X-shooter Science Verification Proposal

Intergalactic metals and ionization on the approach to cosmic reionization

Investigators	Institute	email
Emma Ryan-Weber (PI)	Swinburne, Australia	eryanweber@swin.edu.au
Max Pettini	IoA, Cambridge, UK	pettini@ast.cam.ac.uk
Bram Venemans	ESO	bveneman@eso.org
Piero Madau	UC Santa Cruz, USA	madau@ucolick.org

Abstract:

The details of cosmic reionization have yet to be solved. Metals in the intergalactic medium (IGM) at $z \sim 6$ provide a measure of past star light and ionization state completely independent from the detection of galaxies and the Lyman$-\alpha$ forest. We propose to take the spectrum of the $z_{\rm em}$=6.06 QSO, SDSS J2054-0005 to (1) search for C IV in the IGM at the highest possible redshifts; (2) detect associated ions, C II, Si IV, Si II and N V, to measure the ionization state of the IGM along this line-of-sight. Uniquely, the superior sensitivity and wavelength coverage of X-shooter will allow us to detect ions critical for measuring the ionization balance as cosmic reionization is approached. This single target is the best placed $z > 6$ QSO for observations throughout June and August.

Scientific Case:

In the current era of precision cosmology (e.g. Dunkley et al. 2009, ApJS, 180, 306), the epoch of reionization stands out as an unknown frontier (see review by Fan, Carilli & Keating, 2006, ARA&A 44, 415). We have yet to discover when and over what period the starlight from the first galaxies lit up the Universe, ionizing the surrounding neutral hydrogen gas. We do not know whether this process was uniform or patchy, how massive the galaxies were, or whether they contained the same types of stars as we see today.

The recent discovery of a gamma-ray burst at $z = 8.2$ (Tanvir et al. 2009, GCN circular, 9219) confirms that massive stars exist and explode in the early Universe. However spectroscopic confirmation of objects at high redshift is rare. Despite considerable observational effort, limited progress has been made in pinpointing the end of reionization as the interpretation of the Lyman-α forest becomes increasingly difficult as redshift 6 is approached (e.g. Becker et al. 2007, ApJ, 662, 72). Some bright galaxies are detected at $z > 6$ (e.g. Bouwens et al. 2006, ApJ, 653, 53), and UV-photons from their stellar populations contribute to the background ionizing flux at these redshifts. Whether the level of star formation so far accounted for at $z > 6$ is in fact sufficient to maintain reionization remains to be seen, because it depends on a number of essentially unknown parameters, especially the escape fraction of Lyman continuum photons from the sites of star formation, the degree of clumping of the sources and of the intergalactic medium (IGM), and the slope of the faint end of the galaxy luminosity function at these early times (Madau, Haardt, & Rees 1999 ApJ, 514, 648).

Metal lines with $\lambda_{\rm rest} > 1216$ Å in the high redshift IGM are currently the only method by which modern instrumentation can probe the ionization state of the IGM on the path to reionization. The production of early metals is closely linked to the emission of Lyman continuum photons as it the same massive star that produce both, insensitive to the slope of the stellar initial mass function, IMF (Madau & Shull 1996, ApJ, 457, 551). Metals provide a measure of the total number of ionizing photons and past star formation completely independent from the difficult process of detecting and confirming galaxies at $z \geq 6$.

One of the key scientific objectives of X-shooter is to study the 'Metal enrichment in the early universe through the study of high z absorption systems'. Triply ionized carbon, C IV, is the most common metal ion in the IGM. At intermediate redshifts detailed studies show that the associated species Si IV, C II, Si II and N V are also often detected. In Ryan-Weber, Pettini, Madau & Zych (2009, MNRAS, 395, 1476) we presented the discovery of three C IV absorption systems at $z > 5$. Our measurement of the mass density of triply-ionized carbon, $\Omega_{\rm CIV}$, points to a rapid build-up of intergalactic C IV, over a period of ~ 300 Myrs. According to the detailed cosmological modelling by Oppenheimer et al. (2009), such a build-up is likely to be due to both an increase in metallicity from rising levels of star formation and an increase in cosmic ionization. However, the number of ionizing photons emitted prior to $z = 5.8$ implied by our measurement of $\Omega_{\rm CIV}$ is insufficient, by itself, to maintain an ionized IGM, suggesting that more carbon must be present at these epochs, either in different ionization stages or in C IV-bearing clouds yet to be detected.

Depending on the time allocated (see time justification below), we can achieve either the first or both of these goals:

1. To continue the search for C IV at $z \sim 6$: the detection of one C IV system at $z > 5$ would be significant, since only 3 are known to-date.

2. To detect associated ions of Si IV, C II, Si II and N V to measure the ionization state of the IGM on the approach to the epoch of reionization. The ionization state is a crucial factor in determining the overall metallicity of the IGM. Ultimately our aim is to use the metallicity measurement to determine the integrated star formation history and number of ionizing photons from early stars that contributed to cosmic reionization.

Until now observations of the high redshift IGM have been severely limited by the partial wavelength coverage of existing near-IR spectrographs. Finally with X-shooter we have the means to probe the full pathlength for C IV absorption offered by a single high-z QSO, extend our census to lower column density systems, and detect associated ions to measure the ionization balance.

Calibration strategy:

Standard calibration as described in section 4.1 of the X-shooters users' manual will be sufficient. Absolute flux calibration is unimportant as we are only interested in absorption features, whose strength will be measured with respect to the QSO continuum.

Targets

Target	RA	DEC	mag	Mode	Remarks
SDSSJ2054-0005	20 54 06.49	-00 05 14.8	J=19.18	VIS 0.7″ slit; NIR 0.6″ slit	$z_{\rm em} = 6.06$

Time Justification:

The X-shooter exposure time calculator (ETC) shows that a 10-hour on-source exposure on a point source with $J = 19.18$ and a power law with a spectral index of -0.5, which is typical of the $z \sim 6$ QSOs (Jiang et al. 2007, AJ, 134, 1150), will result in a $\langle$S/N$\rangle$ per spectral bin ranging from $8 - 27$ in the VIS and $8-41$ in the NIR over the wavelength range of interest. In order to minimise the effect of the OH skylines we will use the 0.7″ slit (R=11000) in the VIS arm and the 0.6″ slit (R=8100) in the NIR arm. The X-shooter ETC does not take skylines into account and returns a similar range in $\langle$S/N$\rangle$ for the VIS arm with a slit width of 0.7″ or 0.9″, thus we have chosen the 0.7″ slit. The ETC was run under full moon conditions, an airmass of 1.2 and seeing of 0.8 ″.

What can be achieved with the following total on-source (+ overhead) times?

• **1 hr (+13 min):** increase the total path searched for metals at the highest observable redshifts by detecting C IV in the NIR at the level seen towards other QSOs with ISAAC (Ryan-Weber, Pettini & Madau, 2006, MNRAS, 371, 78).
• **4 hr (+55 min):** use X-shooter's superior wavelength coverage to detect C IV over the full redshift range ($5 < z < 6$) down to column densities of 4×10^{13} cm^{-2}.
• **10 hr (+2.3 hr):** maximise the full potential of X-shooter by detecting C IV at twice the sensitivity as above, together with associated ions, Si IV, C II, Si II and N V, crucial for determining the ionization state and metallicity of the IGM along this line-of-sight.