Discovery Spectroscopy for Unusual Point Sources in DESI

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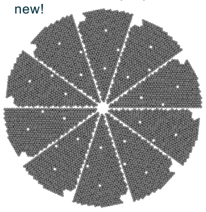
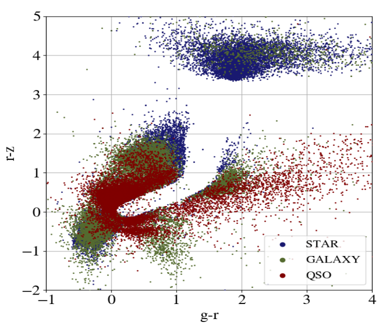
Selection

The **Dark Energy Spectroscopic Instrument (DESI)** on the Mayall Telescope consists of 5000 fibers, the footprint of which is shown below[DES+16a],[DES+16b]. Each of these fibers can target a separate astrophysical source within the field of view of the instrument. Since there are fewer targets in certain tiles than fibers, we were able to use some of the spares to observe targets not selected as part of the cosmological survey. This presents an opportunity for the discovery of rare astrophysical sources given the resolution and field of view we are get to work with – transients, binary systems, and possibly something completely new!



To achieve this, we used g, r, and z-band photometry from the **Legacy Survey Imaging** and **WISE** bands 1 and 2 to identify point sources that lie 10σ off the main locus, which contains all main sequence stars[Zou+17],[Dey+19]. This selection criteria produced 2 million targets across the **DESI** footprint, of which we have observed 96,488 (16819 in **EDR**, 79669 observed is **DESI YR1**).

The full selected targets is shown below, in **rgz** color space. Many of these are incredibly dim – if we are limited to a magnitude of 22 in all bands, the group of targets above $r - z = 3$ all but disappears. The targets are initially categorized by the default fitting pipeline on DESI, **RedRock**[Bai24]. They are shown below in as categorized by RedRock.



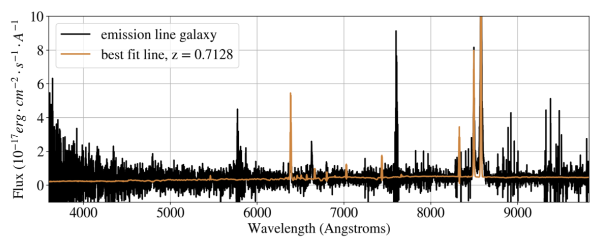
We can take the first- and second-best fits and subtract their χ^2 values, giving us a certainty measure about the initial fit - $\Delta\chi^2$. Low Confidence fits are defined as those with $\Delta\chi^2 \leq 100$, and High Confidence fits are defined as $\Delta\chi^2 > 100$.

Total	*Low Confidence*	*High Confidence*
Galaxies (20.24% Total Population)		
19531	10177 (52.11%)	9354 (47.89%)
Quasars (11.78% Total Population)		
11363	983 (8.65%)	10380 (91.35%)

Stars (67.98% Total Population)

Subtype	*Total*	*Low Confidence*	*High Confidence*
All	19531	10177 (52.11%)	9354 (47.89%)
M.S. (24.22%)	15885	907 (5.71%)	14978 (94.29%)
Late Type (18.73%)	12287	1254 (10.21%)	11033 (89.79%)
WDs (55.27%)	36251	4227 (11.66%)	32024 (88.34%)
CVs (1.79%)	1171	4 (0.34%)	1167 (99.66%)

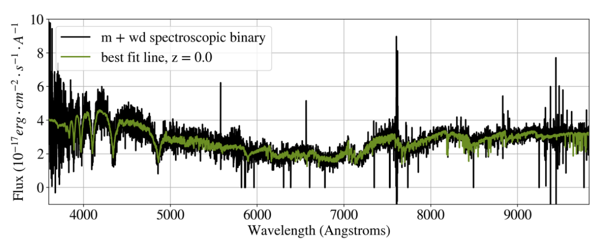
The Diamonds in the Rough



Fitting General Cases

Here are two examples of fit spectra taken from the PSF Outlier population. Both are fit with a homebrew fitting program that uses linear regression to find the eigenvalues given a set of eigenspectra. These eigenspectra were developed by performing a Primary Component Analysis (PCA) on a set of these same objects[Bol+12].

The top spectrum is fit using the RedRock redshift and follows the same general procedure, but not every spectrum is a clean emission line galaxy, or even just one object.

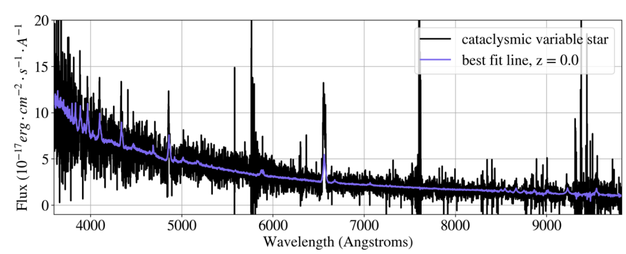


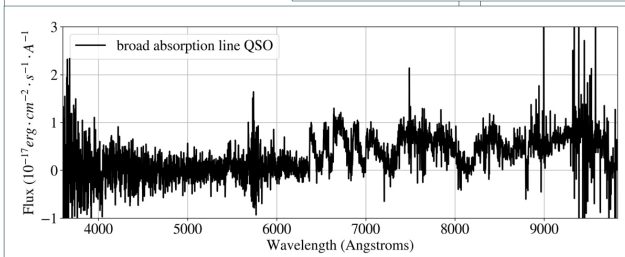
Fitting Spectroscopic Binaries

This spectrum was flagged by RedRock as a high confidence galaxy. Using the homebrew fitting program, I was able to confirm that this spectrum fits much better as a spectroscopic binary with a 0 redshift M-star and White Dwarf. These late-type stars are especially useful for identifying these binaries since they live on opposite sides of the spectrum at the same redshift, making this distinct shape very easy to spot. If these stars are in the Gaia database, then we may be able to confirm whether these two stars are gravitationally linked with proper motion and parallax measurements.

Cataclysmic Variables

These CV stars represent the accretion of mass from a main sequence star to a white dwarf, which will explode once it reaches the Chandrasekhar limit, becoming a supernova. RedRock has a CV-specific template, making the regression fit a fairly simple process.





Quasars!

Quasars are one of the prettiest and varied 'diamonds' among the population we have found. While we have no PCA that we can use to perform linear regression on these weird objects, it seems likely that this is a Broad Absorption Line quasar at high redshift, around $z = 4.3$.

We have found several QSOs at a redshift $z \geq 5$ in this population that were not targeted in their specific survey. We are unsure why these were skipped over by the targeting program.

Next Steps

We will continue this project by implementing the homebrew linear regression software on a large scale using the multiprocessing capabilities of the NERSC supercomputer. We will likely start with the lowest confidence fits, doing our best to filter out junk that is too dim to identify. Much of these low confidence fits are fit by default as galaxies, and even the high confidence fits may contain a gem like a spectroscopic binary! We are also hoping to start a Visual Inspection Campaign for those spectra, which will allow us to catch anything that slipped through the cracks.

References

[Bol+12] Adam S. Bolton et al. "SPECTRAL CLASSIFICATION AND REDSHIFT MEASUREMENT FOR THE SDSS-III BARYON OSCILLATION SPECTROSCOPIC SURVEY". In: The Astronomical Journal 144.5 (Oct. 2012), p. 144. issn: 1538-3881. doi: 10.1088/0004-6256/144/5/144. url: http://dx.doi.org/10.1088/0004-6256/144/5/144.

[DES+16a] DESI Collaboration et al. "The DESI Experiment Part I: Science,Targeting, and Survey Design". In: arXiv e-prints, arXiv:1611.00036 (Oct. 2016), arXiv:1611.00036. arXiv: 1611.00036 [astro-ph.IM].

[DES+16b] DESI Collaboration et al. "The DESI Experiment Part II: Instrument Design". In: arXiv e-prints, arXiv:1611.00037 (Oct. 2016), arXiv:1611.00037. arXiv: 1611.00037 [astro-ph.IM].

[Zou+17] Hu Zou et al. "Project Overview of the Beijing-Arizona Sky Survey". In: 129.976 (June 2017), p. 064101. doi: 10.1088/1538-3873/aa65ba. arXiv: 1702.03653 [astro-ph.GA].

[Dey+19] Arjun Dey et al. "Overview of the DESI Legacy Imaging Surveys". In: 157.5, 168 (May 2019), p. 168. doi: 10 . 3847 / 1538 - 3881 / ab089d. arXiv: 1804.08657 [astro-ph.IM].

[Bai24] Bailey et al. In: (2024). in preparation