The optically selected AGN population at high redshift

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A talk that will live in infamy

The importance of AGN at high redshift is considerable:

- Reionizing UV radiation field
- Connection to massive black holes and bulge formation
- Connection to star formation
- Optical to X-ray: Obscuration?
- AGN lifetimes
- Preference for dense environments
- Evolution of AGN

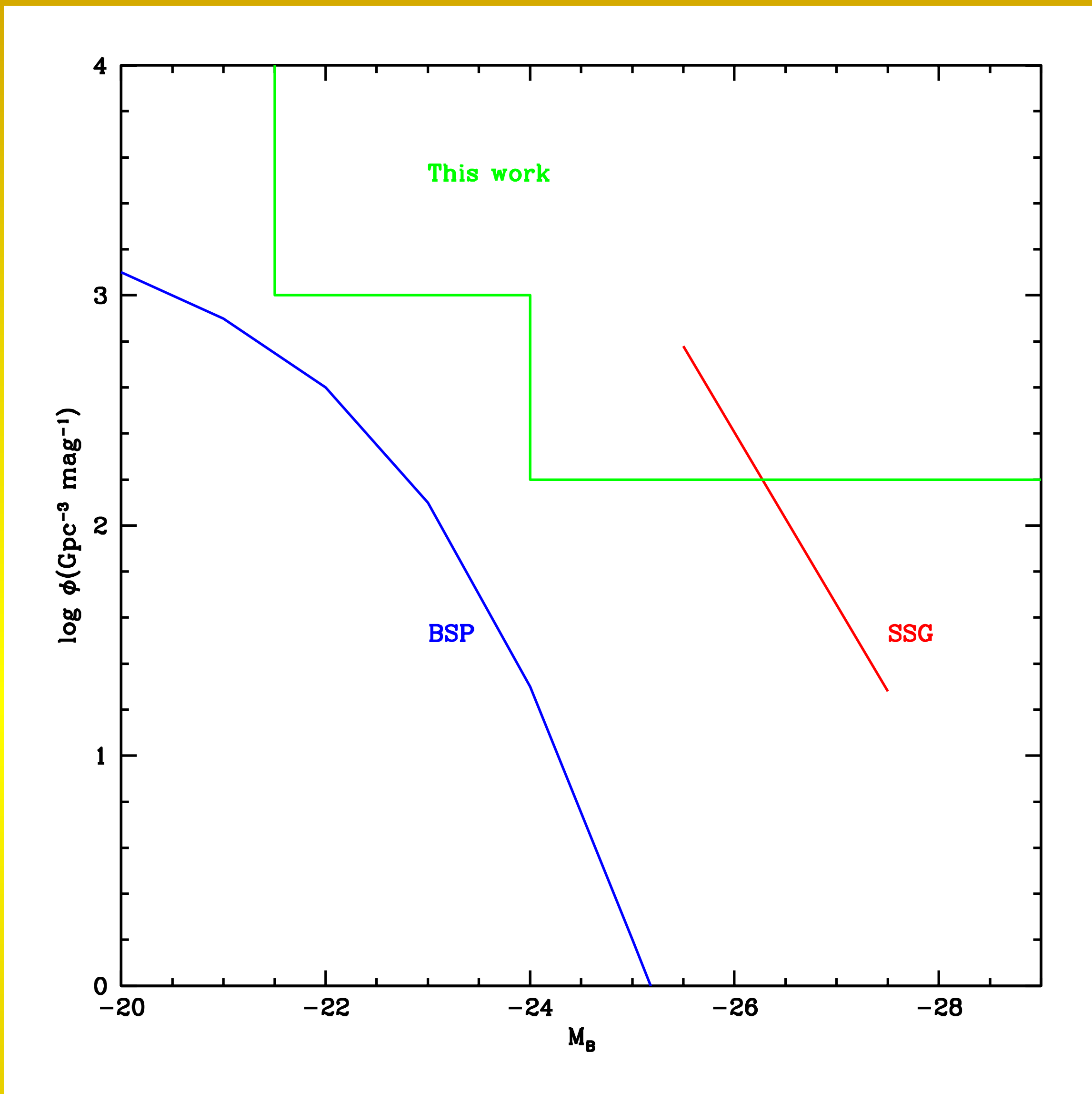
- Existing work has just scratched the surface.
- The QSO luminosity function
  - Usually a double power law
  - $\beta_h \sim 3.5$, $\beta_l \sim 1.6$ (at least at low z)
  - Break at $L_\star$
- At $z \sim 3$, break is at $B \gtrsim 20$
- And what about the narrow-line AGN?

Existing high-redshift QSO surveys are generally too shallow:

SDSS	$i' < 20.0$
DPOSS	$r < 19.6$
SSG	$R < 20.5$
2dF	$b_J < 20.85$
LBQS	$b_J < 18.85$

They probe only the bright end and make assumptions about the faint end!

- Pure luminosity evolution $L_\star = L_\star(z)$
- Pure density evolution is ruled out
- At $z \sim 3$, pure luminosity evolution probably isn't enough:
  - Low z: $\beta_h \sim 3.5$
  - $z \sim 3$: $\beta_h \sim 2.9$ (SSG)
  - $z \sim 4$: $\beta_h \sim 2.6$ (SDSS; DPOSS is consistent)
- Faint end of LF helps accounting for (e.g.) reionization of He II



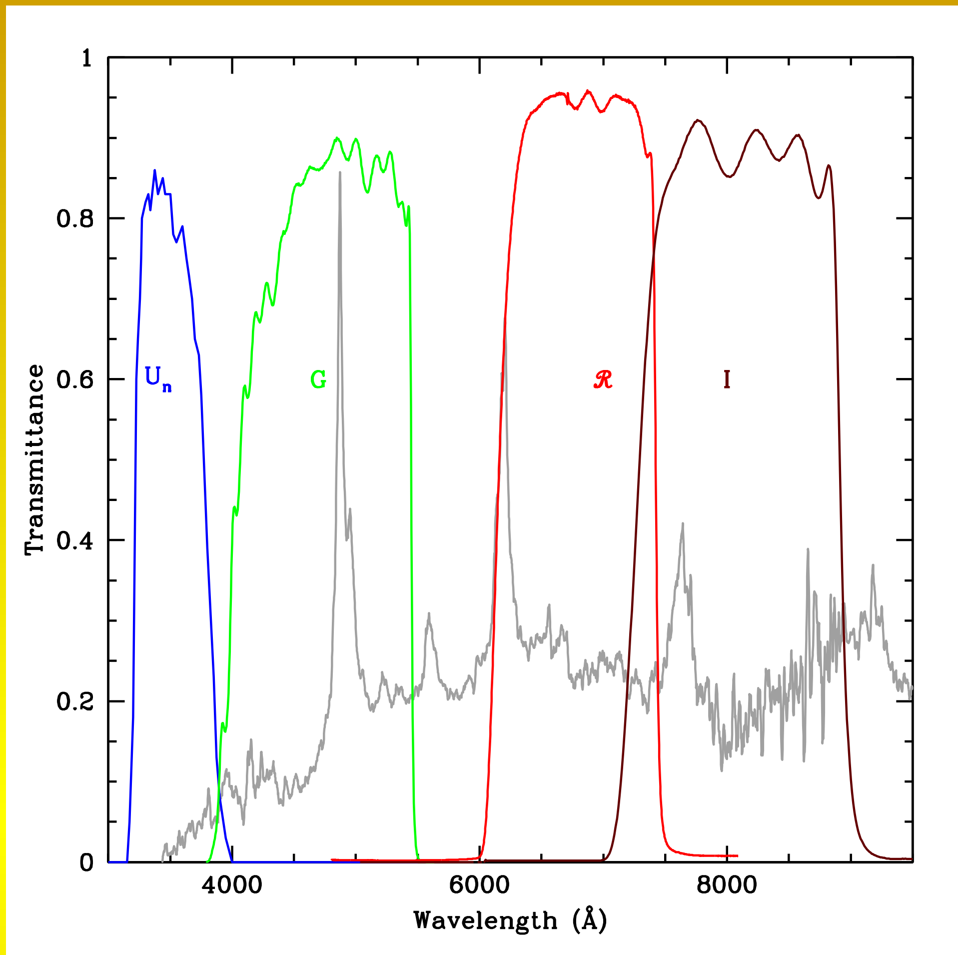
The known $z \sim 0$ and $z \sim 3$ QSO LFs. Proposed work will constrain the $z \sim 3$ LF within the green box.

AGN–Massive black hole relationship

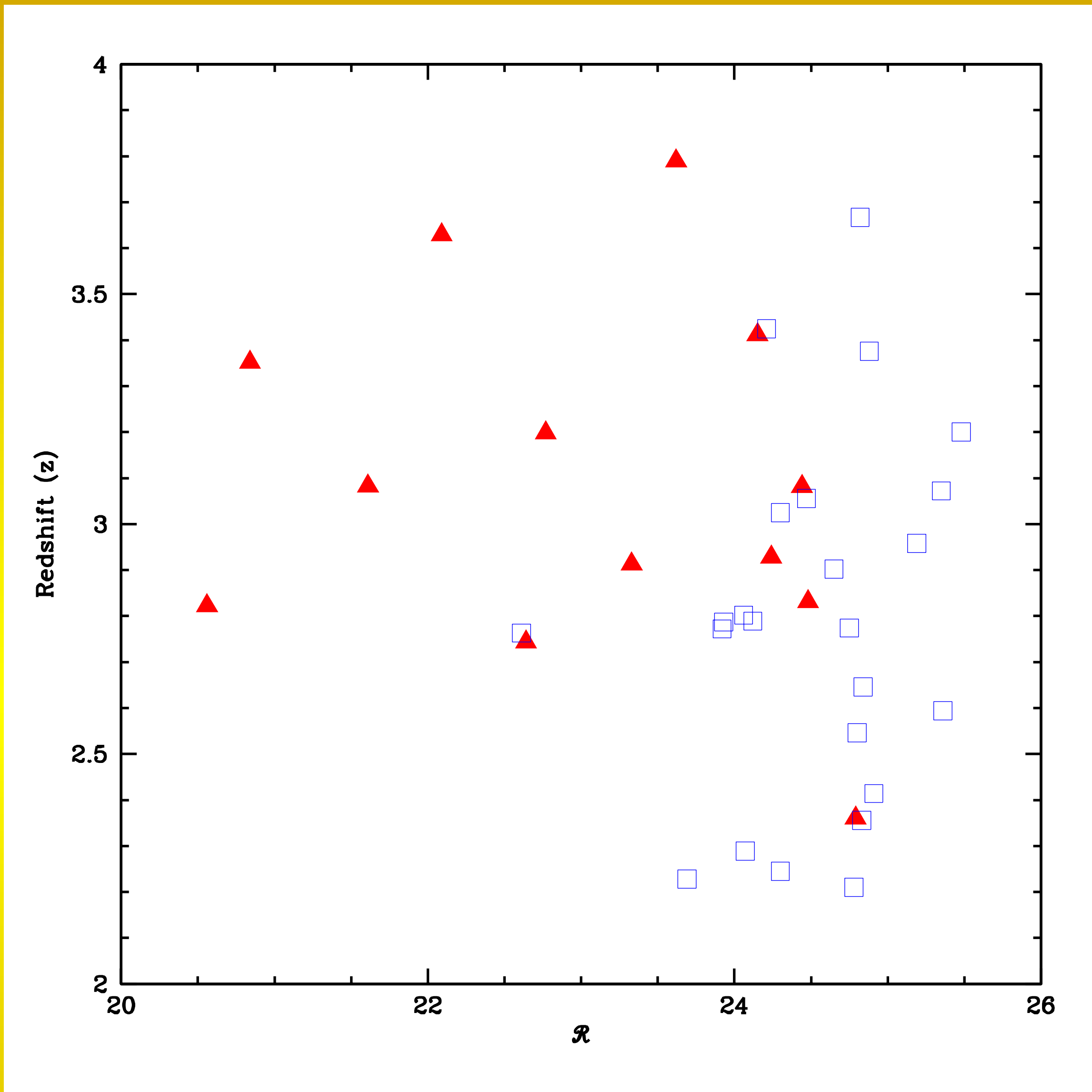
- At low z, MBH mass $\sim 0.15\%$ of bulge mass in normal galaxies or bright QSOs
- Infer $z \sim 3$ LBG $L_{\mathrm{Edd}} = 1 \times 10^{12}\ L_{\odot}$ or $m_{1700} \sim 23$
- Most narrow-line AGN we see are considerably fainter
  - Sub-Eddington accretion?
  - Local relationships don't apply (BHs still growing)?
- Constraints on AGN lifetime via AGN fraction

The existing spectroscopic catalog

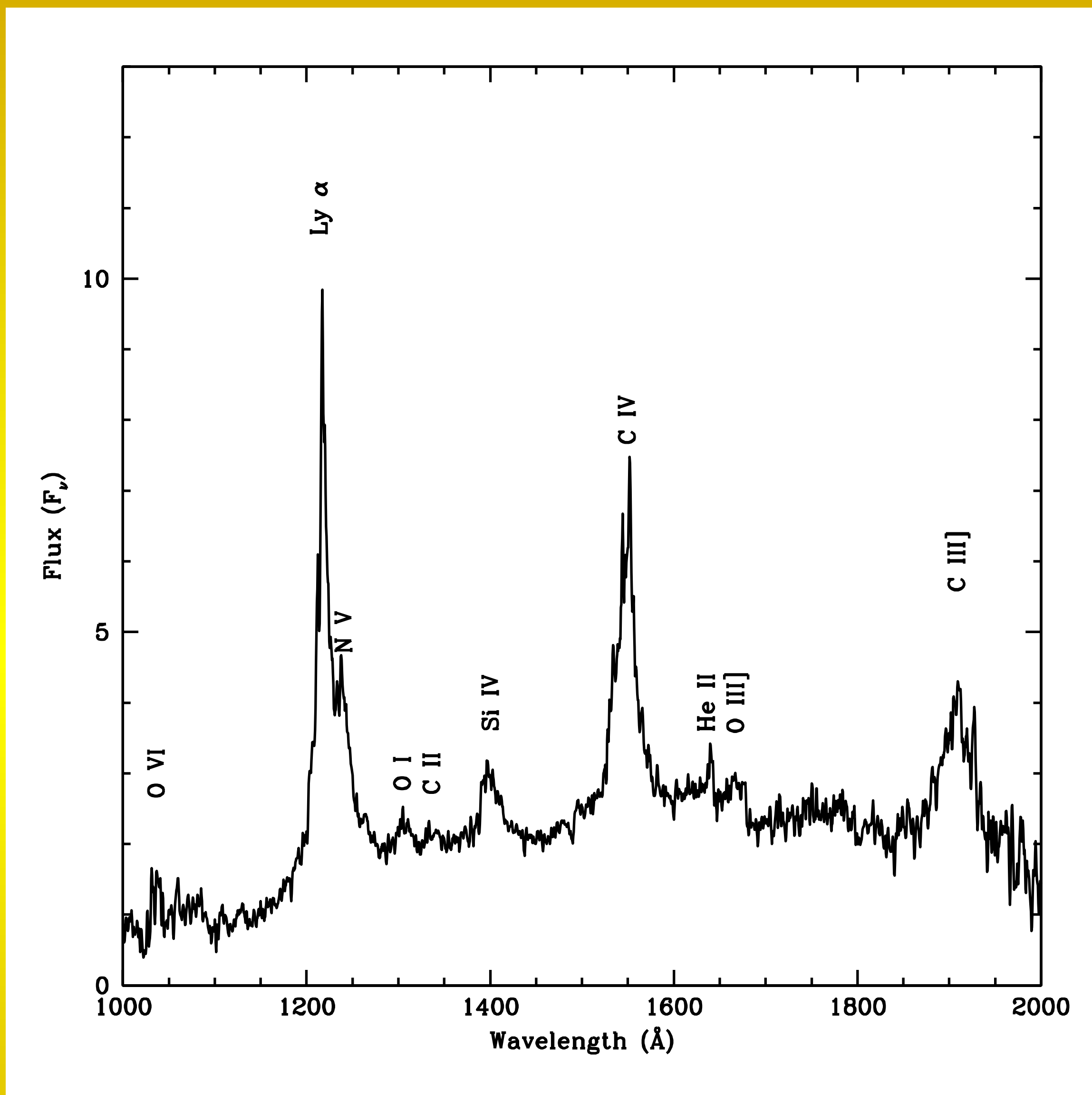
- We have 1,300 spectra (800 galaxies with measured z)
- Catalog spans 0.6 square degrees
- Photometric selection depth $\mathcal{R} < 25.5$
- At $z \sim 3$ AGN selection identical to galaxy selection
- 13 QSOs and 24 narrow-line AGN in current sample



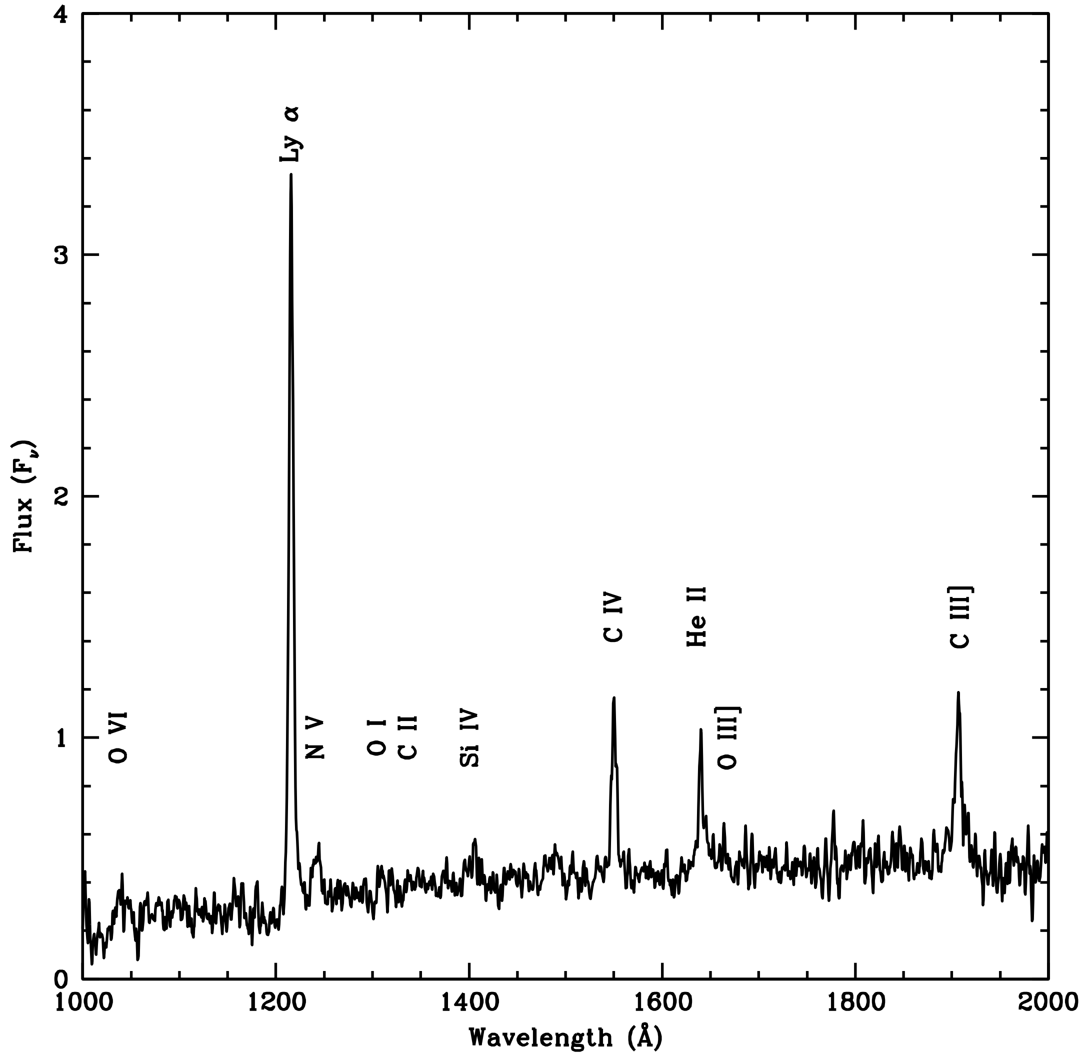
- Normal/active galaxy SED has 912 Å break (intrinsic & IGM)
- At $z \sim 3$, break falls between U_n and G
- Select: $U_n - G > (G - \mathcal{R}) + 1$; $G - \mathcal{R} < 1.2$
- AGN selection harder at $z \sim 2$



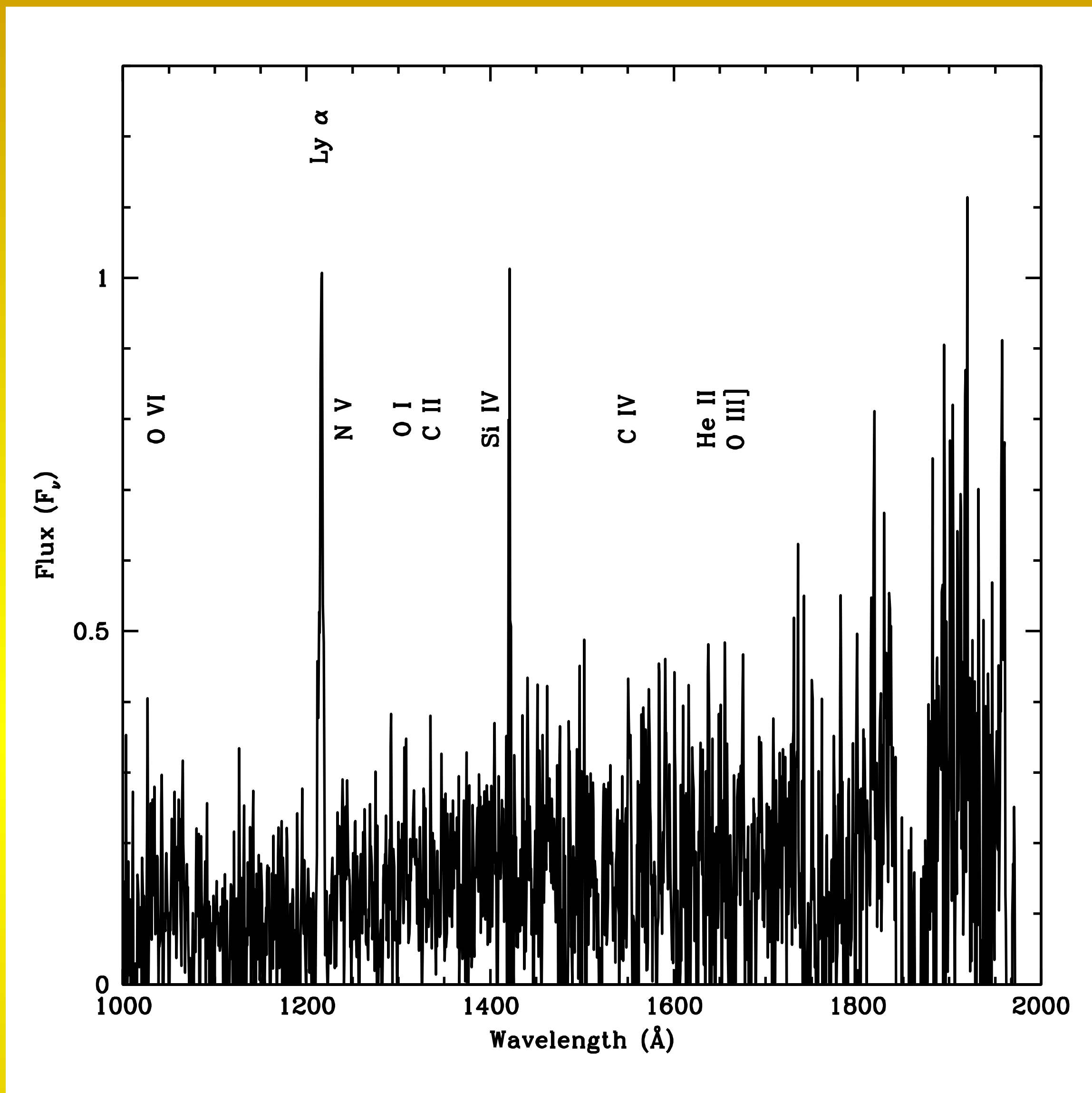
Redshift-magnitude diagram for the 13 QSOs and 24 narrow-line AGN in our spectroscopic sample.



Composite spectrum of 13 QSOs with $20.5 < \mathcal{R} < 24.8$ in our spectroscopic sample.



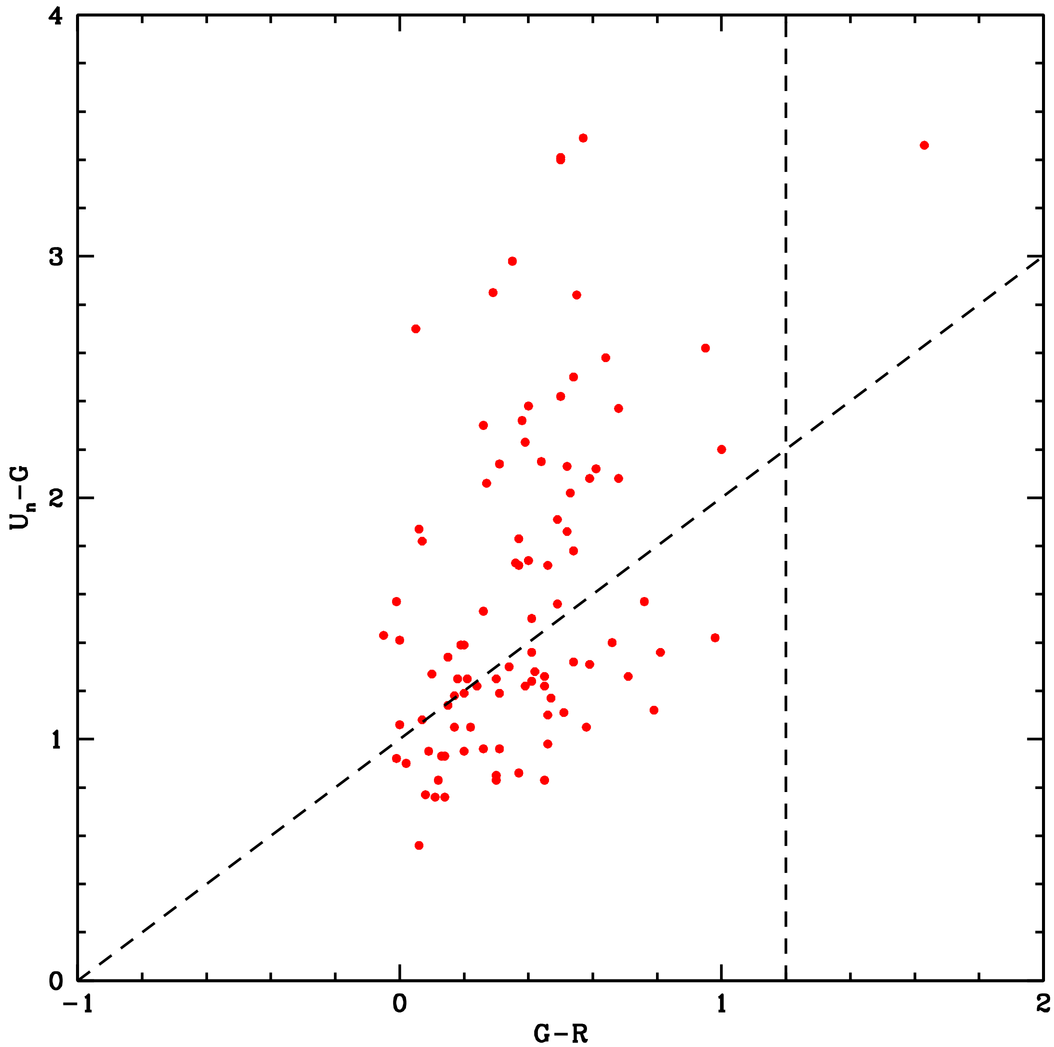
Composite spectrum of 24 narrow-line AGN with $22.6 < \mathcal{R} < 25.5$ in our spectroscopic sample.



For comparison, the spectrum of a normal emission line LBG, SSA22a–C46 ($z = 2.927$). The only emission line is Lyman α. It is easily distinguished from an AGN.

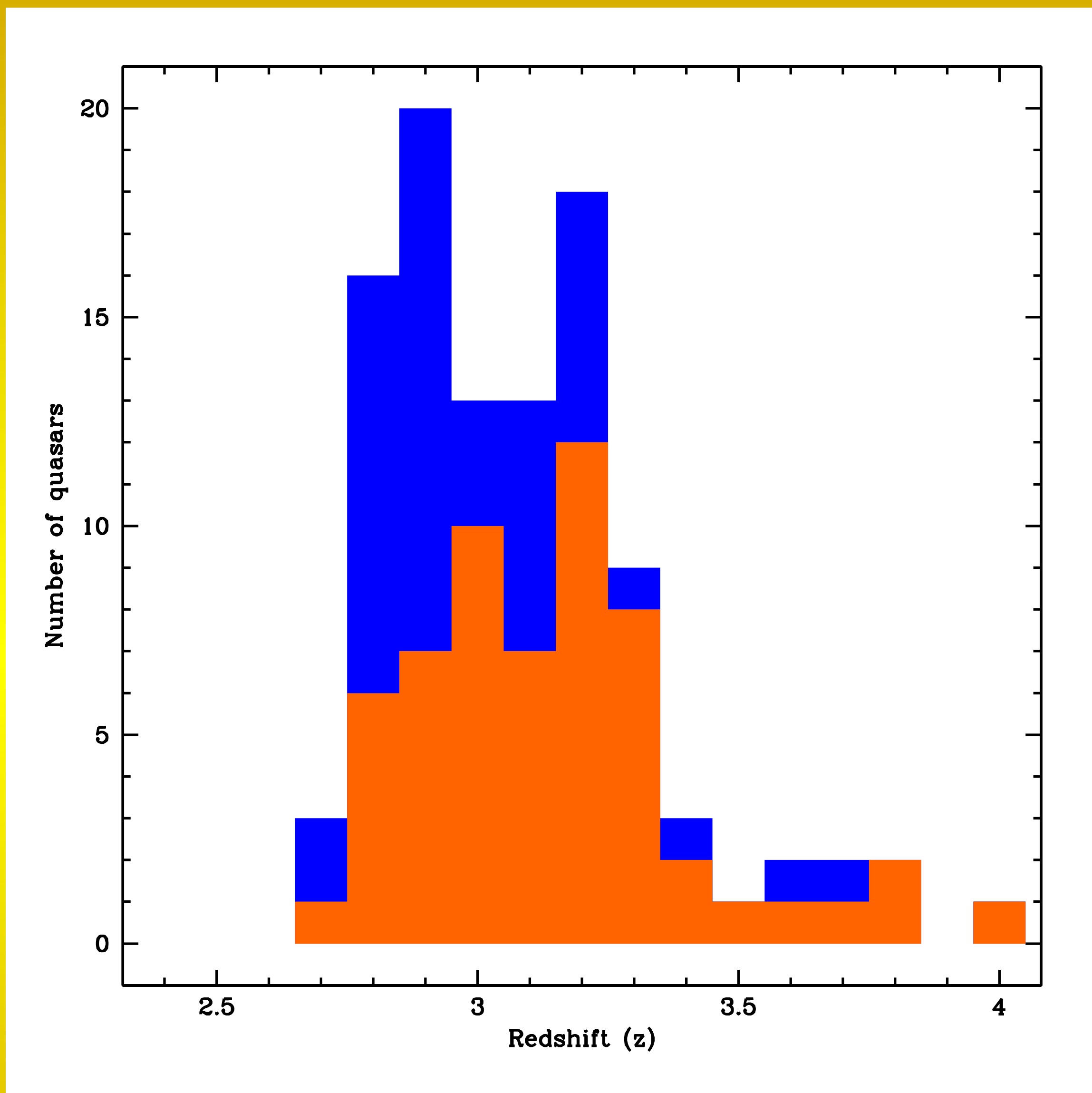
Completeness of the LBG selected sample

- Essential to accurately measure the LF.
- Simulated photometry of 103 QSOs (Sargent *et al.*, 1989; Stengler-Larrea *et al.*, 1995)
- Emission line selected QSOs should be relatively independent of multicolor selection

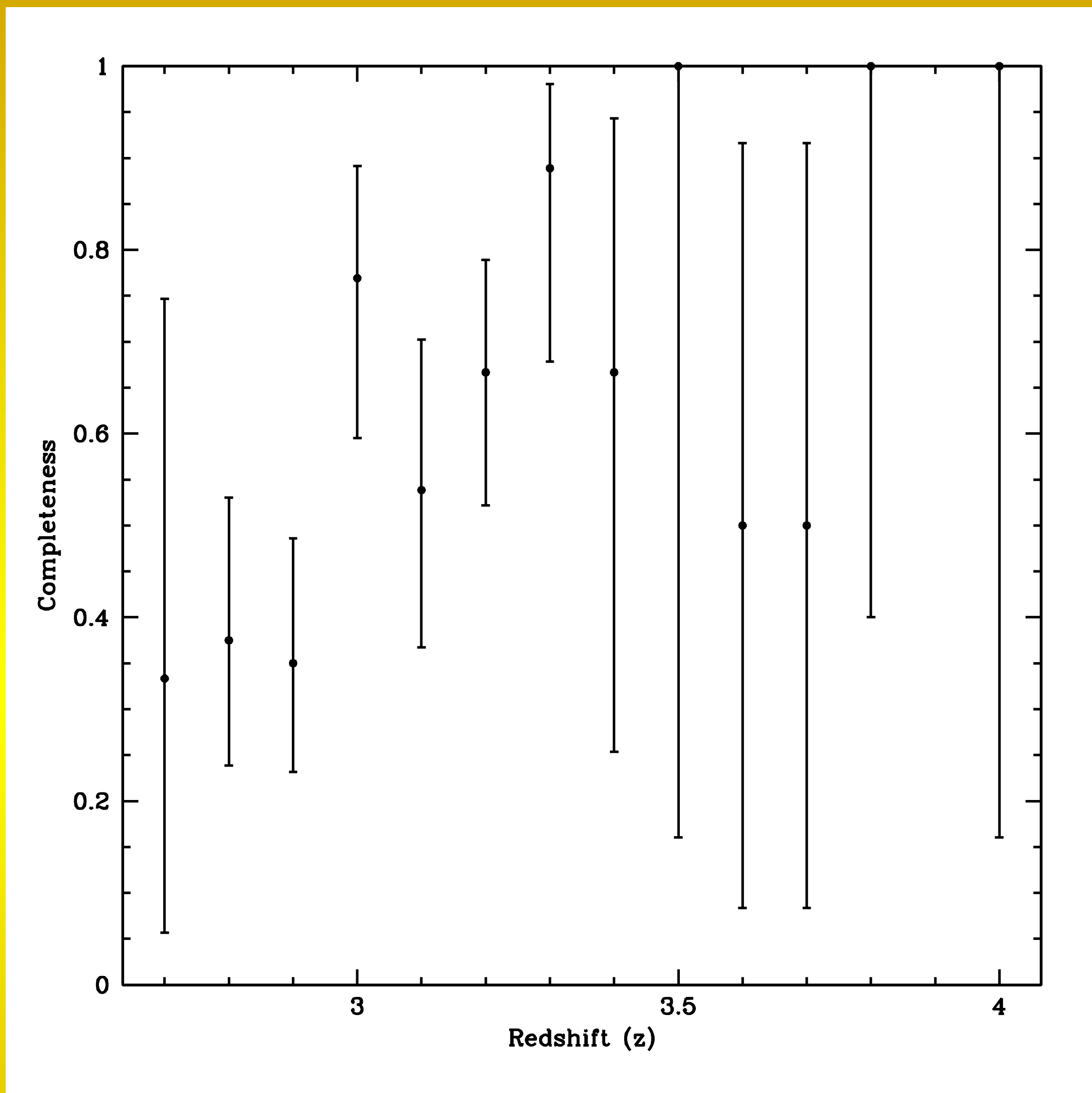


Color-color diagram for the 103 QSOs in the Lyman limit survey. $2.7 < z < 4.1$.

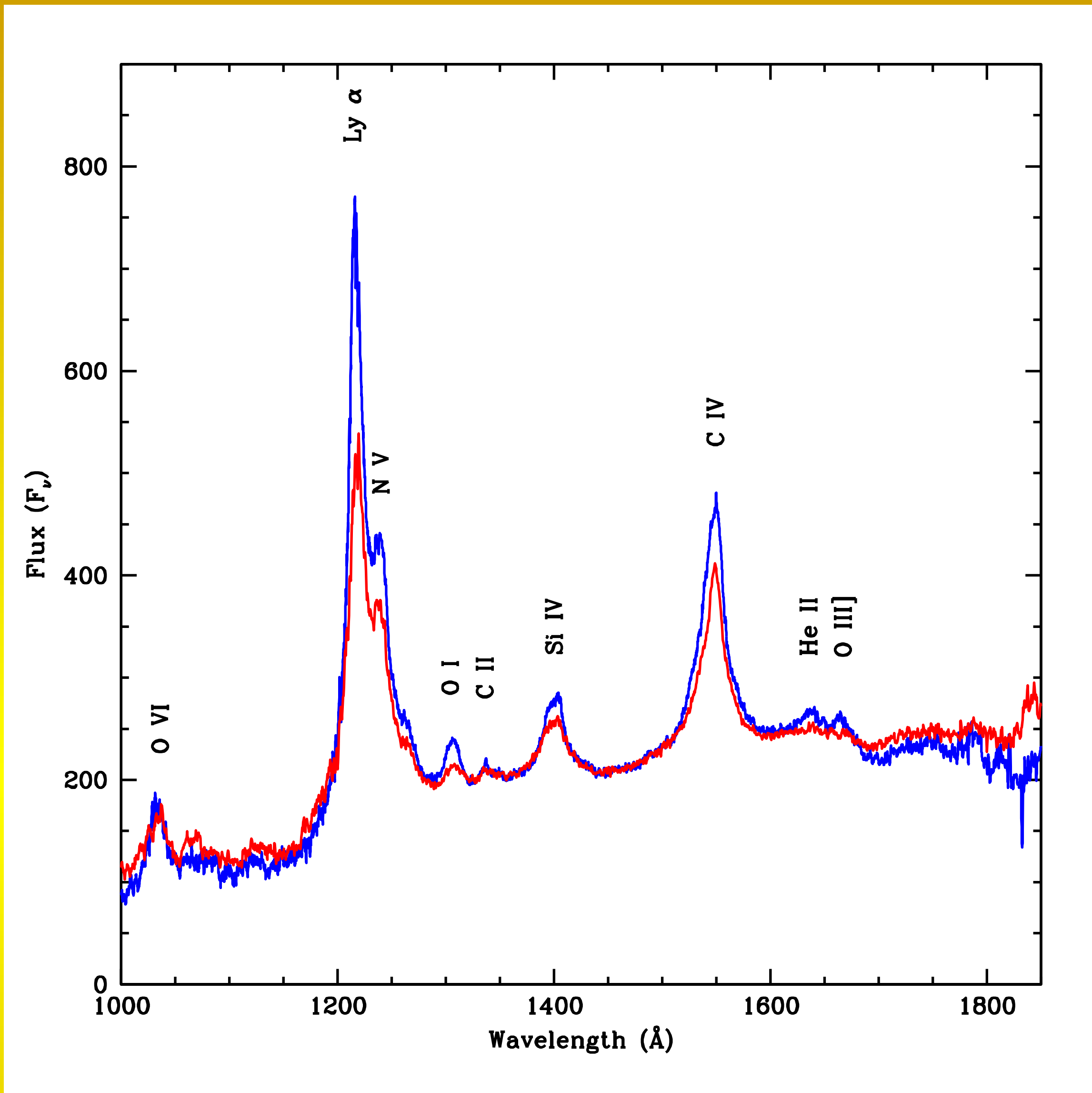
57% complete.



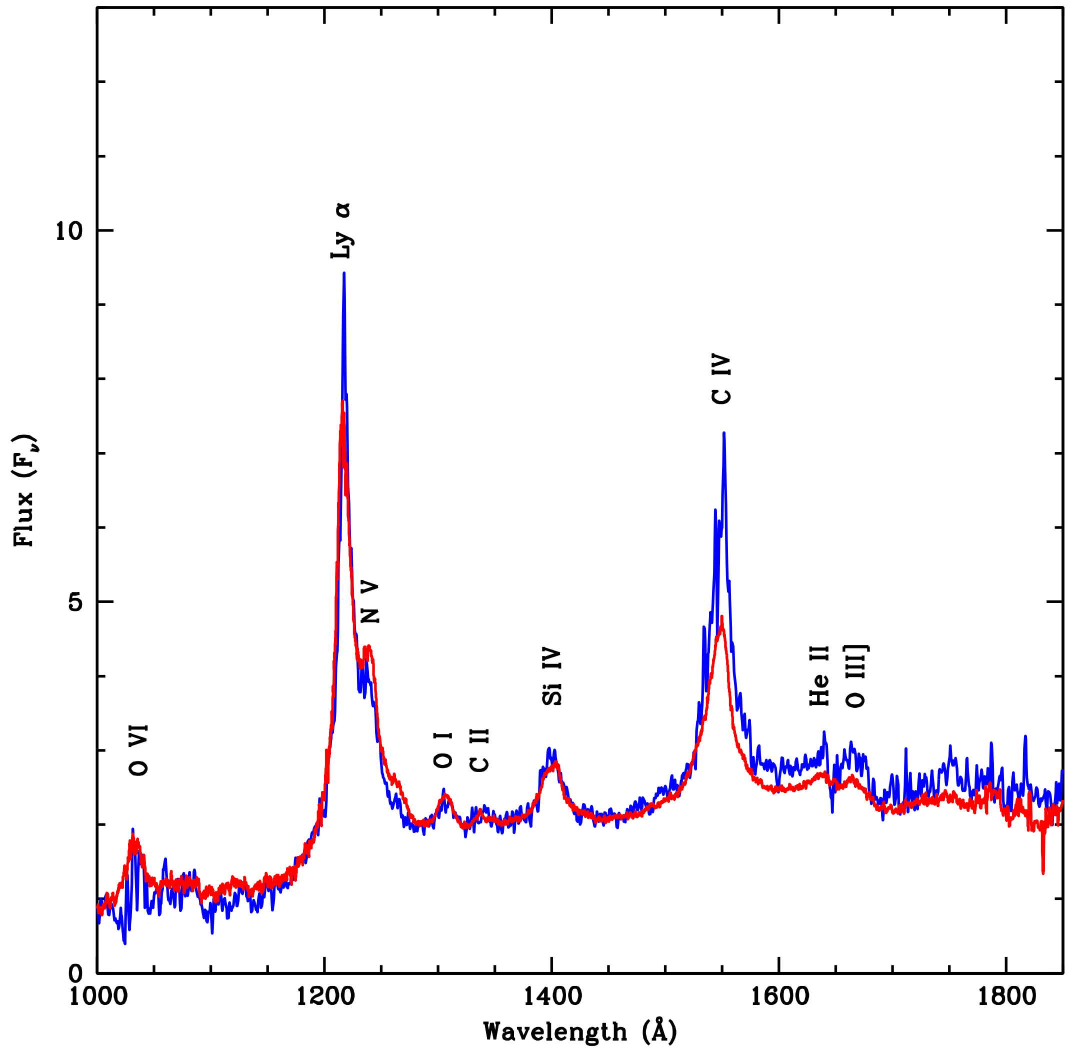
Lyman limit QSO sample in blue, our $z \sim 3$ selected objects in orange.



Selection efficiency as a function of redshift for the Lyman limit QSO sample. Errorbars are 68% confidence.



Composite spectra of the detected and non-detected Lyman limit survey QSOs. Non-detected QSOs have less emission in Lyman α which falls in G, and hence are blue of our $U_n - G$ color cut.



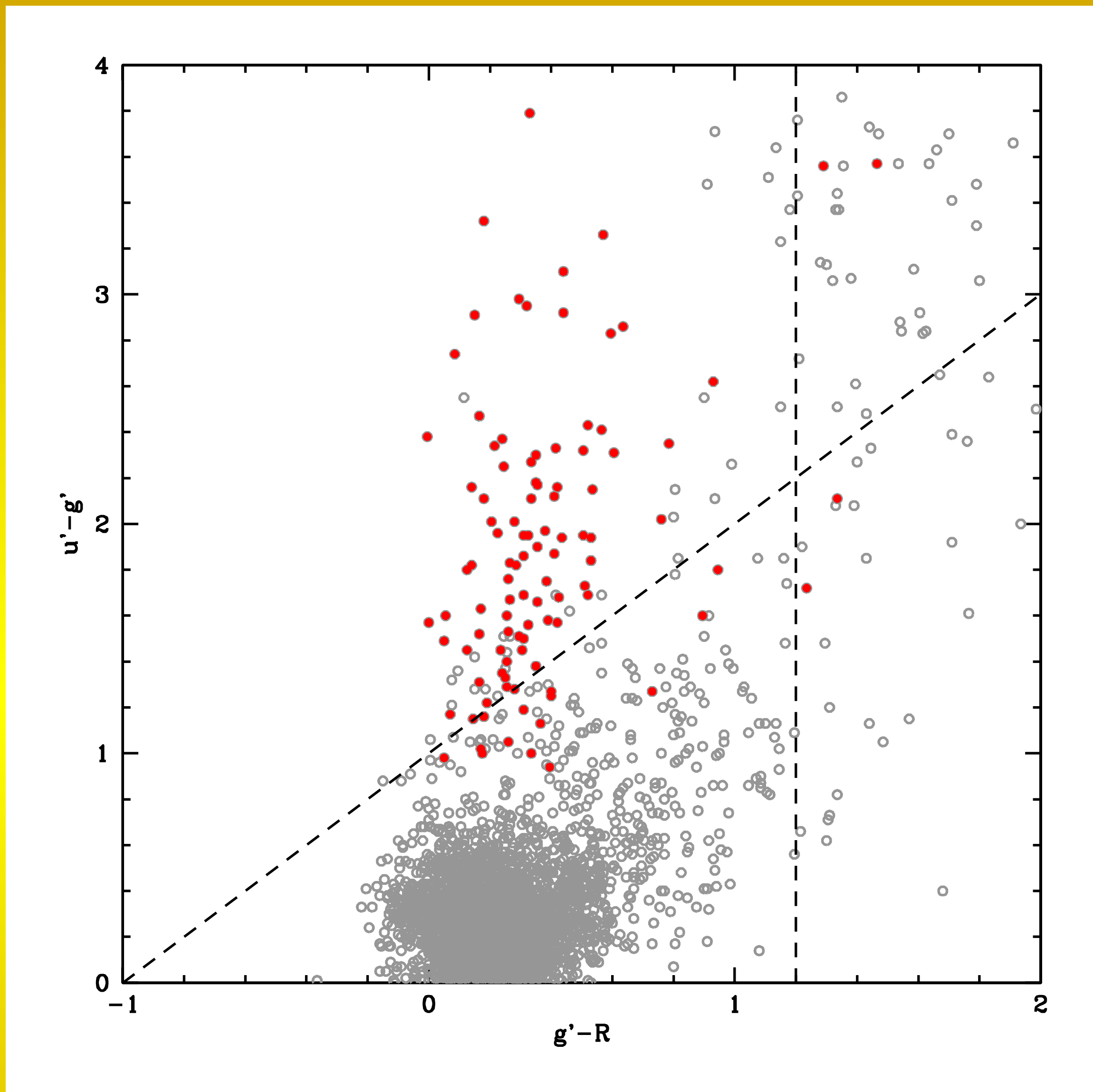
Composites from the Lyman limit survey and the faint LBG sample ($\sim 100\times$ fainter).

Remarkably similar, although C IV a bit stronger in the faint sample? (Baldwin?)

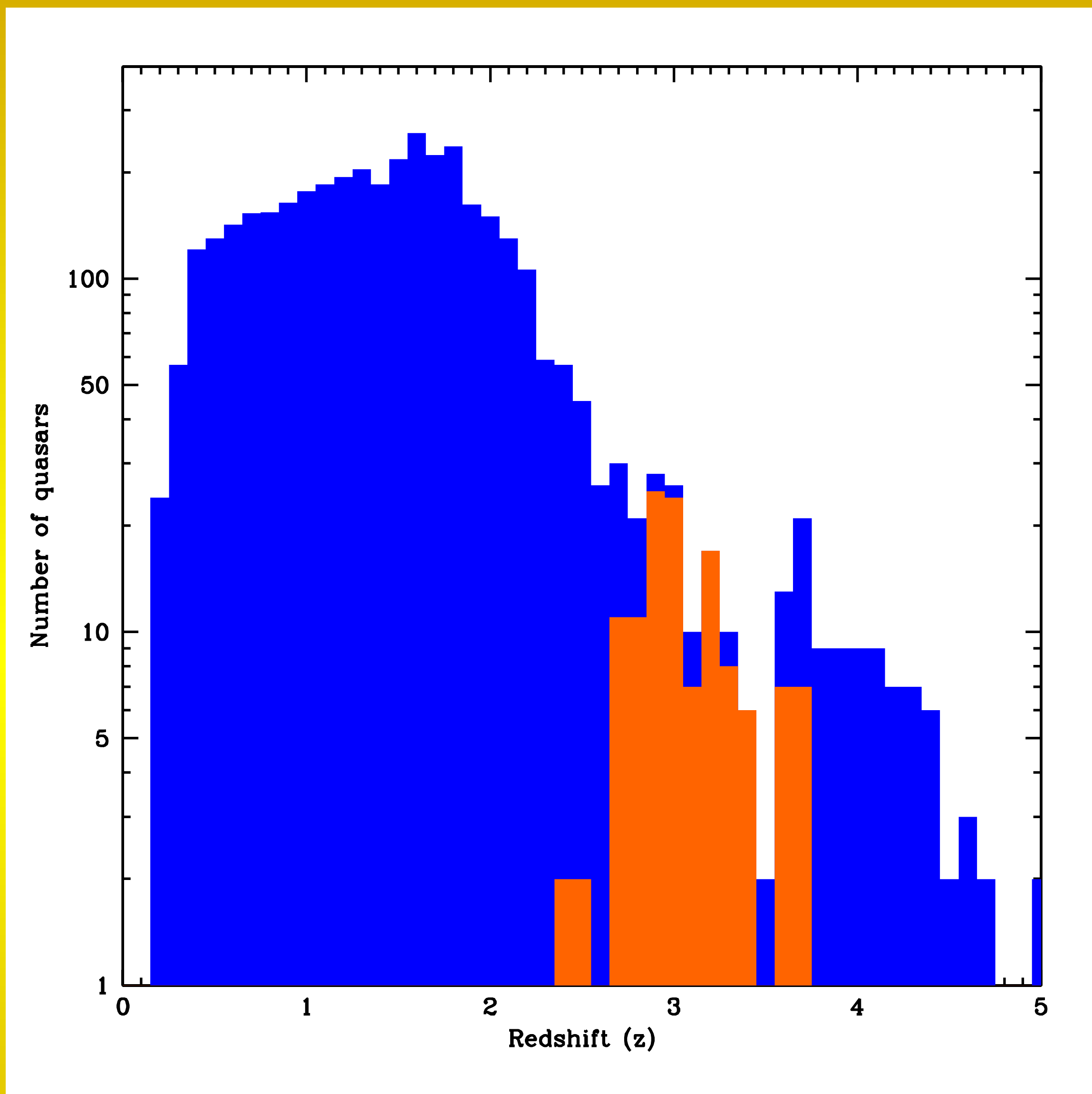
Completeness using the SDSS EDR QSO catalog

(Schneider *et al.*, 2001)

- Photometry from SDSS ($U_n = u'$, $G = g'$, $\mathcal{R} \approx (r' + i')/2$)
- Our color cuts are quite complete, but...
- SDSS is multi-color selected, and hence similar
- SDSS uses 2 more filters plus morphology



Color-color diagram for the SDSS EDR QSOs (Schneider *et al.*, 2001). $2.8 < z < 3.5$ in red, 80% complete in that interval.



SDSS EDR QSO sample in blue, our $z \sim 3$ selected objects in orange.

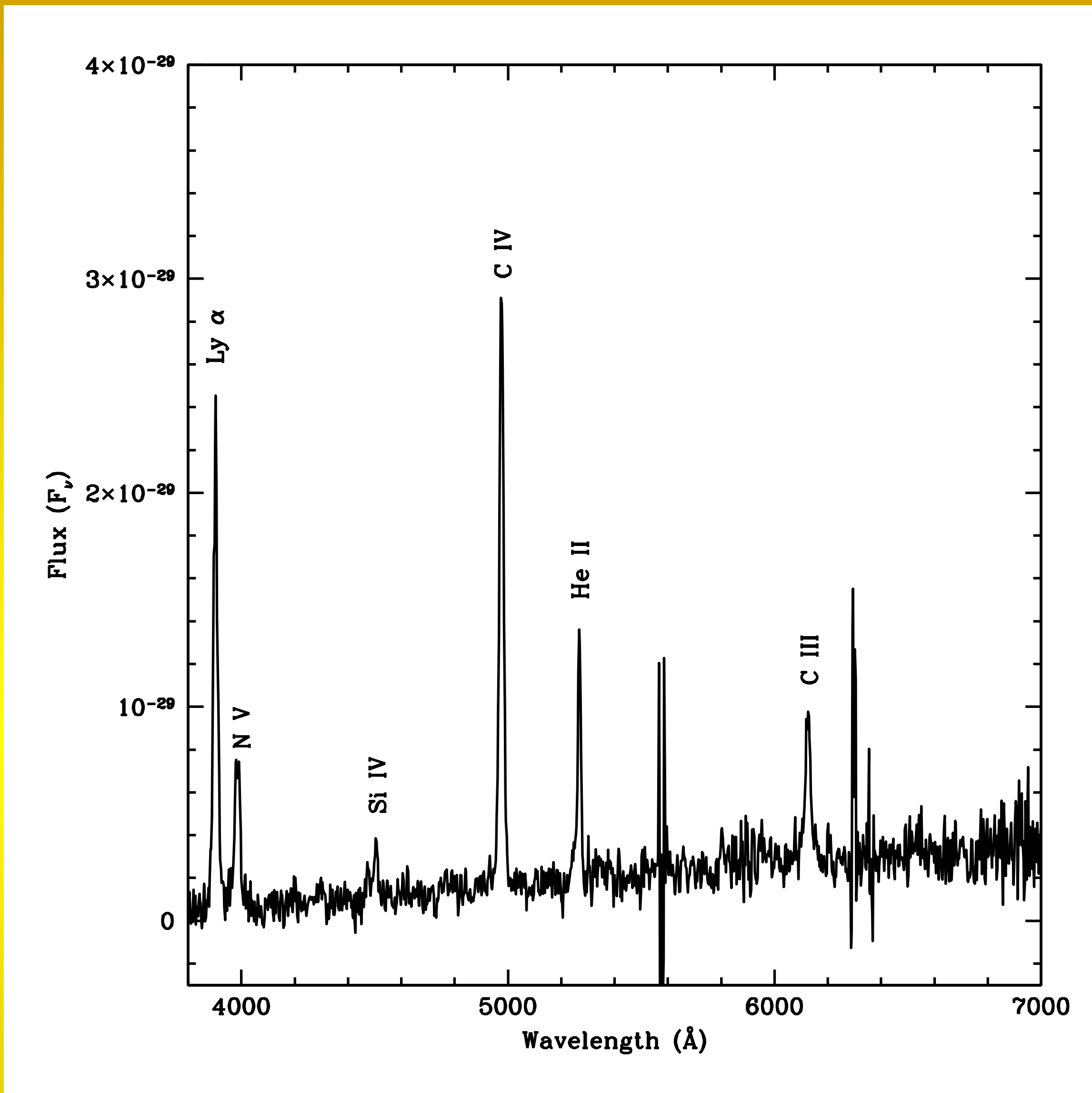
Completeness with respect to narrow-line AGN

- Not yet investigated
- Will simulate photometry using composite with various line strengths, continuum slopes
- At what level can we measure AGN activity in LBGs?

Our faint spectroscopic survey includes observations in two fields with deep *Chandra* coverage:

HDF–N	1 Msec	completed
Groth-Westphal (GWS)	200 ksec	Summer 2002

- Extensive $z \sim 3$ spectroscopy in both
- Adding $z \sim 2$ spectroscopy in Spring 2002
- Relative completeness of optically vs. X-ray selected AGN?
- $\mathcal{R} = 24$ QSO has only $2\times$ CDF–N soft band detection limit (using α_{ox} of Green *et al.* (1995)).



The LBG-selected narrow-line AGN HDF–M49, with $z = 2.209$ and $\mathcal{R} = 24.8$. It is not detected in the 1 Msec *Chandra* observation.

Another curiosity...

- Kuhn *et al.* (2001) report a 2000–3000 Å "bump" in low-z but not high-z QSOs
- Both populations have $1 < L/L_\star(z) < 7$
- $L_\star(z=3)/L_\star(z=0) \approx 50$!
- Bump due to excess Fe II emission?
  - No known iron abundance evolution
  - Something about energy source?
- We should look at faint high-z QSOs!
- Bump is still in the optical at $z \sim 2$.

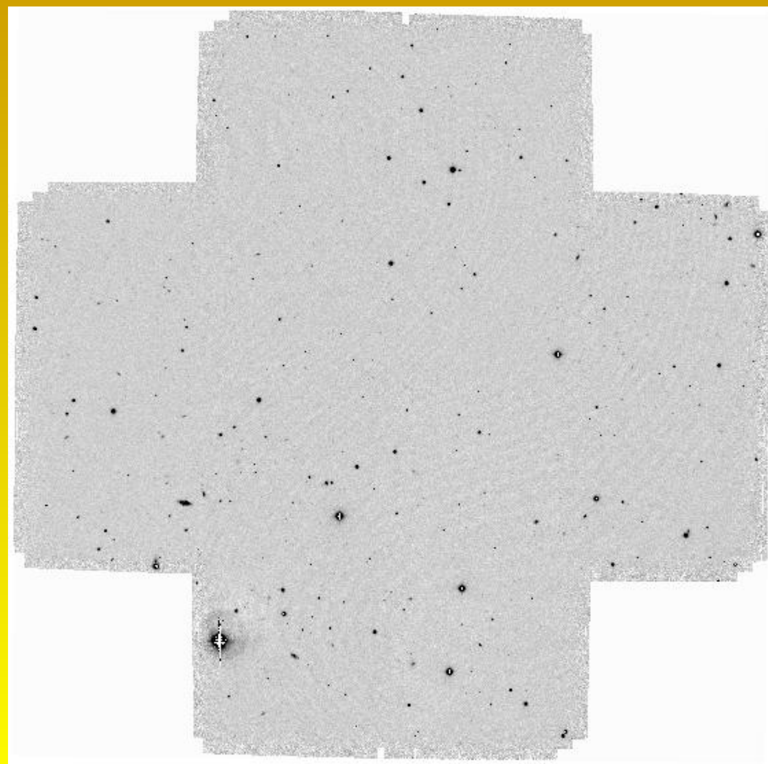
I love to go shopping. I love to freak out salespeople. They ask me if they can help me, and I say, "Have you got anything I'd like?" Then they ask me what size I need, and I say, "Extra medium."

– Stephen Wright

- Our deep surveys find $\mathcal{R} \sim 24 - 25$ AGN
- AGN at $\mathcal{R} \sim 21 - 23$:
  - Too rare for us in 0.6 square degree
  - Too faint for SDSS, POSS II, LBQS, etc.
- **Solution**: Wider survey for medium-luminosity AGN at $z \sim 3$

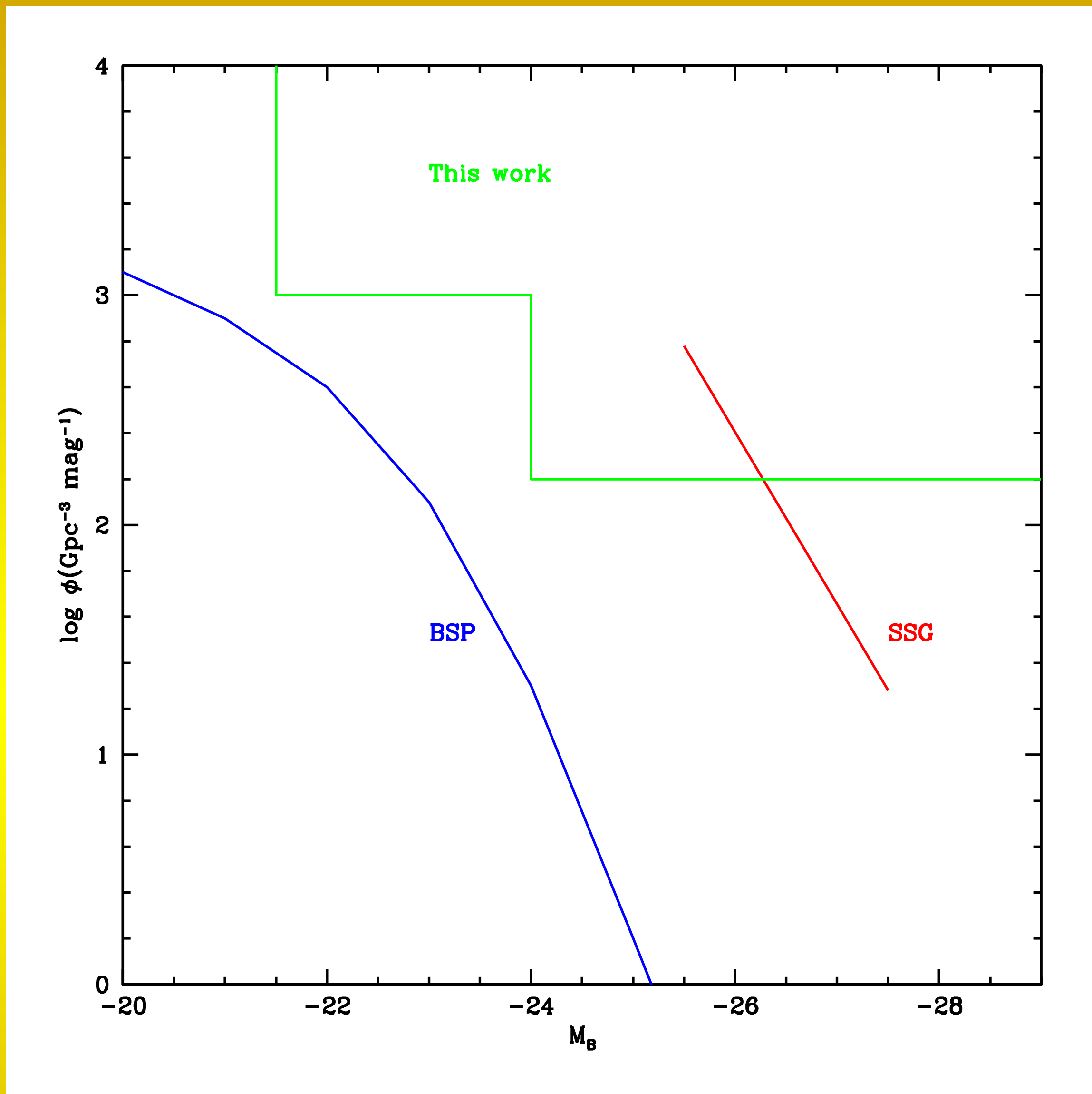
The Palomar survey for medium-luminosity AGN at $z \sim 3$

- Roughly 4 square degrees ($\sim$ 35 LFC pointings)
- $U_n G \mathcal{R}$ imaging (about 30/12/12 minutes/pointing)
- LBG color selection to $\mathcal{R} \sim 23$
- Spectroscopic followup (DBSP to $\mathcal{R} = 21$, LRIS for fainter)
- *Chandra*/SIRTF/NOAO Deep Wide/etc. fields
- 20 QSOs per sq. deg. with $g' < 23$ and $2.6 < z < 3.5$ (Koo and Kron, 1988)
- Bright QSOs also useful for our other projects...



- Efficient LFC reduction possible (**mscred** and my scripts and calibrations)
- Stack has WCS (accurate RA/Dec for LRIS slitmasks; we use it routinely)
- Rapid turnaround possible (maybe even on-site) for spectroscopic followup
- Publicly available. Will be a chapter in my thesis.

The survey of 4 sq. deg. to $\mathcal{R} = 23$, along with spectroscopy of $\mathcal{R} < 21$ candidates, will require 40 hours of integration. Seeing is not critical, but most imaging must be done in photometric conditions. I request 10 nights to allow for instrument overhead and poor weather.



At any magnitude where the QSO LF is inside the green box, we can constrain the LF ($\geq 10f$ QSOs/mag; f = completeness).

Timeline

- By spring 2002
  - Complete photometry for wide-field AGN survey
  - Can we efficiently select AGN at other redshifts?
  - Galaxy–QSO cross-correlation at $z \sim 3$
  - Write paper on spectra of faint AGN in existing sample

- By fall 2002
  - Investigate Fe II bump in low-luminosity $z \sim 2$ sample
  - Correlate optical properties with *Chandra* data in HDF and GWS fields
  - Write paper with full analysis of faint AGN in existing sample
- By spring 2003
  - Complete spectroscopy for wide-field AGN survey

- By summer 2003
  - Properties of $z \sim 3$ AGN: low- vs. medium- vs. high-luminosity; high-z vs. low-z
  - Complete high-redshift LF using (e.g.) SDSS and our wide and deep surveys
- By fall 2003
  - Publish complete AGN LF
  - Write up thesis