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Abstract

Quasars are luminous celestial objects that reside in the core of the most massive galaxies, where a supermassive black hole resides, powering the quasar's system. In some cases, quasars have been observed emitting outflows – matter that is expelled out of the quasar's environment instead of falling into the black hole. Our study's purpose was to determine: (1) how many quasar outflows have speeds larger than 10% of the speed of light (c) and (2) whether there was any correlation between outflow and radio emissions from quasars. Radio emissions are produced by quasars jets, which are another piece of the system but are present only in 10% of quasars [1]. To answer these scientific questions, our group analyzed 6760 quasar spectra from the Sloan Digital Sky Survey Data Release 9 (SDSS DR9), a public data set [2], searching for those outflows with speeds larger than 0.1c and cross-correlating with the corresponding radio information. We have selected the brightest quasars and the ones at the right distance from Earth to be able to study the potential presence of these outflows. This entails that the quasar outflow is in between the quasar and Earth, with the outflow traveling towards Earth. In this paper we discuss the results of searching for extremely high velocity outflows. To complete this endeavor, our team has developed a Python code in order to do this search systematically and have found 37 cases of quasars where the spectra present extremely high velocity outflows.

Introduction

Our solar system lies on an arm of the Milky Way, our spiral galaxy. Our Milky Way has a supermassive black hole in the center, just like most, if not all, galaxies. In some galaxies, the presence of gas around the supermassive black holes at their centers makes then an active galactic nuclei (AGN), which we can observe at large distances due to their large luminosity, which is the amount of light they emit. In the most massive elliptical galaxies, we find the black holes with the largest masses (around 50 billion times our Sun's mass!) and thus the most luminous AGN – quasars. When quasars were first observed they were given the name quasi-stellar objects because of their resemblance to stars; later this name was shortened to "quasars".

Quasars are some of the most luminous objects that reside in the core of the most massive galaxies, and quasars are so distant that they visually resemble stars. Quasars are some of the most distinct objects in our night sky [3]. Visually speaking, they are faint due to their distance from Earth. However, they are among the most luminous, and therefore energetic, objects in the night sky based on the amount of light they emit. Along those same lines, another unique property that distinguishes quasars from other stellar bodies is the fact that they radiate over the entire spectrum.

We are interested in the quasars' outflows; these are composed of matter that is being ejected away from the black hole environment. In these matter outflows there are ionized atoms (such as CIV, which is Carbon ionized three times) that are expelled out as they make their way into the black hole. These outflows are probably related to gas in the accretion disks,which are composed of matter that is orbiting and eventually falling into the black hole. Outflows may have an impact on star formation and galaxy evolution in their surroundings.

Our study aims to determine the number of quasars that present extremely high velocity outflows (EHVO – those outflows with speeds larger than 10% the speed of light [4]), and possible correlations between the presence of these outflows and other properties. To answer this scientific question, our group analyzed 6760 quasar spectra from the Sloan Digital Sky Survey Data Release 9 (SDSS DR9) [2], a public data set, searching for EHVO.

Data

We used two data sources for this study. SDSS DR9, an optical survey of objects in the night sky, and the Very Large Array Faint Images of the Radio Sky at Twenty-Centimeters (VLA FIRST), which is a survey that provides the radiometric data and covers mostly the same region of the sky as SDSS. Both data sets are public. We then were able to cross correlate the data from SDSS DR9 and FIRST by using the SDSS DR9 quasar catalog [5]. One problem we have encountered with using data from SDSS is that the data set can be biased since some objects are targeted for observation based on their radio properties [6].

We worked with the SDSS DR9, a public database containing 87 822 spectral targets. Of those quasars, 78 086 are new discoveries as of 2012. With the two cutoffs explained in further detail in the Methodology, we were able to reduce the number from 78 086 to 6760 quasars.

We then worked with our subsample of 6760 quasar spectra looking for outflows; we selected the brightest ones and the ones at the right distance from Earth. We have developed a Python code in order to do this search more efficiently. Outflows appear as absorption features, and to correctly identify absorption, we need to normalize the quasar spectra first. Our Python code fits a powerlaw to do so (as done by [4]). We subsequently carried out a visual inspection of the normalized data to verify that there was good normalization. In particular, we were interested in gas outflowing at the largest speeds (v > 30 000 km/s, 10% the speed of light!).

Methodology

Establishing CIV Absorption

The starting point was going through the plotted quasar spectra looking for signs of CIV absorption. For this to happen, we needed to establish two cutoffs. The first was making sure that the signal to noise ratio was high. With this the spectra are generally clearer and as a result we can have a more accurate absorption detection rate. And secondly, the redshift must also be 1.9 in order for the CIV and Lyα (Lyman-alpha, first emission line in the Lyman series of Hydrogen) to be included in the sections we are were observing. To solve for the redshift we used the equation,

$$z = \frac{\lambda_{observed} - \lambda_{lab}}{\lambda_{lab}}$$

Where $\lambda_{observed}$ is a value that we get from each individual quasar, and λ_{lab} is the literature wavelength value for CIV.

With these two cutoffs we reduced the number of quasar spectra from 87 822 to 6760.

Normalization of the Quasar's Continuum

With the 6760 quasar spectra, my research partner modified a spectrum normalization program originally written by a past collaborator [7] to fit a powerlaw to each quasar spectrum and normalize it. A separate spectrum analysis program was then used to flag any cases that had signs of broad absorption features, since

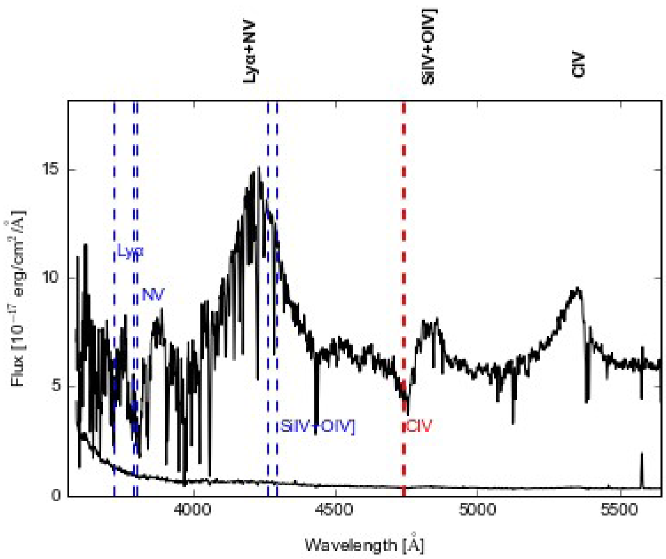

Figure 1. *spec-3826-55563-0860.dr9* Flux vs. Wavelength plot. Blue labeled lines represent possible ion absorption that is accompanying the CIV absorption, which is clearly indicated with red. The ion name is in black at the top of the plot and the labels are of the apparent emission lines.

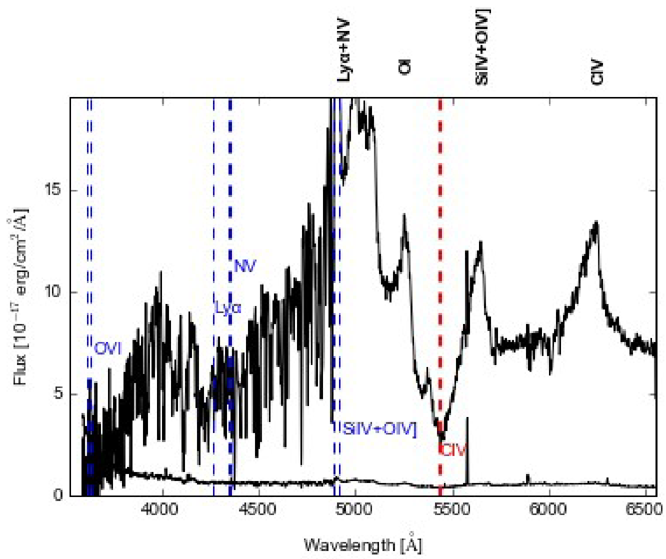

Figure 2. spec-4181-55685-0543.dr9 Flux vs. Wavelength plot. Reference **Fig. 1** caption. This is an example of a quasar with broader CIV absorption (larger width) than **Fig. 1**.

those are the cases relevant to this study. With the flagged normalized quasar spectra plots, we were able to visually inspect those spectra, searching for those that clearly had broad (widths > 1000 km/s) absorption of CIV. After reviewing the quasars, we found 37 cases that have possible CIV absorption. We are currently in a stage of reviewing the previously normalized spectra and preparing a program to manually normalize some quasar's spectra. We are keeping our figures very conservative and to ensure that, we are individually normalizing some questionable quasars to affirm that the CIV absorption really exists.

Preparing Our Data for Publication

Once we completed the visual inspection, we found 37 cases that have confirmed EHVO CIV absorption. Our team created a Python program to plot all the quasar spectra individually, which was tailored for each of the 37 cases that we found. The motive behind this was to ensure that we had a clear visualization of the CIV absorption and any possible accompanying absorption. This was very crucial step because: (1) we want these data to be public and accessible for others who are possibly conducting research on EHVO quasars and (2) if others can reference our database we might be able to discover more trends with this classification of quasars. Two examples can be found in **Figures 1** and **2**. The code had a function where we were able to input the wavelength value of CIV into the program and also align the rest of the ion emissions to their respective locations on the quasar spectra.

Conclusion

Once we completed the visual inspection, we found 37 cases where we have confirmed EHVO CIV absorption.

To make these findings public, our group will be launching a website in late 2018 where the data and plots of these EHVO quasars will be available. In that website the astronomy community will have access to: (1) the EHVO quasar information, (2) plots of all the cases found, (3) outflow information (e.g. width, depth), (4) presence of other ions in the outflow, and (5) links to all the SDSS information on these objects.

Once this database is available, our group and the entire astronomy community will be able to study possible correlations with other properties or look for trends among the EHVO quasar properties. For example, our team is studying whether the presence of EHVO outflows requires the presence of jets, which are radio emission components present in 10% of all quasars. Of the cases found to date, only 3 were found to be radio loud. Typically, 10% of all quasars are radio loud [1]. As of now this implies that radio loudness is not a prerequisite for EHVO. We will be presenting that work in another paper [8].

Future Work

We will continue the process of individually correcting the normalization on some of the quasar spectra in order to be able to upload the corrected plots onto our website. This website will include access to normalized plots as well as the original data. Once we have completed the website, we will expand to the most recent data release, SDSS DR14, in order to find more cases which will increase our statistical sample. This larger sample will allow us to investigate possible trends in black hole masses and quasars with EHVO.

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