Probing the epoch of reionization with high redshift quasars from VISTA and LSST

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Also https://github.com/richardgmcmahon/count_quasars
forked from https://github.com/dhroth/count_quasars

Site choice:

Cerro Paranal (ESO) or
Cerro Pachon (Gemini)

VISTA SCIENCE COMMITTEE

VSC-00-1

Scientific issues concerning VISTA site choice

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Date: 2000 Feb 4

VISTA primary mirror delivered to VISTA telescope; April 2008

The VISTA Mirror

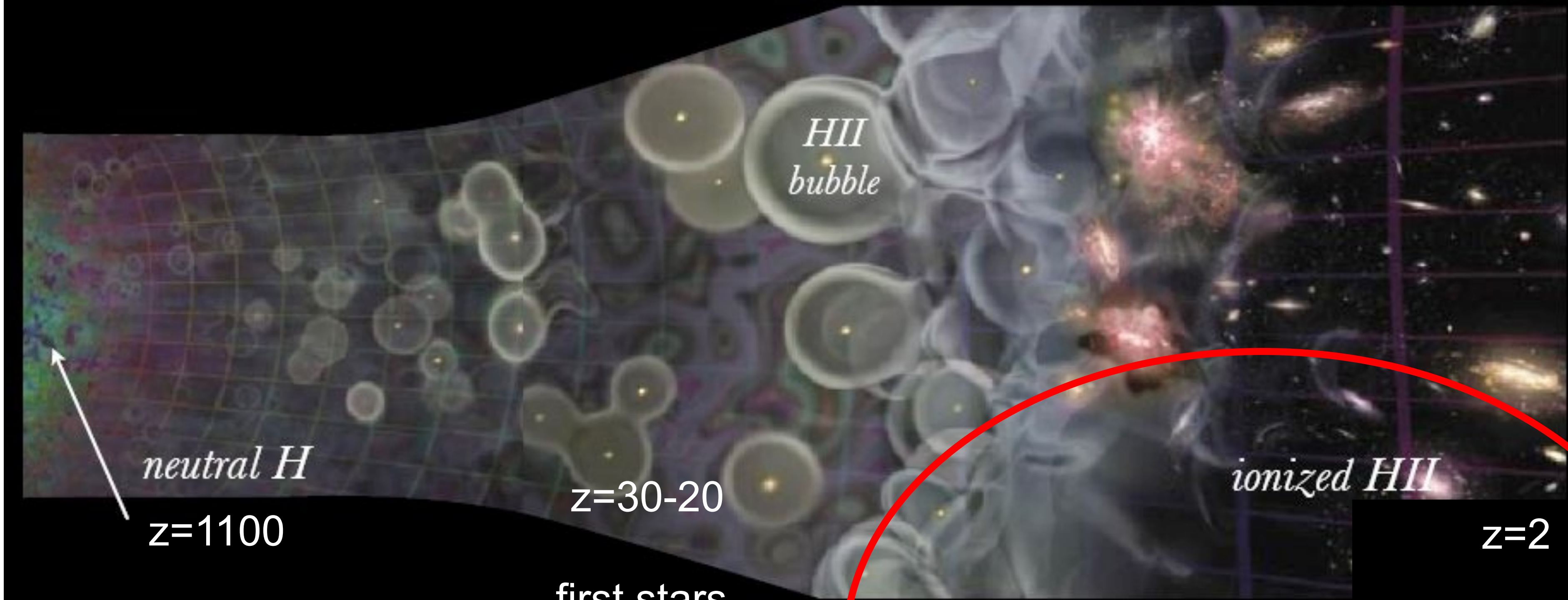
ESO Press Photo 10c/08 (16 April 2008)

4.1 m diameter f/1 primary

Quasars and AGN with z>6.5

- Scientific motivation and background
- Foreground challenges and uncertainties in forecasts
- Need for BOTH LSST and near infra red imaging data (VISTA, Euclid) at both the catalogue and the image pixel level
- How we are getting ready (Raphael Shirley talk)

Scientific Motivation



z=1100

Epoch of
Recombination

first stars
"PopIII"

z=15-6
Epoch of Reionization

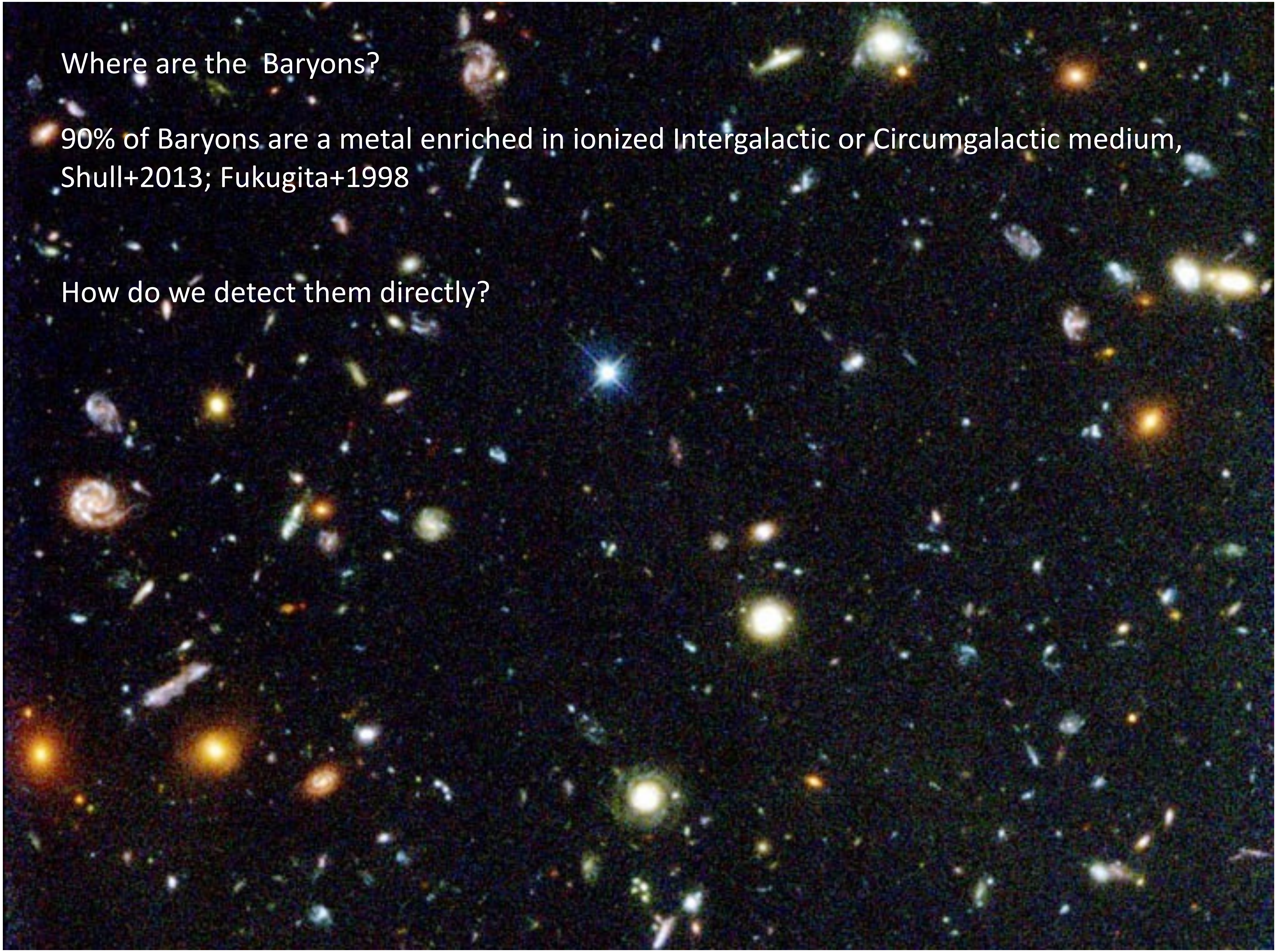
z=2

Epoch of
peak galaxy
and quasar
activity

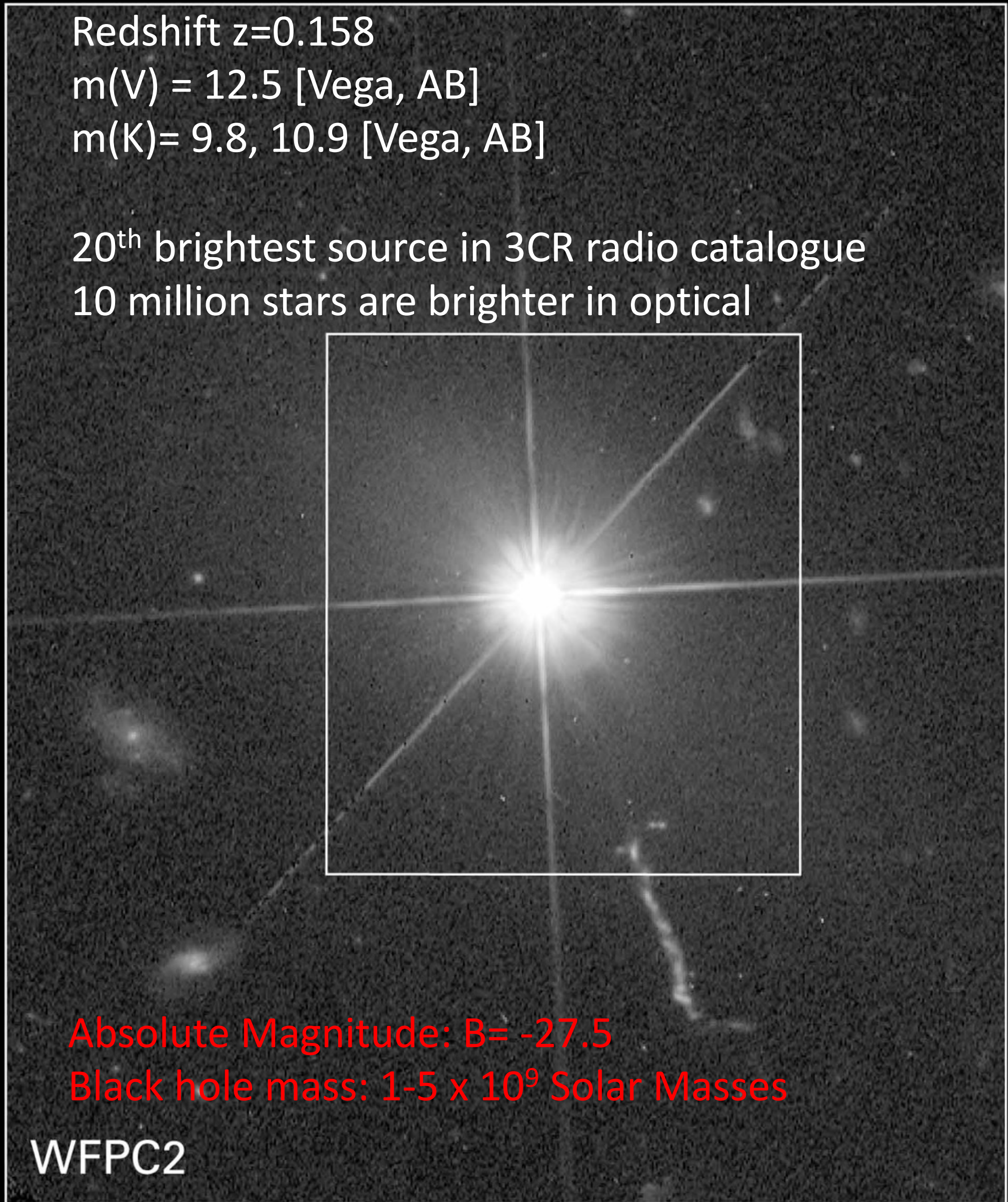
Where are the Baryons?

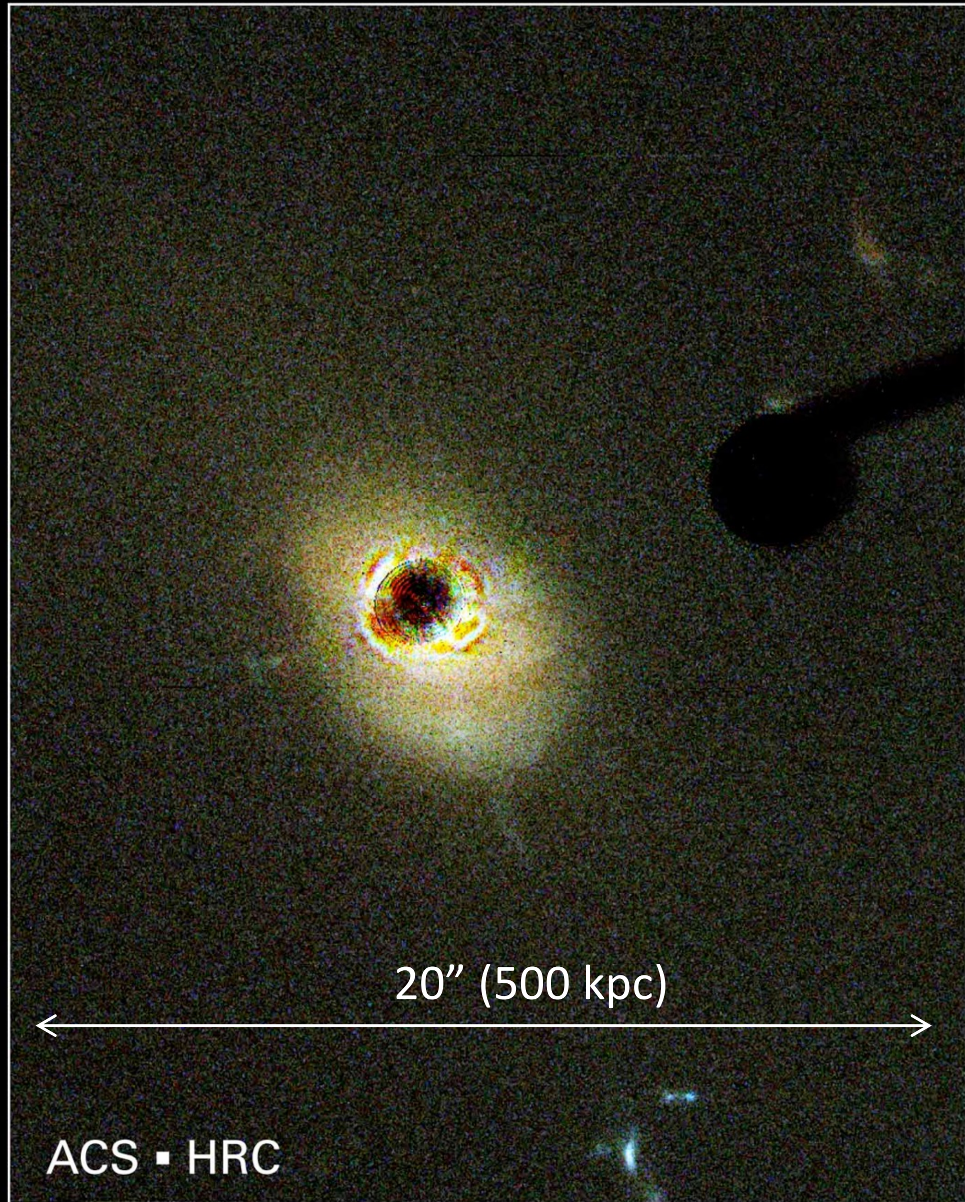
90% of Baryons are a metal enriched in ionized Intergalactic or Circumgalactic medium, Shull+2013; Fukugita+1998

How do we detect them directly?



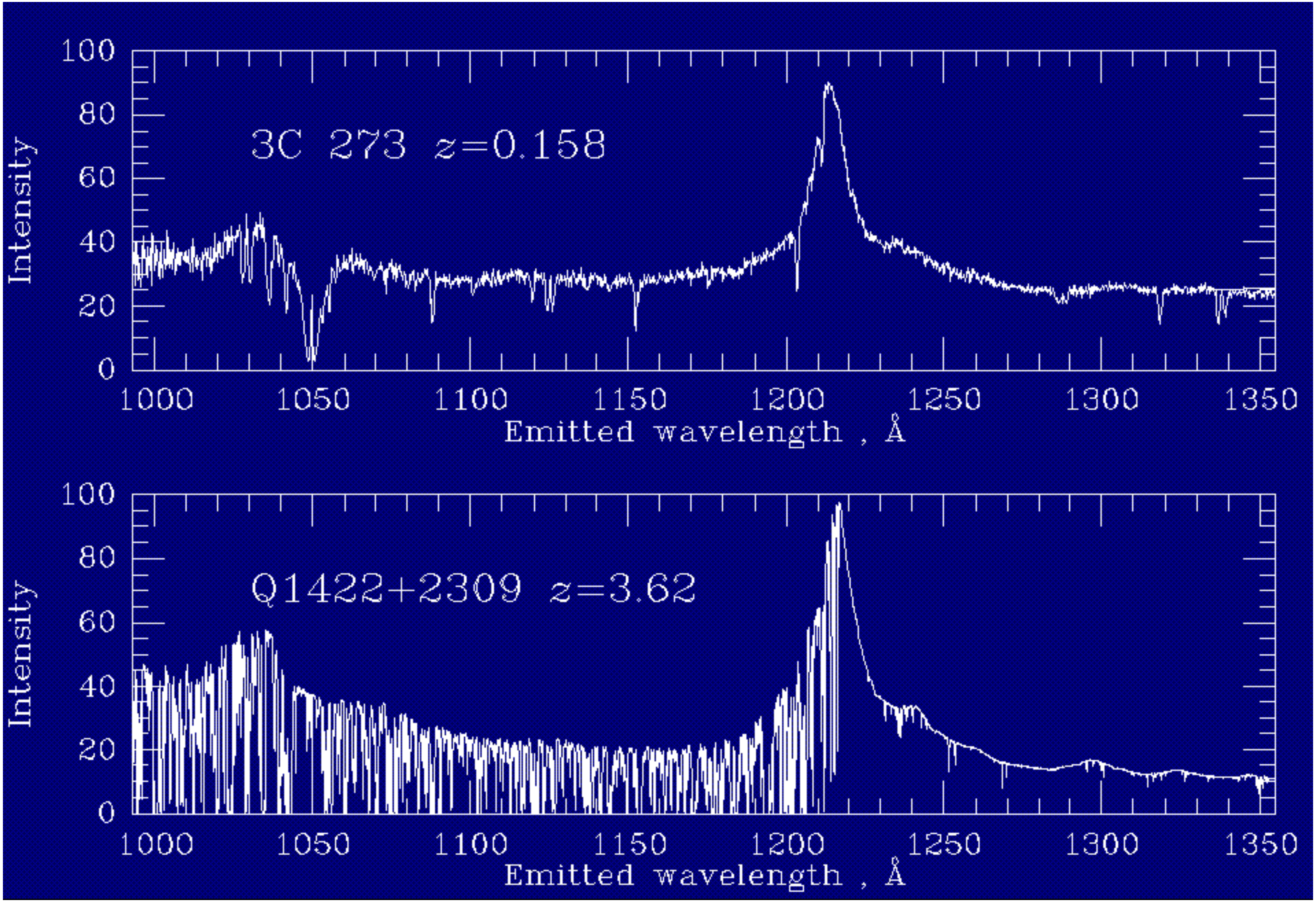
3C273 THE FIRST QUASAR discovered (Hazard+1963, Schmidt, 1963, Nature)





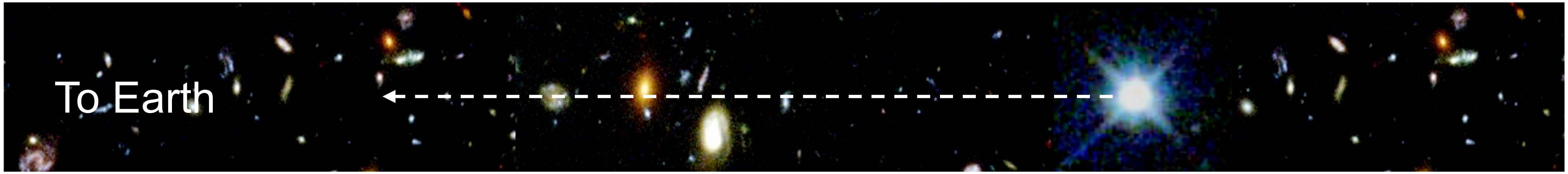
Quasar 3C 273 Martel+2003

Hubble Space Telescope ▪ ACS HRC Coronagraph



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

Heavy elements and HI neutral fraction



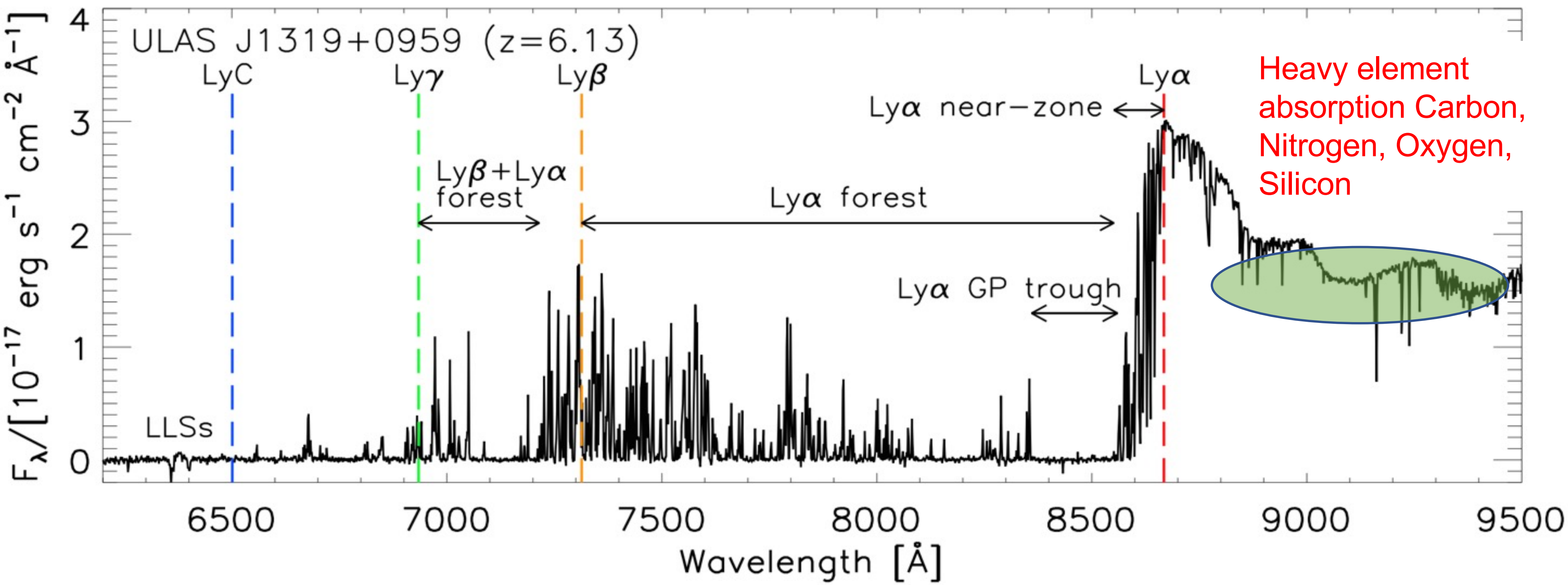
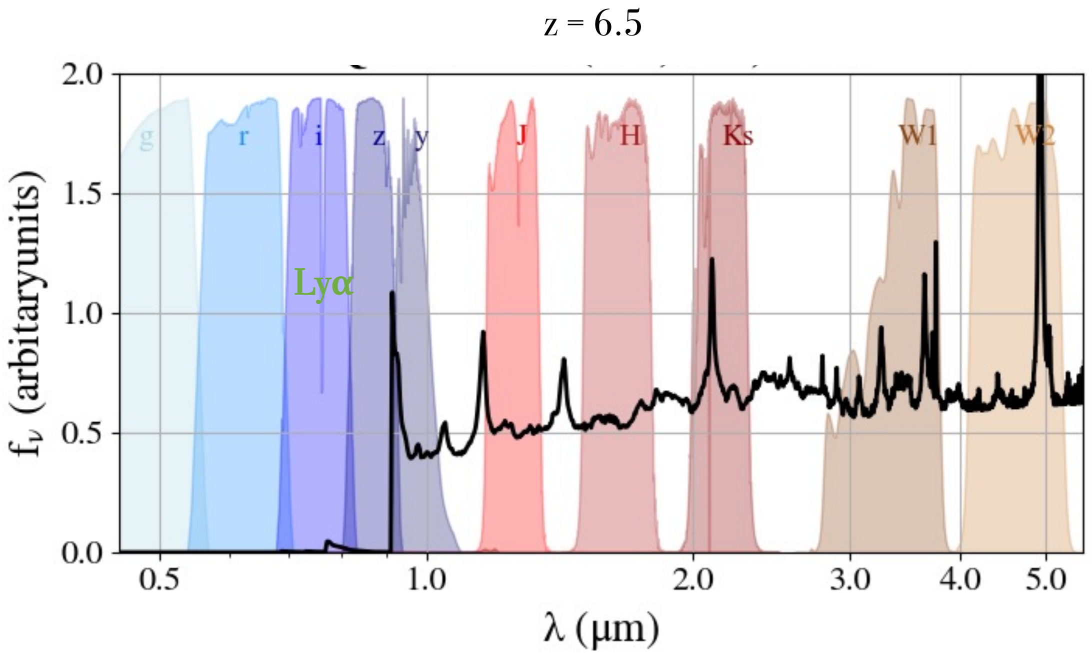


Figure 1. A high signal-to-noise spectrum of the quasar ULAS J1319+0959 at $z = 6.13$ from Becker et al. (2015), obtained with the X-Shooter spectrograph on the Very Large Telescope (VLT). The spectrum has been rebinned to 1.5 Å per pixel for presentation purposes.

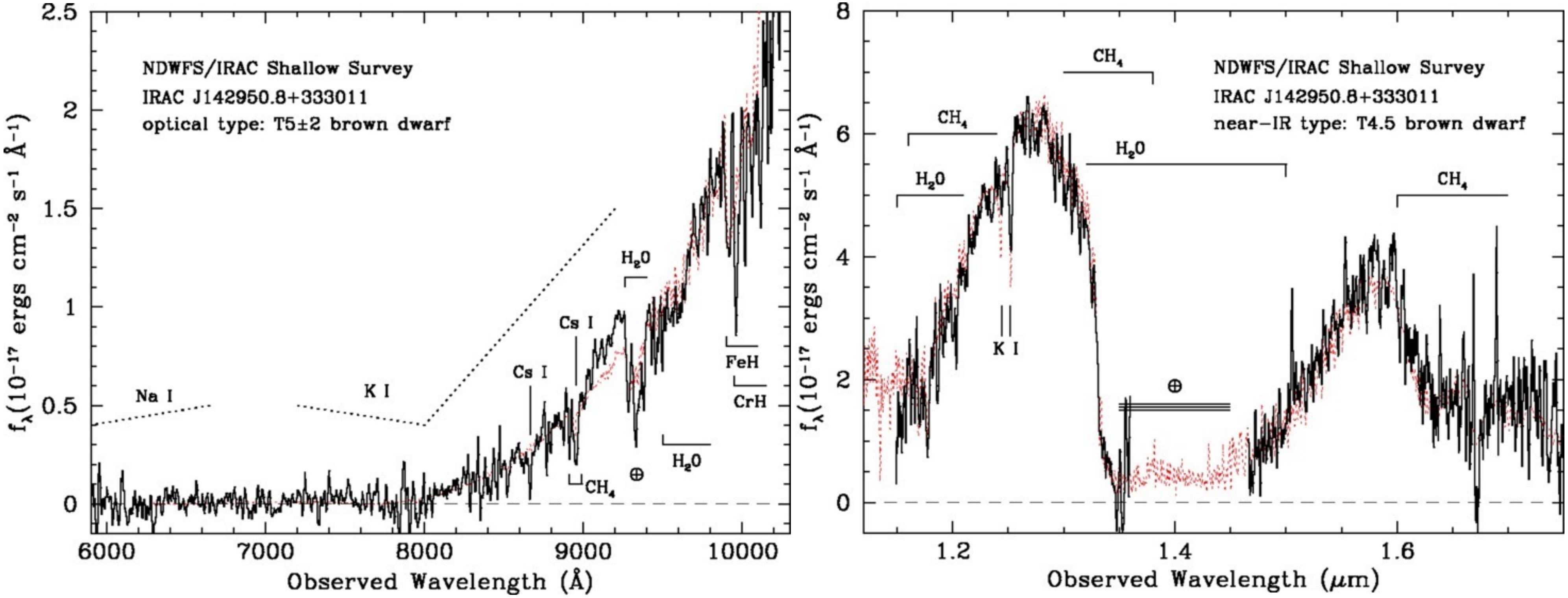
The HI Neutral fraction of the IGM can be inferred in various ways.

High-z Quasars (HzQ) selection challenges

- Dropout: HzQ, flux blueward of the Lyα (1216 Angstroms) emission-line absorbed by neutral Hydrogen
- At z = 6.5, $\lambda_{\mathrm{obs,\,Ly}\alpha} \sim 0.9\mu m$
- HzQ are rare
- Candidates are contaminated by artefacts (image and catalogue junk) and
- Gaussian scatter of foreground LT dwarfs (similar optical colours to HzQ but much more abundant)
- Morphologically misclassified foreground galaxies



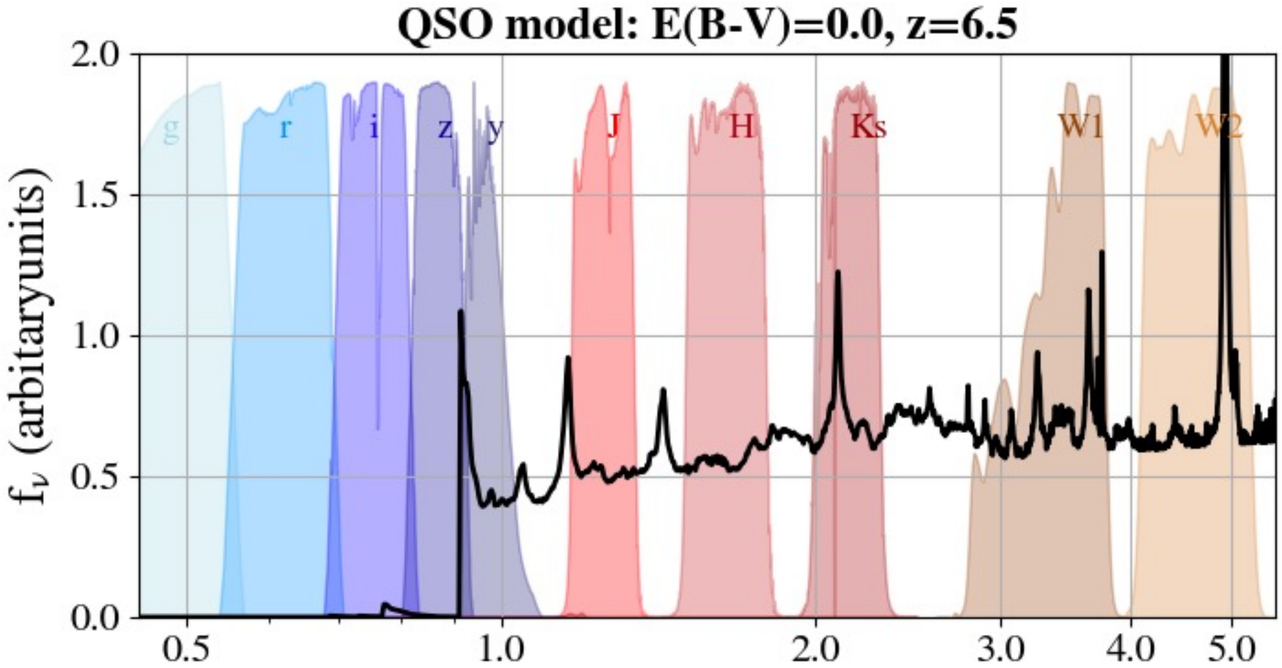
Nuisance foreground objects: L and T Galactic stars (20 Jupiter masses; interesting for other reasons)

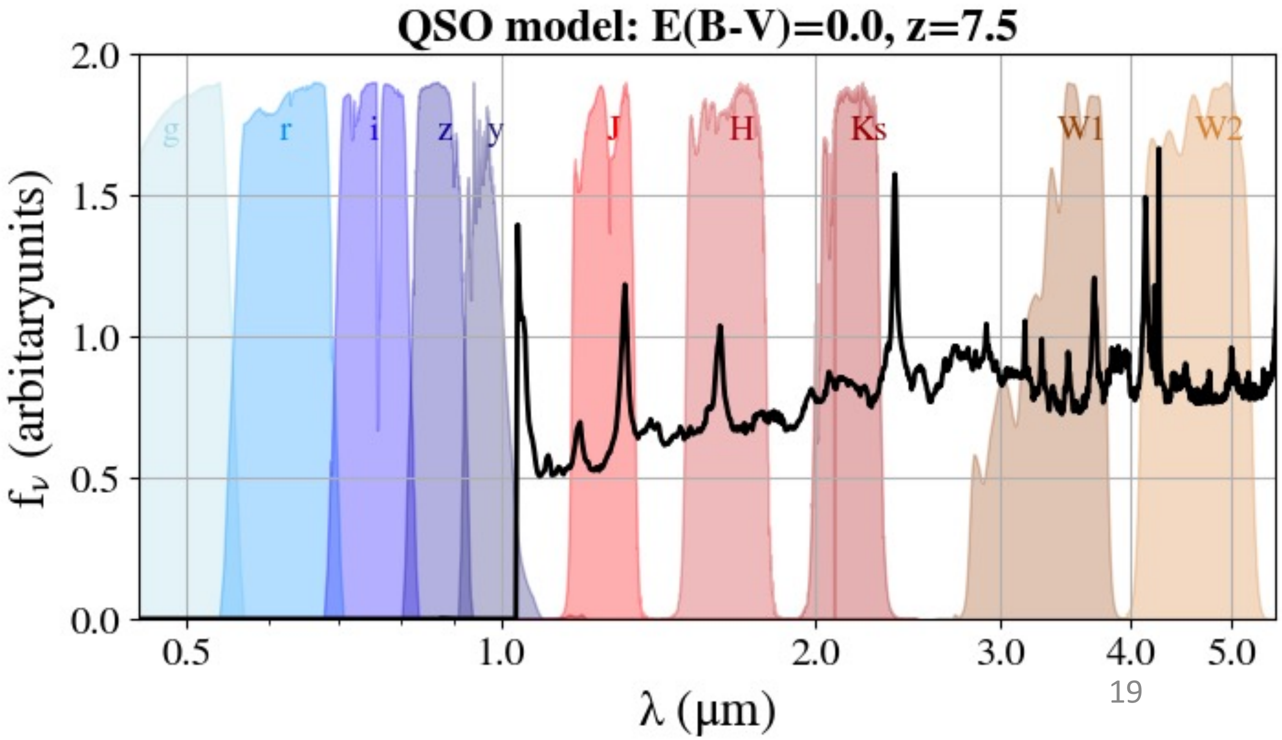


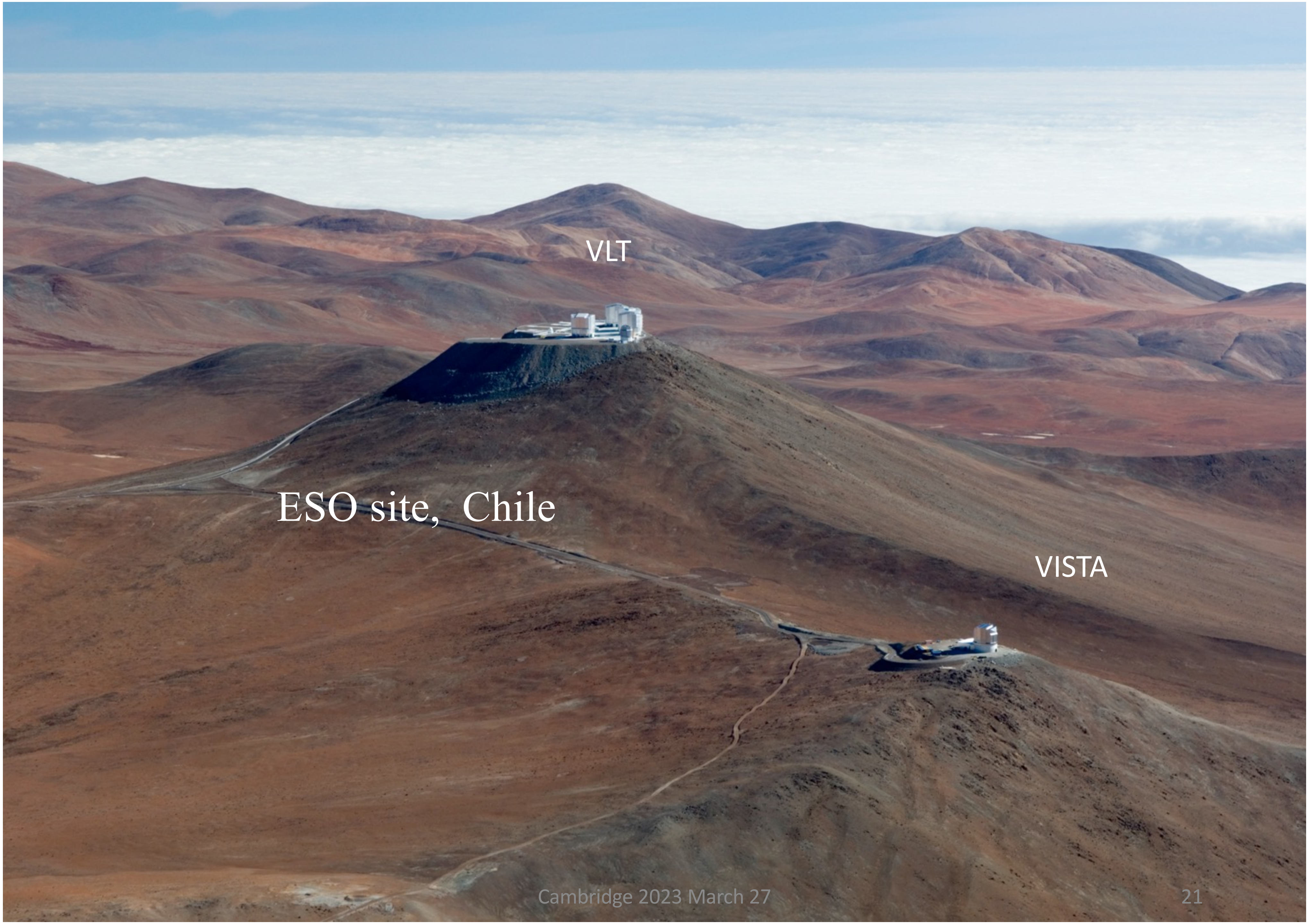
- Very red spectrum rising in optical;
- Redder than M-star in optical

- 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

Spectra from Stern et al, 2007


QSO model: E(B-V)=0.0, z=6.5
g
r
i
z
y
J
H
Ks
W1
W2
f_ν (arbitaryunits)
2.0
1.5
1.0
0.5
0.0
0.5
1.0
2.0
3.0
4.0
5.0

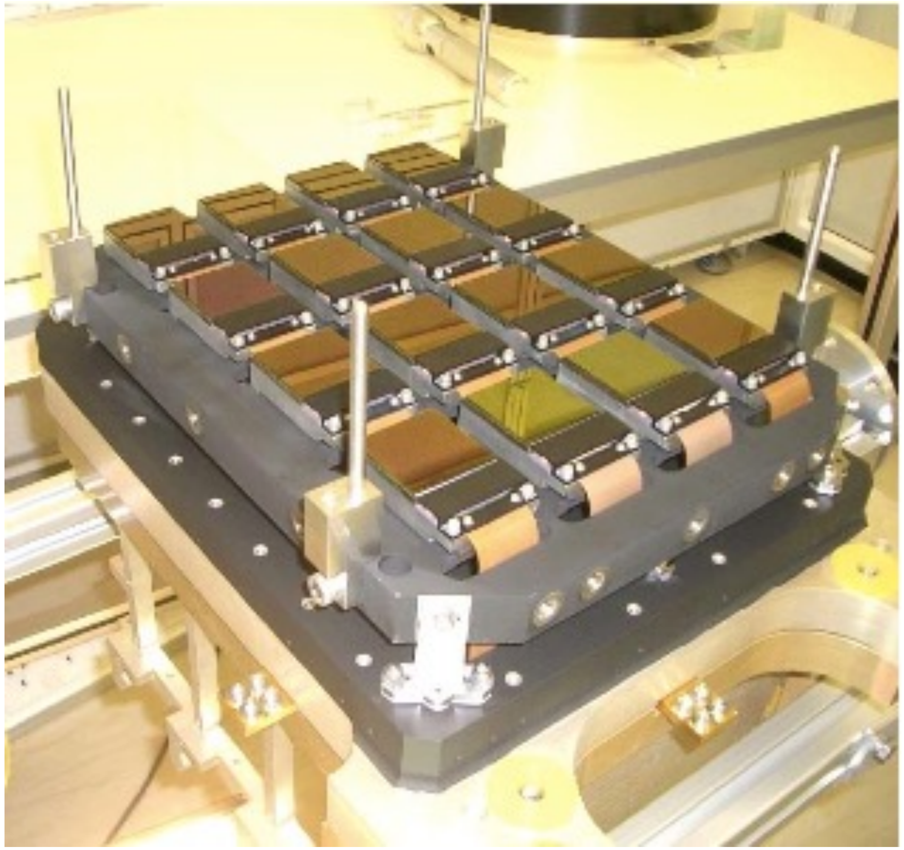

QSO model: E(B-V)=0.0, z=7.5
g
r
i
z
y
J
H
Ks
W1
W2
f_ν (arbitaryunits)
2.0
1.5
1.0
0.5
0.0
0.5
1.0
2.0
3.0
4.0
5.0
λ (μm)


VLT
ESO site, Chile
VISTA

*V*isible and *I*nfrared *S*urvey *T*elescope for Astronomy (VISTA)

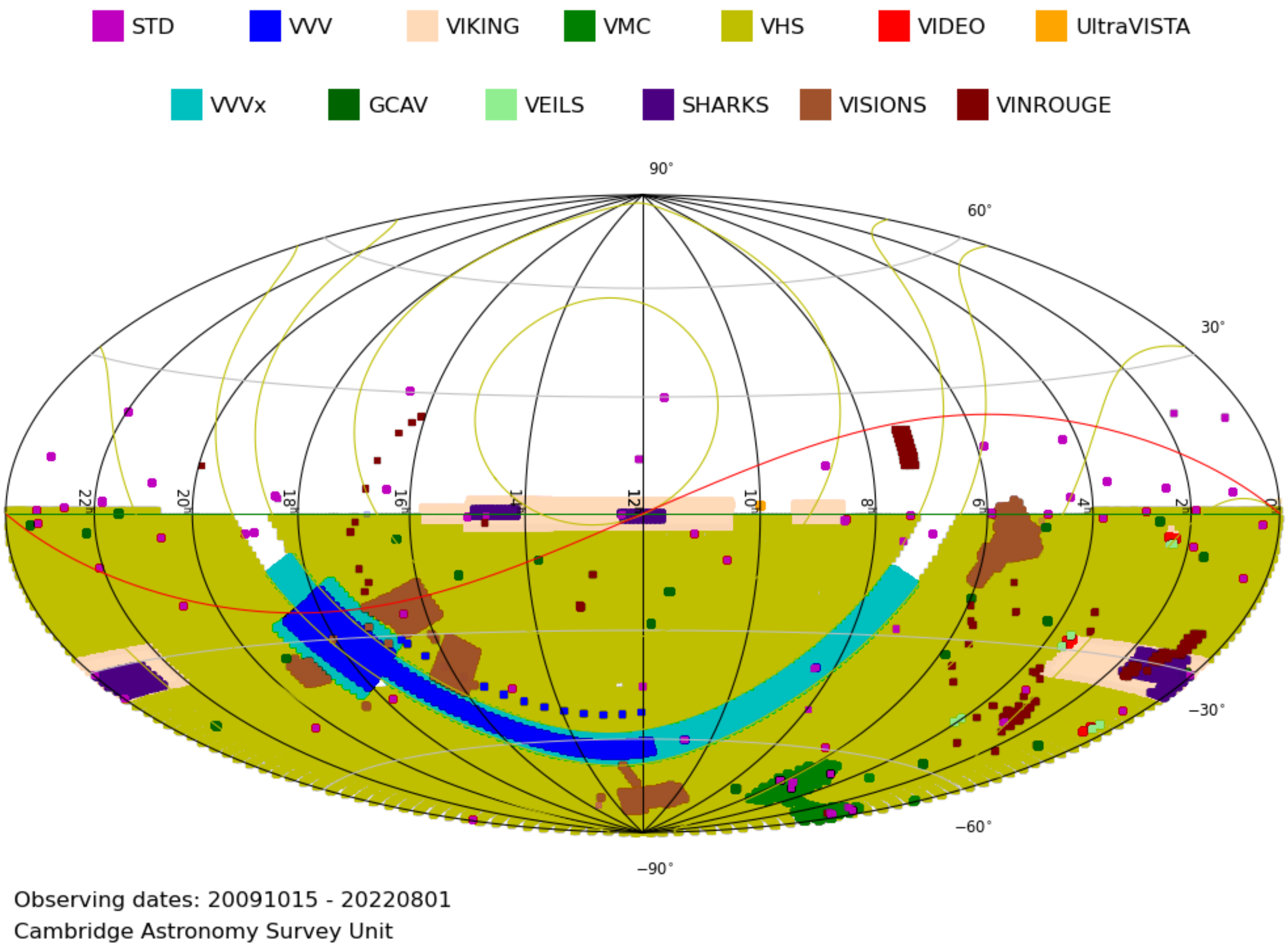
VISTA summary

- **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
- **Surveys started: March 2010**
  Science Verification Oct 2009– Feb 2010



Sparse filled mosaic 90% x 42% spacing

VISTA Survey Coverage



VISTA Large (>100deg²) Area ESO Public Surveys

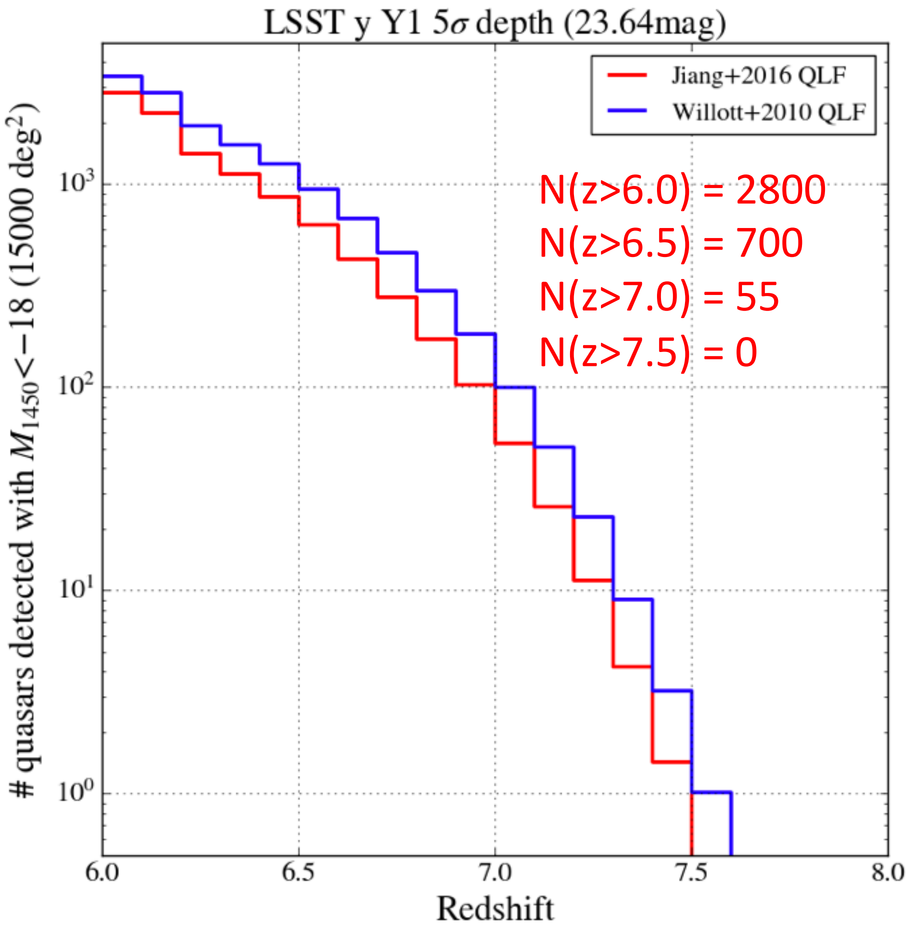
Survey	Area (deg^2)	5σ point source depth (AB mag)				
		Z	Y	J	H	K_s
VISTA Hemisphere Survey	**18, 000**			21.2		19.8
1. VHS-DES 120 secs per band	4500	*24.7*	*23.0*	21.3	(21.0)	20.2
2. VHS ATLAS 60 secs per band	5000		20.9	20.7	(20.6)	19.8
3. VHS-GPS (5° <|b|<30°) 60 secs per band	8000			21.2		19.8
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

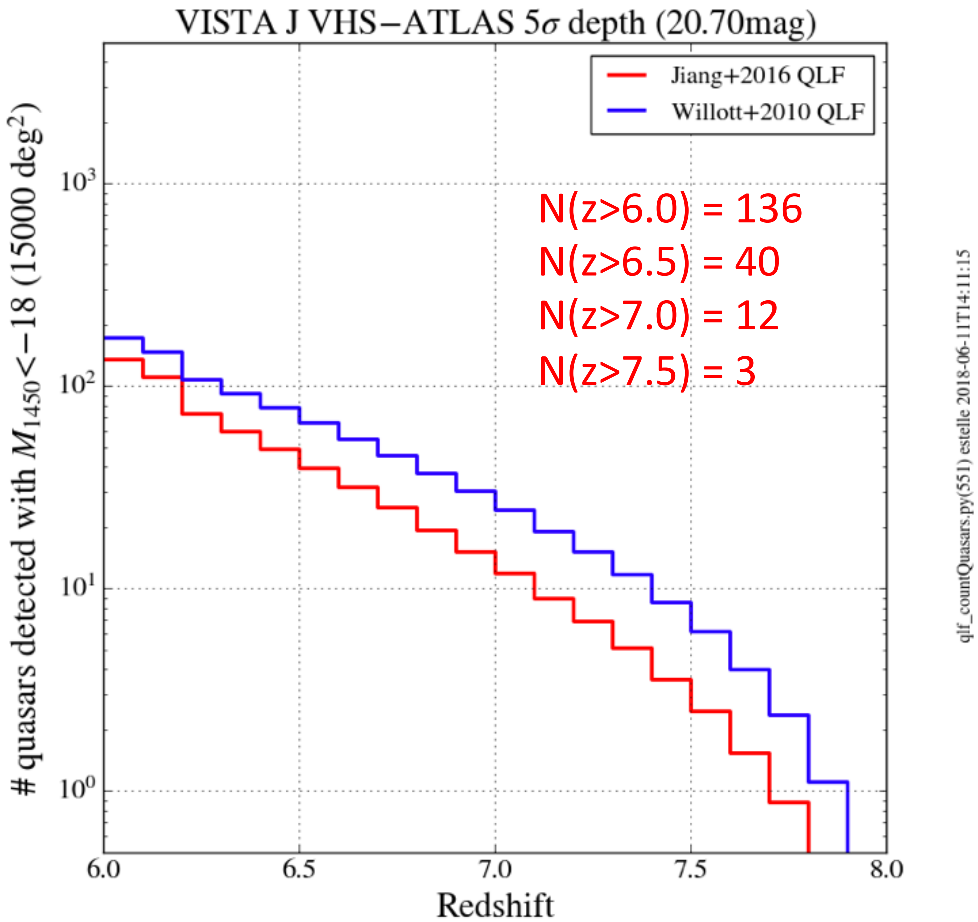
VHS time allocation: inititally 500+ nights on VISTA over 7 years: started 2010; finished 2022

LSST forecasts

- LSST Commissioning Phase Mini-Survey
- LSST Year 1 of 10 observations

Forecast for LSST Year 1 (15,000 deg^2)

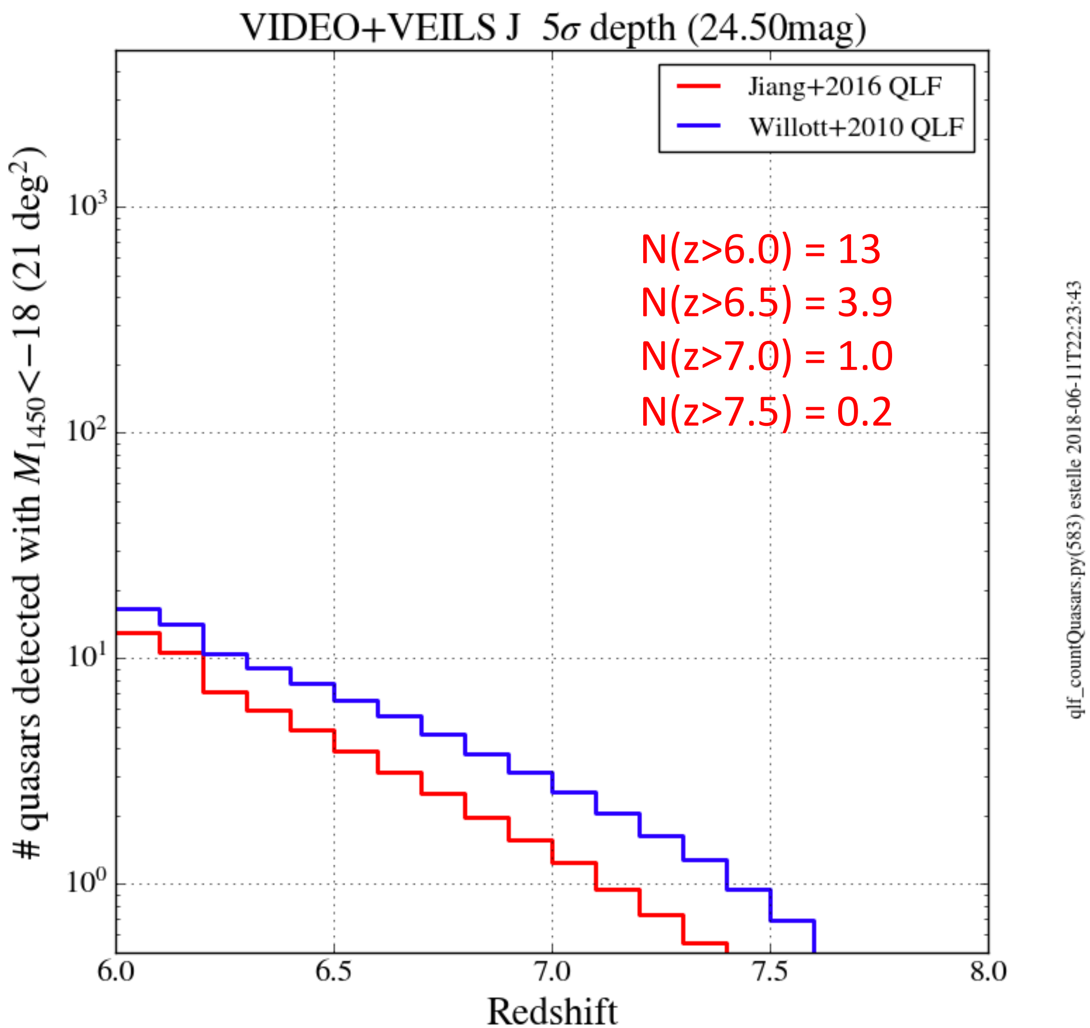




VISTA: VEILS + VIDEO: 20deg^2

centred on 3 LSST Deep Drilling Fields

Banerji, Hoenig, Sullivan, Jarvis +



Summary

- LSST will transform the study of the high redshift Universe as traced by quasars in the redshift range 6.0 to 7.5
  - 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 $z > 6.5$ quasar selection and 'reliable' photometric classification prior to spectroscopy to confirm classification
  - Spectroscopic follow-up of only a subset possible
  - LSST from Year 2 onwards may help by adding variability since luminous AGN vary by 0.1mags rms on **"rest-frame year"** timescale
  - LSST limits on lack of proper motion could be a useful (Gaia not useful since $z>6$ quasars are not detectable in Gaia wavebands)
- Euclid will be deeper in near IT flux but expectations for $z>8$ are low in medium term since footprint growth rate is 3000 deg^2 per year.

EXTRA SLIDES

Example Selection Method:

- classical colour based preselection on DES + VISTA catalogues;
  - J band limit for z>6.5 sample selection;
  - J < 21.0
- Probabilistic SED based classification with listdriven forced flux based photometry on DES (g, r, i) and WISE (W1, W2) to go below catalogue limits (Reed, et al. 2017)