Determining the Location of the Coronal Line Region within Local Active Galactic Nuclei using [Fe VII] Emission Line Properties

A Senior Project
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Physics, Bachelor of Science

by

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Abstract

Given a sample of 99 local AGNs, we study the characteristics of the forbidden [Fe VII] coronal line for the purpose of determining the location of the coronal line region (CLR) within the AGN. We calculate the velocity of the clouds emitting [Fe VII] using the width of the [Fe VII] emission lines compared to [O II] emission lines to establish whether the clouds are inflowing or outflowing. We plot the [Fe VII] and [O II] flux ratios against the AGNs' known black hole masses and stellar velocity dispersions in order to see if there are any correlations between them. The values of the flux ratios will also tell us whether collision de-excitation or radiative de-excitation are dominant within the CLR of the AGNs.

Contents

1 Introduction

Some of the brightest objects in the observable universe are Active Galactic Nuclei (AGN), with a luminosity on the order of $10^{11}L_{\odot}$, a brightness comparable to an entire galaxy yet contained within an area hardly larger than the size of our solar system. It is predicted that the source of AGN luminosity is a supermassive black hole in the host galaxy's center that is accreting approximately $1M_{\odot}$ per year. There may be a correlation between the mass of an AGN's central mass and the behavior of its emission. We will be studying a sample of ≈ 100 AGNs from which we will observe emission of two specific elements, iron (Fe) and oxygen (O), to attempt to find a connection between the properties of these emissions and the mass of the host galaxy's central supermassive black hole.

1.1 Overview

Information on AGNs throughout this thesis is taken primarily from the book by Peterson, *An Introduction to Active Galactic Nuclei*. There are two types of AGNs: Seyfert galaxies and quasars. The primary differences between them is that quasars are brighter (on average) by at least two orders of magnitude than Seyfert galaxies and are much farther away; quasars are beyond the scope of this paper. From Seyfert galaxies, Seyfert 1 AGNs have a visible Broad-Line Region (BLR) and Narrow-Line Region (NLR), and Seyfert 2 AGNs only have an NLR component. A comparison of the spectra from a Seyfert 1 and a Seyfert 2 galaxy is shown in Fig. 1. There are multiple theories that attempt to explain why there exists a difference between Seyfert 1 and 2 AGNs. One states that Seyfert 2 AGNs are oriented edge-on relative to us that the BLR is hidden from view. It could be that Seyfert 2s pass through a Seyfert 1 stage, or vice-versa. There is even a small possibility that Seyfert 2s are Seyfert 1s in a low continuum (not energetic) state. Because the timescales for processes of a single AGN can be on the order of 10^8 years it is impossible to verify these claims through observation of only a single object.

1.2 Structure of Active Galactic Nuclei

The supermassive black hole at the center of an AGN is surrounded by an accretion disk. This disk-shaped cloud is composed of material that is gravitationally bound by the black hole and gradually loses angular momentum as it moves from the outer portion of the disk to the inner portion. The exact mechanism to conserve the accretion disk's angular momentum is still unknown, but it may be that jets emitted from either pole of the black hole account for it (Fig. 2). These jets of sub-relativistic electrons are another source of emission from an AGN that

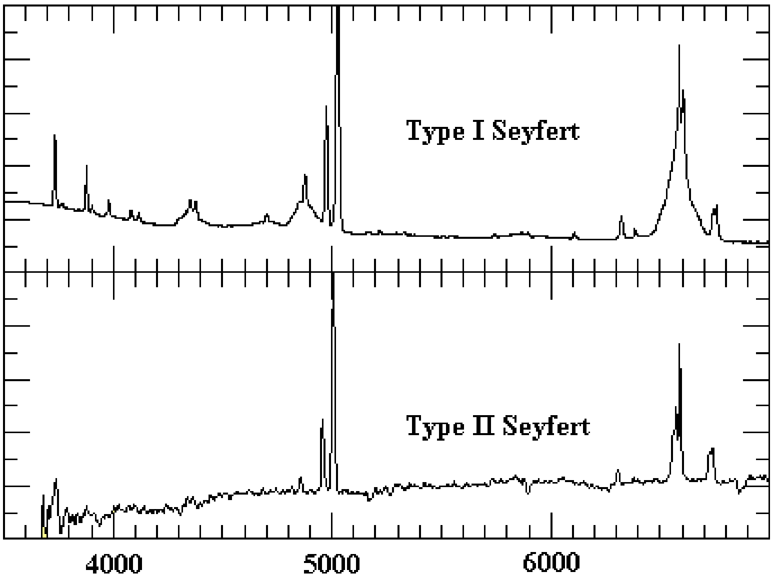

Figure 1: The graph plots the intensities of different emissions against their wavelengths, measured in angstroms (Å). Notice how in the Type 1 spectrum there are multiple broad components that are significantly narrower in the Type 2 spectrum. These are emissions originating from the BLR of the target galaxy; the widths of emission lines are increased due to the relative motion within that region of the AGN. Source: http://gtn.sonoma.edu/

primarily emit in the radio spectrum; AGNs with jets pointed directly towards an observer are a subclass of AGNs known as "blazars."

The viscosity, or density, of the accretion disk increases from more particles being moved closer together. The loss of gravitational potential energy of the particles causes them to emit thermal radiation, making accretion disks very hot. Along the edge of the accretion disk is a torus made up of mostly dust that, when viewed edge-on obscures most of the central AGN.

The hotter BLR lies within the dust sublimation radius (the maximum distance from the black hole inside which solid dust becomes a gas) while the NLR lies beyond it. Active galaxies cannot be modeled similar to stars because their blackbody emission spectra are different from those of stars. For stars, a peak appears in a spectrum depending on what the temperature of the star is. In AGNs, the spectrum resembles a constant slope (Fig. 3); the temperature of the disk has to be calculated from the potential energy of the mass in the accretion disk moving closer to the black hole.

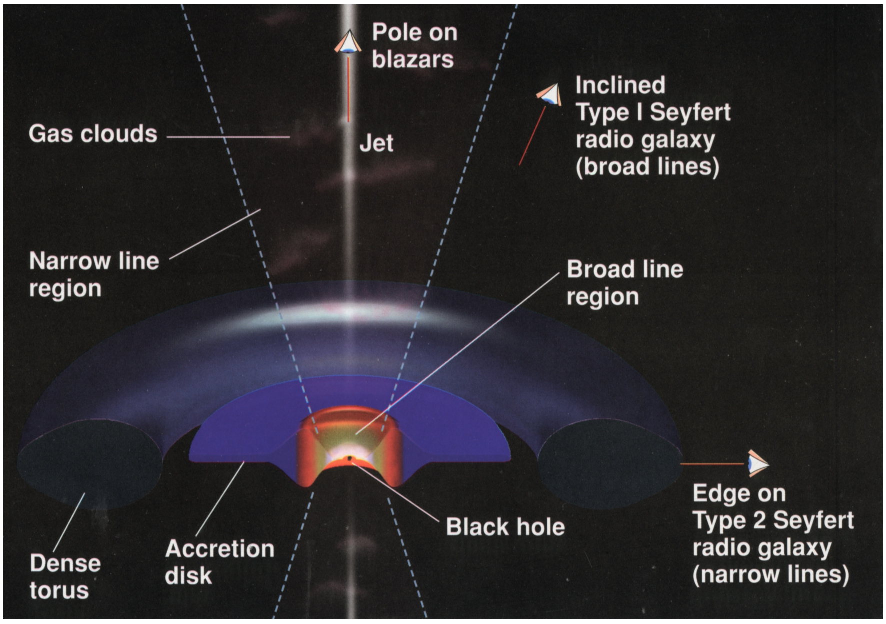

Figure 2: The relevant parts of the AGN are labeled as well as three arrows marking how an observer would classify the AGN if observed from that angle. Source: crab0.astr.nthu.edu

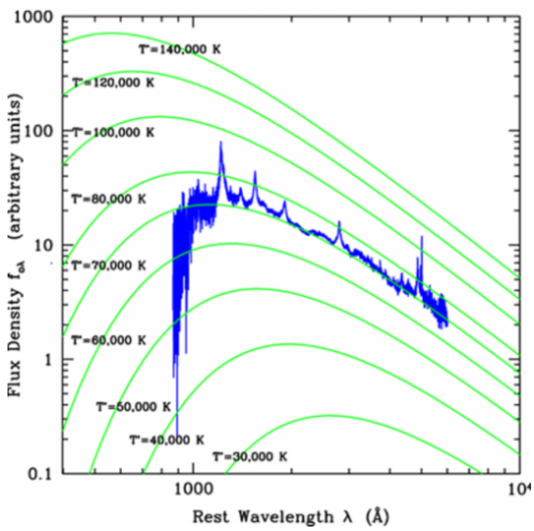

Figure 3: There is no obvious peak in this sample accretion disk emission spectrum so it is more difficult to ascertain the temperature of the disk. With stars, a peak in the spectrum is used to solve for the temperature of the star with Wien's Law. The general downward trend in this figure prevents the relationship between peak wavelength and temperature from being used. Source: https://portal.utpa.edu

1.2.1 Broad Line Region

Outside the accretion disk is the clumpy BLR and NLR (Fig. 2). The BLR is composed of clouds surrounding the black hole. The mass of the entire BLR can be calculated from the density of clouds, volume per cloud, and total number of clouds. Observed broadening of emission lines in the BLR is attributed to Doppler broadening in the movement of the clouds, the apparent change in observed wavelengths due to inflows and outflows of clouds in the BLR. A blueshift, or a wavelength that has decreased below its expected value, signifies an outflow from the NLR; from our perspective an outflow is travelling toward us and an inflow (redshift, a wavelength that has increased above its expected value) is travelling away from us. These speeds can range from 500 km/s to 10^4 km/s.

Emission detected from the BLR is caused by photoionization of particles within the clouds. The process providing for the cohesion between the clouds is still unknown because they are not massive enough to self-gravitate.

1.2.2 Narrow Line Region

Like the BLR, the Narrow Line Region (NLR) has a clumpy cloud structure, but unlike the BLR the NLR is the only part of an AGN that may be resolved in observations. From Fig. 1, the width of emission spectra are smaller than those found in the BLR although the flux of emissions increase toward the blue end of the spectral line. It could be because of a net inflow or outflow of clouds that are responsible for the asymmetry. The speed of the clouds in the NLR is noticeably lower than in the BLR because it is farther from the black hole, measured to travel between 200 and 900 km/s. It explains why there is less of a broadening of the emission lines compared to the BLR.

The NLR stretches out in an axisymmetric, rather than spherically symmetric, shape represented by the dashed lines in Fig. 2. Ionization cones that extend away from the AGN in the same direction as the jets are referred to as the "Extended NLR." Most AGNs exhibit biconal symmetry (one cone emitted from each pole), and in the cases where only one cone is observed, it is assumed that the second is hidden by dust.

Most pertinent to this paper is the electron density of the NLR. Even though the NLR is orders of magnitude more massive than the BLR, its composition is less dense which allows for excited electrons to descend in energy levels by a process called "radiative de-excitation" and emit photons which can be observed. In denser regions of AGNs, electrons are more commonly subjected to "collisional de-excitation" where an excited electron interacts directly with another particle and its energy is transferred; this interaction does not produce photons. The two emission lines we are studying, [Fe VII] and [O II], are produced through radiative de-excitation in a low-density region of the NLR.

1.2.3 Coronal Line Region

Supposedly straddling the border between the BLR and NLR is a region suspected to be between 10 to 1000 pc wide, known as the Coronal Line Region (CLR). In a paper by Murayama et al. (1998) the width of [Fe VII], a coronal line, is studied to determine the exact location of the CLR. "Velocity dispersion" (σ) is the statistical distribution of the widths of emission lines in regions of AGNs; studying it provides clues for whether the clouds in a region are moving into or out of that region. They find that the CLR consists of three components, displayed in Fig. 4.

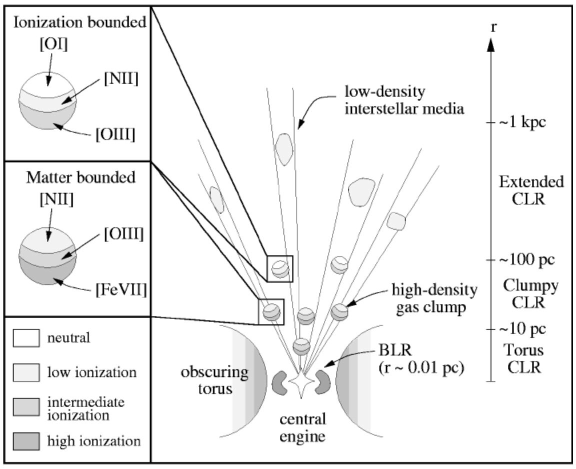

Figure 4: The CLR appears to begin at the outer edge of the BLR and spans outward axisymmetrically through the Extended NLR. In this figure the only coronal line relevant to this thesis is [Fe VII], originating from stars within the Clumpy CLR/NLR. Source: Murayama et al. (1998).

Previous papers by Murayama et al. (1998) and Rodriguez-Ardila et al. (2011) studied the CLR, first to establish its location in AGNs relative to the BLR and NLR, and second to determine the energy of the emission lines. The second paper, "The Near-Infrared Coronal Line Spectrum of 54 Nearby Active Galactic Nuclei," examines eight coronal lines (Si, S, Fe, Al, Ca) to look for patterns in the strength of the emission fluxes. The paper finds that ionization potentials (IPs) are usually within the range of $125 - 450$ eV, but that there also exist IPs as low as 100 eV. The conclusion is that the CLR exists within the NLR.

1.3 Goal of Thesis

We are looking for confirmation of the location of the CLR as well as the relative speeds of [Fe VII] with respect to the black hole mass of each AGN. We plot the flux ratios and widths of [Fe VII] and [O II] emissions of 75 objects against the black hole mass, stellar velocity dispersion, and [Fe VII] cloud velocity of each AGN as well as the flux ratios of broad and narrow $H\beta$ and [O III] to see if there are any correlations in the data. Stellar velocity dispersion (σ_*) differs from velocity dispersion in that it represents the widths of stellar absorption lines due to Doppler broadening rather than the widths of emission lines. In Section 2 we describe where we acquired the data for the objects as well as the steps we followed to reduce noise from the data. In Section 3 we detail what numbers we took from the data reduction process and produce plots using MatLab. Section 4 discusses the results of the data analysis and Section 6 wraps up the ideas we learned from the research.

2 Sample Selection

AGNs were drawn from data collected by the Sloan Digital Sky Survey (SDSS) on the basis of the mass of the black hole between $10^{6.8} - 10^{8.2} M_\odot$ with a redshift range between $z = 0.02 - 0.09$. Higher quality data on these objects was collected by the Keck telescope to determine the AGNs' stellar velocity dispersions.

2.1 Sample

We compiled data from 99 objects (Tables 1 & 2 in the Appendix) to analyze the relative intensities of the [Fe VII] and [O II] emission lines. The logarithmic black hole mass of each central object in its host galaxy and stellar velocity dispersions were determined by Bennert et al. (2011), Harris et al. (2012).

2.2 Observation and Data Reduction

Data reduction includes standard reduction steps such as bias subtraction, flat fielding, and cosmic ray rejection. Wavelength calibration for this sample was completed by Bennert et al. (2011) and Harris et al. (2012) prior to their use in this thesis. Arc-lamps were used for the calibration and AOV stars for relative flux calibration. Further reduction using our Python codes involved accounting for the redshift of the host galaxy and calculating the relative fluxes of [O II] and [Fe VII] compared to each other. The following section details our methods to process this data.

3 Data Analysis

Redshift correction for our sample is already accounted for so we subtract underlying stellar absorption lines before applying a fit to the emissions which gives us the location, width (broadening of the emission lines), and relative flux of [Fe VII] and [O II]. From the location of each line we can derive the velocity of the cloud that the emission originated from (Eqn. 2). Flux ratios and widths are plotted against black hole mass, stellar velocity dispersion (σ_*), and [Fe VII] velocity.

The following subsections detail how these data were acquired.

3.1 Subtraction of Stellar Absorption Lines

The presence of stellar absorption lines in the AGN data prevent an accurate fitting of [Fe VII] and [O II]. The stars' atmospheres absorb the stellar emission which gets mixed up with the emission from the AGN (Fig. 5). A mask for each object was applied to subtract the stellar absorption lines from the AGN emission. The code uses a library of stellar templates that are combined to give the best fit of the host galaxy. Fig. 6 shows the spectrum of the same object after the stellar absorption lines have been subtracted.

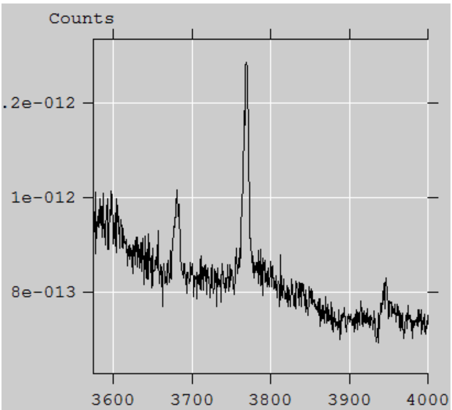

Figure 5: There should be an [O II] emission peak at approximately 3727.425 Å and a smaller peak [Fe VII] peak at 3760.3 Å. In the figure these peaks are offset from their true values due to the redshift of their clouds within the AGN. The black line is the continuum spectrum of the AGN prior to stellar subtraction.

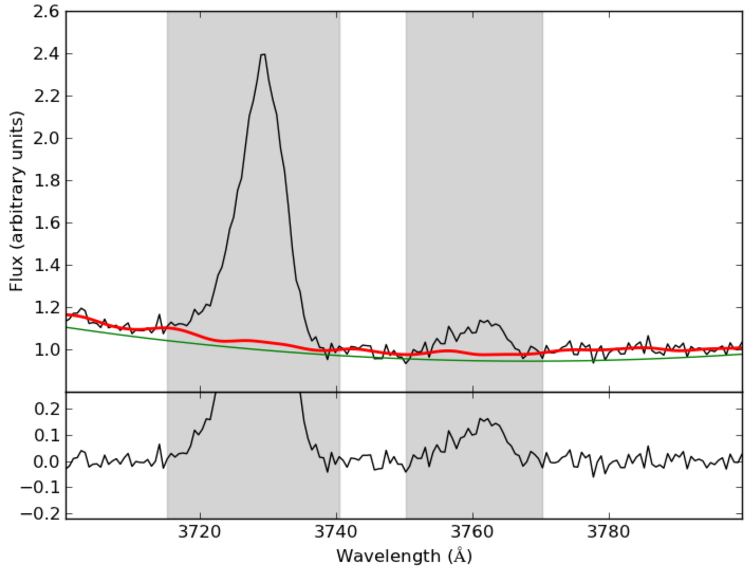

Figure 6: The stellar absorption lines from Fig. 5 have been subtracted using a mask to isolate the [O II] and [Fe VII] lines for the fit. This object now has two clear peaks for the emission and corresponds to the object in Tables 1 & 2 with RA 22 15 42.29 and Dec -00 36 09.6.

3.2 Fitting of Emission Lines

The AGN spectra are fitted with two gaussian profiles to obtain the location, width, and relative flux of the [Fe VII] and [O II] emission. A complete set of plots with gaussian fits of our emission lines may be found in the Plots section of the Appendix.

We calculate the velocities of the inflows and outflows within each galactic nucleus by exploiting the relationship between the wavelength of an emission and the amount it is shifted via the Doppler Effect. Starting with the non-relativistic Doppler effect equation,

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}, \tag{1}$$

we expanded $\Delta\lambda$ to the differences between the observed and known wavelength locations of [Fe VII] and [O II] $(\lambda_{[FeVII]obs} - \lambda_{[FeVII]} - (\lambda_{[OII]} - \lambda_{[OII]obs}))$. The known [O II] location is 3727.425 Å and [Fe VII] is 3760.3 Å.We do this for wavelength calibration correction; by subtracting $(\lambda_{[OII]} - \lambda_{[OII]obs})$ we take into account any errors that may have resulted from wavelength calibration. After substituting, we get,

$$\frac{v}{c} = \frac{\lambda_{[FeVII]obs} - \lambda_{[FeVII]} - (\lambda_{[OII]} - \lambda_{[OII]obs})}{\lambda_{[FeVII]}}, \tag{2}$$

where v is the relative velocity of the [Fe VII] emitting region of the AGN, c is the speed of light, and λ_{obs} are the locations of the emissions unique to each AGN calculated with our Python code. The result is the velocity of the [Fe VII] line with respect to the [O II] line. All results may be found in the Results and Discussion section and the Appendix.

3.3 Comparison to Hβ and [O III] lines

A separate Python code was written to determine the strength of the Hβ lines of the objects in the sample; we compare the ratio of Hβ narrow and broad line fluxes and [O III] flux to black hole mass, stellar velocity dispersion, and [Fe VII] velocity dispersion. The velocity dispersion does not represent the speed of the [Fe VII] emission (which travels at c). Instead it represents the range of speeds that the clouds [Fe VII] is emitted from are moving at. Not every object in our sample had all the data available for Hβ lines and emission spectra so these objects were excluded from our results. Refer to the Data section of the Appendix for tables cross-referencing the accumulated data for all 99 objects.

3.4 Comparison to Black Hole Mass and σ_*

From Bennert (2011) et al. and Harris et al. (2012), numbers and uncertainties for logarithmic black hole mass (MBH) and stellar velocity dispersion for most of the objects in our sample were compiled. Of the 99 objects in the sample, 75 objects had values for MBH and 64 objects had values for both MBH and σ_*. The tables in the Appendix identify which for which objects MBH and σ_* are known.

3.5 Errors

There exists a small amount of variability between the fit of the fluxes of our emission lines and their true values. By studying the fits we determined the uncertainty in relative flux to be ± 0.1 arbitrary units with an uncertainty in location of $\pm$ 0.1 Å and uncertainty in emission profile width of $\pm$ 1 Å. Error propagation in flux ratios and cloud velocities were accounted for in Figs. 9,10, 11, and 12, but ultimately the error bars were omitted for the sake of clarity. Uncertainty in the black hole masses is a constant ± 0.5 dex. Sigma uncertainties were known prior to the writing of this thesis.

4 Results and Discussion

We used data from 75 AGNs to plot flux ratios against the logarithmic black hole mass and the [Fe VII] velocity dispersion of each AGN; the same data from 64 AGNs was plotted with respect to the AGNs' stellar velocity dispersion. The flux ratios calculated were $\frac{[OII]}{[FeVII]}$, $\frac{[OIII]}{H\beta_{narrow}}$, and $\frac{H\beta_{broad}}{H\beta_{narrow}}$. An example of one such plot (Fig. 7) shows how the $\frac{[OII]}{FeVII]}$ flux ratio changes given the range of [Fe VII] velocities it is plotted against.

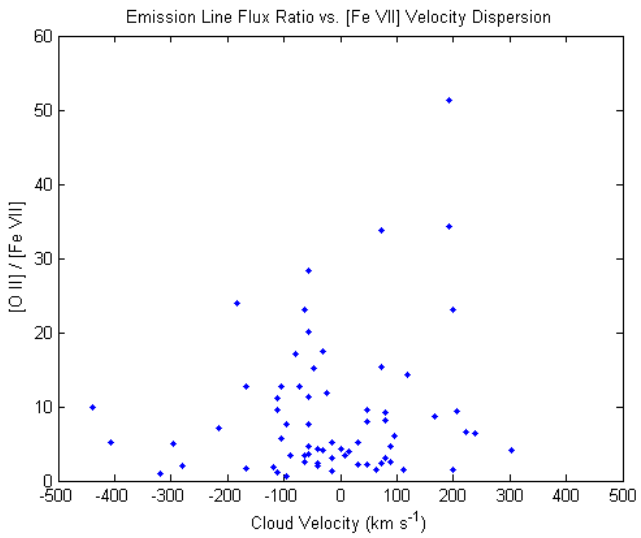

Figure 7: There does not appear to be a strong inclination toward inflowing or outflowing clouds.

With the same flux ratio plotted against the black hole masses of each AGN (Fig. 8), they are contained within a relatively narrow range of masses.

For all quantities we found that the average velocity of the [Fe VII] regions was ≈ -19 km/s (an outflow). The average location for [Fe VII] was 3760.5 Å; compared to its known value of 3760.3 Å this agrees with our findings of the average [Fe VII] cloud velocity oriented towards us. An outflow is blueshifted so we would expect to see a smaller emission location. We also see from the emission profile shapes (in Figs. 13-16 in the Appendix) that there aren't any wings in the blue end of the spectrum coming off of the [Fe VII] or [O II] peaks. They match up very closely with the gaussian fits.

It seems the [Fe VII] coronal line is emitted from the NLR which would suggest that the CLR exists primarily within the NLR, a result in agreement with the Murayama paper. However, there is no correlation between the black hole mass and the location of the CLR. The only correlation we see is an increasing linear

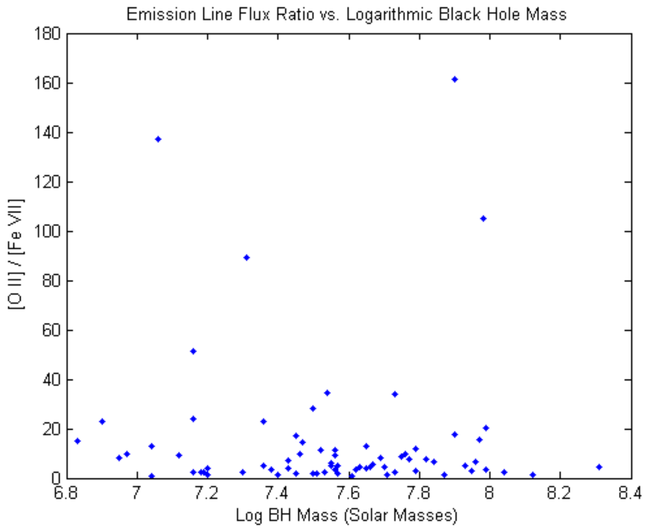

Figure 8: The x-axis has been shifted from the origin to x=6.

trend between the difference in widths between [O II] and [Fe VII] versus stellar velocity dispersion; a greater difference results in a higher σ_*, shown in Fig. 11. This gives us a tentative relationship between the mass of the bulge in AGNs and the location of [Fe VII], but it is not a statistically significant relationship (Fig. 11 is mostly a scatter plot).

5 Summary and Conclusions

From our sample of 99 local AGNs we studied the emission lines of [Fe VII] and [O II], among other lines, with respect to the velocity of the clouds within the NLR, the mass of the galaxy's black hole, and the stellar velocity dispersion of the AGN. The only correlation appears to be between the difference in the widths of [Fe VII] and [O II] plotted versus the stellar velocity dispersion (σ_*). There is an increasing linear trend that shows how larger widths between [Fe VII] and [O II] in the NLR have a higher σ_* which means [Fe VII] is generally broader than [O II] in AGNs with higher values of σ_*.

6 Acknowledgements

I'd like to thank my advisor Dr. Bennert for assisting me with crafting this thesis. Many long nights were spent rewriting and reformatting this only for her to point out how it could be improved even further.

7 References

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8 Appendix

8.1 Plots

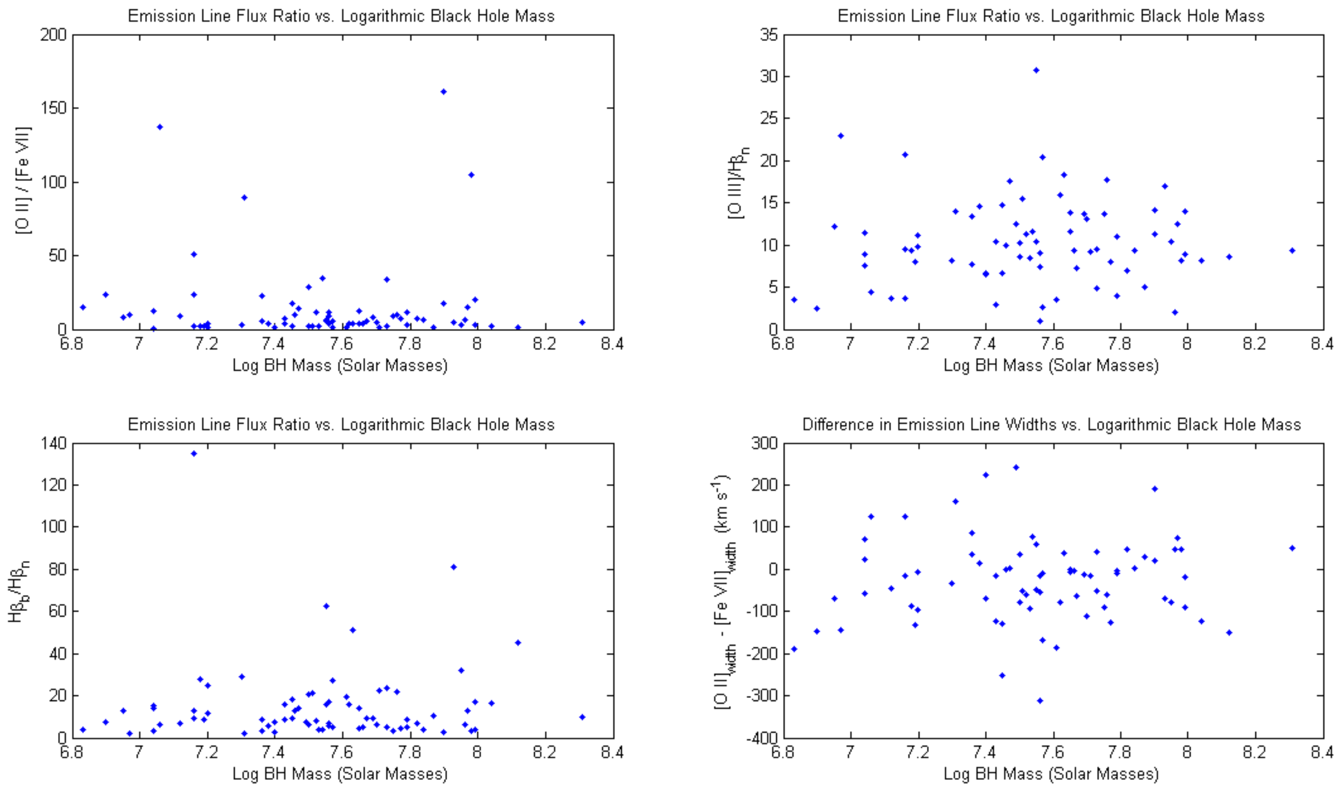


Figure 9

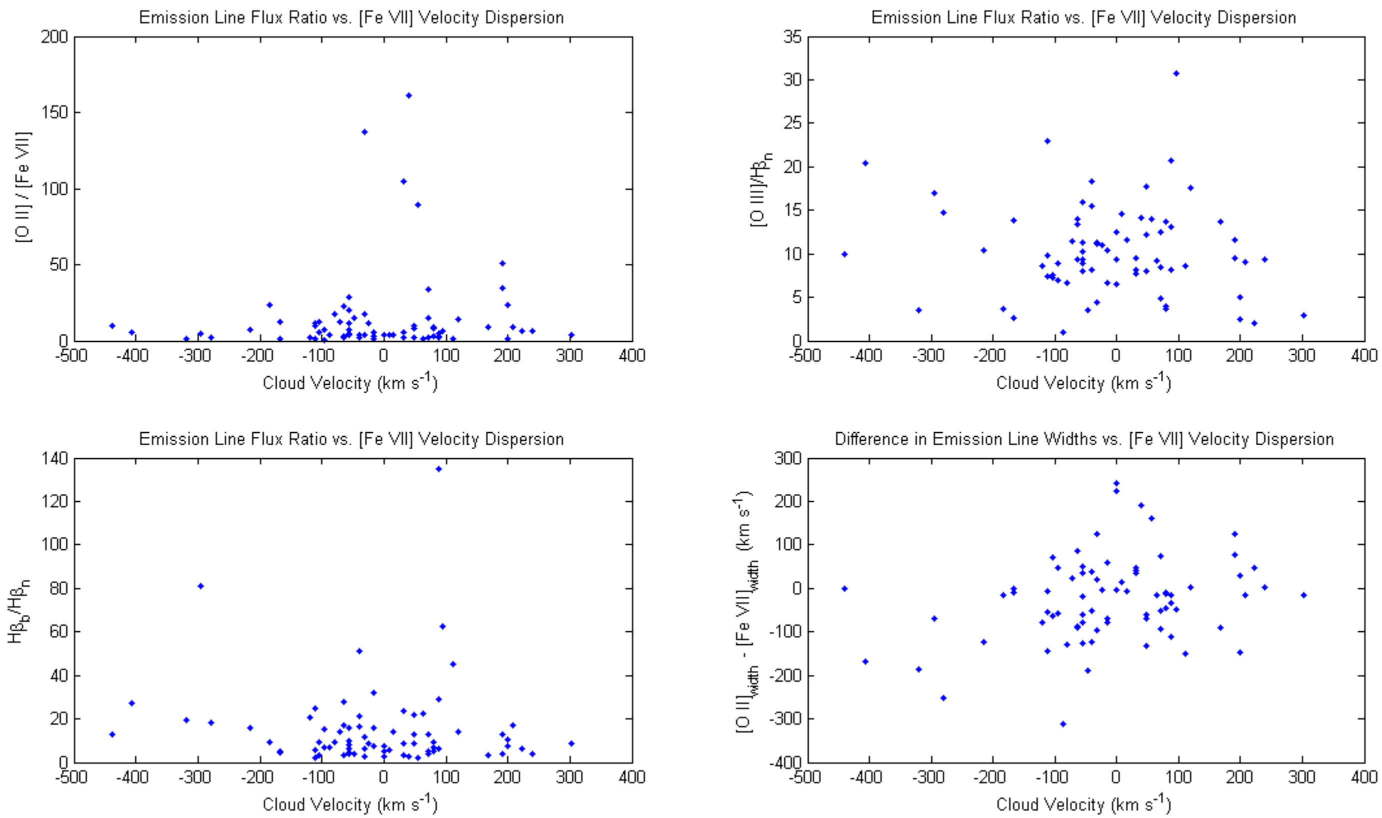

Emission Line Flux Ratio vs. [Fe VII] Velocity Dispersion
[O II] / [Fe VII]
Cloud Velocity (km s^{-1})
Emission Line Flux Ratio vs. [Fe VII] Velocity Dispersion
[O III]/Hβ$_n$
Cloud Velocity (km s^{-1})
Emission Line Flux Ratio vs. [Fe VII] Velocity Dispersion
Hβ$_b$/Hβ$_n$
Cloud Velocity (km s^{-1})
Difference in Emission Line Widths vs. [Fe VII] Velocity Dispersion
[O II]$_{width}$ - [Fe VII]$_{width}$ (km s^{-1})
Cloud Velocity (km s^{-1})

Figure 10

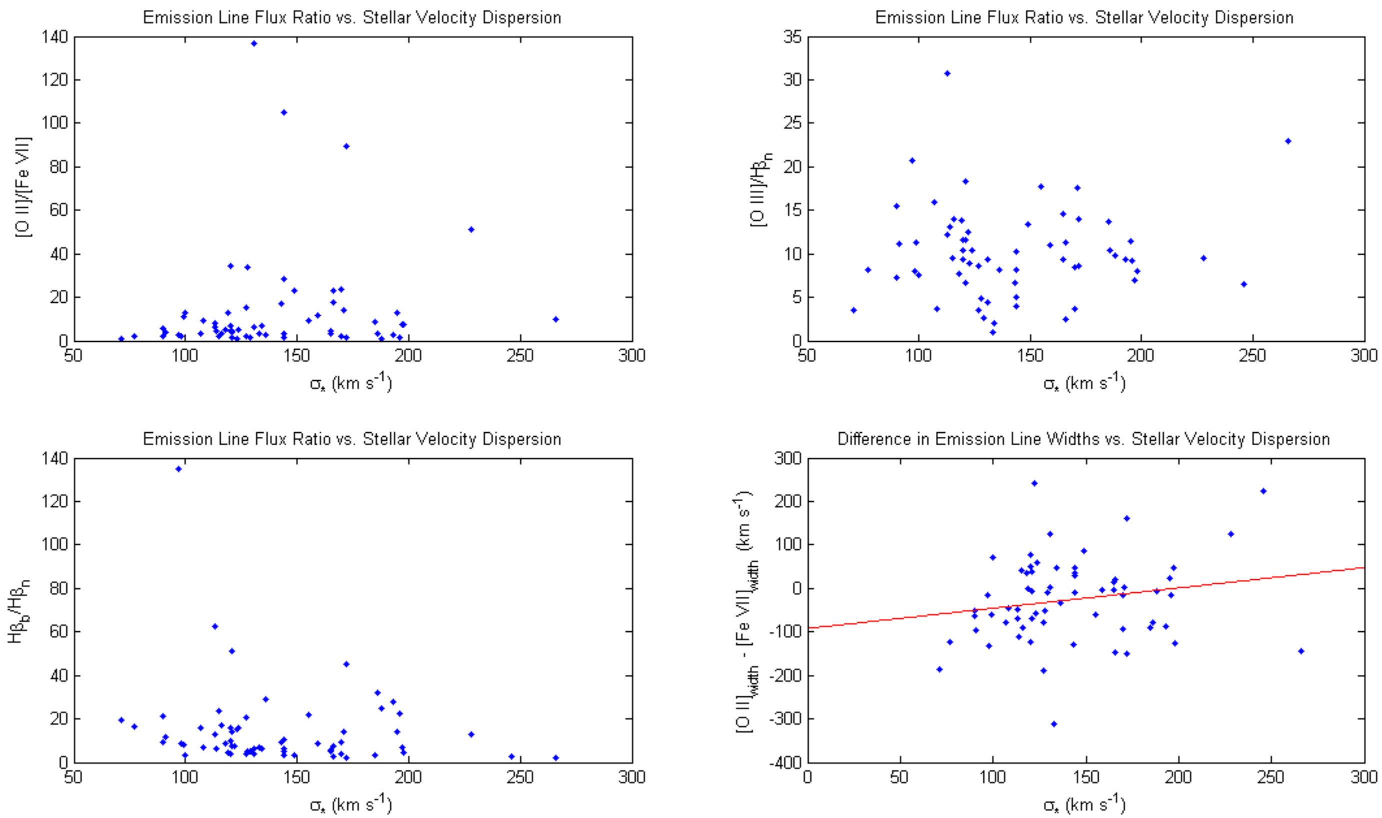

Emission Line Flux Ratio vs. Stellar Velocity Dispersion
[O II]/[Fe VII]
σ_* (km s^{-1})
Emission Line Flux Ratio vs. Stellar Velocity Dispersion
[O III]/Hβ_n
σ_* (km s^{-1})
Emission Line Flux Ratio vs. Stellar Velocity Dispersion
Hβ_b/Hβ_n
σ_* (km s^{-1})
Difference in Emission Line Widths vs. Stellar Velocity Dispersion
[O II]$_{width}$ - [Fe VII]$_{width}$ (km s^{-1})
σ_* (km s^{-1})

Figure 11

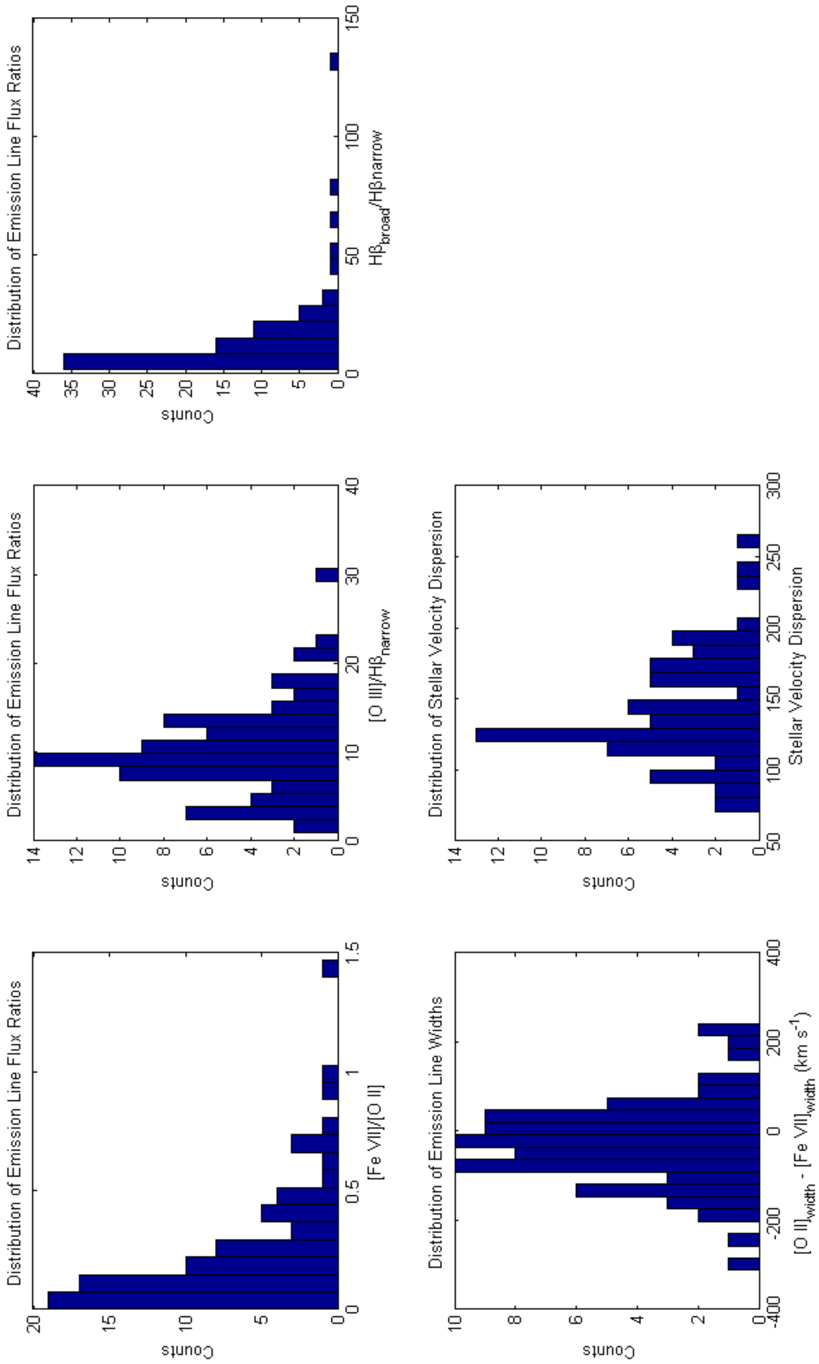
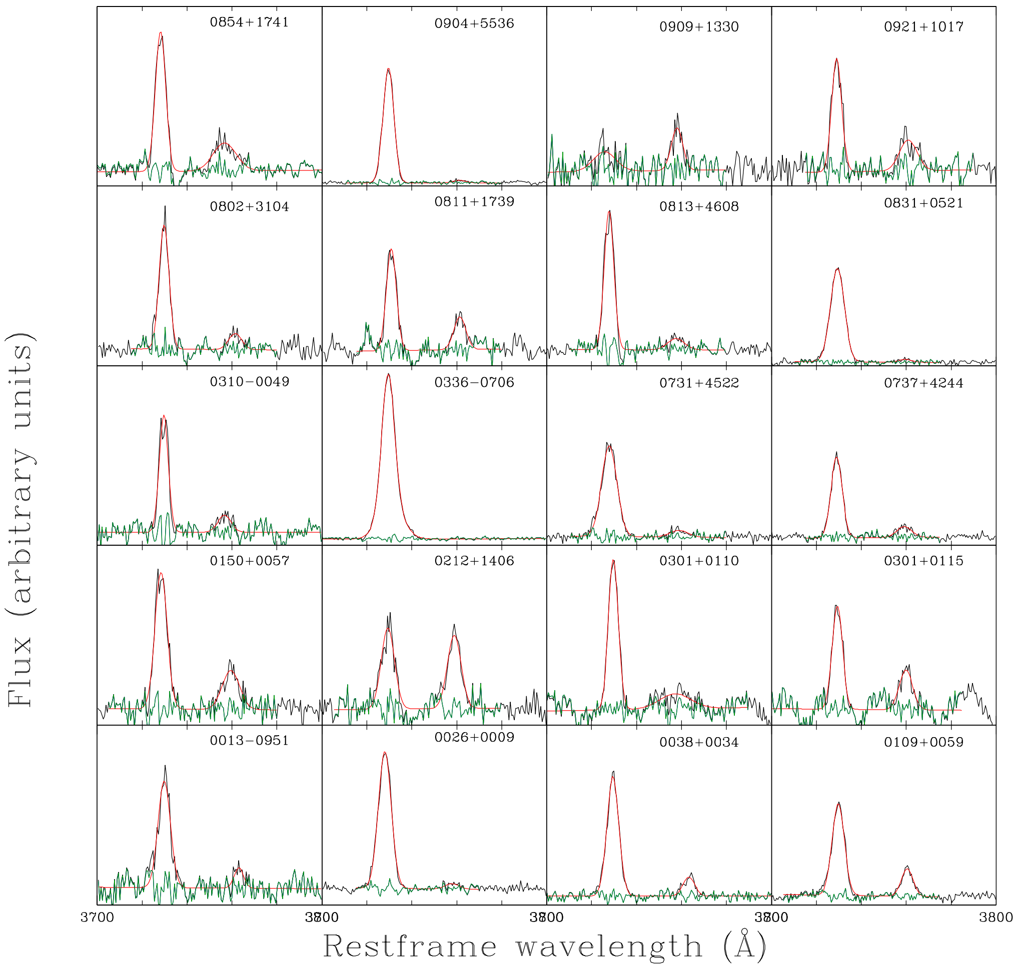

Distribution of Emission Line Flux Ratios
Counts
[Fe VII]/[O II]
Distribution of Emission Line Flux Ratios
Counts
[O III]/Hβnarrow
Distribution of Emission Line Flux Ratios
Counts
Hβbroad/Hβnarrow
Distribution of Emission Line Widths
Counts
[O II]width - [Fe VII]width (km s-1)
Distribution of Stellar Velocity Dispersion
Counts
Stellar Velocity Dispersion

Figure 12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0336−0706
0731+4522
0737+4244
0150+0057
0212+1406
0301+0110
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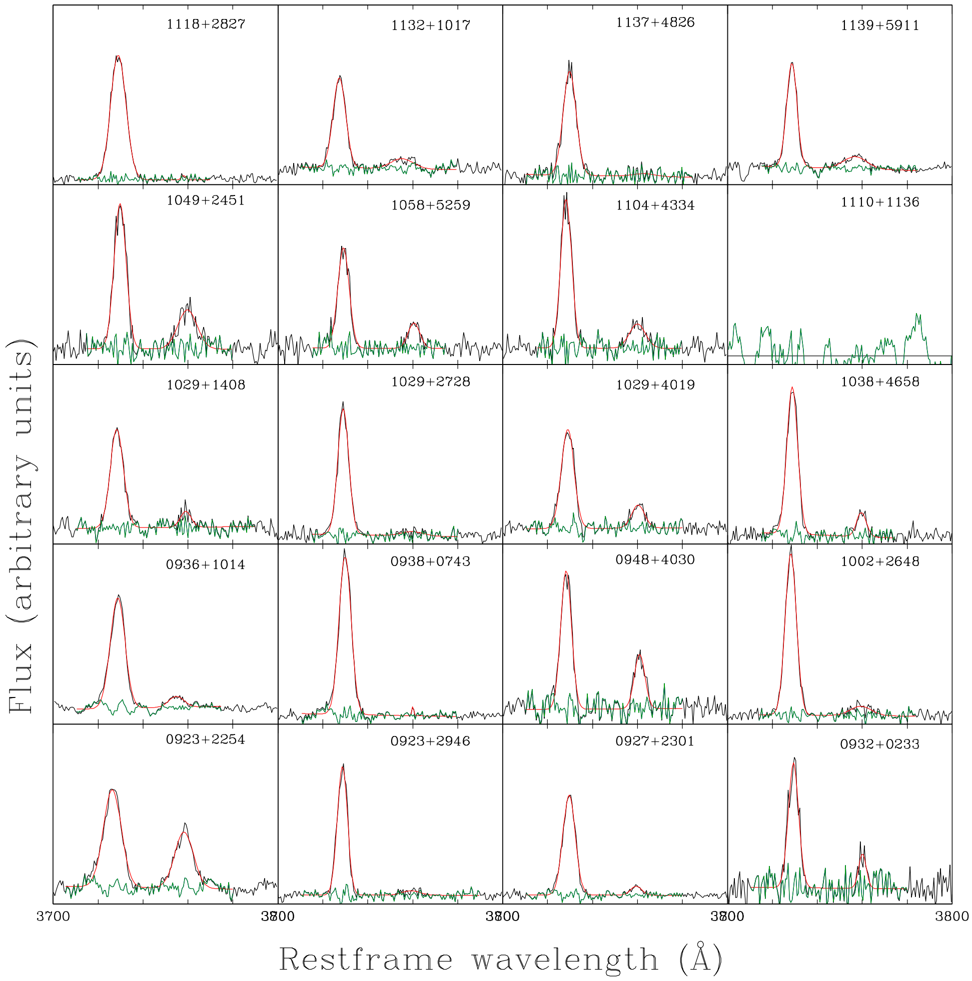
0026+0009
0038+0034
0109+0059
3700
3800
Flux (arbitrary units)
Restframe wavelength (Å)

Figure 13


1118+2827
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1058+5259
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1029+2728
1029+4019
1038+4658
0936+1014
0938+0743
0948+4030
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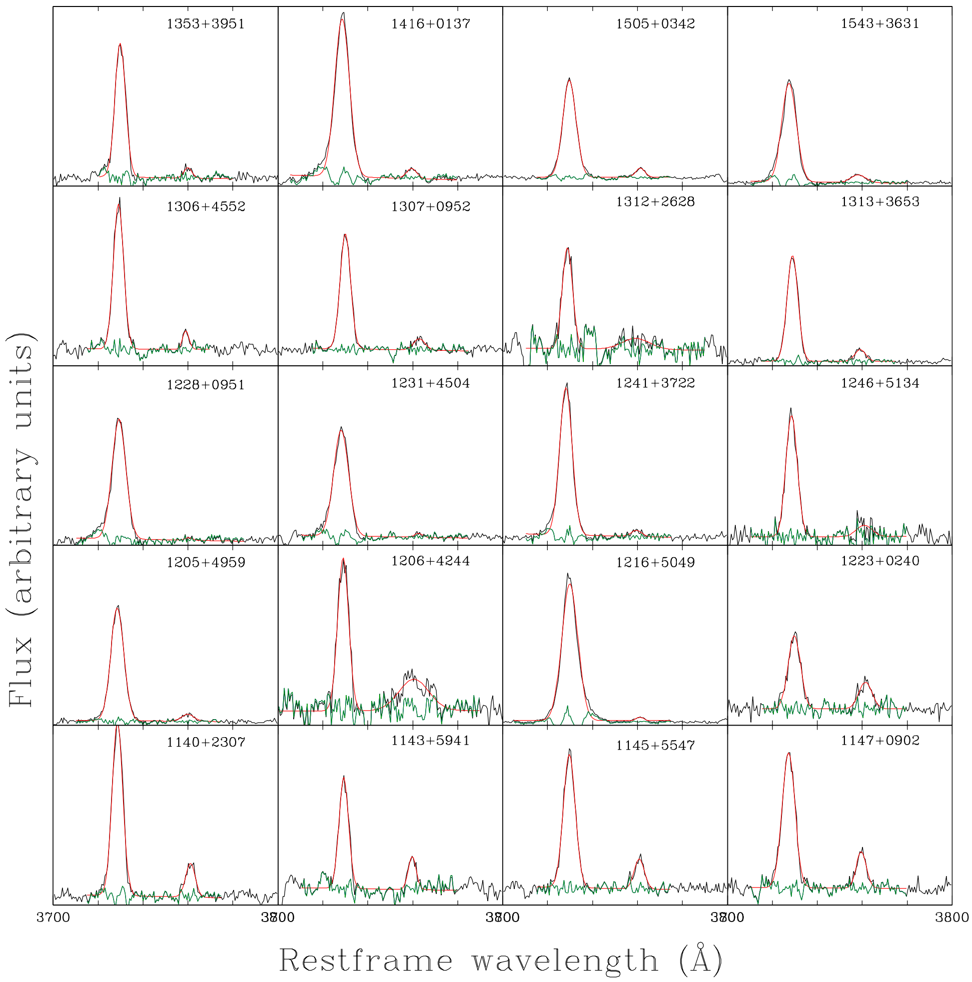
0932+0233
Flux (arbitrary units)
3700
3800
Restframe wavelength (Å)

Figure 14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1241+3722
1246+5134
1205+4959
1206+4244
1216+5049
1223+0240
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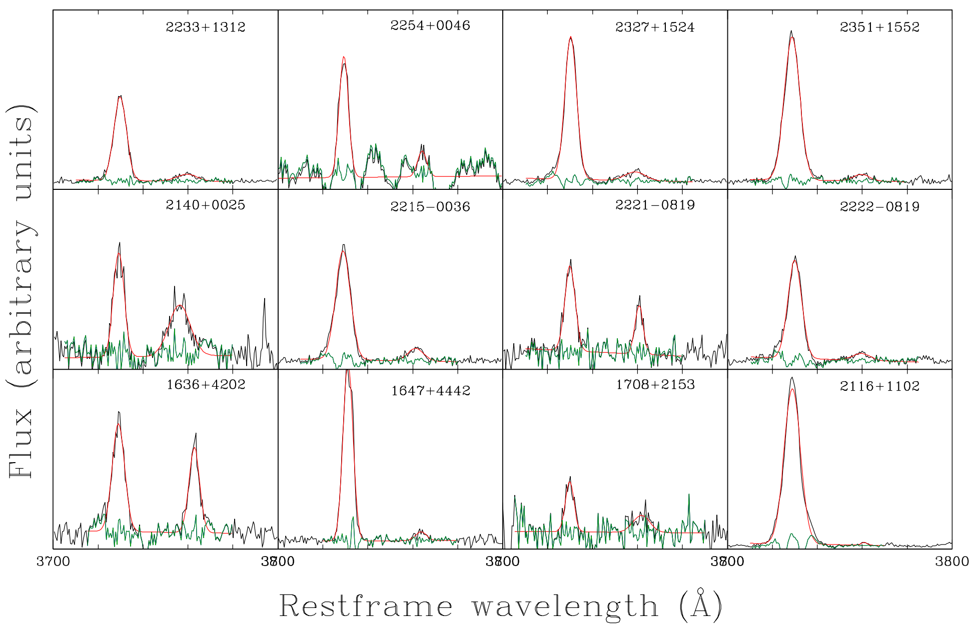
1147+0902
Flux (arbitrary units)
3700
3800
Restframe wavelength (Å)

Figure 15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2221−0819
2222−0819
1636+4202
1647+4442
1708+2153
2116+1102
Flux (arbitrary units)
3700
3800
Restframe wavelength (Å)

Figure 16

8.2 Data Tables

Table 1: [O II] Statistics for all 99 Objects

RA	**Dec**	**[O II] Location (± 0.1 Å)**	**[O II] Width (±1 Å)**	**[O II] Flux (±0.1)**	**[O II] Velocity (km/s)**
22 15 42.29	-00 36 09.6	3729	265	10.52	126.74 ± 0.05
22 21 10.83	-09 06 22.0	3729.9	186	1.51	199.13 ± 0.13
22 22 46.61	-08 19 43.9	3729.9	246	8.81	199.13 ± 0.13
22 33 38.42	+13 12 43.5	3729.8	227	6.92	191.09 ± 0.12
22 54 52.24	+00 46 31.4	3729.3	166	1.94	150.87 ± 0.08
23 51 28.75	+15 52 59.1	3728.7	277	14.48	102.60 ± 0.04
08 13 19.34	+46 08 49.5	3727.8	172	4.57	30.18 ± 0.00
08 11 10.28	+17 39 43.9	3730.9	177	1.72	279.55 ± 0.26
01 21 59.81	-01 02 24.4	3729.7	234	4.29	183.05 ± 0.11
08 45 56.67	+34 09 36.3	3729.2	159	2.34	142.83 ± 0.07
08 54 39.25	+17 41 22.5	3728.2	184	2.48	62.37 ± 0.01
09 23 19.73	+29 46 09.1	3728.7	183	8.55	102.60 ± 0.04
11 16 07.65	+41 23 53.2	3729.7	206	12.33	183.05 ± 0.11
09 36 41.08	+10 14 15.7	3728.7	266	5.59	102.60 ± 0.04
11 32 49.28	+10 17 47.4	3727.4	229	3.92	-2.01 ± 0.00
10 29 25.73	+14 08 23.2	3728.4	240	4.5	78.46 ± 0.02
10 29 46.80	+40 19 13.8	3728.9	230	4.36	118.69 ± 0.05
10 38 33.42	+46 58 06.6	3728.8	193	10.35	110.65 ± 0.04
11 44 29.88	+36 53 08.5	3730.4	196	5.81	239.35 ± 0.19
10 58 28.76	+52 59 29.0	3729.2	201	3.86	142.83 ± 0.07
08 02 43.40	+31 04 03.3	3729.7	179	4.24	183.05 ± 0.11
11 39 08.95	+59 11 54.6	3728.6	188	3.73	94.55 ± 0.03

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Table 1 – *Continued from previous page*

RA	**Dec**	**[O II] Location (± 0.1 Å)**	**[O II] Width (±1 Å)**	**[O II] Flux (±0.1)**	**[O II] Velocity (km/s)**
11 43 44.30	+59 41 12.4	3729.3	176	1.87	150.87 ± 0.08
11 47 55.08	+09 02 28.8	3727.2	229	2.95	-18.11 ± 0.00
12 05 56.01	+49 59 56.4	3728.6	237	23.55	94.55 ± 0.03
08 46 54.09	+25 22 12.3	3728.3	187	1.06	70.42 ± 0.02
12 31 52.04	+45 04 42.9	3728.1	266	10.25	54.32 ± 0.01
12 41 29.42	+37 22 01.9	3728.1	222	11.93	54.32 ± 0.01
08 57 37.77	+05 28 21.3	3727.8	190	2.83	30.18 ± 0.00
08 02 43.40	+31 04 03.3				
12 46 38.74	+51 34 55.9	3728.6	203	8.96	94.55 ± 0.03
13 12 59.59	+26 28 24.0	3728.9	184	0.89	118.69 ± 0.05
16 36 31.28	+42 02 42.5	3729	220	2.27	126.74 ± 0.05
13 53 45.93	+39 51 01.6	3729.9	191	9.32	199.13 ± 0.13
08 31 07.62	+05 21 05.9	3729.3	249	20.54	150.87 ± 0.08
14 23 38.43	+27 20 09.7	3729	196	4.27	126.74 ± 0.05
09 04 36.95	+55 36 02.5	3729.6	192	19.63	175.00 ± 0.10
12 28 11.41	+09 51 26.7	3729.3	251	16.19	150.87 ± 0.08
13 13 48.96	+36 53 57.9	3728.9	193	14.53	118.69 ± 0.05
15 43 51.49	+36 31 36.7	3727.4	260	22.64	-2.01 ± 0.00
09 09 02.35	+13 30 19.4	3725.8	405	1.52	-130.82 ± 0.06
09 21 15.55	+10 17 40.9	3729.1	180	3.91	134.78 ± 0.06
09 23 43.00	+22 54 32.7	3726.3	322	2.99	-90.56 ± 0.03
09 27 18.51	+23 01 12.3	3729.6	224	8.14	175.00 ± 0.10
09 32 40.55	+02 33 32.6	3729.4	192	4.57	158.91 ± 0.08
09 32 59.60	+04 05 06.0	3729.3	191	7.37	150.87 ± 0.08
09 38 12.27	+07 43 40.0	3729.9	218	12.53	199.13 ± 0.13

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Table 1 – *Continued from previous page*

RA	**Dec**	**[O II] Location (± 0.1 Å)**	**[O II] Width (±1 Å)**	**[O II] Flux (±0.1)**	**[O II] Velocity (km/s)**
09 48 38.43	+40 30 43.5	3728.2	194	2.57	62.37 ± 0.01
02 06 15.98	-00 17 29.1	3728.5	211	2.66	86.51 ± 0.02
10 02 18.79	+26 48 05.7	3728.3	201	11.85	70.42 ± 0.02
10 29 01.63	+27 28 51.2	3729.1	201	9.23	134.78 ± 0.06
10 42 52.94	+04 14 41.1	3730.6	189	9.51	255.43 ± 0.22
10 43 26.47	+11 05 24.3				
10 49 25.39	+24 51 23.7	3729.9	216	3	199.13 ± 0.13
11 01 01.78	+11 02 48.8	3730.6	248	66.12	255.43 ± 0.22
11 04 56.03	+43 34 09.1	3728.3	189	5.39	70.42 ± 0.02
11 10 45.97	+11 36 41.7	3727.4	187	4.48	-2.01 ± 0.00
11 18 53.02	+28 27 57.6	3729	277	18.57	126.74 ± 0.05
11 37 04.17	+48 26 59.2	3729.9	232	8.8	199.13 ± 0.13
11 40 54.09	+23 07 44.4	3728.6	193	12.25	94.55 ± 0.03
11 45 45.18	+55 47 59.6	3729.6	215	5.46	175.00 ± 0.10
12 06 26.29	+42 44 26.1	3729.1	198	2.89	134.78 ± 0.06
12 10 44.27	+38 20 10.3	3729.8	208	4.22	191.09 ± 0.12
12 16 07.09	+50 49 30.0	3729.9	288	34.84	199.13 ± 0.13
12 23 24.14	+02 40 44.4	3729.7	223	1.55	183.05 ± 0.11
12 50 42.44	-02 49 31.5	3730.2	225	3.48	223.26 ± 0.17
13 06 19.83	+45 52 24.2	3729	184	5.09	126.74 ± 0.05
13 07 21.93	+09 52 09.3	3730.1	187	4.11	215.22 ± 0.15
13 23 10.39	+27 01 40.4	3730.1	242	9.06	215.22 ± 0.15
08 46 54.09	+25 22 12.3				
13 55 53.52	+38 34 28.5				
14 05 14.86	-02 59 01.2	3730.2	188	1.66	223.26 ± 0.17

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Table 1 – *Continued from previous page*

RA	**Dec**	**[O II] Location (± 0.1 Å)**	**[O II] Width (±1 Å)**	**[O II] Flux (±0.1)**	**[O II] Velocity (km/s)**
14 16 30.82	+01 37 07.9	3728.6	264	15.18	94.55 ± 0.03
14 19 08.30	+07 54 49.6	3730.4	248	12.63	239.35 ± 0.19
14 34 52.45	+48 39 42.8	3729.2	197	14.87	142.83 ± 0.07
14 39 20.80	+09 28 17.9	3728.4	210	8.26	78.46 ± 0.02
15 05 56.55	+03 42 26.3	3729.7	238	8.41	183.05 ± 0.11
15 35 52.40	+57 54 09.3	3728.2	199	4.61	62.37 ± 0.01
15 45 07.53	+17 09 51.1	3729.4	198	5.26	158.91 ± 0.08
15 54 17.42	+32 38 37.6	3728.8	251	18.75	110.65 ± 0.04
00 26 21.29	+00 09 14.9	3728	229	5.98	46.28 ± 0.01
15 57 33.13	+08 30 42.9				
16 05 02.46	+33 05 44.8	3729.8	177	2.33	191.09 ± 0.12
16 06 55.94	+33 24 00.3	3728.3	215	8.11	70.42 ± 0.02
16 11 56.30	+52 11 16.8	3729.2	236	10.61	142.83 ± 0.07
16 47 21.47	+44 42 09.7	3731.2	177	5.7	303.68 ± 0.31
03 53 01.02	-06 23 26.3	3730.3	228	1.56	231.30 ± 0.18
23 27 21.97	+15 24 37.4	3730.2	213	11.08	223.26 ± 0.17
00 13 35.38	-09 51 20.9	3729.8	221	2.25	191.09 ± 0.12
00 38 47.96	+00 34 57.5	3729.5	210	9.12	166.96 ± 0.09
01 09 39.01	+00 59 50.4	3729.7	220	7.37	183.05 ± 0.11
01 50 16.43	+00 57 01.9	3728.4	219	2.85	78.46 ± 0.02
02 12 57.59	+14 06 10.0	3729.4	236	1.82	158.91 ± 0.08
03 01 24.26	+01 10 22.8	3729.7	177	2.55	183.05 ± 0.11
03 01 44.19	+01 15 30.8	3729.3	185	1.82	150.87 ± 0.08
03 10 27.82	-00 49 50.7	3729.7	165	0.91	183.05 ± 0.11
07 31 26.68	+45 22 17.4	3727.9	274	9.07	38.23 ± 0.00

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Table 1 – *Continued from previous page*

RA	**Dec**	**[O II] Location (± 0.1 Å)**	**[O II] Width (±1 Å)**	**[O II] Flux (±0.1)**	**[O II] Velocity (km/s)**
07 35 21.19	+37 52 01.9	3728.9	191	11.6	118.69 ± 0.05
07 37 03.28	+42 44 14.6	3729	200	5.88	126.74 ± 0.05
16 55 14.21	+20 14 42.0	3730.4	291	18.01	239.35 ± 0.19
08 47 48.28	+18 24 39.9				
17 08 59.15	+21 53 08.1	3729.8	153	0.37	191.09 ± 0.12
21 16 46.33	+11 02 37.3	3728.9	293	40.3	118.69 ± 0.05
21 40 54.55	+00 25 38.2	3729.2	195	0.97	142.83 ± 0.07
03 36 02.09	-07 06 17.1	3729.4	225	26.63	158.91 ± 0.08

Table 2: [Fe VII] Statistics for all 99 Objects

RA	**Dec**	**[Fe VII] Location (± 0.1 Å)**	**[Fe VII] Width (±1 Å)**	**[Fe VII] Flux (±0.1)**	**[Fe VII] Velocity (km/s)**
22 15 42.29	-00 36 09.6	3761.3	279	1.29	79.77 ± 0.02
22 21 10.83	-09 06 22.0	3760.7	145	0.68	31.91 ± 0.00
22 22 46.61	-08 19 43.9	3759.6	308	0.78	-55.85 ± 0.01
22 33 38.42	+13 12 43.5	3759.6	354	0.91	-55.85 ± 0.01
22 54 52.24	+00 46 31.4	3764.1	181	0.48	303.01 ± 0.31
23 51 28.75	+15 52 59.1	3759.6	295	0.72	-55.85 ± 0.01
08 13 19.34	+46 08 49.5	3757.6	296	0.64	-215.49 ± 0.15
08 11 10.28	+17 39 43.9	3761.4	210	0.66	87.75 ± 0.03
01 21 59.81	-01 02 24.4	3759.6	312	1.2	-55.85 ± 0.01
08 45 56.67	+34 09 36.3	3760.1	228	1.89	-15.96 ± 0.00
08 54 39.25	+17 41 22.5	3756.8	435	1.19	-279.36 ± 0.26
09 23 19.73	+29 46 09.1	3759.3	311	0.5	-79.79 ± 0.02

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Table 2 – *Continued from previous page*

RA	**Dec**	**[Fe VII] Location (± 0.1 Å)**	**[Fe VII] Width (±1 Å)**	**[Fe VII] Flux (±0.1)**	**[Fe VII] Velocity (km/s)**
11 16 07.65	+41 23 53.2	3759.9	82	0.09	-31.91 ± 0.00
09 36 41.08	+10 14 15.7	3754.8	268	0.56	-439.12 ± 0.64
11 32 49.28	+10 17 47.4	3755.2	398	0.76	-407.16 ± 0.55
10 29 25.73	+14 08 23.2	3759.1	193	0.59	-95.75 ± 0.03
10 29 46.80	+40 19 13.8	3760.3	233	1.03	0.00
10 38 33.42	+46 58 06.6	3759.6	176	1.56	-55.85 ± 0.01
11 44 29.88	+36 53 08.5	3760.9	256	0.61	47.86 ± 0.01
10 58 28.76	+52 59 29.0	3760.5	207	1	15.96 ± 0.00
08 02 43.40	+31 04 03.3	3761.5	228	0.7	95.72 ± 0.03
11 39 08.95	+59 11 54.6	3756.8	416	0.97	-279.36 ± 0.26
11 43 44.30	+59 41 12.4	3759.8	138	0.44	-39.89 ± 0.01
11 47 55.08	+09 02 28.8	3759.6	179	0.63	-55.85 ± 0.01
12 05 56.01	+49 59 56.4	3759.9	215	1.35	-31.91 ± 0.00
08 46 54.09	+25 22 12.3	3759.9	274	0.53	-31.91 ± 0.00
12 31 52.04	+45 04 42.9	3762.7	141	0.2	191.41 ± 0.12
12 41 29.42	+37 22 01.9	3759.6	186	0.42	-55.85 ± 0.01
08 57 37.77	+05 28 21.3	3758.8	268	1.56	-119.70 ± 0.05
08 02 43.40	+31 04 03.3				
12 46 38.74	+51 34 55.9	3760.9	273	1.13	47.86 ± 0.01
13 12 59.59	+26 28 24.0	3759.2	496	0.26	-87.77 ± 0.03
16 36 31.28	+42 02 42.5	3762.8	192	1.58	199.39 ± 0.13
13 53 45.93	+39 51 01.6	3760	141	0.54	-23.94 ± 0.00
08 31 07.62	+05 21 05.9	3759.6	211	0.55	-55.85 ± 0.01
14 23 38.43	+27 20 09.7	3759.9	174	0.77	-31.91 ± 0.00
09 04 36.95	+55 36 02.5	3761.2	243	0.58	71.79 ± 0.02

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Table 2 – *Continued from previous page*

RA	**Dec**	**[Fe VII] Location (± 0.1 Å)**	**[Fe VII] Width (±1 Å)**	**[Fe VII] Flux (±0.1)**	**[Fe VII] Velocity (km/s)**
12 28 11.41	+09 51 26.7	3760.3	134	0.18	0.00
13 13 48.96	+36 53 57.9	3759.1	189	1.59	-95.75 ± 0.03
15 43 51.49	+36 31 36.7	3758.2	259	1.79	-167.59 ± 0.09
09 09 02.35	+13 30 19.4	3758	205	1.67	-183.55 ± 0.11
09 21 15.55	+10 17 40.9	3760.9	311	1.84	47.86 ± 0.01
09 23 43.00	+22 54 32.7	3758.2	332	1.79	-167.59 ± 0.09
09 27 18.51	+23 01 12.3	3759.4	201	0.64	-71.81 ± 0.02
09 32 40.55	+02 33 32.6	3760.1	134	0.89	-15.96 ± 0.00
09 32 59.60	+04 05 06.0	3762.3	205	0.74	159.52 ± 0.08
09 38 12.27	+07 43 40.0	3760.1	34	0.12	-15.96 ± 0.00
09 48 38.43	+40 30 43.5	3760.9	188	0.99	47.86 ± 0.01
02 06 15.98	-00 17 29.1	3758.3	387	0.48	-159.60 ± 0.08
10 02 18.79	+26 48 05.7	3759.4	373	1.28	-71.81 ± 0.02
10 29 01.63	+27 28 51.2	3759.7	392	0.61	-47.87 ± 0.01
10 42 52.94	+04 14 41.1	3761.3	234	1.03	79.77 ± 0.02
10 43 26.47	+11 05 24.3				
10 49 25.39	+24 51 23.7	3759.8	339	1.28	-39.89 ± 0.01
11 01 01.78	+11 02 48.8	3760.7	202	0.63	31.91 ± 0.00
11 04 56.03	+43 34 09.1	3759.9	287	1.33	-31.91 ± 0.00
11 10 45.97	+11 36 41.7	3757.7	298	2.57	-207.50 ± 0.14
11 18 53.02	+28 27 57.6	3758.1	77	0.18	-175.57 ± 0.10
11 37 04.17	+48 26 59.2	3762.8	379	0.38	199.39 ± 0.13
11 40 54.09	+23 07 44.4	3761.1	172	2.13	63.82 ± 0.01
11 45 45.18	+55 47 59.6	3760.7	180	1.04	31.91 ± 0.00
12 06 26.29	+42 44 26.1	3760.6	533	1.62	23.93 ± 0.00

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Table 2 – *Continued from previous page*

RA	Dec	[Fe VII] Location (± 0.1 Å)	[Fe VII] Width (±1 Å)	[Fe VII] Flux (±0.1)	[Fe VII] Velocity (km/s)
12 10 44.27	+38 20 10.3	3761.3	218	1.37	79.77 ± 0.02
12 16 07.09	+50 49 30.0	3761	126	0.39	55.84 ± 0.01
12 23 24.14	+02 40 44.4	3761.4	238	0.61	87.75 ± 0.03
12 50 42.44	-02 49 31.5	3762.6	175	1.95	183.44 ± 0.11
13 06 19.83	+45 52 24.2	3759	114	0.4	-103.73 ± 0.04
13 07 21.93	+09 52 09.3	3762.9	203	0.44	207.36 ± 0.14
13 23 10.39	+27 01 40.4	3774.5	0	0	
08 46 54.09	+25 22 12.3				
13 55 53.52	+38 34 28.5				
14 05 14.86	-02 59 01.2	3759.1	245	2.44	-95.75 ± 0.03
14 16 30.82	+01 37 07.9	3759.5	178	0.66	-63.83 ± 0.01
14 19 08.30	+07 54 49.6	3762.4	337	1.46	167.49 ± 0.09
14 34 52.45	+48 39 42.8	3761.4	309	3.17	87.75 ± 0.03
14 39 20.80	+09 28 17.9	3759.5	391	1.84	-63.83 ± 0.01
15 05 56.55	+03 42 26.3	3761.2	163	0.55	71.79 ± 0.02
15 35 52.40	+57 54 09.3	3759.5	288	1.36	-63.83 ± 0.01
15 45 07.53	+17 09 51.1	3761.8	196	0.37	119.65 ± 0.05
15 54 17.42	+32 38 37.6	3760	256	1.59	-23.94 ± 0.00
00 26 21.29	+00 09 14.9	3758	243	0.25	-183.55 ± 0.11
15 57 33.13	+08 30 42.9				
16 05 02.46	+33 05 44.8	3760.1	255	0.76	-15.96 ± 0.00
16 06 55.94	+33 24 00.3	3761.2	309	3.46	71.79 ± 0.02
16 11 56.30	+52 11 16.8	3762.7	158	0.31	191.41 ± 0.12
16 47 21.47	+44 42 09.7	3763.7	193	0.31	271.13 ± 0.25
03 53 01.02	-06 23 26.3	3761.1	243	1.06	63.82 ± 0.01

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Table 2 – *Continued from previous page*

RA	**Dec**	**[Fe VII] Location (± 0.1 Å)**	**[Fe VII] Width (±1 Å)**	**[Fe VII] Flux (±0.1)**	**[Fe VII] Velocity (km/s)**
23 27 21.97	+15 24 37.4	3758.9	357	1.15	-111.71 ± 0.04
00 13 35.38	-09 51 20.9	3763.1	172	0.34	223.30 ± 0.17
00 38 47.96	+00 34 57.5	3763.3	206	1.43	239.25 ± 0.19
01 09 39.01	+00 59 50.4	3760.4	207	2.11	7.98 ± 0.00
01 50 16.43	+00 57 01.9	3759.5	307	1.15	-63.83 ± 0.01
02 12 57.59	+14 06 10.0	3758.9	243	1.71	-111.71 ± 0.04
03 01 24.26	+01 10 22.8	3757.2	557	0.8	-247.42 ± 0.20
03 01 44.19	+01 15 30.8	3759.8	237	0.91	-39.89 ± 0.01
03 10 27.82	-00 49 50.7	3756.6	233	0.18	-295.33 ± 0.29
07 31 26.68	+45 22 17.4	3758.9	330	0.81	-111.71 ± 0.04
07 35 21.19	+37 52 01.9	3761	83	0.28	55.84 ± 0.01
07 37 03.28	+42 44 14.6	3759	264	1.04	-103.73 ± 0.04
16 55 14.21	+20 14 42.0	3821.7	0	0	
08 47 48.28	+18 24 39.9				
17 08 59.15	+21 53 08.1	3761.7	303	0.25	111.67 ± 0.04
21 16 46.33	+11 02 37.3	3760.8	103	0.25	39.89 ± 0.01
21 40 54.55	+00 25 38.2	3756.3	380	0.93	-319.29 ± 0.34
03 36 02.09	-07 06 17.1	3730.6	0	0	

Table 3: Hβ and [O III] Flux, Logarithmic Black Hole Mass, and σ_*

RA	**Dec**	**Hβ_{narrow} Flux** (±0.1)	**Hβ_{broad} Flux** (±0.1)	**[O III] Flux** (±0.1)	**Log MBH** ($M_\odot$ ±0.5 **dex**)	σ_* **(km/s)**
22 15 42.29	-00 36 09.6	5.127	48.268	70.113	7.69	
22 21 10.83	-09 06 22.0	1.642	38.954	15.716	7.73	115 ± 17
22 22 46.61	-08 19 43.9	6.338	50.414	71.204	7.52	99 ± 8
22 33 38.42	+13 12 43.5	4.92	21.497	39.279	7.77	198 ± 6
22 54 52.24	+00 46 31.4	2.608	22.231	7.599	7.43	
23 51 28.75	+15 52 59.1	5.218	19.038	46.493	7.99	
08 13 19.34	+46 08 49.5	2.043	32.394	21.144	7.43	120 ± 4
08 11 10.28	+17 39 43.9	0.944	27.219	7.701	7.3	136 ± 6
01 21 59.81	-01 02 24.4	2.538	40.264	40.536	7.62	107 ± 11
08 45 56.67	+34 09 36.3	4	29.482	26.74	7.4	121 ± 5
08 54 39.25	+17 41 22.5	2.421	43.555	35.721	7.45	±
09 23 19.73	+29 46 09.1	2.331	21.34	15.543	7.45	143 ± 3
11 16 07.65	+41 23 53.2	2.475	15.171	11.091	7.06	131 ± 4
09 36 41.08	+10 14 15.7	4.951	64.46	49.159	7.46	
11 32 49.28	+10 17 47.4	1.676	45.613	34.274	7.57	
10 29 25.73	+14 08 23.2	3.511	23.551	24.571	7.82	197 ± 5
10 29 46.80	+40 19 13.8	3.098	15.804	28.94	7.66	165 ± 6
10 38 33.42	+46 58 06.6	5.176	1.693	54.327		
11 44 29.88	+36 53 08.5	2.309	49.886	41.018	7.76	155 ± 8
10 58 28.76	+52 59 29.0	1.493	20.574	17.41	7.65	121 ± 3
08 02 43.40	+31 04 03.3	0.746	46.596	22.879	7.55	113 ± 4
11 39 08.95	+59 11 54.6	2.863	52.451	27.013		
11 43 44.30	+59 41 12.4	0.684	34.986	12.493	7.63	121 ± 6
11 47 55.08	+09 02 28.8	3.344	33.372	31.158	8.31	120 ± 18

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Table 3 – *Continued from previous page*

RA	**Dec**	**Hβ_{narrow} Flux** ($\pm$0.1)	**Hβ_{broad} Flux** ($\pm$0.1)	**[O III] Flux** ($\pm$0.1)	**Log MBH** ($M_{\odot}$ $\pm$0.5 **dex**)	σ_* **(km/s)**
12 05 56.01	+49 59 56.4	9.615	28.248	108.152	7.9	166 ± 6
08 46 54.09	+25 22 12.3					
12 31 52.04	+45 04 42.9	2.031	26.709	19.151	7.16	228 ± 7
12 41 29.42	+37 22 01.9	3.864	25.353	39.65	7.5	144 ± 4
08 57 37.77	+05 28 21.3	2.734	56.295	23.606	7.5	127 ± 5
08 02 43.40	+31 04 03.3	2.17	30.433	32.402		
12 46 38.74	+51 34 55.9	2.285	29.977	27.919	6.95	113 ± 5
13 12 59.59	+26 28 24.0	3.692	25.361	3.433	7.56	133 ± 9
16 36 31.28	+42 02 42.5	2.825	28.897	14.103	7.87	144 ± 10
13 53 45.93	+39 51 01.6	5.178	3.723	28.903		168 ± 11
08 31 07.62	+05 21 05.9	6.441	3.017	62.399		201 ± 13
14 23 38.43	+27 20 09.7					128 ± 7
09 04 36.95	+55 36 02.5	9.849	50.662	47.795	7.73	128 ± 9
12 28 11.41	+09 51 26.7	3.075	5.712	32.517		184 ± 10
13 13 48.96	+36 53 57.9	10.241	42.243	80.682		183 ± 24
15 43 51.49	+36 31 36.7	7.804	33.391	108.245	7.65	119 ± 9
09 09 02.35	+13 30 19.4	0.078	46.823	5.262		91 ± 5
09 21 15.55	+10 17 40.9	2.554	21.906	20.564	7.19	98 ± 3
09 23 43.00	+22 54 32.7	9.843	47.73	26.212	7.57	129 ± 6
09 27 18.51	+23 01 12.3	3.573	50.144	40.636	7.04	195 ± 2
09 32 40.55	+02 33 32.6	2.35	37.334	24.536	7.55	124 ± 4
09 32 59.60	+04 05 06.0					96 ± 6
09 38 12.27	+07 43 40.0	2.118	4.296	14.489		124 ± 3
09 48 38.43	+40 30 43.5	2.654	20.736	25.83		140 ± 3
02 06 15.98	-00 17 29.1				8.12	218 ± 6

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Table 3 – *Continued from previous page*

RA	**Dec**	**Hβ_{narrow} Flux** ($\pm$0.1)	**Hβ_{broad} Flux** ($\pm$0.1)	**[O III] Flux** ($\pm$0.1)	**Log MBH** ($M_\odot$ $\pm$0.5 **dex**)	σ_* **(km/s)**
10 02 18.79	+26 48 05.7	3.428	4.554	33.178		154 ± 8
10 29 01.63	+27 28 51.2	3.016	10.978	10.813	6.83	127 ± 6
10 42 52.94	+04 14 41.1	5.796	38.753	21.067	7.12	108 ± 10
10 43 26.47	+11 05 24.3	19.565	62.504	158.242	7.82	
10 49 25.39	+24 51 23.7	3.365	54.71	27.442	8.04	77 ± 17
11 01 01.78	+11 02 48.8	13.974	47.839	113.483	7.98	144 ± 14
11 04 56.03	+43 34 09.1	2.407	28.008	26.887	7.2	91 ± 7
11 10 45.97	+11 36 41.7	2.335	44.813	21.305		
11 18 53.02	+28 27 57.6	3.111	2.358	20.545		119 ± 3
11 37 04.17	+48 26 59.2	4.394	32.761	10.814	6.9	166 ± 7
11 40 54.09	+23 07 44.4	5.868	12.807	52.519		82 ± 2
11 45 45.18	+55 47 59.6	3.543	30.894	27.307	7.36	118 ± 6
12 06 26.29	+42 44 26.1	1.589	75.89	12.279		157 ± 6
12 10 44.27	+38 20 10.3	8.822	45.663	35.246	7.79	144 ± 5
12 16 07.09	+50 49 30.0	13.831	28.615	193.157	7.31	172 ± 7
12 23 24.14	+02 40 44.4	0.406	54.883	8.424	7.16	97 ± 8
12 50 42.44	-02 49 31.5	4.833	41.32	31.226		107 ± 8
13 06 19.83	+45 52 24.2	1.97	6.893	14.746	7.04	100 ± 4
13 07 21.93	+09 52 09.3	1.819	31.544	16.502	7.56	
13 23 10.39	+27 01 40.4	3.172	24.574	39.655	7.49	122 ± 9
08 46 54.09	+25 22 12.3	0.698	37.971	9.713		251 ± 12
13 55 53.52	+38 34 28.5	24.375	0.81	141.15	8.12	
14 05 14.86	-02 59 01.2	2.667	40.446	23.828	7.04	123 ± 4
14 16 30.82	+01 37 07.9	4.371	14.978	58.464	7.36	149 ± 4
14 19 08.30	+07 54 49.6	7.272	25.929	99.617	7.75	185 ± 10

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Table 3 – *Continued from previous page*

RA	**Dec**	**Hβ_{narrow} Flux** ($\pm$0.1)	**Hβ_{broad} Flux** ($\pm$0.1)	**[O III] Flux** ($\pm$0.1)	**Log MBH** ($M_\odot$ $\pm$0.5 **dex**)	σ_* **(km/s)**
14 34 52.45	+48 39 42.8	8.718	54.639	113.678	7.7	114 ± 7
14 39 20.80	+09 28 17.9					
15 05 56.55	+03 42 26.3	4.205	54.602	52.207	7.97	
15 35 52.40	+57 54 09.3	4.677	79.53	65.735	7.99	116 ± 4
15 45 07.53	+17 09 51.1	1.605	22.807	28.325	7.47	171 ± 5
15 54 17.42	+32 38 37.6	6.99	62.023	76.704	7.79	159 ± 4
00 26 21.29	+00 09 14.9	1.391	13.093	5.093	7.16	170 ± 2
15 57 33.13	+08 30 42.9	3.857	43.89	21.146	7.65	
16 05 02.46	+33 05 44.8	1.559	50.272	16.195	7.95	186 ± 8
16 06 55.94	+33 24 00.3	11.159	40.783	93.807	7.53	170 ± 8
16 11 56.30	+52 11 16.8	2.416	8.828	27.958	7.54	120 ± 5
16 47 21.47	+44 42 09.7	1.567	39.392	7.843		
03 53 01.02	-06 23 26.3	1.001	22.686	9.155	7.71	196 ± 11
23 27 21.97	+15 24 37.4	2.576	6.014	59.075	6.97	266 ± 3
00 13 35.38	-09 51 20.9	5.011	30.764	10.435	7.96	134 ± 5
00 38 47.96	+00 34 57.5	5.078	19.775	47.734	7.84	131 ± 6
01 09 39.01	+00 59 50.4	3.793	22.341	55.363	7.38	165 ± 17
01 50 16.43	+00 57 01.9	1.556	43.279	14.481	7.18	193 ± 4
02 12 57.59	+14 06 10.0	2.103	52.348	20.539	7.2	188 ± 4
03 01 24.26	+01 10 22.8	1.841	23.766	8.016		97 ± 4
03 01 44.19	+01 15 30.8	1.625	34.377	25.251	7.51	90 ± 6
03 10 27.82	-00 49 50.7	0.443	35.847	7.517	7.93	
07 31 26.68	+45 22 17.4	7.997	44.031	58.752	7.56	
07 35 21.19	+37 52 01.9					156 ± 23
07 37 03.28	+42 44 14.6	4.377	39.574	31.73	7.67	90 ± 18

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Table 3 – *Continued from previous page*

RA	**Dec**	**Hβ_{narrow} Flux** (±0.1)	**Hβ_{broad} Flux** (±0.1)	**[O III] Flux** (±0.1)	**Log MBH** ($M_\odot$ ±0.5 **dex**)	σ_* **(km/s)**
16 55 14.21	+20 14 42.0					199 ± 6
08 47 48.28	+18 24 39.9	4.265	7.288	16.756		
17 08 59.15	+21 53 08.1	0.718	32.616	6.177	8.12	172 ± 13
21 16 46.33	+11 02 37.3	12.87	35.562	182.467	7.9	
21 40 54.55	+00 25 38.2	1.616	31.641	5.654	7.61	71 ± 28
03 36 02.09	-07 06 17.1	6.512	15.96	42.605	7.4	246 ± 3

Table 4: Flux Ratios

RA	**Dec**	**[O II]/[Fe VII]** (±0.99)	**[O III]/Hβ_{broad}** (±0.99)	**Hβ_{broad}/Hβ_{narrow}** (±0.99)
22 15 42.29	-00 36 09.6	8.16	13.68	9.41
22 21 10.83	-09 06 22.0	2.22	9.57	23.72
22 22 46.61	-08 19 43.9	11.29	11.23	7.95
22 33 38.42	+13 12 43.5	7.60	7.98	4.37
22 54 52.24	+00 46 31.4	4.04	2.91	8.52
23 51 28.75	+15 52 59.1	20.11	8.91	3.65
08 13 19.34	+46 08 49.5	7.14	10.35	15.86
08 11 10.28	+17 39 43.9	2.61	8.16	28.83
01 21 59.81	-01 02 24.4	3.58	15.97	15.86
08 45 56.67	+34 09 36.3	1.24	6.69	7.37
08 54 39.25	+17 41 22.5	2.08	14.75	17.99
09 23 19.73	+29 46 09.1	17.10	6.67	9.15

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Table 4 – *Continued from previous page*

RA	**Dec**	**[O II]/[Fe VII]** (±0.99)	**[O III]/H**β_{broad} (±0.99)	**H**β_{broad}/**H**β_{narrow} (±0.99)
11 16 07.65	+41 23 53.2	137.00	4.48	6.13
09 36 41.08	+10 14 15.7	9.98	9.93	13.02
11 32 49.28	+10 17 47.4	5.16	20.45	27.22
10 29 25.73	+14 08 23.2	7.63	7.00	6.71
10 29 46.80	+40 19 13.8	4.23	9.34	5.10
10 38 33.42	+46 58 06.6	6.63	10.50	0.33
11 44 29.88	+36 53 08.5	9.52	17.76	21.61
10 58 28.76	+52 59 29.0	3.86	11.66	13.78
08 02 43.40	+31 04 03.3	6.06	30.67	62.46
11 39 08.95	+59 11 54.6	3.85	9.44	18.32
11 43 44.30	+59 41 12.4	4.25	18.26	51.15
11 47 55.08	+09 02 28.8	4.68	9.32	9.98
12 05 56.01	+49 59 56.4	17.44	11.25	2.94
08 46 54.09	+25 22 12.3	2.00		
12 31 52.04	+45 04 42.9	51.25	9.43	13.15
12 41 29.42	+37 22 01.9	28.40	10.26	6.56
08 57 37.77	+05 28 21.3	1.81	8.63	20.59
08 02 43.40	+31 04 03.3		14.93	14.02
12 46 38.74	+51 34 55.9	7.93	12.22	13.12
13 12 59.59	+26 28 24.0	3.42	0.93	6.87
16 36 31.28	+42 02 42.5	1.44	4.99	10.23
13 53 45.93	+39 51 01.6	17.26	5.58	0.72
08 31 07.62	+05 21 05.9	37.35	9.69	0.47
14 23 38.43	+27 20 09.7	5.55		
09 04 36.95	+55 36 02.5	33.84	4.85	5.14

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Table 4 – *Continued from previous page*

RA	**Dec**	**[O II]/[Fe VII]** (±0.99)	**[O III]/H**β_{broad} (±0.99)	**H**β_{broad}/**H**β_{narrow} (±0.99)
12 28 11.41	+09 51 26.7	89.94	10.57	1.86
13 13 48.96	+36 53 57.9	9.14	7.88	4.12
15 43 51.49	+36 31 36.7	12.65	13.87	4.28
09 09 02.35	+13 30 19.4	0.91	67.46	600.29
09 21 15.55	+10 17 40.9	2.13	8.05	8.58
09 23 43.00	+22 54 32.7	1.67	2.66	4.85
09 27 18.51	+23 01 12.3	12.72	11.37	14.03
09 32 40.55	+02 33 32.6	5.13	10.44	15.89
09 32 59.60	+04 05 06.0	9.96		
09 38 12.27	+07 43 40.0	104.42	6.84	2.03
09 48 38.43	+40 30 43.5	2.60	9.73	7.81
02 06 15.98	-00 17 29.1	5.54		
10 02 18.79	+26 48 05.7	9.26	9.68	1.33
10 29 01.63	+27 28 51.2	15.13	3.59	3.64
10 42 52.94	+04 14 41.1	9.23	3.63	6.69
10 43 26.47	+11 05 24.3		8.09	3.19
10 49 25.39	+24 51 23.7	2.34	8.16	16.26
11 01 01.78	+11 02 48.8	104.95	8.12	3.42
11 04 56.03	+43 34 09.1	4.05	11.17	11.64
11 10 45.97	+11 36 41.7	1.74	9.12	19.19
11 18 53.02	+28 27 57.6	103.17	6.60	0.76
11 37 04.17	+48 26 59.2	23.16	2.46	7.46
11 40 54.09	+23 07 44.4	5.75	8.95	2.18
11 45 45.18	+55 47 59.6	5.25	7.71	8.72
12 06 26.29	+42 44 26.1	1.78	7.73	47.76

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Table 4 – *Continued from previous page*

RA	**Dec**	**[O II]/[Fe VII]** (±0.99)	**[O III]/H**β_{broad} (±0.99)	**H**β_{broad}**/H**β_{narrow} (±0.99)
12 10 44.27	+38 20 10.3	3.08	4.00	5.18
12 16 07.09	+50 49 30.0	89.33	13.97	2.07
12 23 24.14	+02 40 44.4	2.54	20.75	135.18
12 50 42.44	-02 49 31.5	1.78	6.46	8.55
13 06 19.83	+45 52 24.2	12.73	7.49	3.50
13 07 21.93	+09 52 09.3	9.34	9.07	17.34
13 23 10.39	+27 01 40.4		12.50	7.75
08 46 54.09	+25 22 12.3		13.92	54.40
13 55 53.52	+38 34 28.5		5.79	0.03
14 05 14.86	-02 59 01.2	0.68	8.93	15.17
14 16 30.82	+01 37 07.9	23.00	13.38	3.43
14 19 08.30	+07 54 49.6	8.65	13.70	3.57
14 34 52.45	+48 39 42.8	4.69	13.04	6.27
14 39 20.80	+09 28 17.9	4.49		
15 05 56.55	+03 42 26.3	15.29	12.42	12.99
15 35 52.40	+57 54 09.3	3.39	14.05	17.00
15 45 07.53	+17 09 51.1	14.22	17.65	14.21
15 54 17.42	+32 38 37.6	11.79	10.97	8.87
00 26 21.29	+00 09 14.9	23.92	3.66	9.41
15 57 33.13	+08 30 42.9		5.48	11.38
16 05 02.46	+33 05 44.8	3.07	10.39	32.25
16 06 55.94	+33 24 00.3	2.34	8.41	3.65
16 11 56.30	+52 11 16.8	34.23	11.57	3.65
16 47 21.47	+44 42 09.7	18.39	5.01	25.14
03 53 01.02	-06 23 26.3	1.47	9.15	22.66

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Table 4 – *Continued from previous page*

RA	**Dec**	**[O II]/[Fe VII]** (±0.99)	**[O III]/H**β_{broad} (±0.99)	**H**β_{broad}/**H**β_{narrow} (±0.99)
23 27 21.97	+15 24 37.4	9.63	22.93	2.33
00 13 35.38	-09 51 20.9	6.62	2.08	6.14
00 38 47.96	+00 34 57.5	6.38	9.40	3.89
01 09 39.01	+00 59 50.4	3.49	14.60	5.89
01 50 16.43	+00 57 01.9	2.48	9.31	27.81
02 12 57.59	+14 06 10.0	1.06	9.77	24.89
03 01 24.26	+01 10 22.8	3.19	4.35	12.91
03 01 44.19	+01 15 30.8	2.00	15.54	21.16
03 10 27.82	-00 49 50.7	5.06	16.97	80.92
07 31 26.68	+45 22 17.4	11.20	7.35	5.51
07 35 21.19	+37 52 01.9	41.43		
07 37 03.28	+42 44 14.6	5.65	7.25	9.04
16 55 14.21	+20 14 42.0			
08 47 48.28	+18 24 39.9		3.93	1.71
17 08 59.15	+21 53 08.1	1.48	8.60	45.43
21 16 46.33	+11 02 37.3	161.20	14.18	2.76
21 40 54.55	+00 25 38.2	1.04	3.50	19.58
03 36 02.09	-07 06 17.1		6.54	2.45

Table 5: Averages with Standard Deviations from the Mean

[O II] Location	**[O II] Width**	**[O II] Flux**	**[Fe VII] Location**	**[Fe VII] Width**	**[Fe VII] Flux**
3729.1 ± 0.9	216 ± 38	8.5 ± 9.2	3760.5 ± 7.2	240 ± 105	1.0 ± 0.7

Table 6: Averages with Standard Deviations from the Mean

[Fe VII] Velocity	**[O II] Velocity**	**H**β_{narrow} **Flux**	**H**β_{broad} **Flux**	**[O III] Flux**	**Log MBH**	σ_*
-19.7 ± 138.2	136.0 ± 74.3	4.3 ± 3.9	32.5 ± 17.1	39.4 ± 37.2	7.56 ± 0.32	144 ± 41

8.3 Python Code

```
# FIRST SCRIPT: APPLY MASKS TO EMISSION SPECTRUM FOR STELLAR SUBTRACTION
# Import various subroutines
import vnb_vdfit as vd
from vnb_mostools import resolution
from vnb_vdfit import vnb_velocity_dispersion as vnbvd
from vnb_mostools import vnb_spectools as vnbst
import pyfits,scipy,glob
import numpy as np

DEFAULT_RMASK  = [[3715,3740],[3750,3770]];

# Get redshift of objects from file "objectlist.txt"
def getz(ob):
  rf = open("objectlist.txt").readlines();
  for line in rf:
    if line[0]!='L': continue;
    obname,z = line.split()[0], line.split()[9];
    if obname==ob:
      z=float(z);
      break;
  return z;


def asktoredo(ob,dispguess,velguess,rmask,wfn,\
              commentfilename="vel_mbh_comments.txt"):
  # After fit_vel_mbh shows you the fit to your initial guess, this will allow
  # you to make adjustments on the fly. I use this so that I can have a huge
  # file that calls fit_vel_mbh for each object, and I don't want to
  # stop and start the program every time the initial guess isn't the right
  # one.

  # initialize return variables
  # new goes like [disp,vel,rmask]
  new = [DEFAULT_RMASK];

  # use raw_input() rather than input() to pass strings without quotes
  redo = "undefined";
  while (redo not in ['y','Y','yes','n','N','no']):
    redo = raw_input("Would you like to refit? (y/n) ");
```

```
  if redo in ['y','Y','yes']:
    #which = "undefined";  # initialize as garbage
    #while (which not in ["disp","0","vel","1","rmask","2"]):
      #print "Enter disp (or 0), vel (or 1), or rmask (or 2)...";
      #which = raw_input("...What would you like to change? ");

    #if which in ["rmask","2"]: print "current mask: ",rmask;

    newguess = input("New value for rmask: ");     # use input() to pass lists
    #if   which in ["disp","0"]:  new[0]=newguess;
    #elif which in ["vel","1"]:   new[1]=newguess;
    #elif which in ["rmask","2"]: new[2]=newguess;
    new=newguess
    #else:                        print "No parameters have been changed."

    # refit
    fit_vel_mbh(ob,dispguess=dispguess,velguess=velguess,rmask=new,wfn=wfn);
    asktoredo(ob, dispguess, velguess, new, wfn);
  ## IF USER DOES NOT WANT TO REFIT ##
  #else:
    #comments = raw_input("Comments about this fit?:  ")
    #commentfile = open(commentfilename,'a');
    #if comments not in ['n',"no","None"]: commentfile.write("ob\n"+comment+"\n")


def getguess(ob):
  # This sets up an initial guess of the velocity dispersion and velocity
  # for the object based on my measurement from the MgIb region,
  # or the CaHK region if the MgIb region didn't allow for a measurement
  # of sigma due to redshift shortening

  if 'L' not in ob:
    obnum=ob;
    ob='L%s'%ob
  else:
    obnum=ob[1:]

  rfn_g = 'apdisps_mg1b_center.txt'
  rf_g = open(rfn_g).readlines()
```

```
found = False
for line in rf_g:
  obname=line.split()[0];
  if 'L' in obname: obname=obname[1:];
  if obname==obnum:
    cendisp, cenvel = float(line.split()[1]), float(line.split()[2])
    cendispul = 1
    cenvelul = 1
    found = True

if not found:
  rfn_b = 'apdisps_cahk_center.txt'
  rf_b = open(rfn_b).readlines()
  for line in rf_b:
    obname=line.split()[0];
    if 'L' in obname: obname=obname[1:];
    if obname==obnum:
      cendisp, cenvel = float(line.split()[1]), float(line.split()[2])
      cendispul = 1
      cenvelul = 1
      found = True

if not found:
  rfn_b = 'apdisps_cat_center.txt'
  rf_b = open(rfn_b).readlines()
  for line in rf_b:
    obname=line.split()[0];
    if 'L' in obname: obname=obname[1:];
    if obname==obnum:
      cendisp, cenvel = float(line.split()[1]), float(line.split()[2])
      cendispul = 1
      cenvelul = 1
      found = True


if not found:
  cendisp, cenvel = 200., 0.
  cendispul = 150
  cenvelul = 400
```

```
    print "object not found, set cendisp=200, cenvel=0"

  # Return a dictionary for easier retrieving later -- it might be that
  # the default dispersion guess is fine while the velocity guess isn't,
  # or vice versa (see fit_vel_mbh).
  Guess = { 'disp': [cendisp, cendisp-cendispul, cendisp+cendispul],
  'vel': [cenvel, cenvel-cenvelul, cenvel+cenvelul] }
  return Guess


def fit_vel_mbh(ob,dispguess=None,velguess=None,\
                rmask=DEFAULT_RMASK,wfn='starsub_fitresults.txt'):
  # ob        ::= object name, as a string. "L#" or "#"
  # dispguess ::= guess of dispersion [guess, lower limit, upper limit]
  # velguess  ::= guess of velocity [guess, lower limit, upper limit]
  # rmask     ::= wavelength intervals to be masked, rest-frame
  # wfn       ::= file name to write results to (will be appended,
  #               not overwritten)

  if 'L' not in ob: obnum = ob ; ob='L%s'%ob
  else:             obnum = ob[1:]

  # Name of the spectrum's FITS file
  feiifiles = glob.glob('feiiDATfiles/s%s04FeII.dat'%obnum)+\
              glob.glob('feiiDATfiles/n%s04FeII.dat'%obnum);
  hasfeii = len(feiifiles)==2; print "needs FeII subtraction{}".format(hasfeii)
  if hasfeii: file=feiifiles; fitsfile='mbh_1Dspectra/%s_blue_mbh.fits'%ob;
  else:       file = 'mbh_1Dspectra/%s_blue_mbh.fits'%ob
  outname = 'mbh_subspectra/%s_sub_mbh.fits'%ob

  # Calculate the resolution of the science data automagically
  #res = resolution.get_resolution(file)
  if hasfeii: res = resolution.get_line_resolution(5577,fitsfile)
  else:       res = resolution.get_line_resolution(5577,file)
  # or set the resolution of science data by hand
  #res = 50.
  #Redshift of object
  z = getz(ob)
```

```
# You can leave dispguess and velguess as None
# and use those with preset upper and lower limits
DefaultGuess = getguess(obnum)
if dispguess==None: dispguess = DefaultGuess['disp'] ; print "retrieved
disp{}".format(dispguess)
if velguess==None:  velguess = DefaultGuess['vel']   ; print "retrieved
vel{}".format(velguess)
# Guess of velocity dispersion and range of prior
vdisp, vdisp1, vdisp2 = dispguess
# Guess of initial velocity
vel, vel1, vel2 = velguess

# Regions to fit
#regions = [[4500,5450]]
#regions = [[3700,4300]]
regions = [[3700,3800]]
# Order of polynomial continuum -- use lowest possible order; 1-3
fit = 2
# Calculate template resolution -- probably does not need to be changed!!
tres = 1.2*299792./(0.5*(regions[0][0]+regions[-1][1]))
tres /= 2.355
# Choose which templates to fit to
#tmps = vd.INDOTEMPS
tmps = vd.INDOTEMPS
# Regions to be masked in the observed frame
omask = [[5887.5,5898],[5573,5581]]
# Regions to be masked in the rest frame
#rmask = [[5195,5202],[4821,5023]]
#rmask = [[4678,4695],[4840,5020],[5154,5164],[5194,5205],[5305,5313]]
#rmask = [[5154,5161],[5194,5201],[5305,5313],[4678,4690],[4780,5040]]
#output name of spectra - model - continuum

#res=90.

# Run the code
a = vnbvd.pipeline(file,tmps,z,res,tres,fit,regions,sigma=vdisp,s1=vdisp1,s2=vdis
omask=omask,rmask=rmask,v1=vel1,v2=vel2,vel=vel)

# Print sigma, vel, sigma_err, vel_err
sigma_err,vel_err = a['errors']
```

```
  print "{0:<7.2f} {1:<7.2f} {2:<9.2f} {3:<9.2f}".format(a['sigma'],a['vel'],
  sigma_err, vel_err)
  print "{0:<7.2f}".format(res)

  # Stellar fraction
  sfs = np.ones(len(a['model']))-a['continuum']/a['model']
  avgsf = sum(sfs)/float(len(sfs))
  stdvsf = ( sum( sfs**2-(avgsf*np.ones(len(sfs)))**2 )/(len(sfs)-1) )**(0.5)
  sf_erronmean = stdvsf/np.sqrt(len(sfs))

  # Make plots
  vd.plot(a)
  #vd.showContours(a)
  #vd.showVel(a)
  #vd.showSigma(a)

  cond = (a['fullwave']>=a['wave'][0])&(a['fullwave']<=a['wave'][-1])
  spec = a['fullsci'][cond]-a['model']
  wave = a['wave']
  varspec = a['var'][cond]

  #vnbst.create_spec(spec,wave,outname,clobber=True)
  vnbst.make_spec(spec,varspec,wave,outname,clobber=True)

  # Print results
  #dowrite = raw_input("Would you like to save these results? y/n: ")
  #if dowrite=='y':
  wf = open(wfn,'a')
  newline = "{0:<9} {1:>9.2f} {2:>9.2f} {3:>6.2f} {4:>6.2f}".format\
            (obnum,a['sigma'],sigma_err,a['vel'],vel_err) +\
            "{0:>12.4f} {1:>18} {2:>12}".format\
            (z,regions,fit) +\
            "{0:>11.4f} {1:>8.4f} {2:<30}    {3:<100}".format\
            (avgsf,stdvsf,omask,rmask)+\
            "{0:10.2f} {1:10.2f} {2:10.2f} {3:10.2f}\n".format\
            (dispguess[1],dispguess[2],velguess[1],velguess[2])
  wf.write(newline)


def do_subtraction(ob,dispguess=None,velguess=None,\
```

```
                rmask=DEFAULT_RMASK,wfn='starsub_fitresults.txt'):
  fit_vel_mbh(ob,dispguess=dispguess,velguess=velguess,rmask=rmask,wfn=wfn);
  asktoredo(ob,dispguess,velguess,rmask,wfn);


def main():
  # Object List
  objects = ['L100','L102','L103','L106','L108','L109','L10','L114','L11','L126'
,'L130','L138','L13','L143','L14','L155','L156','L157','L15','L162','L16'
,'L174','L177','L180','L187','L18','L196','L197','L19','L1','L202','L204',
'L205','L207','L208','L209','L20','L210','L213','L214','L21','L22','L23','L24',
'L25','L26','L27','L28','L29','L2','L30','L31','L32','L34','L35','L36','L37','L38'
'L39','L40','L41','L42','L43','L44','L45','L46','L47','L48','L49','L4','L51','L52'
'L53','L54','L55','L56','L57','L58','L59','L5','L61','L62','L63','L64','L6','L70',
,'L73','L74','L76','L77','L78','L79','L80','L81','L82','L83','L88','L91','L96','L9

  for ob in objects:
    do_subtraction(ob);

if __name__=='__main__': main()

------------------------------------------------------------------------------------------

# SECOND SCRIPT: FIT GAUSSIANS TO EMISSION LINES
# Import various subroutines
import numpy,pylab,pyfits,sys
import special_functions as sf
from scipy import optimize as optim
from scipy.special import gamma
from mostools import spectools as st


#### THINGS THE USER WILL BE PLAYING WITH ####

## Command-line inputs: ##
# Input arguments go:
# 1(Object Number)
# 2(write or don't write -- y/[n])
# 3(lower fit bound,'lo') 4(upper fit bound,'hi')
# 5(lower sig bound,'wl') 6(upper sig bound,'wh')
```

```
# defaults = [object,write?,lo,hi]
defaults = ['00','n',3700,3800]

# Set variables to either their default values or the user-specified value
varlist = [sys.argv[1]]    # initialize varlist with the object number
# check for whether to write
if (len(sys.argv)>2) and (sys.argv[2]=='y'):
    varlist.append(sys.argv[2])
else:
    varlist.append(defaults[1])
# check all other parameters (fit bounds, sig bounds, fit orders)
#for i in range(3,9):
for i in range(3,5):
    if (i>len(sys.argv)-1) or (sys.argv[i]=='0'):
        varlist.append(defaults[i-1])
    else:
        varlist.append(int(sys.argv[i]))

# use varlist to initialize these variables
obj,dowrite,lo,hi = varlist
print varlist

# Information for the plots:
title = '' #title for plot
y1 = -0.1 #flux limits y1 for plot
y2 = 2.5 # flux limits y2 for plot 0.8

# Get the full spectrum from list of objects
filename = 'stellarsuboii/mbh_subspectra/L%s_sub_mbh.fits'%obj
fullIm = pyfits.open(filename)
wave = st.wavelength(filename,1)
spec = fullIm[1].data.copy()
noise = fullIm[3].data**(0.5)

# Isolate the part of the spectrum that we want to fit
cond = (wave>lo)&(wave<hi)    # places where wave is within our limits
specn = spec[cond]            # spectrum in these limits
waven = wave[cond]            # wavelength in these limits
noisen = noise[cond]          # noise in these limits
```

```
# Define the model (for fitting)
def model(parameters,w,s,n,\
          dofit=True,getFit=False):
    # The parameters could change each time
    OiiLoc1,OiiWid1,FeviiLoc1,FeviiWid1 = parameters

    # Additional Constraints
    if dofit:
        if OiiWid1<0.:
            return s/n
        if FeviiWid1<0.:
            return s/n


    # The model is:
    #   first order polynomial ‘continuum’
    #   Oii (gaussian)

    #   That’s 2+1 components
    Model = numpy.empty((4,w.size))

    # First order polynomial continuum
    Model[0] = 1.
    Model[1] = numpy.linspace(0.,1.,Model.shape[1])

    # Oii
    Model[2] = numpy.exp(-0.5*(OiiLoc1-w)**2/OiiWid1**2)

    # Fevii
    Model[3] = numpy.exp(-0.5*(FeviiLoc1-w)**2/FeviiWid1**2)

    lhs = (Model/n).T


    # Create fake data so non-negative is meaningful (ie ensure that the
    #   polynomial coefficients will be greater than 1 by adding a bias)
    data = s+5*Model[0]+5*Model[1]
    rhs = data/n
```

```
    # Perform the linear fit to find the weight of each component
    sol,chi = optim.nnls(lhs,rhs)

    sol[:2] -= 5 # Remove the bias from the polynomial weights

    if getFit:
        return (Model.T*sol).T,sol

    if dofit:
        M = (Model.T*sol).sum(1)
        return (M-s)/n

    return (Model.T*sol).sum(1)

# Define the initial guess
zp = 0.          # set continuum to zero, was already subtracted
Oii1Amp = 9.     # fit 5007 with two gaussians
Oii1Loc = 3727.
Oii1Wid = 5.
Fevii1Amp= 0.5
Fevii1Loc = 3760.
Fevii1Wid = 5.

pars = [Oii1Loc,Oii1Wid,Fevii1Loc,Fevii1Wid]
coeff,ier = optim.leastsq(model,pars,(waven,specn,noisen))

chi2 = (model(coeff,waven,specn,noisen)**2).sum()
print "%5.3f  --  chi^2"%(chi2)

# Get the best fit
fitModel,solution = model(coeff,waven,specn,noisen,getFit=True)


# Calculate flux ratios
#flux_nHbeta = solution[2]*(2*numpy.pi*coeff[1]**2)**0.5
flux_nOii = solution[2]*(2*numpy.pi*coeff[1]**2)**0.5 # This is just 3727
print "%5.1f  --  flux of [OII] "%(flux_nOii)
flux_nFevii = solution[3]*(2*numpy.pi*coeff[3]**2)**0.5 # This is just 3760
print "%5.1f  --  flux of [FeVII] "%(flux_nFevii)
```

```
#print locations of central peak
#print "%5.1f -- velocity offset of [OII]_center (km/s)"%((coeff[0]-3727.43)/
3727.43*299792)
print "%5.1f -- location of [OII]_center (Angstroms)"%(coeff[0])
print "%5.1f -- location of [FeVII]_center (Angstroms)"%(coeff[2])


# The line widths are trivial because of the model; the second moment doesn't
#    mean anything
sigmaOii = (299792*coeff[1]/coeff[0])
print "%5.1f  --  \sigma [OII]_center (km/s)"%(sigmaOii)
sigmaFevii = (299792*coeff[3]/coeff[2])
print "%5.1f  --  \sigma [FeVII]_center (km/s)"%(sigmaFevii)

#### PLOT ####
# Import plotting scripts
import pylab
fit = fitModel.sum(0)
diff = specn-fit
pylab.plot(waven,specn,'k') #plots data in black
pylab.plot(waven,fit,'r')   #overplots total fit in red
pylab.plot(waven,diff,'b')  #overplots (data-totalfit) in blue
pylab.xlim(lo,hi)
pylab.title(title)
pylab.ylabel('Flux (arbitrary units)')
pylab.xlabel('Wavelength ($\AA$)')

pylab.figure()
pylab.plot(waven,fit,'k',label='total fit')
pylab.plot(waven,fitModel[2],'g',label='Oii')
pylab.plot(waven,fitModel[3],'b',label='Fevii')
pylab.xlim(lo,hi)
pylab.title(title)
pylab.ylabel('Flux (arbitrary units)')
pylab.xlabel('Wavelength ($\AA$)')
pylab.legend(loc="upper right")

pylab.show()
```

```
#### PRINT RESULTS ####

ofile_pref = 'oiifit_outputDATfiles/%s_'%obj
# Write the data to disk
ofile = ofile_pref+"onegaussdata.dat"
f = open(ofile,'w')
for i in range(wave.size):
    f.write('%8.3f  %.4e\n'%(wave[i],spec[i]))
f.close()
# Write the fit to disk
ofile = ofile_pref+"onegaussfit.dat"
f = open(ofile,'w')
for i in range(waven.size):
    f.write('%8.3f  %.4e\n'%(waven[i],fit[i]))
f.close()
# Write the residual to disk
ofile = ofile_pref+"onegaussresid.dat"
f = open(ofile,'w')
for i in range(waven.size):
    f.write('%8.3f  %.4e\n'%(waven[i],diff[i]))
f.close()
#write the Fevii fit to disk
ofile = ofile_pref+"feviiwingfit.dat"
f = open(ofile,'w')
for i in range(waven.size):
    f.write('%8.3f  %.4e\n'%(waven[i],fitModel[3,i]))
f.close()


writefile = open('oiifevii_results.txt','a')
if dowrite == 'y':
    # write all of the relevant output information
    # NOTE: If you modify this part, take care to keep the assigned spacing
    # for each entry
    newline = '{0:5}{1:6}{2:6}{3:8.1f}{4:10.1f}{5:10.2f}{6:8.1f}{7:8.1f}{8:8.2f}
    {9:10.3f}'.format\
              (obj,lo,hi,coeff[0],sigmaOii,flux_nOii,coeff[2],sigmaFevii,flux_nFevi
```

```
# also record if these parameters were changed from their default value
#initvars = [HbAmp,HbLoc,HbWid,OiiAmp,OiiLoc,OiiWid,Loc,Wid,Amp,x1]
#varlabels = ['HbAmp','HbLoc','HbWid','OiiAmp','OiiLoc','OiiWid','Loc','Wid','
#defaultvals = [1.7,4861.332,1.,9.,5006.85,1.,4861.332,35.,1.,0.]
#for i in range(len(initvars)):
#    var = initvars[i]
#    label = varlabels[i]
# defval = defaultvals[i]
# if var != defval:
#     newline = newline+'{0:10}{1:15.10f}'.format(label,val)

writefile.write(newline+"\n")
```