Probing the epoch of reionization with high redshift quasars from LSST

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See Reed, McMahon et al, 2015, 2017, Pons, McMahon et al, in prep; Reed, Banerji et al in prep;

Also https://github.com/richardgmcmahon/count_quasars

Quasars with z>6.5

- Scientific motivation
- Uncertainties in forecasts
- Need for LSST and near infra red imaging data (VISTA, Euclid) at the pixel level

Scientific Motivation



Scientific Motivation

- Most (around 90%) of the baryons (H, He, C, O etc) in the Universe are are not in stars or planets at any epoch. They are in an ionized metal enriched highly ionized intergalactic medium between galaxies.
 - Studies of this ionized and neutral gas phase is only possible via the spectroscopic study foreground intervening quasar absorption lines superposed on background quasars
- High redshift quasars are the physical manifestation of accretion onto supermassive black holes: > 10⁷-⁹ solar masses
 - The formation and growth of these extreme objects is a fundamental open question in astrophysics



Evolution of HI: 3C273 spectrum from HST/FOC z=0; z=3.6 CSO HiRES/Keck spectrum from M. Rauch (both are radio selected)

Heavy elements and HI neutral fraction





Figure 1. A high signal-to-noise spectrum of the quasar ULAS J1319+0959 at z = 6.13 from Becker et al. (2015), obtained with the X-Shooter spectrograph on the Very Large Telescope (VLT). The spectrum has been rebinned to 1.5 Å per pixel for presentation purposes.

The HI or Neutral fraction of the IGM can be inferred in various ways.

LSST@Lyon, 2018 June



LSST@Lyon, 2018 June

 $\log_{10}(\chi^2)$

Hydrogen Ionized near zones



Radial size determined by neutral fraction, luminosity and age of quasar radiation front

LSST@Lyon, 2018 June

Nuisance foreground objects: L and T Galactic stars



- Very red spectrum rising in optical;
- Redder than M-star in optical

- Near IR Broad band colours are 'blue'
- Similar to A star photometrically in JHK
- Spectrum is heavily absorbed in near IR
- Spectrum similar to Jupiter; water and Methane

Quasar Photometry at z ~ 6





Reduced chi-squared including model error or floor on statistical errors





VISTA Large (>100deg²) Area ESO Public Surveys

	Survey	Area (deg ²)	5σ point source depth (AB mag)				
			Z	Y	J	Н	K _s
	VISTA Hemisphere Survey	18, 000			21.2		19.8
	 VHS-DES 120 secs per band 	4500	24.7	23.0	21.3	(21.0)	20.2
	 VHS ATLAS 60 secs per band 	5000		20.9	20.7	(20.6)	19.8
	3. VHS-GPS (5° < b <30°) 60 secs per band	8000			21.2		19.8
	VIKING	1,500	23.1	22.3	22.1	21.5	21.2
	VVV (Galactic Centre)	520	22.4	21.8	21.1	19.6	20.0
	VMC (Magellanic Clouds)	184		23.3	23.1		23.0

VHS time allocation: 500+ nights on VISTA over 7 years: started 2010; almost finished



Visible and Infrared Survey Telescope for Astronomy (VISTA)

VISTA summary

- Location: ESO, Paranal, Chile
- **Aperture:** 4.2 m diameter f/1 primary
- Field of view: 1.65 degree diameter
- Instrumentation: VIRCAM 8k x 8k mosaic near-infrared camera
- **Detectors**: 16 x 2k x 2k pixel (Raytheon VIRGO HgCdTe); 67 megapixels
- Wavelength range: 0.84–2.5 microns
- Pixel scale: 0.34 arcseconds/pixel





Sparse filled mosaic 90%, 42% spacing

Uncertainties in quasar luminosity function evolution with redshift



LSST forecasts

- Commission Phase Mini-Survey
- Year 1

Forecast for LSST Commissioning Mini-survey: catalogue level



Forecast for LiSST Year 1 (15,000 deg²)



Current census of 17 known z>6.5 quasars (2 with z>7.0)



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Summary

- LSST will transform the study of the high redshift Universe as traced by quasars in the redshift range 6.0 to 8.0
 - Near IR photometry from VISTA will be essential for efficient rejection of foreground low mass galactic stars
- Pixel level combination of LSST and near IR data from VISTA will be essential at z > 6.5 selection, 'reliable' photometric classification
 - Spectroscopic follow-up of only a subset possible
 - LSST from Year 2 onwards may help by adding variability since most luminous AGN vary by 0.1mags rms on rest-frame year timescale
 - Also lack of proper motion could be a useful (Gaia not useful since z>6 quasars are not detectable by Gaia)
- Euclid?

EXTRA SLIDES



VISTA: VEILS + VIDEO: 21deg² (centred on 3 Deep Drilling Fields; CDFS, XMM-LSS, EL) Banerji, Hoenig, Sullivan, Jarvis +







z=7 quasar with Optical and Near IR wavebands

