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)

**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

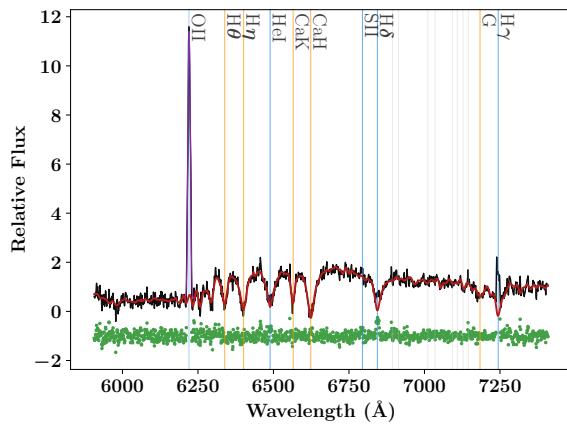
After extracting the individual galactic objects from the main MUSE cube, the data had to be verified and then fitted using two different routines: (i) O[II] doublet fitting, and (ii) pPXF absorption line fitting.

### 1. Gaussian doublet fitting

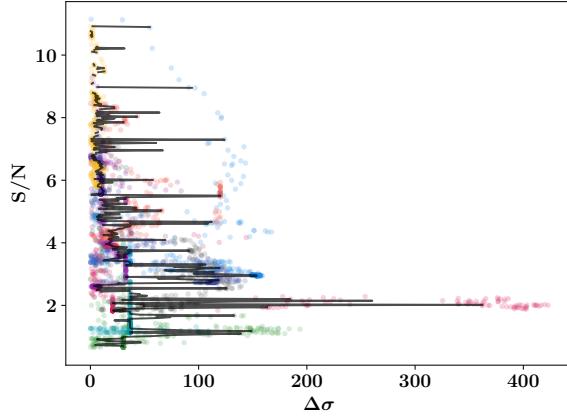
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### 2. Voigt fitting

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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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