ID: S009 **PI: J. X. Prochaska** **Instr.: Kast** **Req.: 5 nights**

The HI gas of 2175 Å Absorbers

1. Scientific Justification

Background:
The high-z quasar 2175 Å absorbers, first identified by co-I J. Ge in 2004[15], are a new, extremely rare population of quasar absorption line systems[14,1], distinguished by broad dust absorption bumps at 2175 Å of the absorbers' rest-frame in the extinction curves derived from quasar spectra (Fig. 1). Recent studies of a small sample of these absorbers suggest that they may be associated with metal-rich systems and a set of them have detectable molecular gas[4,5,12,8,18,16]. Due to a factor of ten times larger sample of $z > 2$ quasar spectra from SDSS-III (over SDSS) and a recent, much improved searching algorithm, our team has been able to identify a total of 426 quasar 2175 Å absorbers at $z_{\rm abs} \sim 0.7$–2.3 among strong Mg II absorbers[6] from a total of $\sim 120,000$ quasar spectra. This represents the largest, homogeneous sample of quasar 2175 Å absorbers[6], which gives us the statistical power to study properties of quasar 2175 Å absorbers.

Several results have emerged from the early analysis of the sample: $\sim 10\%$ of the dust absorbers show Milky Way (MW) like extinction curves, the majority of which are at $z \sim 1$, while most show Large Magellanic Clouds (LMC) like extinction curves. The bump for most systems is shallower but broader than the MW bumps (Fig. 1). These results have illustrated a possible evolution trend of the UV bumps in cosmic time (from the LMC type to the MW type). Furthermore, the average UV bump strength increases from $z \sim 2$ to $z \sim 1$ and is projected to evolve to the MW value at the present time (Fig. 2). This trend has been confirmed with 166 new 2175 Å absorbers at $z \sim 2$–2.5 (Fig. 2), independently identified through strong Lyα absorption systems in DR9 data[10].

Follow-up observations:
We are performing follow-up observations of these targets at higher spectral resolution with the Keck and MMT telescopes, which PI Prochaska began in 2008[15]. Fig. 3 shows part of spectral data for J1211+0833 ($z_{abs} = 2.1166$). Preliminary data analysis show that the entire sample (~ 15 systems) have high dust depletion with [Fe/Zn] ~ -0.9 to -1.9, much stronger than most of the quasar absorbers reported in the recent literature[7]. All seven systems with $z_{abs} > 1.6$ show strong C I absorption ($N_{\rm CI} > 1 \times 10^{14}$ cm^{-2}); two have possible detections of CO absorption. The five $z_{abs} > 2.0$ systems with measured $N_{\rm HI}$ show higher metallicity than the MW diffuse clouds. Four of them show super solar metalicity, two of which have the highest metallicity among all of the known quasar absorbers. They are significantly different from the majority of DLAs and sub-DLAs in metallicity and dust depletion. The 2175 Å absorbers appear to trace metal rich galaxies with plenty of dust, as well as neutral and molecular gas for star formation at high redshifts. This suggests that quasar 2175 Å absorbers are the missing absorption line systems that astronomers have looked for to trace star formation and chemical enrichment in high redshift galaxies for the past 25 years.

The high resolution data provide measurements of the metal column densities, depletion ratios, and the assessment of weak transitions. To assess the metallicity of the gas, however, we require coverage of the HI Lyα line which is generally not covered in the SDSS or BOSS spectra. This is the scientific focus of this proposal with the Lick/Kast.

Lick's role:
Using measurements of the Lyα absorption line, we will estimate N_{HI}. If the damping wings of Lyα are observed, we will be able to derive N_{HI} accurately by modeling the optical depth with a Voigt profile[19]. If no damping wings are observed, we will still be able to provide a value for N_{HI} assuming the equivalent width of the Lyα absorption line lies on the $\sqrt{N}$ part of the curve of growth. Such absorbers would be of special interest as they would undoubtedly require supersolar metallicity.

This study will help to address how gas components probed through quasar absorption line systems are linked to star formation and chemical enrichment in high-z galaxies and the data will be used to contrain galaxy formation and evolution models with various gas components, outflows, star formation rates and feedback. It will also help to solve the mystery of the origins of the broad 2175 Å absorption bump. Although the feature is observed ubiquitously in the MW and LMC, the origin of the bump, its dependence on environment, and its evolution remain poorly understood for the past 47 years since its first discovery[13,2].

Lastly, the broad wavelength coverage of the Kast spectrometer, which extends $\approx$ 500Å blueward of the SDSS/BOSS spectra, enables a more precise assessment of the extinction law of the dust in the 2175 Å absorbers. The UV coverage is especially important because extinction is much greater at shorter wavelengths. These data will establish if the dust grains have sizes more reflective of MW dust, LMC dust, or a new composition altogether. For this reason, we include a small set of quasars with $z_{\mathrm{abs}} < 1.6$ where we cannot measure Lyα but these have very strong 2175 Å bumps and we wish to more precisely constrain the extinction law.

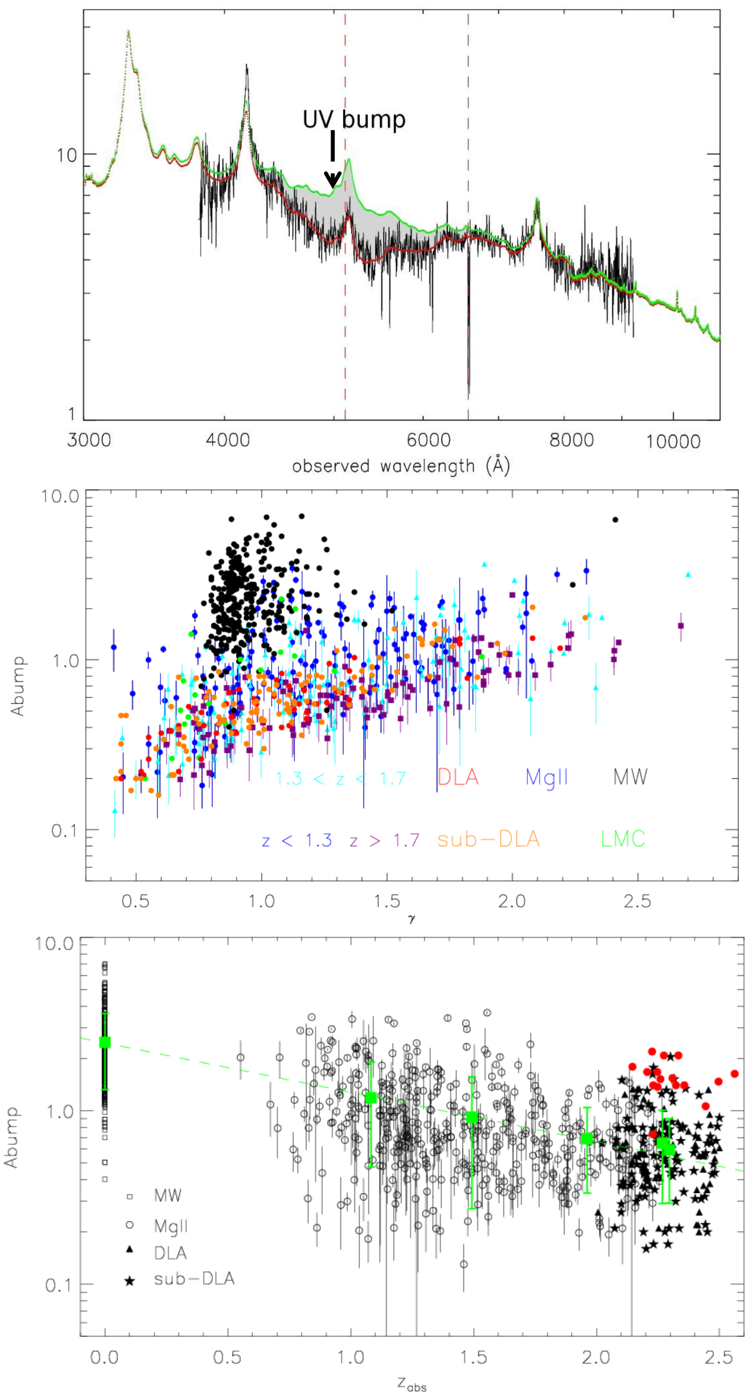

Fig. 1: (Top). Example of 2175 Å bump detection. The green and red lines represent a reddened quasar composite spectrum without and with an LMC-like UV bump, respectively. Only the LMC like extinction curve fits the quasar continuum. The left red vertical dash line mark the location of the center of the 2175 Å absorption bump. The right red vertical dash line marks the location of Mg II absorption line. (Bottom panels). Comparison of bump strengths with 2175 Å extinction bumps in MW (black filled circles, Fitzpatrick & Massa 2007) and the LMC2 (green dots, Gordon et al 2003) supershell. 426 Mg II absorption selected 2175 Å absorbers at $z_{abs} < 1.3$, $1.3 \leq z_{abs} \leq 1.7$ and $z_{abs} > 1.7$ are marked with three different color dots. 166 strong Lyα absorber selected 2175 Å absorbers at $z_{abs} \sim 2.0$–2.5 are also marked with two groups (48 with DLAs and 118 with sub-DLAs) from SDSS-III BOSS DR9 quasar spectra.

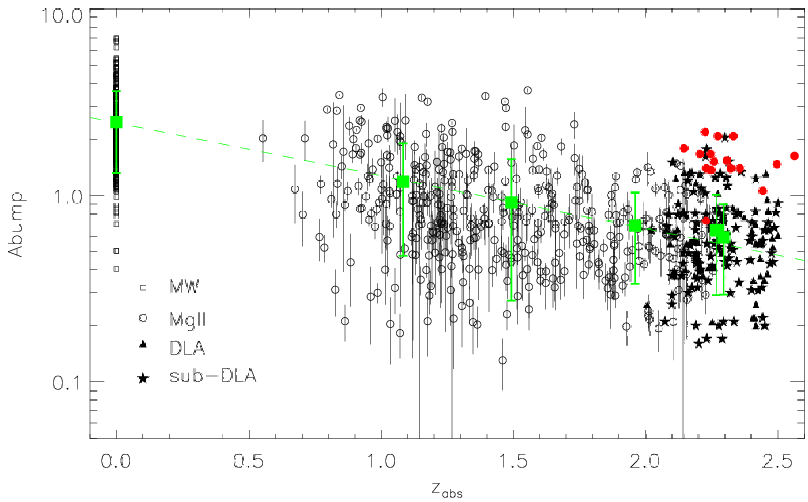

Fig. 2: Evolution of the 2175 Å bump strength as a function of the absorber's redshift. The open circles represent Mg II absorption selected 2175 Å absorbers, while filled stars and triangles represent Lyα absorption selected 2175 Å absorbers at $z_{abs} \sim 2.0$–2.5. The green squares represent the mean values at each of the redshift bins and also the MW. We will be targeting systems at $z < 2$ for HI measurements.

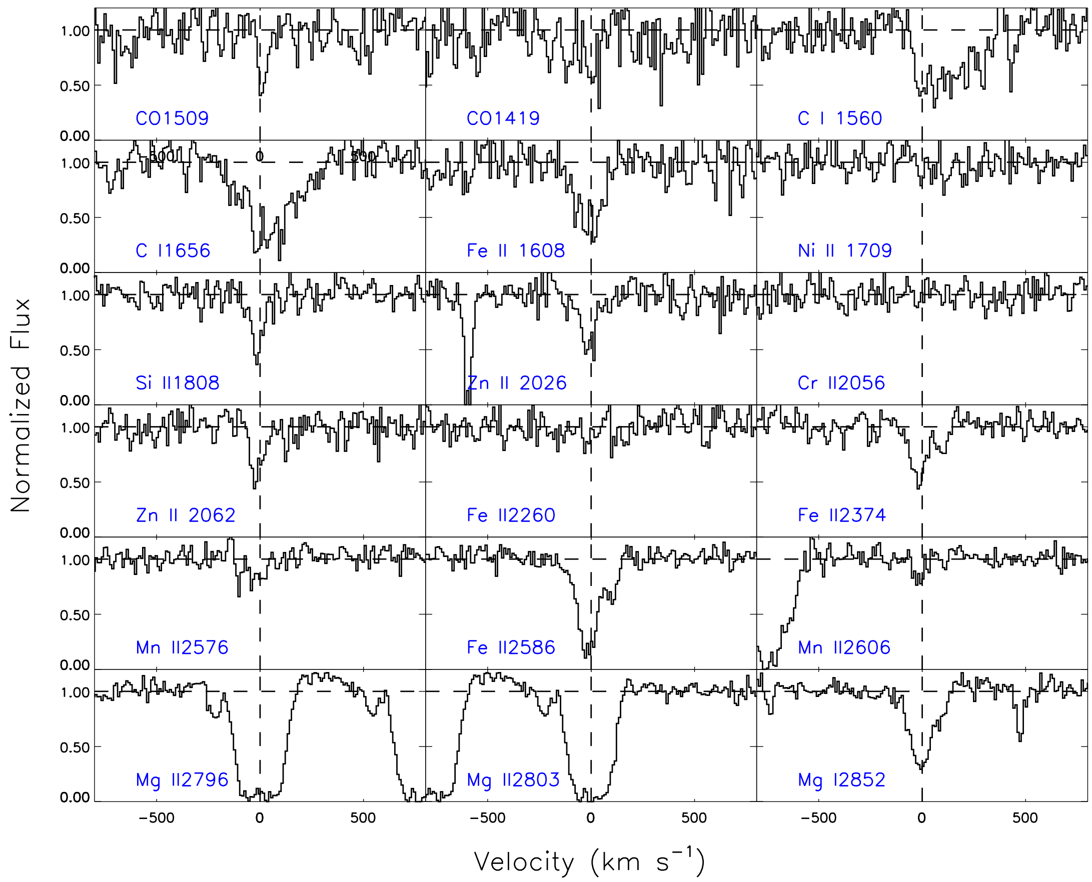

Fig. 3: Part of Keck ESI spectral data for J1212+0833 ($z_{abs} = 2.1166$) in 3600 s exposure: Velocity profiles of metal lines and CO lines for the 2175 Å absorption system toward quasar J1212+0833. The verical black dash lines corresponding velocity = 0 km/s at the absorber redshift (Ma et al. 2013, in preparation). The main velocity components have been resolved with ESI. It is clear that this system shows extremely strong Zn II lines while extremely weak Cr II lines, indicating high metallicity and dust depletion[11]. It also shows extremely strong C I absorption lines and CO absorption bands, rarely detected in known damped Lyα absorbers (DLAs)[9].

2 Technical Remarks

2.1 Progress Report

This program was awarded 5 nights in the semester 2014A and 5 nights in the semester 2014B. Six of the nights were successful, while four were lost to bad weather. In that time, we established the optimal exposure times (1 to 4 hours) and setup for our program and acquired science-grade observations on ~ 20 quasars. These data have been reduced and analysis is ongoing. We then found some of these dust absorbers have very low blue flux because of the dust, and will require longer integration time to achieve enough S/N. We have 5 upcoming nights in 2015A, and we will continue to add a lot more absorbers to the target list. We will balance more exposures on those past targets with poor quality and new high priority targets.

2.2 Targets and Exposures

We will use the Shane 3m telescope and the Kast spectrometer to observe a sample of ≈ 50 QSOs where SDSS/BOSS spectra indicate strong absorption from the 2175 Å extinction feature. These all lie at $z < 2$ where Lyα cannot be observed in the SDSS/BOSS data. We are targeting the Lyα transition which will lie at observed wavelengths $\lambda = 3100 - 3800$Å. We will use the Kast spectrometer with the G3 grism (FWHM ≈ 1.2Å) to best measure this absorption line. With a S/N > 10 per pixel, we will be sensitive to log $N_{\rm HI} \geq 19$ through standard Voigt profile analysis (e.g. O'Meara et al. 2007). Our targets span a rather large dynamic range of magnitudes ($V = 18 - 19$) requiring exposure times of 2 hours to 5 hours. We estimate that we can complete our highest priority targets with an allocation of 5 nights in 2015B. These would be optimally scheduled in September when we are most available to observe. Our second priority would be January as it coincides with the SDSS imaging footprint. Because we are observing at very blue wavelengths, we require new moon conditions.

2.3 Backup Program

In poor observing conditions we will increase exposure times.

2.4 Status of Previously Approved 3-m Programs

We completed our campaign for HeII sources drawn from Pan-STARRS imaging in 2013A. Several of these formed the basis of our Cycle 22 HST submission.

Table 1: Target List

Object	α (J2000)	δ (J2000)	r [AB]	$z_{\rm qso}$	$z_{\rm abs}$
J0733+3451	07:33:02.39	+34.51:02.78	18.26	1.6422	0.8312
J0751+2721	07:51:05.17	+27:21:16.8	18.61	2.1064	1.1509
J0758+1457	07:58:24.27	+14:57:52.4	18.75	2.568	1.115
J1201+1626	12:01:04.81	+16:26:14.33	18.51	1.401	1.034
J1203+0634	12:03:01.01	+06:34:41.5	18.91	2.1799	0.8623
J1220+6832	12:20:59.91	+68:32:26.04	18.61	1.178	1.089
J1240+2735	12:40:11.74	+27:35:57.27	18.80	1.598	1.237
J1247+5003	12:47:08.42	+50:03:20.78	19.02	2.268	2.133
J1256+0053	12:56:19.03	+00:53:26.2	18.46	2.3896	1.2625
J1303+3510	13:03:49.92	+35:10:24.7	18.89	1.8510	1.1453
J1308+1331	13:08:41.19	+13:31:30.5	18.86	1.9440	0.9519
J1310+0108	13:10:58.14	+01:08:22.2	18.18	1.389	0.862
J1319+4310	13:19:03.38	+43:10:34.1	18.54	1.9818	1.6533
J1328+3723	13:28:46.25	+37:23:02.6	18.81	1.7078	1.1453
J1331+0044	13:31:25.92	+00:44:14.04	18.59	2.021	1.310
J1348+4241	13:48:14.07	+42:41:42.5	18.98	1.6470	1.1741
J1402+0756	14:02:55.68	+07:56:41.92	18.49	1.731	1.353
J1409+4353	14:09:14.75	+43:53:08.95	18.88	1.230	1.182
J1409+0048	14:09:18.72	+00:48:24.36	18.95	2.0008	1.6950
J1410+0015	14:10:51.25	+00:15:46.9	18.35	2.5917	1.1707
J1422+1716	14:22:39.26	+17:16:20.02	18.91	1.243	0.926
J1425+3757	14:25:39.38	+37:57:36.77	18.49	1.8971	0.8502
J1429+2210	14:29:06.93	+22:10:01.6	19.01	1.9588	0.9222
J1435+0420	14:35:12.94	+04:20:36.96	19.03	1.944	1.657
J1438+0831	14:38:23.52	+08:31:28.64	18.20	2.838	1.779
J1440+0326	14:40:27.00	+03:26:37.9	18.92	2.1362	1.0212
J1441+0845	14:41:18.09	+08:45:08.3	18.34	2.6908	1.7556
J1447+6148	14:47:37.4	+61:48:20.76	19.07	1.667	0.949
J1454+3435	14:54:32.54	+34:35:23.9	18.80	2.37	1.58

2.5 Supplementary Observations

2.6 Technical Concerns

We have none.

2.7 Experience and Publications

Prochaska and Lau have extensive experience with Kast.

2.8 References

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