GHOST SV Observation Evaluation Form

Title: Resolving the “trees” of the Lyman-alpha Forest

Program ID: GS-2023A-SV-107

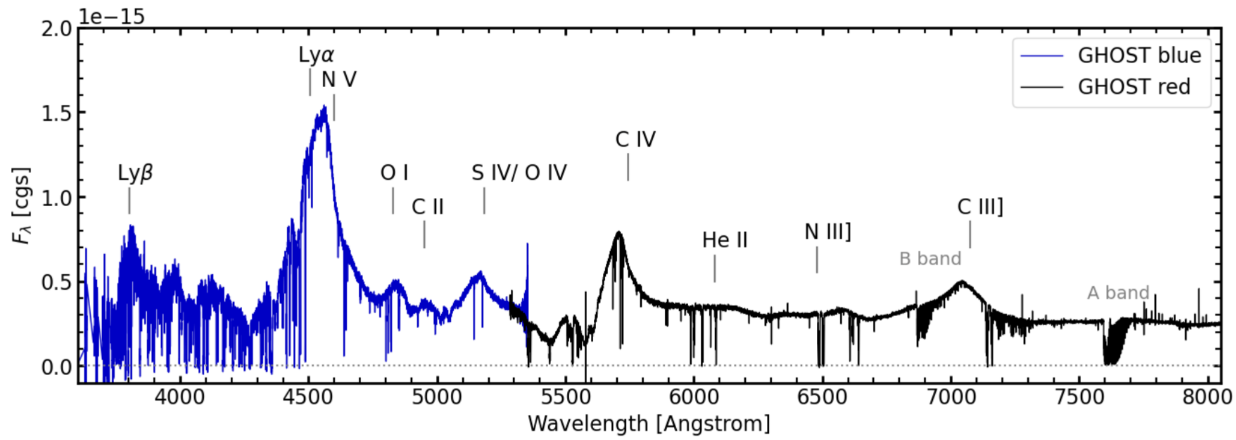
Authors: Stephanie Juneau & Siyi Xu

Description of the primary goals and the main findings

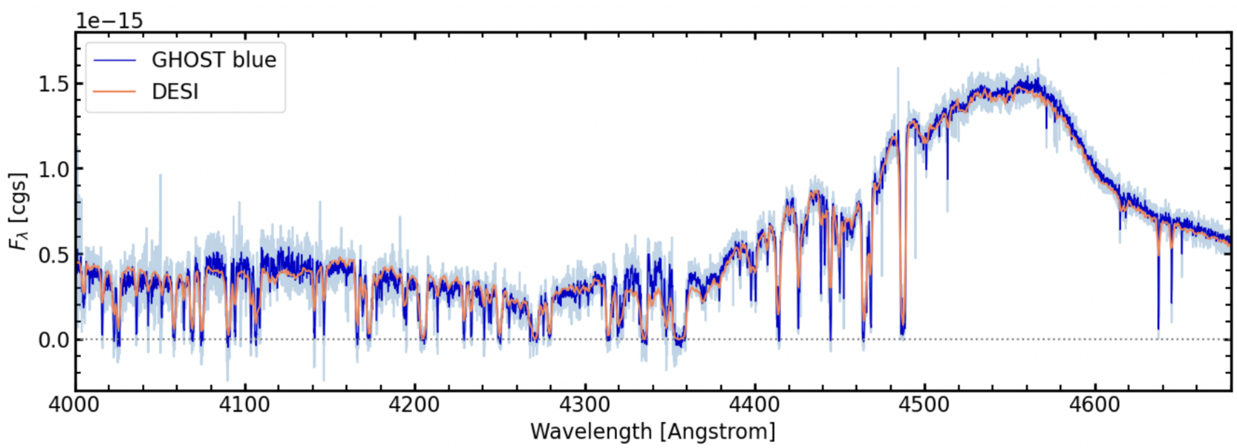
Optical spectra of quasars at redshift z>2.1 probe the Lyman-alpha forest made by a series of hydrogen-absorbing intervening clouds from the circumgalactic medium (CGM) and intergalactic medium (IGM). In addition, absorbers from galaxies along the line-of-sight create metal absorption lines such as magnesium and carbon absorbers, which further tell us about galaxy evolution and the formation and distribution of metals in the CGM (Zou et al. 2023; arXiv:2302.13357).

We aim to observe the distant (z=2.7) quasar J1215-0034 and compare the high resolution GHOST spectrum with previous spectra obtained with the SDSS and DESI surveys. Of particular interest, we will investigate the Lyman-alpha forest and search for the presence of metal absorbers along the line-of-sight to this bright quasar, starting with confirming MgII absorbers and associated FeII, CIV, and Si IV absorption features (Napolitano et al. 2023; arXiv:2305.20016).

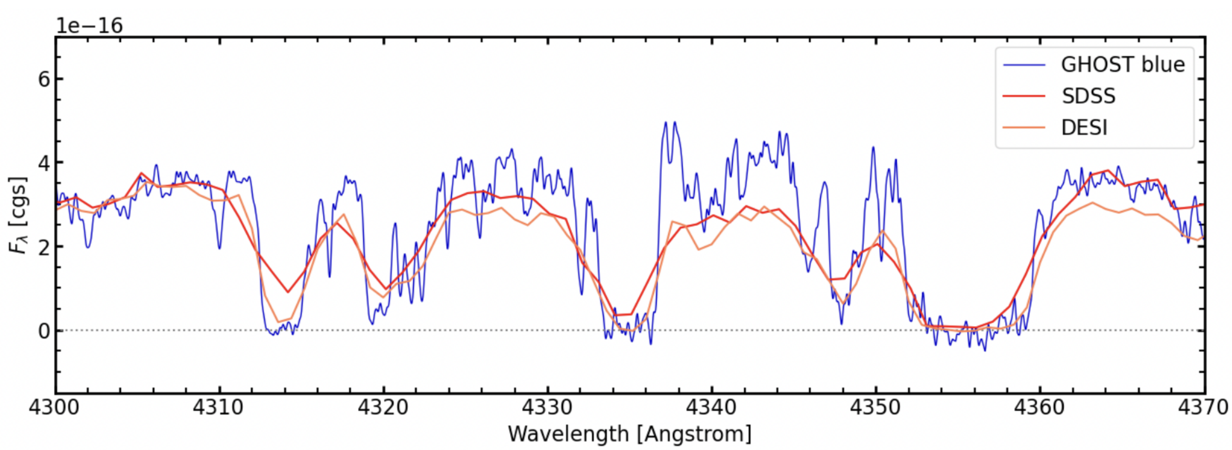
The figure below shows the GHOST spectrum from stacking the three exposures and we show the blue and red channels separately as labeled as well as the location of emission lines and of atmospheric band absorption. The GHOST spectrum has been smoothed with a Gaussian kernel with width sigma=3. In addition to the labeled features, we see an obvious Lyman-alpha forest (<4500 Angstrom), several metal absorbers (e.g., around 4650, 4800, 5700, 6000, 6500 Angstrom), and broad absorption lines (BALs; e.g., around 5500 Angstrom).



Zooming in the Lyman-alpha forest region (below) shows that GHOST reveals finer details compared to the previous DESI spectrum of the same target (light orange).

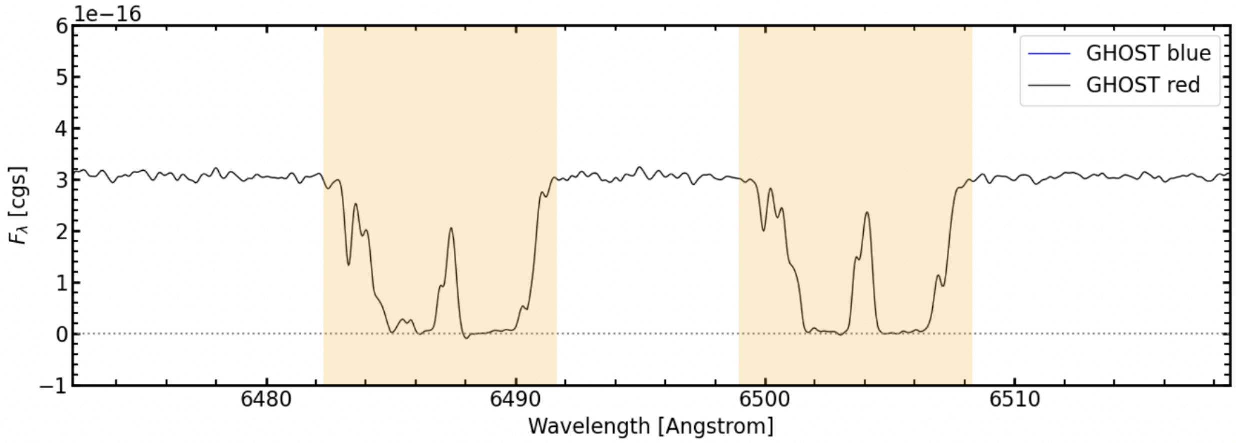


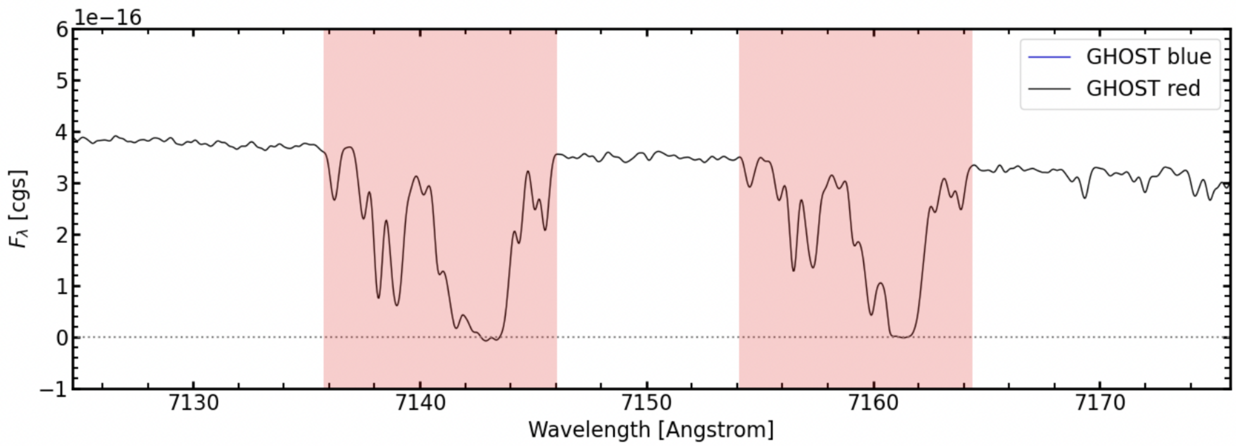
Interestingly, several absorption lines reach a zero flux, indicating a significant absorbing column density. We further highlight one especially interesting region with a damped Lyman absorption feature by zooming in further below (for comparison, the SDSS spectrum in red and DESI spectrum in orange do not resolve the detailed profiles of the intervening absorption features).



Metal Absorbers

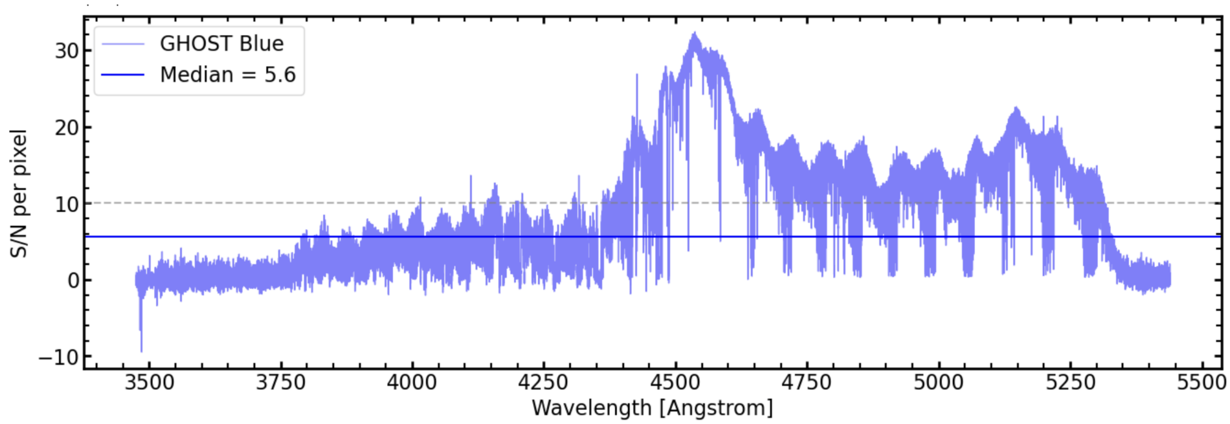
We started by following on previously identified Mg II absorbers (Napolitano et al. 2023) and namely below we show two absorbing systems where each component of the Mg II doublet reveals an interesting structure with a grouping of several absorption components. The top panel shows an absorbing system around z~1.3148 while the bottom panel shows an absorbing system around z~1.55365. Each colored band corresponds to one component of the doublet, and in this case all these systems are in the Red arm (black line).

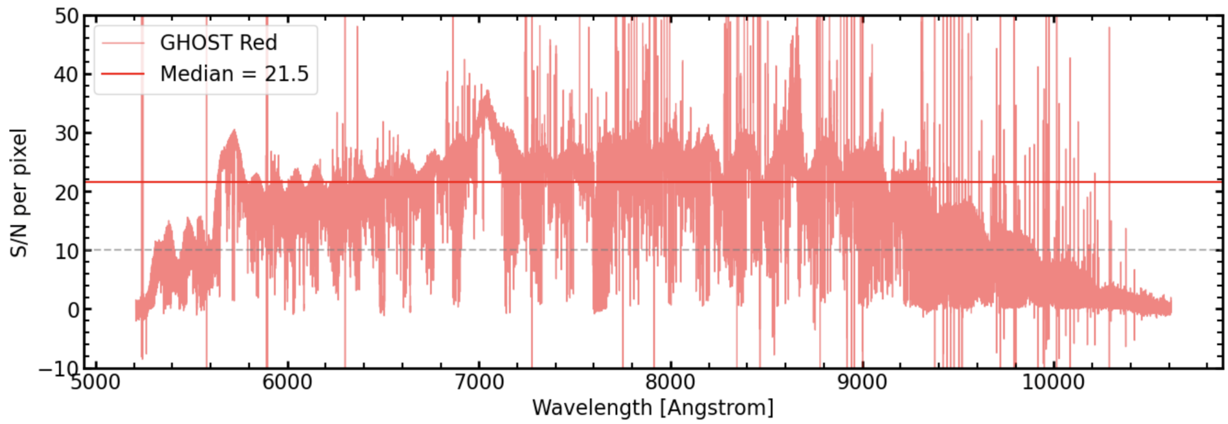




Additional comments on GHOST performance:

The figure below shows the S/N per pixel in the blue channel (top) and red channel (bottom). Our goal was to reach S/N per pixel > 10 in the continuum (excluding the absorption lines themselves) in 2 hours on-source, indicated with the horizontal dashed lines. We ended up having 1.25 hour on source, and the median S/N=5.6 in the blue and S/N=21.5. As the plots show, most of the spectrum (excluding the Lyman-alpha forest blueward of 4500 Angstroms) did reach S/N>10 in this shorter time. The S/N is slightly improved for our analysis by smoothing slightly with a Gaussian kernel (with width sigma=3).

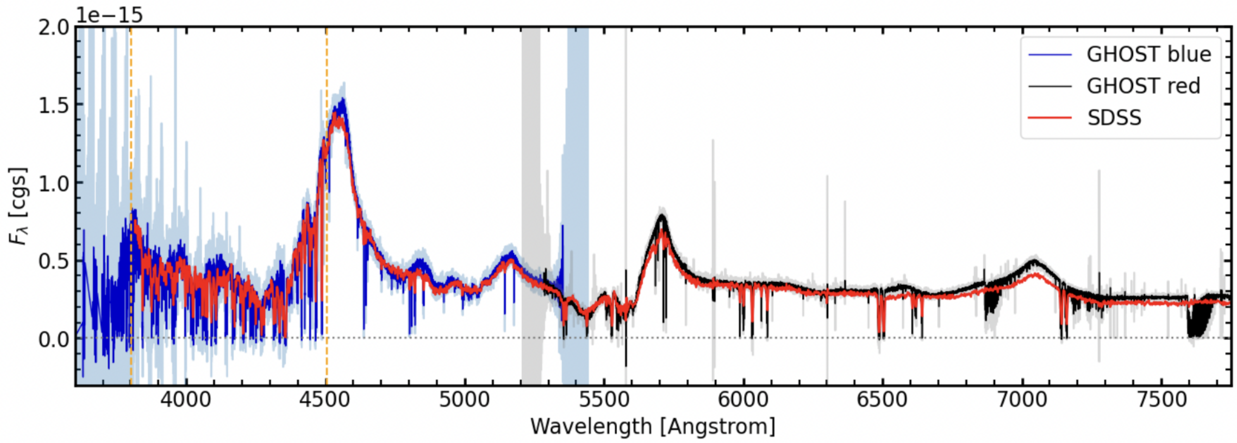




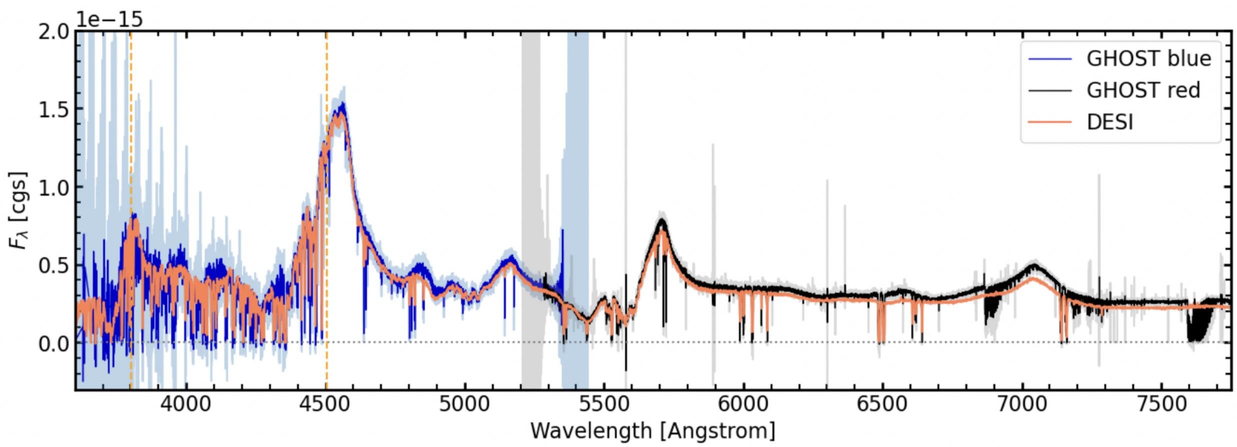
Comparison with other Instruments: SDSS & DESI

In addition to the comparison plots shown in the results above, here are a few more comparing the GHOST spectra with previous spectra from SDSS and from DESI Early Data Release (EDR).

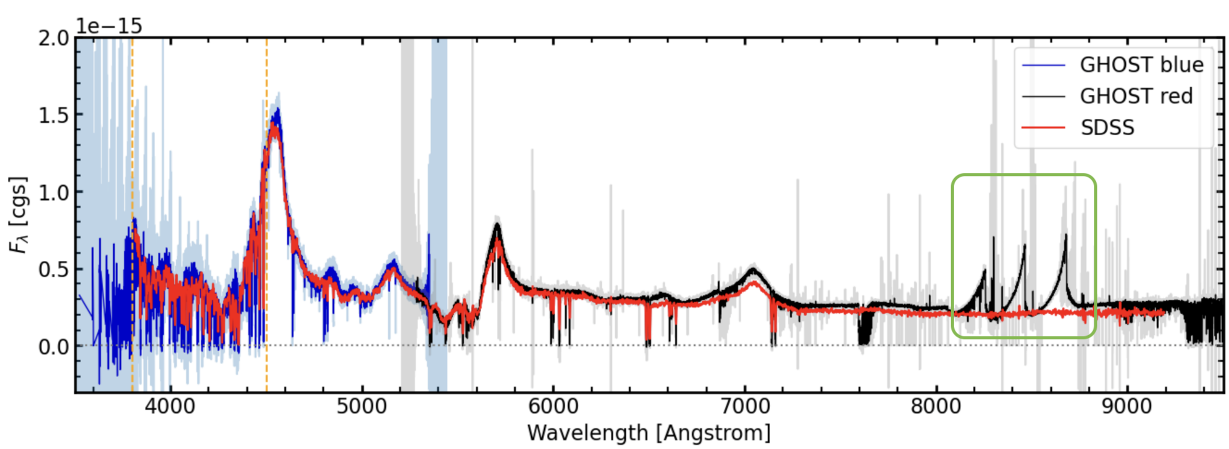
First, the comparison up to wavelengths 7750 Angstroms shows an overall good agreement. The unsmoothed GHOST spectrum is very noisy at the ends (light color). These regions have large errors and are masked when smoothing with a Gaussian kernel to obtain the better quality spectrum shown in dark colors (dark blue for the Blue channel; black for the Red channel). Some differences in the red side could be due to a flux calibration difference or possibly some intrinsic variations of the power-law continuum and/or emission lines of the quasar itself (or a combination of both factors).



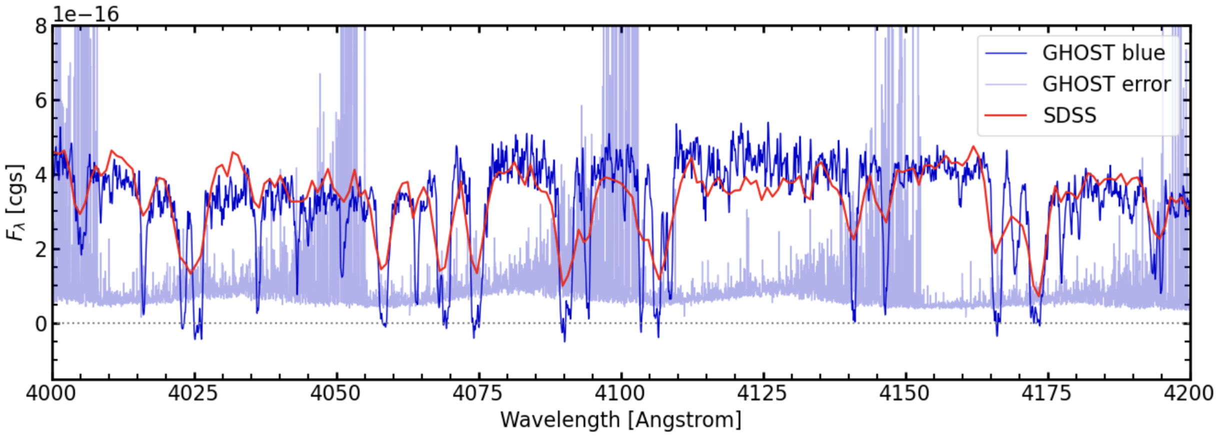
The next figure is similar but the GHOST spectrum is compared to the DESI EDR spectrum of the quasar in light orange.



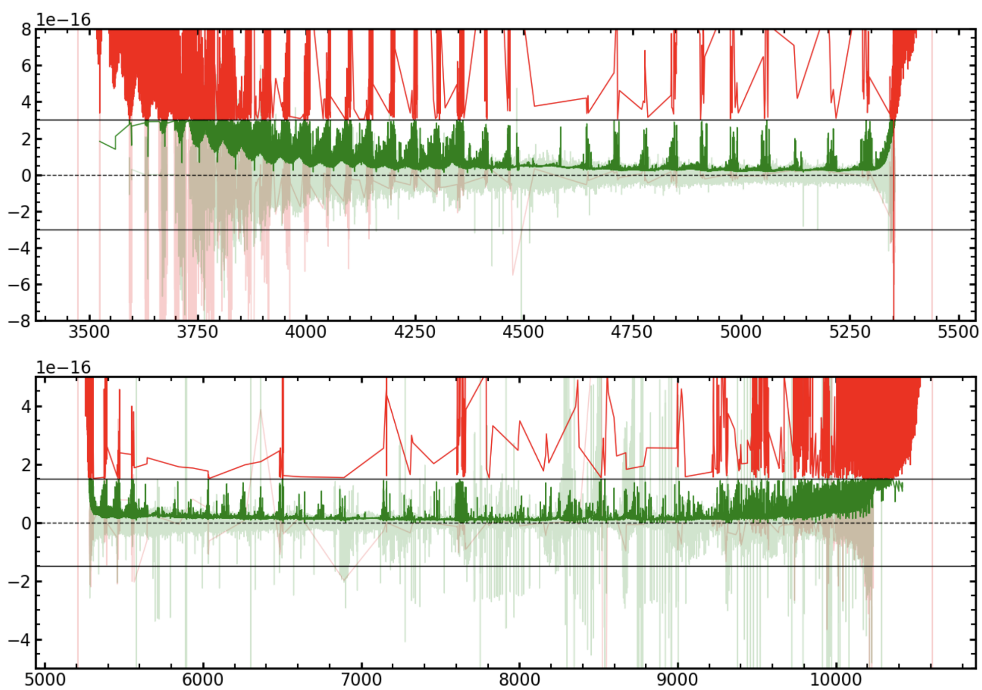
However, there remains some issues with the latest version of the pipeline used (v0.9.4) in the red part of the spectrum as shown below in the green rectangular region. We are unsure about the underlying cause but it was reported to the pipeline team for investigation.



The error spectrum is shown below for a small spectral region to compare it directly with the spectrum itself and the SDSS spectrum, as labeled.



We further compared the error spectrum to the difference between the unsmoothed GHOST spectrum and a smoothed version with a larger Gaussian kernel (width sigma=5). The latter can show strong pixel to pixel variations and will pick up for instance cosmic rays or other single pixel artifacts. The difference (unsmoothed - smoothed) is shown with lighter partially transparent colors whereas the error spectrum is shown in solid dark colors. A green color mean that the values are below the thresholds marked with horizontal lines; a red color means that the values are above the "large error" thresholds set to 3e-16 erg/s/cm**2/AA for the Blue channel and 1.5e-16 erg/s/cm**2/AA for the Red channel, respectively.



Suggestions for improvements:

This case has been interesting given the many absorption lines that reach zero flux, and which in turn revealed issues with earlier versions of the pipeline (see figure above with the green rectangle showing artifacts around 8000-9000 Angstrom).

Aside from these few artifacts, the spectrum generally has a very high quality with sufficient signal to detect a large number of absorption lines and assess their line profiles.

The data format is manageable with the astrodata package but would be more convenient if compatible with specutils and namely the Spectrum1D object. This may already have been implemented but I am working with the DRAGONS (Py 3.7) kernel that is installed on the Astro Data Lab platform and it's not yet supported there.

Any additional comments about GHOST SV

N/A