**Project Description**

One of the biggest questions in astronomy and astrophysics is “How do galaxies form?” Because of the large time scales involved in the formation of galaxies, the only way to learn about the formation of galaxies is through studying galaxies outside the Milky Way by observation and simulation. In the late 20th century astronomers began observing and investigating galaxies that contain supermassive black holes in their center that produce more light than all of the stars within the galaxy. These galaxies are hosts active galactic nuclei (AGN). An active galactic nucleus is divided into several regions, based mainly on the distance from the central black hole. One of the outermost regions of an AGN is the narrow line region, which typically have a diameter on the order of 100,000,000 times the distance from the Earth to the Sun. I will be running simulations of the narrow line region of a specific type of AGN galaxy. With the data from these simulations, I will make graphs that show how bright the region is at different wavelengths of light. For example, a graph may show that the narrow line region may have brighter blue light than red light. The results from my research should provide a greater insight into the structure of the narrow line region, which can be used in conjunction with other research to help answer the question of galactic formation.

A noteworthy characteristic of the NLR in Seyfert galaxies is the similarity between their emission spectra. In many older models, this meant that the ratio of ionizing photons to particles (known as the ionization parameter) was nearly constant. Groves et al. established a new paradigm for modeling the narrow line region in Seyfert galaxies. In the past, photoionization models did not account for the effects of dust and radiation pressure on the emission spectra. Interstellar dust also absorbs photons, meaning that it can prevent all the atoms in gas clouds in the NLR from ionizing and producing a complete emission spectrum. Groves et al. introduced dusty, radiation pressure-dominated photoionization models, which were shown to accurately fit observed data without the introduction of arbitrary assumptions and parameters. After using dusty models became prevalent, researchers looked into what the shape of the dust cloud takes.

When Groves et al. established this new paradigm, they used the dust grain compositions and size distributions that were consistent with the solar neighborhood, which even then they noted as not applicable to more detailed models of the NLR. Research has shown that the distribution of dust in AGN is not smooth and uniform. The most common model presently is a dusty torus that surrounds the central supermassive black hole (Nenkova et al. 2002). However, this model does not account for dust emission from the NLR, due to the distance between the region and the central black hole (Groves et al. 2006). Current research has not established the shapes of the dust clouds in the NLR. To account for this, Groves et al. instead used the general shape of the gas clouds in the NLR, then determined the total dust-to-gas mass ratio by using the depletion of heavy elements onto dust. Another parameter that they constrain is the distribution of dust grain size using a power law. This allowed for the variation of dust sizes, which effects the amount that the emission spectrum of an object is changed when accounted for dust. However, Groves et al. only used a single power law index to model their SED, which seems too simple when trying to fit the model to the entire domain of the SED.

Modern day models often plot the spectral energy distribution (SED) using three different power law indices (the value that a number is raised to in a power law function), which provide the slopes connecting the different ranges of light (Tananbaum et al. 1979). The three power law indices used today are αx, which describes the slope of the x-ray spectrum of light, α­ uv, which connects light from the optical spectrum to light from the ultraviolet (UV) spectrum, and αox which connects the optical spectrum to the x-ray spectrum (Grupe et al. 2010).

In 1998, Grupe et al. noted that the spectral slopes αx and αox are correlated. Since then, multiple papers have commented on the correlations between the x-ray spectral slope αx and the ultraviolet spectral slope αUV and between the x-ray spectral slope and optical-to-x-ray spectral slope in the narrow line region of Seyfert galaxies. AGN with steeper αx tend to have weaker x-ray emission lines than AGN with flatter αx (Grupe et al. 2010). However, research into this correlation is lacking. Most research extending from Grupe et al. 2010 has been on the correlation between αox and the Eddington luminosity ratio, the ratio of the observed luminosity of the object and the maximum luminosity the object can reach with the force of radiation pushing out and the force of gravity pushing in staying at equilibrium. One reason for this lack of research is due to the lack of simultaneous observations in the UV and X-ray band. Researchers observed the same AGN years apart, and AGN have been found to be variable in UV and X-ray bands. One of the biggest accomplishments of Grupe et al. 2010 was the compilation of observational data of 92 different AGN over the course of 5 years. This allows for better observational data that models can fit. This data allows for the establishment of average values for all three power law indices, which were given in the paper as both the mean and the median of the results. They noted that the median provided a more accurate representation than the mean.

In order to check the accuracy of their models, researchers compare ratios of certain emission lines in diagnostic diagrams. These diagrams can be used to classify the type of AGN based on their primary excitation mechanism, as well as act as a check for multiple parameters that we have to consider for our simulations. From using

*Does constraining the power law indices according to slopes derived from past research create an accurate model of Narrow Line Seyferts that can be used to simulate their properties across the AGN Sequence and can these models be extended to modeling emission lines from Low Ionization Nuclear Emitting Region (LINER) galaxies?*

**Methods**

Using the data from Grupe et al. 2010, I will determine the average power law indices that will be used in the baseline spectral energy distribution that will be run through our simulations. To vary these indices in our models, I will use the data given from the same paper to determine if the correlations between the different power law indices are significant enough that linear regression slopes between the indices can be used to constrain the values. Because the data from the paper includes Broad Line Seyfert Galaxies, I will have to reduce the data by removing any sources that have a Full Width at Half Maximum (FWHM), which is the spectral width of the light wave at half of the maximum amplitude, greater than 2000 units. From there I will then look at the values for the power law indices and remove any of the sources that do not give αx and αuv values that have been corrected for galactic reddening. Then I will plot linear regression curves to and use the slopes to vary αx, αox, and αuv.

Once these slopes have been determined I will begin running simulations through the CLOUDY program. In the simulation, I will use the parameters established by Groves et al. 2004b to make the cloud that the light will be run through. These parameters include the metallicity, chemical abundances, hydrogen density, dust grain size distribution, dust grain composition, and ionization parameter. Once the simulations have been run, I will look at the predicted line emission ratios for a large variety of atomic transitions. Many of these ratios are between one ionized state of an element and the first two ionizations of hydrogen (Hα and Hβ). The most important of these ratios are those established by Baldwin, Philips, and Terlevich 1981. I will gather data on how these specific ratios change according to the model.

The next stage of the research is to fit our model to existing observations. Many of these observations will be from sources outside of Elon because we do not have the time to apply for time to use space telescopes that are used to observe AGN. The observational data would also have to be gathered over a period of years in order to get a significant number of different sources. A starting point for matching our models would naturally be Grupe et al. 2010, since they have data from 92 AGN.

After determining that our models are good fits for the NLR of Seyfert galaxies, we will adjust our models to simulate LINER galaxies, and then examine the data produced by the simulations to determine if we can accurately simulate them as well.

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**Educational Benefits**

Completing this project holds many educational benefits. First and foremost, I gain experience writing research proposals and grant applications, which is a skill that is required for graduate school and doing research professionally. I also gain experience with coding in Python and Linux based systems. Like most research projects, I learn how to approach a problem analytically, or in some cases determine what the problem/question is that we are trying to solve. I learn how to organize research and data files so that they are easy to access and simple to navigate.