Spectral Analysis of NGC 1365 Using the MUSE-VLT

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November 2022

Abstract

We looked at the spectra of three different regions around the AGN of NGC 1365. These regions were at the center of the AGN, to the east of the AGN, and to the west of it. We chose these regions in order to calculate the change in redshift. We found that the region to the east had a redshift of 0.0004461 greater than the base redshift of NGC 1365, which was $z = 0.005476$. We then found that the region to the east had a redshift change of -0.0000729. From these calculations we have found that the galaxy is spinning clockwise relative to us. We then looked closer at the isolated $[OIII]$ and $H\alpha$ lines. We found that there was an interesting amount of visible $[OIII]$ being jetted out by the AGN, and also, surprisingly enough, that it was most visible directly around the AGN, which seems to be uncharacteristic for a forbidden line such as $[OIII]$.

1 Introduction

We will investigate the ionized gas emissions (especially [OIII]) and some kinematics of galaxy NGC 1365, a local narred spiral galaxy. We did this using data taken from MUSE, which is located in the UT4 of the Very Large Telescope (VLT), and was taken on 10/12/2014 with around 1 hour of observation time. We will first create a total integrated map of our FoV, meaning the total flux over all wavelengths in MUSE's spectral range. We will then choose three points of interest to inspect further by looking at their spectra, and comparing. Finally we will isolate the $[OIII]$ line to analyze the pattern of the ionized gas, and the $H\alpha$ line to better understand the structure of the galaxy. Afterwards we will discuss our findings and any possible errors we might have made along the way.

2 Method

MUSE is an integral field spectrograph (IFS), which is an instrument that performs imagery and spectroscopy simultaneously. This means that the instrument creates a spectrum from each pixel in the FoV. The pixels of an IFS are known

Figure 1: Our FoV is but a small portion of the galaxy, close to the AGN, where you can see another spiral forming on the bar. [3]

as spaxels, and each of them have 3 dimensions, the spatial dimension, and a spectral dimension, along with a flux density value F_ν. For example, a pixel at $(x, y, \lambda) = (164, 158, 5000\mathring{A})$ has $F_\nu = 2278 Jy$(we will not use Jansky(Jy) in this paper, this is simply as an example). Because of the spaxels 3D nature, IFS data is commonly known as "data cubes" (See Figure 2). MUSE has two different modes, Wide-Field mode, and Narrow-Field mode, and the data we used was taken in Wide-Field mode, which has a total FoV of roughly $1 \times 1 arcmin^2$. See Table 1 for further specifications of MUSE.

Spatial Resolution	$0.65099'' \pm 0.3''$
Spatial Res. with seeing included	$0.86''$
Pixel Size	$0.2''$
FoV	$320px \times 317px$
Spectral Range	$4750 - 9351$ [Å]
Spectral Resolution	2000 at 4600[$\mathring{A}$] - 4000 at 9351[$\mathring{A}$]
Flux density units	$10^{(-20)} erg/s/cm^2/\mathring{A}$

Table 1: Most values were collected from the actual data using QFitsView, the spectral resolution was collected from the MUSE website. [7]

The dimensions of our data cube were $(x, y, \lambda) = (320, 317, 3682)$, MUSE has a pixel size of $0.2''$ which corresponds to an FoV of $(64'', 63.4'')$.

From the SIMBAD database, we found that the redshift of NGC 1365 was $z = 0.005476$ [6]. We found that the distance of our galaxy is roughly $23.386 Mpc$ away from Earth, which corresponds to a scale of $0.113 kpc/''$, and which in turn corresponds to a linear FoV of $7.16 kpc \times 7.1 kpc$ or $50.8 kpc^2$ [4]. We then used the redshift to estimate the wavelengths of the main optical emission lines in

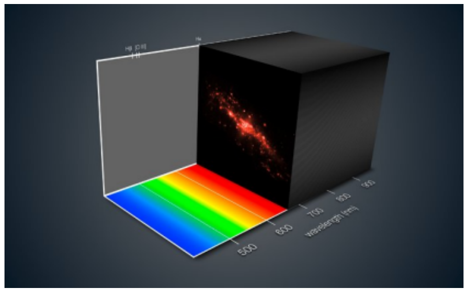

Figure 2: A visual representation of a datacube. [5]

our wavelength range (see Table 2).

Emission Line	Known Wavelength [Å]	Expected Wavelength [Å] at Z = 0.005476
H_β	4861.3	4887.9
OIIIN1	4958.9	4986.05
OIIIN2	5006.8	5034.2
OI	6300.3	6335.0
NII	6548.1	6583.4
H_α	6562.8	6598.7
NII	6583.4	6619.5
SII	6717.0	6753.8
SII	6731.3	6768.2

Table 2: The brightest visible emission lines in our range at their known location vs. expected at $Z = 0.005476$.

3 Analysis and Results

3.1 Total Integrated Map

Using the software QFitsView we produced a total integrated map of the source (see Figure WHATEVER).

3.2 Spectra of the Three Sources of Interest

We then chose three areas of interest in our FoV (see Figure 3) to extract spectra and identify as many emission and/or absorption lines as possible.

Point A is in the middle of the active galactic nucleus (AGN). Point B and C are both points that are rich in $[OIII]$, B being to the east of the AGN, and C being to the west. We chose those points so that we could compare the redshift

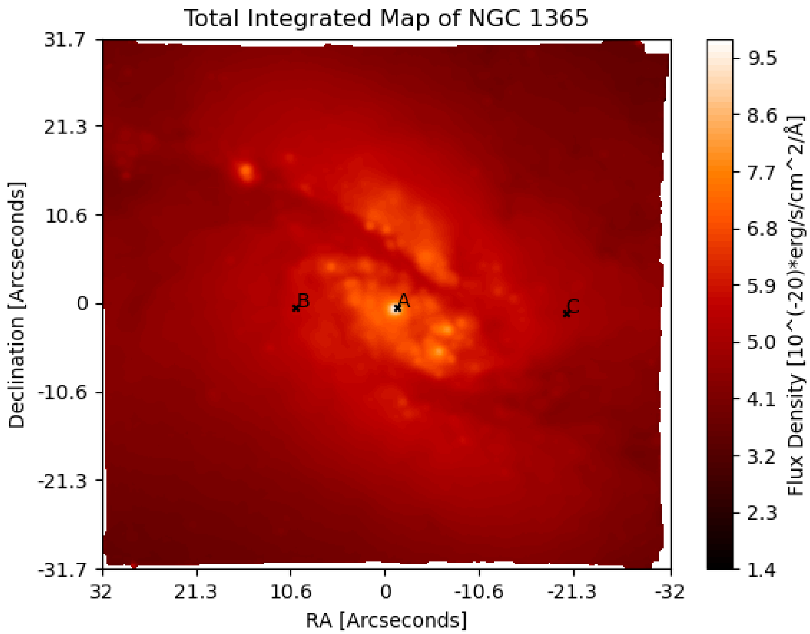

Figure 3: Total integrated map of the FoV with our points A, B, C.

of the spatially collapsed spectra in order to get a small bit of understanding behind the kinematics of NGC 1365.

Source	Coordinates with respect to the AGN [RA, De]	Aperture
A	$(0'', 0'')$	Circle with $D = 9px, 1.8''$
B	$(11.4'', 0'')$	Circle with $D = 11px, 2.2''$
C	$(-19'', -0.6'')$	Circle with $D = 11px, 2.2''$

Table 3: The points with their coordinates and aperture.

Something note worthy about Point A (see Figure 4) is that it is much less noisy yet the spectral resolution is worse than the other two.

In general, at point B, the lines are slightly blueshifted. To be more specific, we calculated the cosmological redshift for all the visible lines, and we then took the average. We found the redshift of Point B to be $z = 0.0059221$, which is 0.0004461 greater than the base redshift of NGC 1365. This means that point B is moving slightly more aware from us.

Point C has a average redshift of $z = 0.0054031$, a difference of -0.0000729, meaning that this point is moving ever so slightly less away from us than the

	Point A	
Emission Line	Expected Wavelength [Å] at Z = 0.005476	Observed Wavelength [Å]
H_β	4887.9	4887.54
OIIIN1	4986.05	4985.64
OIIIN2	5034.2	5033.83
OI	6335.0	6334.09
NII	6583.4	6584.2
H_α	6598.7	6597.7
NII	6619.5	6618.5
SII	6753.8	6752.7
SII	6768.2	6767.5
		8488.3

Table 4: The brightest visible emission lines in Point A at expected λ for $Z =$ 0.005476 vs observed.

	Point B	
Emission Line	Expected Wavelength [Å] at Z = 0.005476	Observed Wavelength [Å]
H_β	4887.9	4885.1
OIIIN1	4986.05	4983.9
OIIIN2	5034.2	5031.4
OI	6335.0	6334.09
NII	6583.4	6581.6
H_α	6598.7	6595.
NII	6619.5	6616.2
SII	6753.8	6750.2
SII	6768.2	6765.2

Table 5: The brightest visible emission lines in Point B at expected λ for $Z =$ 0.005476 vs observed.

entire galaxy, albeit with a order of magnitude less than point B's Δz. With this we believe we can conclude that the galaxy is moving in a clockwise rotation relative to us, as to be expected by its formation.

3.3 Total [OIII] and $H\alpha$ Emission

When inspecting the isolated $[OIII]$ line we can see outflows to the southeast and the northwest, normal to the disc. We believe this is due to the immense speed the AGN is spinning at, which is near the speed of light [3]. The AGN is spinning and creating vortexes that are throwing mass amount of gas out of

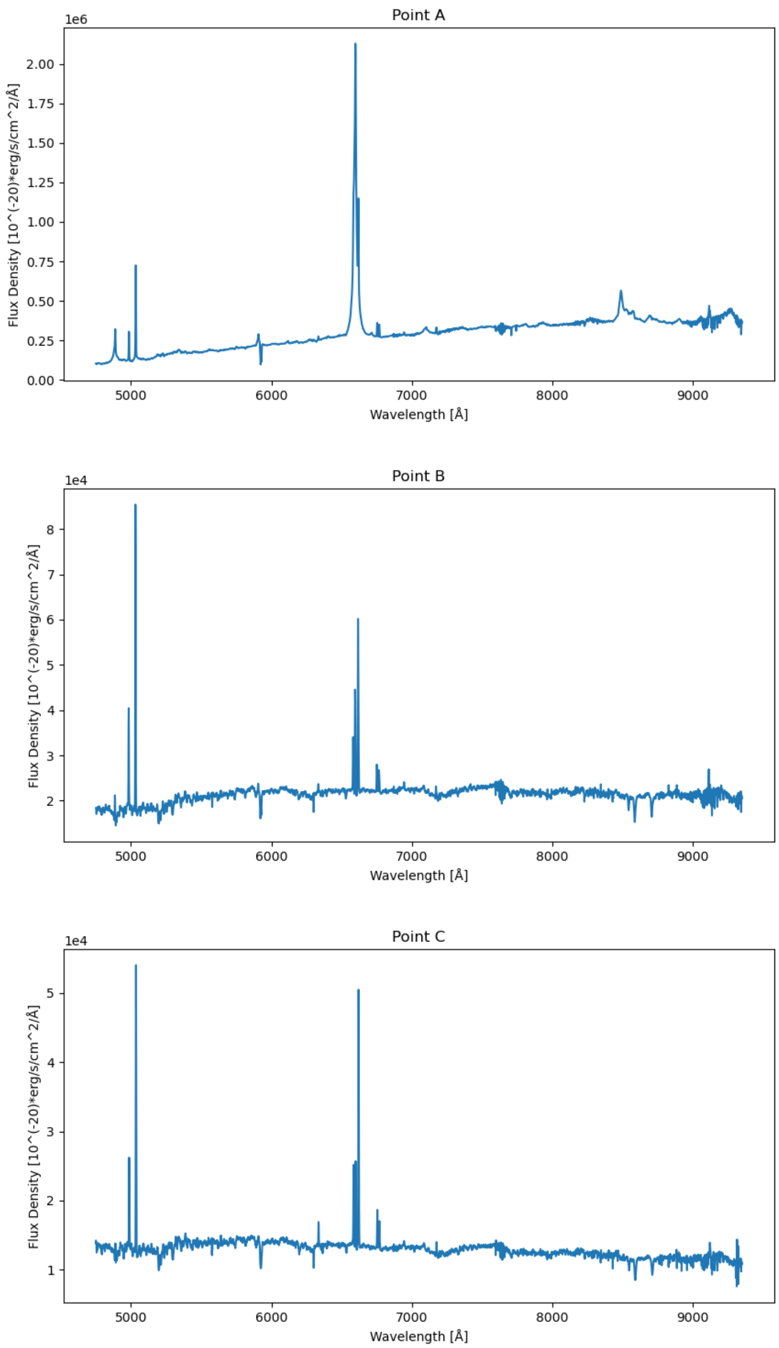

Figure 4: The spectra of our three points.

	Point C	
Emission Line	Expected Wavelength [Å] at Z = 0.005476	Observed Wavelength [Å]
H_β	4887.9	4887.2
OIIIN2	5034.2	5035.08
OI	6335.0	6335.6
NII	6583.4	6584.9
H_α	6598.7	6599.17
NII	6619.5	6620.3
SII	6753.8	6753.85
SII	6768.2	6768.4

Table 6: The brightest visible emission lines in Point C at expected λ for $Z = 0.005476$ vs observed.

the center normal to the disc [2].

When looking at the spectrally collapsed image of the $H\alpha$ line, we see quite a large concentration in the disc itself, which points to the galaxy being moderately young and still star-forming. One can also see pockets of hydrogen coalescing around the disc which will most likely stellar nurseries.

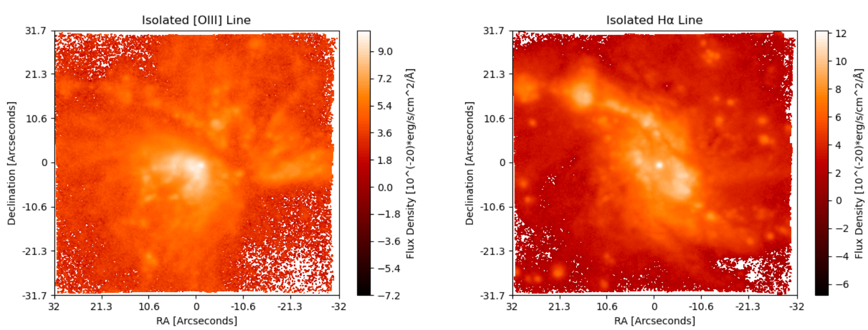

Figure 5: Spectrally collapsed images created using QFitsViewer.

We calculated the average noise (or RMS) of our data. We did this by first finding a flat region in the spectral range with no emission lines ($6775-7620\mathring{A}$). We then looked at the spectra for each individual pixel and calculated the standard deviation. From that we took the average, which we found to be $14.2[10^{(-20)}erg/s/cm^2/\mathring{A}]$. We then multiplied by 10 for purposes we will explain further in the discussion section.

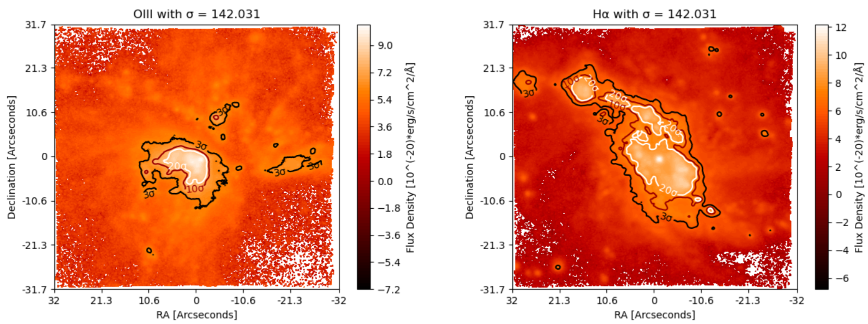

Figure 6: Spectrally collapsed images created using QFitsViewer, with several levels flux based on the found sigma.

4 Discussion

We found several sources with different opinions on the linear distance from us to NGC 1365. This would affect our $kpc/''$ conversion. So there is no absolute certainty when it comes to our FoV's linear size [2][4].

When looking at our three points, we made the conscious decision to use circular aperture with diameters larger than $0.86''$, our spatial resolution, in order to make sure that our sources would be resolved.

When looking at the $H\alpha$ line of the AGN, we noticed that the line was blending together with the surrounding NII lines. We then zoomed out and noticed that this was the case for all the lines, they were all "stretched out". We first thought that it was due to a low spectral resolution in this area, but after thinking, we now hypothesis that this is due to the fact that the material this close to the AGN is moving with so much angular velocity, near the speed of light [3], that the lines are being both red and blue-shifted much greater than anywhere else in the FoV. Therefore, doing any meaningful spectroscopy at the AGN would seem to be futile.

Something strange that we noticed when inspecting our spectra was that in the range $7600 - 7680\mathring{A}$, there is an artifact that looks like a wave packet and is present in almost every pixel. This is around the transition from visible to infrared light, and the atmosphere greatly affects infrared astronomy. Because of this, we are assuming it is an atmospheric distortion, which is quite interesting since MUSE uses adaptive optics.

When calculating the average RMS we found it to be $\sigma = 14.2$, but when looking at the spectra at several points, we found it more likely that it would be an order of magnitude larger, therefore, we multiplied it by 10. The error might lie in how we calculate the baseline, instead of simply using the mean of the data as a baseline, we could have taken a linear regression from the beginning to the end of the data and used that as the baseline for σ.

We noticed something interesting about the spectrally collapsed $[OIII]$ image, there is still most [OIII] around the nucleus. [OIII] is a "forbidden line" meaning that it can only keep in it's state if it doesn't collide with anything else [5]. Meaning, in theory, one would see the most of it in less dense areas. But this seems to not be the case. Possibly the sheer amount of it close to the AGN overtakes the amount we see being thrown out into less dense areas.

5 Conclusion

We have looked at the spectra of three different regions, the AGN, to the east of the AGN, and to the west. The 2 later points were chosen to calculate the change in redshift. From these calculations we have found that the galaxy is spinning clockwise relative to us. We then looked closer at the isolated $[OIII]$ and $H\alpha$ lines. We found that there was an interesting amount of visible $[OIII]$ being jetted out by the AGN, and also, surprisingly enough, that it was most visible directly around the AGN, which seems to be uncharacteristic for a forbidden line such as $[OIII]$. When looking at $H\alpha$ we concluded that the area around the AGN is quite rich in hydrogen and must therefore be quite young and star-forming.

References

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