REVISITING THE *FUSE* DATA ARCHIVE - FINDING *O-VI*

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Abstract

A significant majority of the galactic baryonic matter exists in the form of diffuse gas, known as the circumgalactic medium (CGM). The Far-UV *O VI* emission lines ($1031.93, 1037.62$ Å), corresponding to 6-times ionized Oxygen provide a crucial, but observationally challenging signal of warm-hot gas around a temperature of $10^5 - 10^6$ K. Simulations of star forming galaxies indicate warm-hot gas contributes more mass than stars to the parent galaxy. This project revisited the entirety of the NASA *FUSE* (Far Ultraviolet Spectroscopic Explorer, 1999-2007) data archive, searching for more detections of extra-galactic *O VI* signal to 3σ. A high-performance data pipeline was created to look for this signal using a combination of computational methods, and manual observations. The goal of this project is to increase the number of *O VI* detections, which will inform the target selection for the NASA Aspera mission, a CubeSat spectroscopic telescope to be launched in 2025. While still in development, after a year of funding, this project did not make a contribution to the current known *O VI* emission product list.

Acknowledgements

I would like to thank Dr. Haeun Chung for his long hours and dedication on this project.

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Contents

Chapter 1

Introduction

1.1 CGM Background

Understanding galactic evolution is incredibly important in modeling our universe. Even just recently, the Astronomy community has been active in debate as JWST data has revealed galaxies that exist at very large Redshift's. Current and past galactic evolution models are far from perfect, as there a huge amount of processes are not well understood. In 1956, Spitzer predicted that the Milky Way is surrounded by a filamentous, hot corona (4). Spitzer's original argument was that significant regions of hot gas could extend above/below the galactic Disk, while staying beneath the thermal escape velocity. His arguments were generalized into the galactic fountain model (Shapiro & Field 1976; Bregman 1980) (4) which roughly states that within spiral disk galaxies, multiple violent supernovae may overlap within the cold disk, and the resulting hot gas will become extremely buoyant in the thin, cold disk of gas. As it rises quickly from the disk into the halo, the hot gas forms filaments, exhibit thermal shocks, and cools, condensating into neutral material and falling back towards the thin disk as a high/intermediate velocity cloud (4). This matter within a galaxies outer halo exists in a complex, multiphase medium, and is named the circumgalactic medium (CGM) (1, 5).

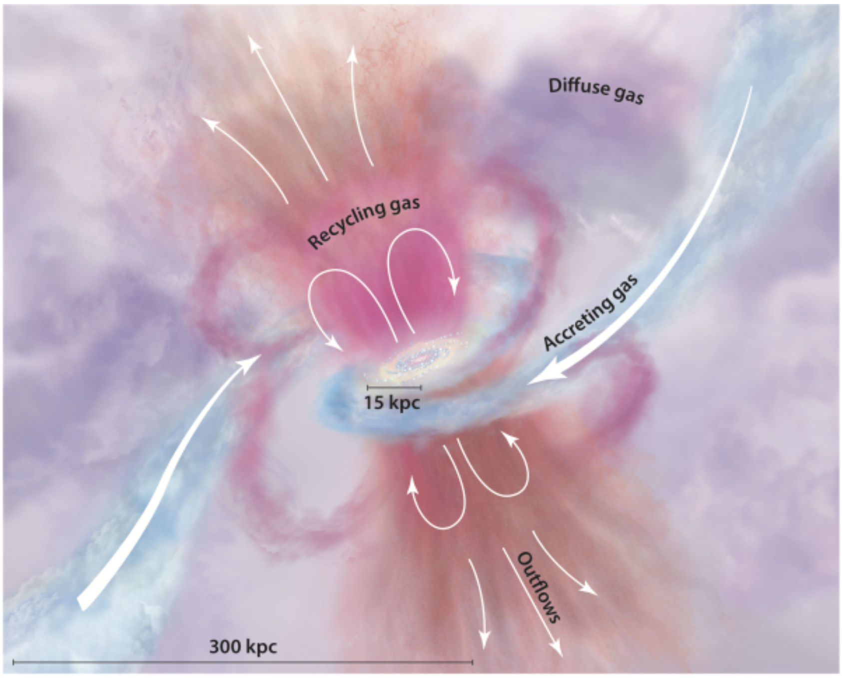

Figure 1.1: A cartoon of the CGM. The blue spiral disk galaxy is accreting gas from the purple IGM (intergalactic medium), red outflows are powered by supernovae. The diffuse gas varies in color indicating it is contributed by a variety of states. (5)

Figure 1.1 illustrates the nature of the CGM with colors representing the different phases of gas. In general, the CGM includes all baryonic matter within the galaxy, typically excluding stars. While stars are hugely impactful on the galactic evolution and emission, stars make up a minority of the baryonic matter within a galaxy and can be treated separately. The CGM contains the vast majority of the baryonic matter, as around only 20% of the total baryonic mass will ever be made into stars by most galaxies (1, 5). Baryonic matter can be considered all galactic matter that is visible, i.e. not Dark Matter which will be neglected by this entire discussion. It may seem surprising that more mass is outside of stars than within stars, as most people usually consider galaxies to be groups of stars. This neglects the CGM that exists in-between the stars and throughout the halo. It makes sense to, as stars are certainly the brightest thing within the visible light spectrum, which is what we are familiar with.

The CGM is a source of a galaxy's star-forming fuel, the main venue for galactic feedback and recycling, and perhaps even the main controller of the galactic gas supply (5). Understanding the rich dynamics and complex ionization states of the CGM is key to modeling galactic evolution at all redshifts. As it contains the dominant component of baryonic matter, the CGM plays an incredibly important role in galaxy formation and evolution. Studying the evolution of the CGM allows for the refining of our theoretical models, and comparison of actual observations to galactic modeling. The CGM is a venue for the different gas flows, acquiring, ejecting, recycling, forming stars, and accretion onto Black Holes, Neutron Stars, and White Dwarfs (5). Understanding the CGM is incredibly important to obtaining an accurate timeline of the universe, but observing diffuse gas is inherently more difficult than bright, dense, stars.

Making any sort of measurement on the CGM is going to be extremely difficult due to the complex, multiphase, diffuse nature of the CGM. The only chance there is at measuring CGM emission, or absorption, is though another wavelength band than the visible spectrum. Within the complex CGM, the warm-hot phase $(10^5 - 10^6)$ K has been found to be one of the largest components, larger than stellar mass (1, 5). The warm-hot phase gas emits in the UV region of the spectrum, and cools rapidly through line emission. Around this temperature is the transition for *O VI*, or 6-times ionized Oxygen. The *O VI* emission line is actually a doublet at $1032/1038$ Å and occurring at such a high temperature, this doublet can be the primary coolant for gas of near-solar metallicity which cools most effectively at this temperature(4).

Measuring this warm-hot gas is definitely possible, as there is a significant portion of baryonic matter in this state. While it is possible, there are numerous natural factors making any sort of astronomical UV observation difficult. Atmospheric scattering being the most pressing, any UV observations must be done from space. The other difficulty is that the CGM is significantly less dense than stars, so the emission occurs at a very low surface brightness, requiring long spectral exposures. While it is very difficult to observe, the presence of filamentous, warm-hot gas existing outside of the disk was finally confirmed by X-ray emission data combined with Far-Ultraviolet data. NASA's *Far Ultraviolet Spectroscopic Explorer* (*FUSE*) (1999-2007) (1, 3, 4) was the first of its kind that made UV (Ultraviolet) Astronomy possible, as ground based observation is not possible due to atmospheric scattering. *FUSE* was able to confirm the presence of warm-hot phase gas through spectral observation of *O VI* absorption in the CGM in the Milky Way.

1.2 Far Ultraviolet Spectroscopic Telescope: FUSE

FUSE was a joint NASA mission with the Canadian Space Agency and the Centre National d'Etudes Spatiales of France to explore the far-ultraviolet portion of the universe. It was functional over a region of $905 - 1187$ Å. Overall, the FUSE Spectroscope had a relatively wide field of view, extremely high resolution, with two out of the four total spectral channels optimized for *O VI* emission. It was a very large satellite, coming in at 5.5 m and a mass of 1300 Kg (3). As this telescope was to operate in the UV, where optical coatings preform much worse, the number of reflections must be minimized. Additionally, as the goal of the mission is high resolution spectroscopy, high focal numbers and hence long instruments are required. To get around this, the FUSE satellite was split into four separate almost-identical co-aligned prime-focus telescopes feeding light to four Rowland spectrographs (3). Two of the channels had coatings highly optimized in the $1000 - 1187$ Å range for *O VI* detection, while the other two a more broad range for other transitions.

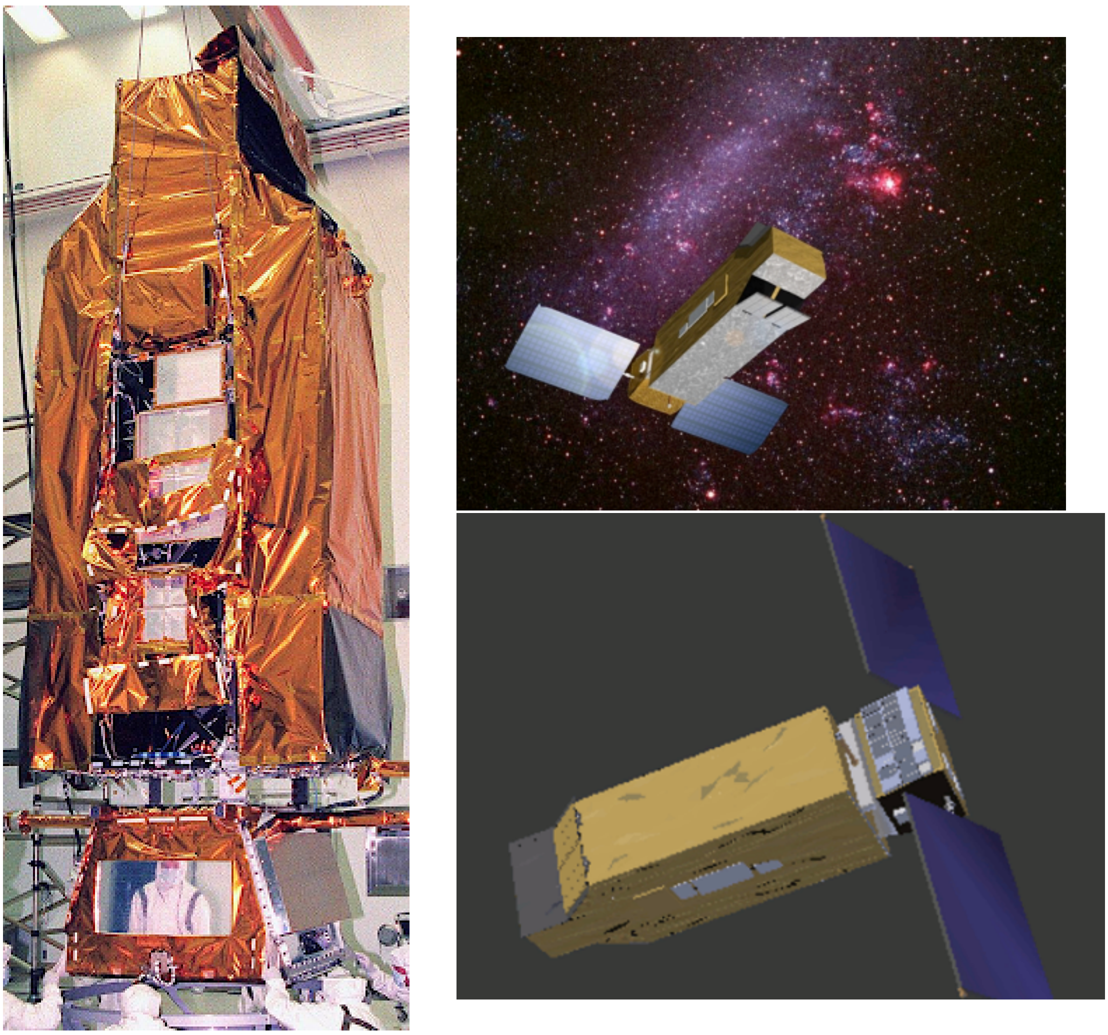

Figure 1.2: NASA Instrument Handbook Images of *FUSE* & 3D Models

Figure 1.3 displays the full *FUSE* instrument in its glory. In the laboratory image on the left, within the window along the bottom a lab technician can be seen, illustrating the scale and size of the space satellite. The right images show two 3D renders of the instrument, taken from the NASA *FUSE* Data Instrument Handbook. The *FUSE* mission was overall a huge success and enabled many new fields of astronomy to increase the amounts of measurements (3, 4). Many different key transitions, AGNs, and QSOs for both the Milky Way and relatively close extragalctic objects. The *FUSE* mission produced 5061 exposures on 2735 different fields, organizing them into 100 different classes. The total number of exposures is close to twice the amount of different object fields, which is no coincidence. The general procedure for the observing mission was to have two exposures of every object, one during the Day and one during the Night, to help offset the systematic error.

FUSE utilized multiple different channels in order to maximize the instrument throughput. Two of the channels used were SiC, while the other two were Al + LiF coated mirrors, which are the two channels of interest with efficiencies spiking around the *O VI* emission line (2). The LiF/Al mirrors are approximately twice as effective at wavelengths near the *O VI* emission line ($1032/1038$ Å), but drop off quickly at shorter wavelengths. The SiC channel achieved much higher throughput and effective reflectivity for shorter wavelengths, and hence was not used as the primary aperture in this search for *O VI* emission. The LiF/Al apertures were the apertures and produced the highest resolution in the wavelength band of interest, so this search through the *FUSE* archive prioritized these apertures.

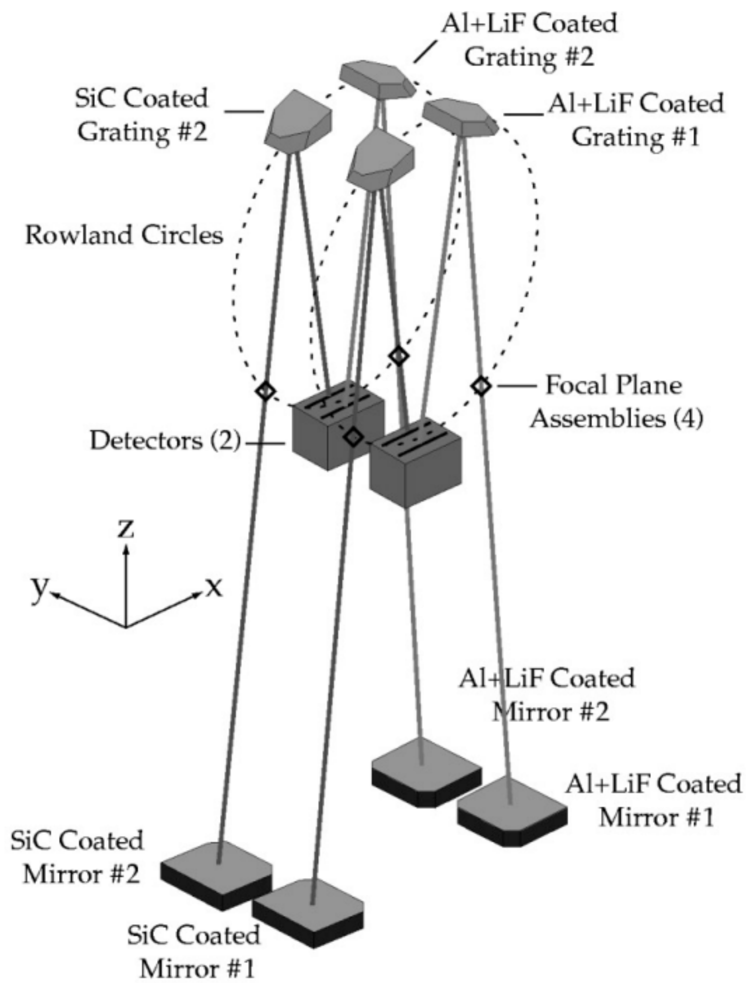

Figure 1.3: Optical layout of the *FUSE* instrument with four channels but two detectors (2).

The above figure 1.3 shows a simplified optical layout of the instrument. Each side of the instrument produces two spectra, making four total, two from the LiF channel and two from the SiC channel. There are two detectors, so each side of the instrument has two spectra falling onto the single detector (2). Each detector located at the Focal Plane Assembly (FPA) on the above figure had four laser drilled apertures, each with different dimensions to give different resolutions. Three primary apertures were constructed and labeled HIRS, MDRS, and LWRS for the respective resolutions (High, Mid, Low), where the highest resolution slit is the smallest. The fourth aperture was a half inch pinhole that was never actually used or located operationally due to pointing errors (2). The three primary apertures are aligned co-linearly with respect to the field, while the pinhole is slightly above the primary axis. The Highest resolution aperture (HIRS) was designed to maintain the highest resolution, but lacks photometric accuracy from the small slit and significant pointing errors. This aperture was used sparingly during the mission due to these effects (2). The mid range aperture, MDRS, achieved resolutions only slightly below the HIRS aperture, but also suffered severely from struggling to maintain alignment. As opposed to the small slits, the LWRS aperture was a large square, intended for diffuse, faint objects. For normal operations, this was the default aperture as it suffered the least from the pointing error and was located in the preferred/primary location for point source viewing (2). Each of the apertures could be moved independently along the Rowland circle, and radially to achieve focus. Overall, this instrument was named the *FUVS* or Far Ultraviolet Spectrograph, utilizing four spectrograph channels and four separate apertures to maximize throughput throughout a wide region in the far UV.

1.3 Previous Results of NGC 4631 and 891

Due to atmospheric scattering, detector Quantum-Efficiency in the UV band, coating reflectivity, and necessity for space based observation, extra-galactic *O VI* measurements are extremely difficult. So far, there are only two known detections of *O VI* emission in galaxies outside of the milky way (1, 4). $NGC4631$ is a confirmed detection of *O VI* emission, by multiple independent papers, while the other galaxy $NGC891$ is still being confirmed, but is likely to contain the signal.

Field	Program ID	z (kpc)	I_{1032} (cnts s^{-1} cm^{-2} sr^{-1})	I_{1032} ($\times 10^{-18}$ ergs s^{-1} cm^{-2} arcsec^{-2})	Signal, Background (counts, counts)	Line Center (Å)	Line FWHM (Å)
NGC 4631-A	p1340101	4.9	6000 ± 1200	2.7 ± 0.5	73, 127	1034.23 ± 0.09	0.56 ± 0.25
NGC 4631-B	p1340201	2.7	8300 ± 1300	3.7 ± 0.6	76, 76	1034.41 ± 0.07	0.41 ± 0.19
NGC 4631-F	c0570201	2.8	2900 ± 1000	1.3 ± 0.4	23, 35	1034.36 ± 0.08	0.15 ± 0.15
NGC 4631-H	c0570301	2.4	4700 ± 1000	2.1 ± 0.5	53, 71	1033.69 ± 0.06	0.34 ± 0.12
NGC 4631-I	c0570401	1.6	8600 ± 1800	3.9 ± 0.8	41, 32	1034.32 ± 0.07	0.39 ± 0.29
NGC 891-1	b1140101	2.0	<2200[a]	<1.0[a]			
NGC 891-2	b1140201	1.5	2300 ± 700	1.1 ± 0.3	40, 124	1033.11 ± 0.17	0.36 ± 0.49
NGC 891-3	b1140301	4.1	<2700[a]	<1.2[a]			

Note.
[a] These values are a 3σ upper limit from 1 Å-wide extraction window at around 1033.3 Å.

Figure 1.4: Detections of *O VI* within NGC 4631 & NGC 891 (1).

Figure 1.4 tabulates the background reduced photon count of the 1032 Å emission line on the two different extragalctic galaxies, with exposures ranging from $5 - 8$ hours in duration. There are multiple exposures per galaxy, as the pointings are shifted slightly in order to obtain the spectra at a new pointing. This is done in order to try and map where the *O VI* emission is coming from, using different pointing locations. These are the known preliminary *O VI* detections, and the overall search through this catalog should verify these sources as known *O VI* emitters (1, 4).

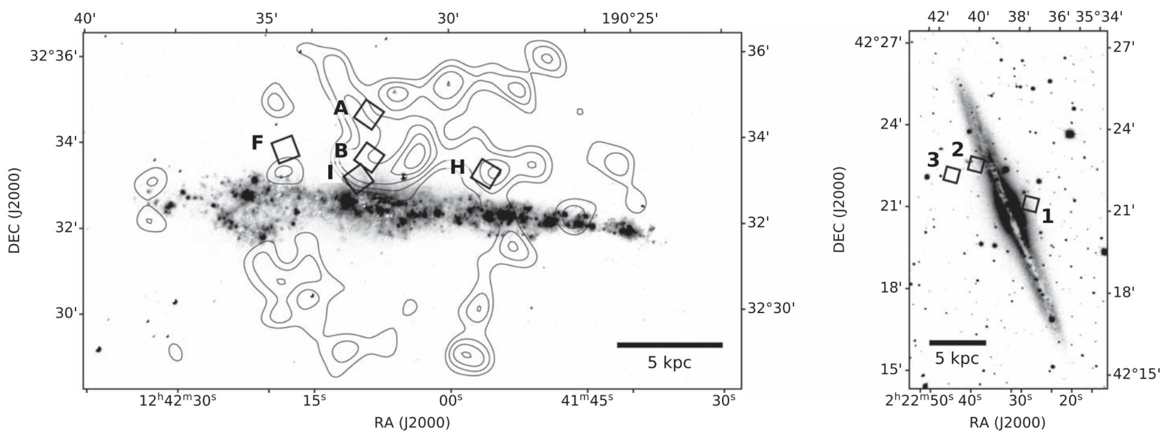

Figure 1.5: Corresponding LWRS pointings of the previous figure (1). For NGC 4631 on the left the contours represent X-ray Band emission. NGC 891 is on the right.

Figure 1.5 shows the pointings of the *FUSE* LWRS aperture on background visible light images. All of the $NGC891$ observations contain *O VI* signal except observation F, which lies significantly away from any X-ray contour. This shows significant correlation between *O VI* signal and X-ray emission, which is expected from the significant black body radiation of the hot gas. All of the LWRS pointings lie slightly off of the galactic disk, as if the spectroscope was pointed directed at the disk, the signal would be swamped by stellar black body emission (1). For NGC 891, only a single detection out of the three contains the singal to 3σ accuracy, while the others simply set limits on the maximum emission level.

Additionally, in figure 1.5, the Signal column indicates that over these 5-8 hour long exposures, the amount of signal is on the order of 10-100 photons. This is an extremely low number, and indicates that the instrument must be sensitive to signal photon detections, which is very difficult to accomplish with the overall low UV throughput. The project will attempt to reproduce these known detections of the *O VI* signal in NGC 4631 and 891 that have been verified by many different independent sources (1, 4).

Chapter 2

Project Goal and Methodology

2.1 Project Goal & CalFUSE

The tentative goal of this project was to revisit the entirety of the raw *FUSE* data archive, which is publicly available, to search for *O VI* emission. In the ideal case, the previous detections of NGC 4631 and NGC 891 will be confirmed to a similar signal level. The main hope of the project is to find more detections of the *O VI* signal within the *FUSE* observation catalog, to increase the amount of *O VI* detections above 2. After analyzing every object observed by *FUSE*, a product list will be created to be used in a more careful manual analysis, or in the next FUV spectral mission, Aspera.

In order to process the raw *FUSE* data, the *CalFUSE* (2007) data reduction pipeline was used, which was developed specifically for reducing the *FUSE* data with optimal fitting parameters (1, 2). This program uses a combination of C and Fortran routines to estimate the background level, and combines the relative exposures with respective normalizations and error propagation in order to obtain a background subtracted spectra.

Before measuring the signal-to-noise ratio (S/N) of the *O VI* emission line, it was fit a model profile. The model profile used is a convolution of three simple functions, a Gaussian as the line emission model, the Gaussian *FUSE* PSF (Point Spread Function), and a top-hat function corresponding to the width of the LWRS slit. This corresponds to a four parameter model, amplitude, FWHM, central location of the line, and the overall background level (1). The fit was then continued using the described model and MCMC fitting with 1000 attempts per observation. The mean of the 1000 attempts was taken and the corresponding error reported within figure 1.5. The total signal is taken as 95% of the area of the final convolved function.

2.2 Project Methodology

The project began with plotting visible light images of the every target in the textitFUSE catalog, using the Digitized Sky Survey 2nd edition (DSS2). The corresponding *FUSE* pointings are then mapped on top of of the background image. This allows for the comparison of the textitFUSE slit pointing location with respect to the celestial object (usually a spiral/disk galaxy). The following figure illustrates the first step in the data reduction procedure. Comparing the *FUSE* pointings to the center of the galactic disk is very important in understanding where the spectral emission is actual being taken from. This allows us to actually understand where the data is coming from, the exact pointing on the night sky where these 3 different slit/box apertures are pointed to obtain UV spectra.

Overall, there is a ton of data to reduce. In total, there 5061 raw spectral data files for 2735 targets, corresponding to around 2 raw files per target/ object field. Again, each specific object field was observed for $4-8$ hours during the day, and night (2). The preliminary plotting routine which is detailed in the previous paragraph, and displayed graphically in the following figure, can assist in reducing the total amount of targets of interest. Many of the fields observed by *FUSE* correspond to galaxies or objects at very high distances, so much so that the emitting object may appear as a point source. Taking spectra of these distant galaxies is made extremely difficult, almost impossible from a few different reasons. The first, is that the signal is overall very weak, and decays proportional to the inverse square of the distance, as well as decaying due to other types of Interstellar dust. The second, is that pointing alignments are made increasingly difficult. The solid angle the object takes up shrinks according to the inverse distance squared as well, so the overall total area or margin of error for slit pointing drops. As *FUSE* suffered from pointing errors, aligning an aperture/slit to a distant galaxy with the extreme level of precision necessary to ensure that it is "just off disk" was impossible, and not in the instrument's capabilities.

So, this preliminary plotting routine of the *FUSE* pointings is very useful in indicating what objects will be of interest, typically those that are closer with distinguishable spiral arms/features, and objects that are not of interest, distant point source like galaxies. This procedure was able to reduce the total number of targets down by about a factor of 2, so about 1350 observation fields that could potentially contain the *O VI* signal. This step was done very carefully, and with caution, so if I had any doubt about an object, it would be included as a potential target.

Naively, the idea is to then loop over all remaining fields of interest, preforming data reduction on the raw spectral data. This is done by fitting the spectra with a line profile, and estimating the S/N. Objects with S/N larger than 3 are designated as detections of the *O VI* signal for this study, while the future Aspera mission will be using a 5σ minimum level.

The project was developed using only Python. A combination of Astropy, Astroquery, and HTTP requests were used to obtain the raw *FUSE* data, visible light images from the DSS2 archive and the corresponding NGC object location. This was for the initial step, reducing the total amount of objects to just the relatively close transients that are not face on. Face on galaxies make observing anything that isn't stellar extremely difficult, which is not ideal for this search. Additionally, this allowed for the pairing to *FUSE* pointings/observation ID's to a known field.

2.3 GitHub and Project Development

The full project can be viewed on GitHub here, the source code contained within the multiple .ipynb files. The first python file used and developed was is under the name "Working adap", which is a pipeline that produces the preliminary *FUSE* pointing plots. The second python file developed was the "Reduced Notebook.ipynb" and "The Pickler.ipynb". These files were essentially a more general version of the first plotting routine in order to work on all 100 object classes within the *FUSE* catalog. The pickler notebook was used to "pickle" or locally download python product lists and queried arrays that could take hours to retrieve from a external database. In general, the amount of data was fairly manageable with respect to my computer, so I opted to download every piece of data I could locally, including *FUSE* spectra. This had the benefit of helping run-time, but at the cost of a significant amount of required bookkeeping in order to keep everything in order.

The "Untar+raw.ipynb" notebook is currently in development. The goal for this file is to be able to function on every *FUSE* object class, downloading the corresponding *FUSE* raw spectral data files. Then it will generate the corresponding *CalFUSE* commands in order to reduce every objects' spectra. It will then plot the corresponding intensity spectrum of each pointing, within the desired wavelength regime, $1025-1045$ Å. The two "fuse_data_reduction" notebooks are semi-functional examples of the goal of this notebook, but instead of working for the entire *FUSE* class, they only work for manually inputted objects, fields, and spectral data. The hard part is making this process automatic and seamless for each of the $1300/2600$ exposures of interest. The Project is an open source project that is copyright under the MIT license.

Chapter 3

Results

3.1 Visible Plots with FUSE Pointings

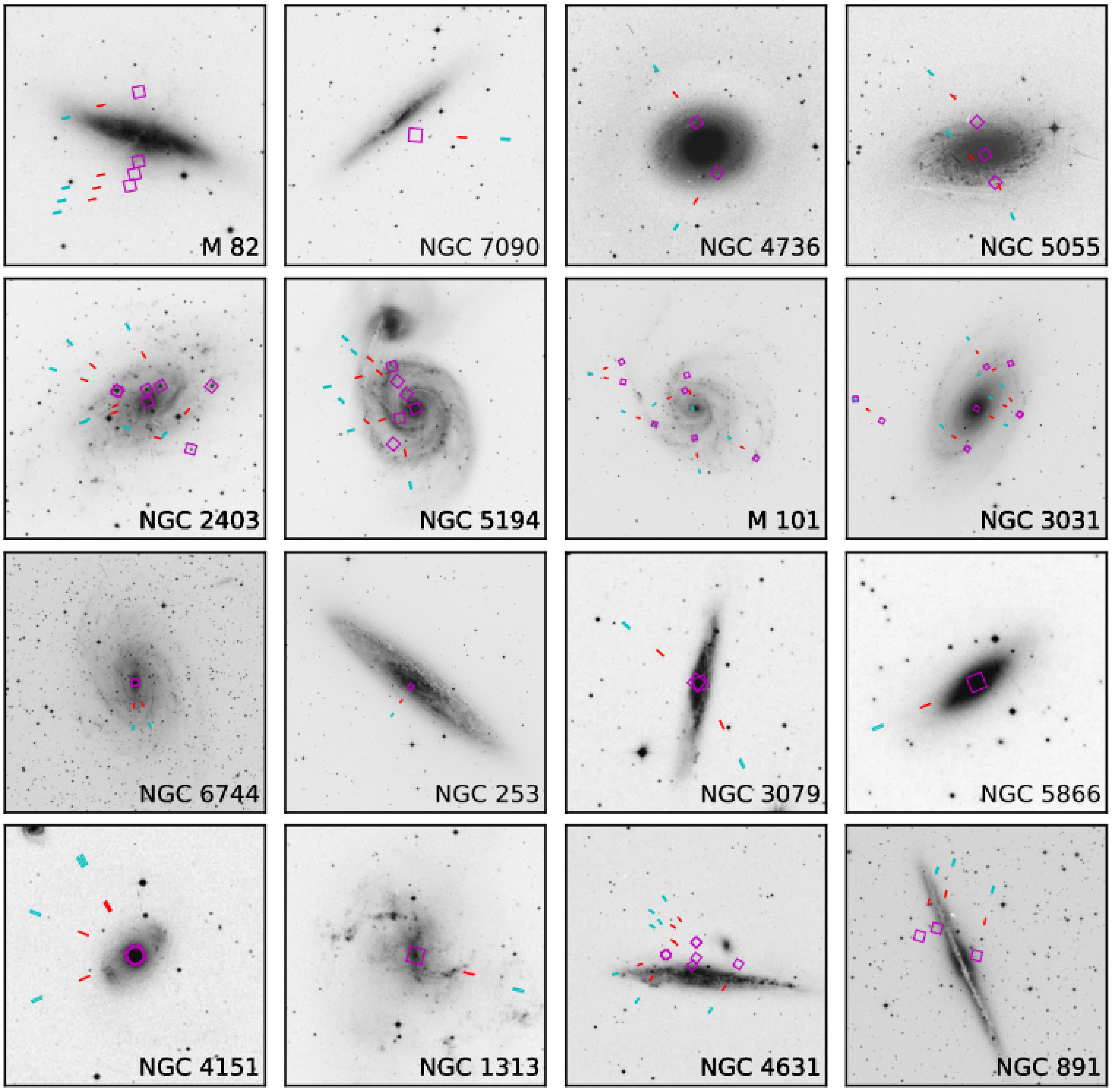

Figure 3.1: Visible light DSS2 Plots overlaid with *FUSE* Pointings. The LWRS aperture is the purple box, the MWRS is Red, the HIRS is Cyan. The pinhole is not shown. These objects are of high interest, edge on and relatively close. NGC 4631 and 891 are both in the bottom right, with the 5 and 3 pointings shown respectively (1).

The above figure shows that the primary aperture, the LWRS purple square, is usually pointed slightly off of the galactic disk. Aforementioned, this is desirable in order to try and resolve the *O VI* emission, in order to not pickup on stellar emission. These 16 images are all the same project procedure repeated, a visible light background image of the object from the DSS2 archive, with *FUSE* pointings overlaid as the purple, red, and cyan symbols. Figures 1.5 can be compared to the two primary sources, NGC 4631 and 891 in the bottom right corner. The pointing of the LWRS aperture match clearly, which was the primary aperture used for searching for the *O VI* signal.

Figure 3.1 shows the plotting routine images for 16 spiral galaxies that are all relatively close, close to edge on, with features that can be distinguished. These objects are therefore of very high interest to this project, with a much higher change of containing *O VI* signal.

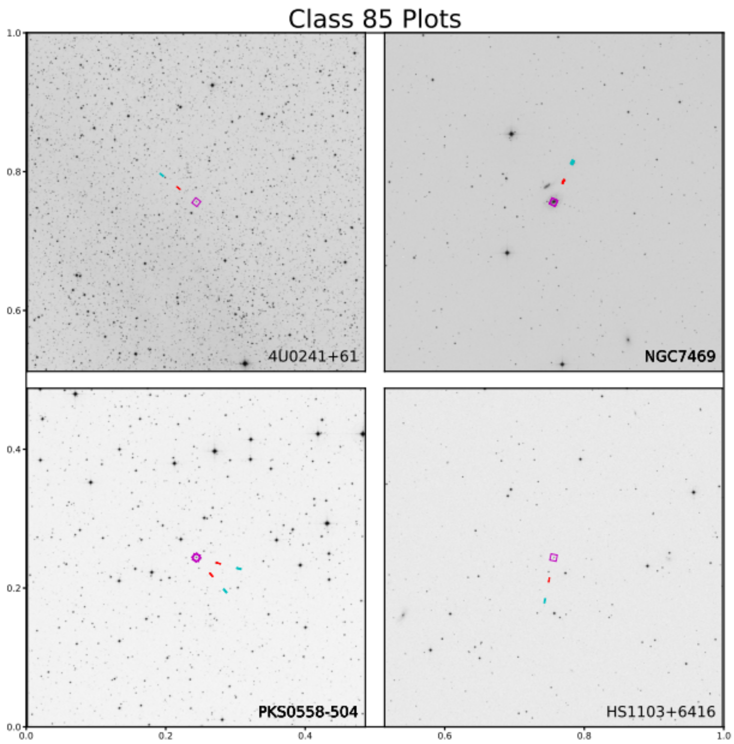

Figure 3.2: A few of the visible images + *FUSE* pointing plots for class 85, Quasars. These are far too far away, and relatively dim within the narrow FUV passband of the instrument. These objects are of low interest and can be disregarded from the search for *O VI* signal.

Figure 3.2 shows a few plots for object classification 85, which corresponds to Quasars. The majority of these objects lie very far away, and are relatively dim within the FUV narrowband. These objects, if present at all within the visible images, appear point source like in nature, and any spectra taken will undoubtedly be stellar. As stellar spectra are not of interest for this search, purely the emission/ UV spectra by the warm-hot CGM, these objects are not considered within the *FUSE* catalog search.

For every object of high interest, again the disk-on, close, spiral galaxies which we understand decently, the plan is to use *CalFUSE* to reduce the raw data and obtain and spectra. This step is still in progress at this time, as there is significant amount of bookkeeping and organizational work required to reduce that many exposures, while performing an ordered/organized search.

3.2 Spectral Results

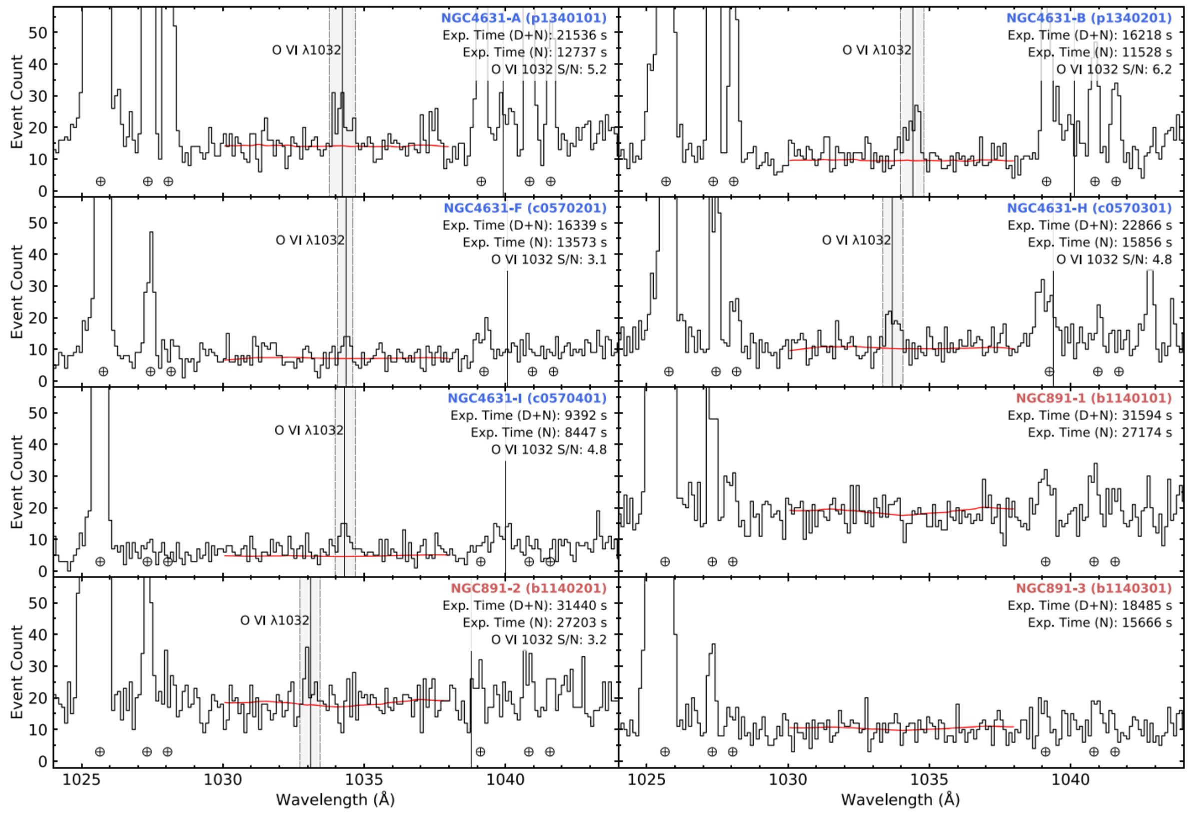

Figure 3.3: Corresponding reduced spectra of the above *FUSE* pointings. The mean of the background level is plotted as the red line, and the fitted center of the *O VI* doublet is contained with the two shaded central bands. Earth air glow emission is marked by the circular symbol (1).

Figure 3.3 displays the reduced spectra of the pointings tabulated by 1.4 (1). The fit line emission strength matches that of Otte in 2003 (4). Again, all of the NGC 4631 pointings contain the signal to around 5σ accuracy, except the F observation which is debatable, where $S/N = 3$. This confirms the previous statement, that the F field is likely to have the least *O VI* emission due to lacking strong X-ray contours in that region. Only one of the NGC 891 observations contains the signal to reasonable accuracy, and even then it is comparable to the F observation of NGC 4631 which is the worst of the bunch. Clearly this illustrates the difficulty of measuring and observing *O VI* signal. These are the best targets we have ever found outside the milky way, and even then only a few of the observations are definitive, meaning $\geq 3\sigma$ accuracy.

Chapter 4

Conclusions

4.1 Product List

Currently the biggest step of this project is still in development, which is the mass reduction of spectra before fitting and extracting S/N ratios. There is potential for the project to continue, as there is still a significant amount of time before the next UV high-resolution spectroscopy mission. As of now, this project cannot contribute to the product list in a meaningful manner. Figure 1.4 presents the current foremost observations ID's and corresponding emission level of *O VI* signal, within objects NGC 4631 and 891 (1, 4). The general final goal of this project would again be to improve upon 1.4, adding multiple observation fields to the list of extra-galactic detections of the *O VI* signal.

4.2 Summary

Overall, I would say this project was partially successful. It did not accomplish the goal of contributing to the list of every *FUSE* observed target with *O VI* emission to 3σ accuracy. Figure 1.4 stands with no changes made by this analysis.

This project took place over the course of a full academic year. The majority of the time lost on the project was in the computer programming, not necessarily the Astronomy or Physics of spectroscopy. The issue of the 5061 exposures, 2735 unique celestial objects, of which 1350 objects are of high interest. It presents a significant problem in data science, computer programming, and good code practice habits, all skills which Physicist's typically lack.

In hindsight, it likely would have been more productive to restrict analysis to a specific amount of objects, say the 16 of high interest in figure 3.1. The restricted analysis could continue from start to finish of the *CalFUSE* data reduction pipeline, in order to refine it for those 16. Additionally, they would be correspondingly fit by the four parameter line emission model. This would have made generalizing the procedure to the rest of the 1300 objects much simpler, as I would have had an ideal 16 case to work off of. A majority of the time was spent working on compatibility between object classes, which would have been avoided by the restrictive analysis.

Chapter 5

Limitations and Future Work

5.1 Limitations

While theoretically *O VI* signal can be detected within by the *FUSE* telescope observation archive, it remains to be determined the exact number of detections that exist within the catalog. Even if more detections of the signal were to be found, it is likely to be on the order of $1-3$ more. This is stemming from the overall difficulty of detection due to inherent *O VI* surface brightness. The *FUSE* mission was widely successful, producing a fully functional high resolution UV spectrograph. The last FUSE observation was made in May of 2007, which is approximately 16 years to this date. So, with regard to UV spectroscopy, we are limited by the resolution of the *FUVS/FUSE* mission.

5.2 Future Work and the NASA Aspera Mission

Funding for this project is stopping within the next few weeks, so the active development has been winding down. This project is published on GitHub and will operate open-source, under the MIT licensing. I plan to continue development, utilizing the restricted analysis development method to a small target list, in order to refine the code from beginning to end. The software developed in python is fairly function, with a decent structure or ability to be adapted to a similar use case. In reality, it likely will not see much future use, or will have to be revamped significantly, as *CalFUSE* was designed in 2008, 15 years ago. The Aspera mission will likely require a completely new spectral data reduction pipeline to be developed, which could potentially be interfaced with this searching software again.

This project was fully in the support ongoing NASA Aspera mission. This is a new CubeSat/SmallSat high resolution UV spectrograph to be launched within the next 2-4 years. The goal of this satellite is solely to observe *O VI* emission from nearby edge on galaxies, which in itself indicates how important this signal is, and how little detections we have (1). The Aspera SmallSat will achieve a higher sensitivity *FUSE*, *CETUS*, or *LUVOIR* per resolution element, despite its small size and low cost. Aspera will be able to achieve a higher proportion of time that is spent on sky observing as well, due to recent developments in solar, thermal, and data-transfer technology within the past decade and a half. Aspera will likely repeat the main observations of interest from the *FUSE* mission, along with a few other object fields of interest correlating with other fields of multi-messenger astronomy. The Aspera satellite is in a very unique position to increase the amount of detections of this incredibly important signal, extra-galactic *O VI* emission. Significantly more observations will be used to more tightly constrain our galactic evolution modeling with respect to the CGM inflows, outflows, and dynamics of the complex gas (1, 4, 5).

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