Studying Extremely High-Velocity Outflows in Sloan Digital Sky Survey Data Release 16 Quasars

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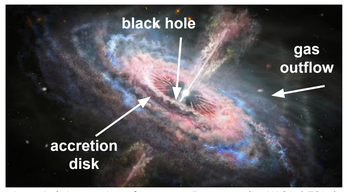
Background

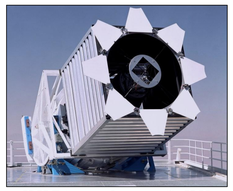
What is a quasar?
Quasars are the most luminous class of active galactic nuclei (AGN). Their immense luminosity comes from an accretion disk orbiting the central supermassive black hole within each galaxy. We study their properties by looking at archival spectra from the Sloan Digital Sky Survey (SDSS).

What is an extremely high-velocity outflow vs. an ultra-fast outflow?
Quasar spectra show signatures of energetic outflows originating from the accretion disk as absorption features. These outflows are like winds, carrying energy and matter from the center of the quasar outwards their host galaxies. Extremely high-velocity outflows (EHVOs) are those winds moving at speeds between 0.1*c* and 0.2*c* in the UV/optical spectra. Ultra-Fast-Outflows (UFOs) are defined as highly ionized outflows, which have average velocities ranging from 0.1c and 0.3c detected in the X-Ray spectrum.



An artist's impression of a quasar. Image credit: NASA / ESA / J. Olmsted, STScI.

← Gas from the outflows blocks our line of sight to the accretion disk, which appears in absorption in the spectrum.
SDSS has observed 750,414 quasars. →


SDSS Telescope. Image credit: SDSS

Samples

Original Sample: We used data from the Sloan Digital Sky Survey (SDSS) Data Release 16 Quasar catalog[3] (DR16Q). Our research group had previously searched for EHVOs in 17477 DR16Q spectra, and had found **98 quasars with EHVOs.** See some examples in Figure 1 below.

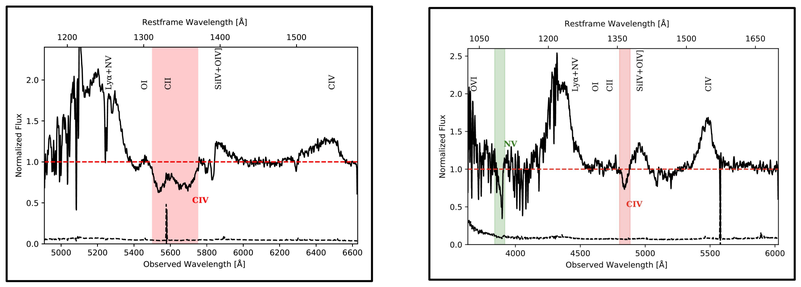


Figure 1 shows two examples of EHVOs detected in DR16Q spectra through CIV detection. Figure 1 (right) also shows NV in the same outflow as CIV.

Sample for variability study:
The quasars from the DR16 containing EHVOs were already previously normalized by our research group. Now, we have searched the database for multiple observations and found 51 quasars that include, at least, two observations.

Sample for Ultra-Fast Outflows study:
We used the sample described in Chartas+2021 composed of quasars with detections of Ultra-Fast Outflows in X-ray spectra. We selected the quasars with large enough redshift to search for EHVOs or absorption at large speeds (z > 1.733) and downloaded the SDSS spectra. This sample has 6 quasars.

Variability Study

What was the process for studying variability?

To search for variability in quasars with EHVOs, we started by visually inspecting the 51 quasars with multiple epochs. We overplotted all normalized spectra and flagged and measure all absorption. We measured BALnicity Index, and minimum and maximum outflow speeds, and contrast values between different epochs to determine if variability has occurred. In the studied cases, we find examples from no or little variability (see Figure 2 right) to large variability (see Figure 2 left), and even cases where the absorption has appeared or disappeared completely. We find that variability in EHVO quasars occurs often in time differences of ~0.5 years in the quasar rest-frame, and even disappeared in ~2.5 years in the quasar rest-frame.

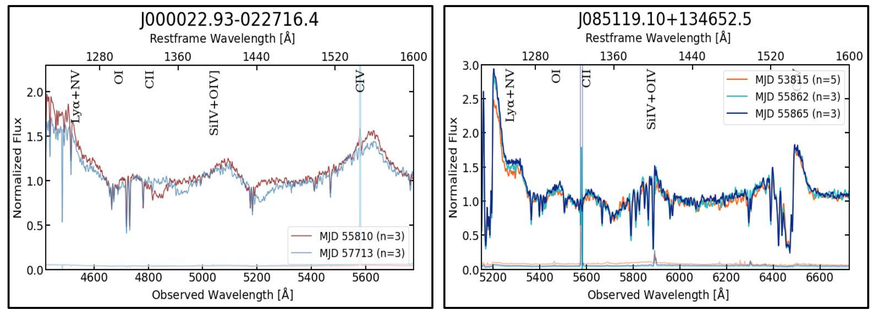


Figure 2a (left) shows the absorption variability in velocity between the observations. Figure 2b (right) shows by contrast an example with no variability

Search for EHVOs in Quasars with Ultra-Fast Outflows

Using the sample of known quasars with UFOs in the X-Ray spectrum, we searched for EHVOs in the UV/optical part of the spectrum. We normalized the quasar spectra, and then flagged potential absorption of EHVOs. After running the samples through this process, we did not find any case of broad EHVOs (>1,000 km/s), but we found examples of narrow absorption in some of them.

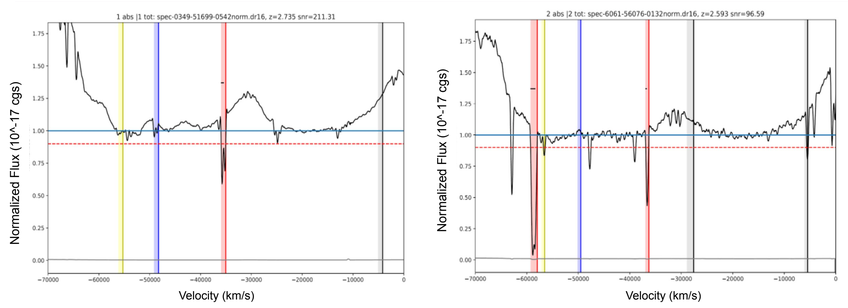


Figure 3 shows two examples of detected narrow absorption (marked in red) in the wavelength region of interest, but not broad absorption was detected. Both show potential CIV absorption, that if confirmed they are EHVO, would be outflowing at ~0.1c (left) and ~0.2c (right). Other colors are just to help us visualize the absorption is not due to other ionic transitions.

Study of the EHVO Quasars Properties

Why study the quasars properties?
With the 98 confirmed cases of quasars with EHVOs, we can study the relationship between EHVOs and other samples to show whether quasars with EHVOs exhibit any special properties. Cross-correlating our sample with DR14Q data (Rakshit et al. 2020) tells us how EHVOs and parent sample quasars' black hole masses (M_{BH}), bolometric luminosities (L_{bol}) and Eddington ratios contrast between the two samples. Obtaining these values is also important for theorists to investigate mechanisms of accretion disks via theoretical simulation.

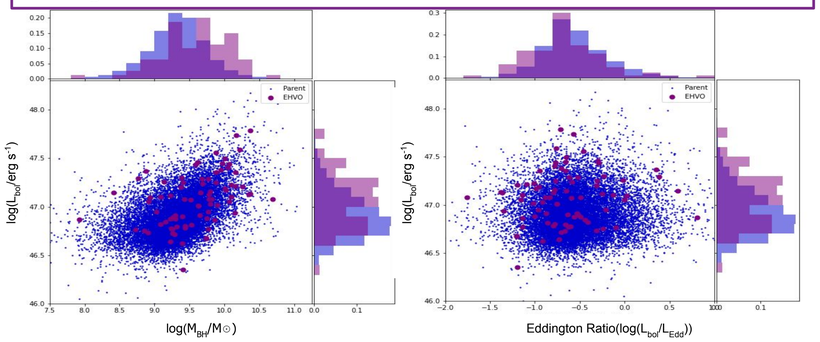


Figure 4 shows the L_{bol} vs M_{BH} (left) and L_{bol} vs Eddington Ratio (right). When compared to the parent sample, the plots show that EHVOs are mostly concentrated on a slightly higher black hole mass region and tend to have higher bolometric luminosities. The values of the Eddington ratio of EHVOs are slightly lower on average but the distribution does not change significantly from the parent sample's.

Photoionization Study

Variability in outflows might be due to changes in the amount of outflow mass (measured by column density). SimBAL, introduced in Leighty+18, generates the most likely spectrum parameters (such as ionization and column density) via "a spectral-synthesis procedure that uses grids of ionic column densities created by the photoionization code". UW Bothell is one of the two beta testing sites for this novel spectral tool. This summer we worked on starting a framework so undergraduate students can learn to use it.

Current & Future Work

- Our sample of quasar spectra included 51 cases with multiple observations. From these, we have already studied 25 quasar spectra. We are currently analyzing the remaining 26 quasars to complete the longitudinal study of EHVO variability.
- Searching for other epochs of the 6 quasars in the study of Ultra-Fast Outflow will allow us to determine if the absorption is outflowing at fast speeds.
- We will continue developing the guide to be able to use SimBAL.
- We are planning on comparing the quasar properties of EHVOs to the properties of quasars with outflows at lower speeds – Broad Absorption Line quasars (BALQSOs). We will determine, by using measurements in Lyke+2020 and Rakshit+2020, the BALQSOs in our parent sample and contrast their values to EHVOs.

References: [1] Chartas *et al* 2021 *ApJ* 920 24 ; [2] Filiz Ak *et al* 2013 *MNRAS 434 222* ; [3] Lyke *et al* 2020 *ApJS* 250 8; [4] Paris *et al* 2012 A&A 548 A66; [5] Rakshit *et al* 2020 *ApJS* 249 17; [6] Rodríguez Hidalgo *et al* 2020 *ApJ* 896 151

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