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Searching for a Connection Between Radio Emission and UV/Optical Absorption in Quasars

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Introduction

Characteristics of Quasars

Quasars are among the most distinctive and most energetic objects in the night sky. Powered by accretion onto an accretion disk around the central supermassive black hole, quasars emit huge amounts of radiation over the entire electromagnetic spectrum. Quasars are also very distant, making them difficult to study.

Spectral observations are the main tool used to study quasars, due to this combination of distance and strong emissions [1]. The characteristics of observed quasar spectra differ greatly from the spectra of stellar bodies. Quasar emissions cover a large range of wavelengths instead of resembling a discrete blackbody curve, as observed in stellar spectra. Additionally, quasar spectra are highly variable, especially in the UV/optical region. That is to say, a quasar's spectrum can change dramatically over time [2].

Outflows and Jets

One of the more prominent features of quasars are axial radio jets, which are present in roughly 10% of quasars. These jets, composed of highly accelerated charged particles, emit large amounts of radio waves [2]. These radio emissions make it possible to detect quasar jets by simply measuring the object's radio flux. Quasar outflows are another more recently documented phenomenon of note. An outflow is an event where a quasar ejects large amounts of matter. These outflows can be observed in UV/optical spectra as blueshifted absorption features. This blueshift occurs as matter ejected from the quasar travels towards Earth while absorbing light from the quasar. One problem with this observation method is that only outflows positioned between the quasar and Earth, and traveling towards the Earth, can be detected. Another spectral signature of these outflows is that their absorption features tend to appear as broad absorption lines (BALs) rather than thin absorption lines. This broadening of absorption lines is due to the matter in the outflow moving at differing speeds. The speed of these outflows can be measured by comparing the location of the BAL to its expected location in the quasar's rest frame. Outflows with higher observed velocities, $v > 0.1c$ (10% the speed of light), are termed extremely high velocity outflows (EHVO) [3].

Usage of CIV

The absorption of CIV, triple-ionized carbon, is one of the most commonly used markers for these observations. This ion is chosen for a few reasons. Firstly, carbon is a very common element, so it can be assumed that any given outflow will contain at least some amount of carbon. Secondly, CIV absorption features are easy to observe, as they fall into the UV/optical region of the electromagnetic spectrum. This combination of factors makes CIV a useful marker for studying outflows in quasars.

Methods

Two main data sources were used in this study: the SDSS DR9 and VLA FIRST. SDSS is an automate UV/optical survey of the night sky. Data from this survey are periodically published as numbered data releases and are made available online in the form of optical imagery and spectrographic data. SDSS DR9 was used as a source of spectra for the spectral analysis program. VLA FIRST is a radiometric survey of the night sky that targets faint objects and was chosen for this study because it contains observations for many of the objects surveyed in SDSS. Cross correlation used the DR9 Quasar Catalog, a value-added catalog of quasar data that contains information from SDSS DR9 and VLA FIRST [4].

Inputs for the spectrum analysis program were chosen using a number of criteria. One consideration was signal to noise ratio (S/N). Samples with S/N ≥ 10 were chosen because BAL proved to be hard to detect over noise in spectra with lower S/N. Another consideration was redshift (z). Redshift is a measurement of how fast something is moving away from us which is observed by measuring how the Doppler effect shifts the entire spectrum. A redshift greater than one means the entire spectrum will be shifted towards larger wavelengths. Due to the expansion of the universe we can use redshift to tell how far away an object is. CIV was used as a marker for absorption, as it is a common ion in quasar outflows and, therefore, produces strong absorption features. Since this study investigated outflows with 0.1c < v < 0.2c, CIV features would appear at around 1200 Å in the rest frame of the spectra. Due to this, quasars with z ≥ 1.9 were chosen, as this redshift moves the CIV features to around 3600 Å, within the range of DR9's coverage wavelengths [4]. The SDSS DR9 catalog contains 87 822 quasar samples. After applying these filtering criteria, S/N ≥ 10 and z ≥ 1.9, the sample was reduced to 6760 quasars.

The first step in the study was to find a sample set of quasars with EHVO so that their radio properties could be examined. A Python program was written to search for quasars with EHVO. These quasars were found by searching quasar spectra from the SDSS DR9 quasar catalog for broad CIV absorption features between the SiIV emission line and the Lyman alpha forest. This region was used because it can reasonably be assumed that any broad absorption features in the region are blueshifted CIV absorption features, and, therefore, evidence of outflows. This search was accomplished by first applying a powerlaw fit to normalize the spectra's continuum. After normalization a three point median boxcar method was applied to smooth the continuum. Next, the program identified quasars with possible EHVO by searching for BALs by integrating between the powerlaw fit and the continuum. Using this process, the program was able to generate a list of quasars with possible evidence of EHVO. The quasars that this program identified as having evidence of EHVO were then visually inspected. From this inspection a set of quasars with definite evidence of EHVO was selected. These samples were then cross correlated with VLA FIRST to identify their radio properties. This cross correlation was car-

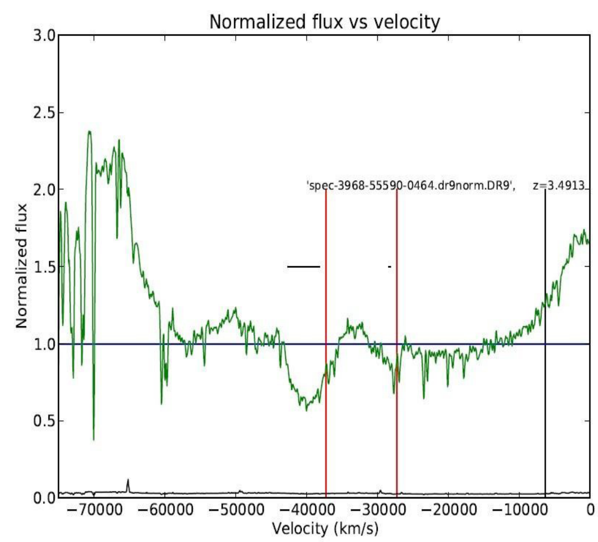

Figure 1. Example of normalized quasar spectra from our final data set. SDSS spectra (green) smoothed and plotted with a guide line at 1 to aid visual inspection (blue), CIV absorption found outflowing at speeds between 0.1c and 0.2c (red), and where CIV would be if the absorption marked with a red line were SiIV absorption instead (black). The feature at -40 000 km/s is a BAL corresponding to CIV, indicative of an outflow.

ried out using the DR9 Quasar Catalog [4]. An example of a spectrum with evidence of EHVO found by this program is shown in **Figure 1**.

Conclusions

Results of Spectral Analysis

From the filtered set of 6760 spectra from the SDSS DR9 catalog, the analysis program identified 41 spectra as having possible evidence of EHVO. Visual inspection was carried out to remove obvious non-EHVO spectra and reduced this set to 23 quasars with definite evidence of EHVO. Cross correlation with VLA FIRST radiometric observations was carried out using data in the SDSS DR9 quasar catalog. From this cross correlation it was found that none of the quasars in the final sample set had any measured radio flux.

Conclusions

From these results, it is evident that radio emissions are not a prerequisite for EHVO in quasars. Additionally, since axial jets are strong radio emitters, this evidence suggests that jets are not a prerequisite for EHVO in quasars.

SDSS Targeting

A total of 3076 quasars in the SDSS DR9 quasar catalog, about 3.5% of samples, have some radio flux. However, this sample may not be completely representative of the general population of quasars. Originally, SDSS surveys targeted quasars based on their radio properties. Specifically, some early targets in the SDSS-I/II were selected due to their radio emissions as measured in VLA FIRST [5]. Due to this targeting there may be a disproportionately large amount of quasars with measurable radio flux in SDSS sample sets than would be found in the general population of quasars. This sampling bias needs to be considered when using SDSS data sets.

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