Mining quasars from the Palomar-QUEST survey

SC4DEVO (Caltech: 12-15 Jul 2004)

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(+ Djorgovski, Graham, Williams …)

(+Yale, NCSA, …)

Overview

- Large multi-dimensional datasets
- Finding quasars with PQ survey

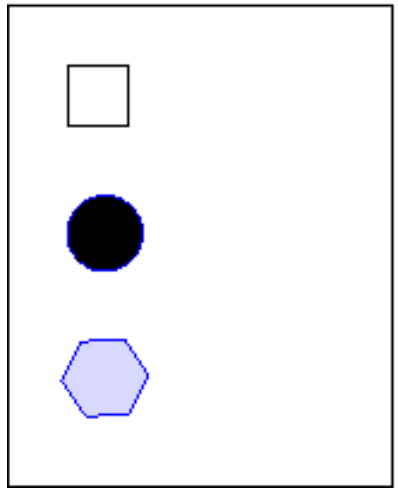
  (a science case for VO)

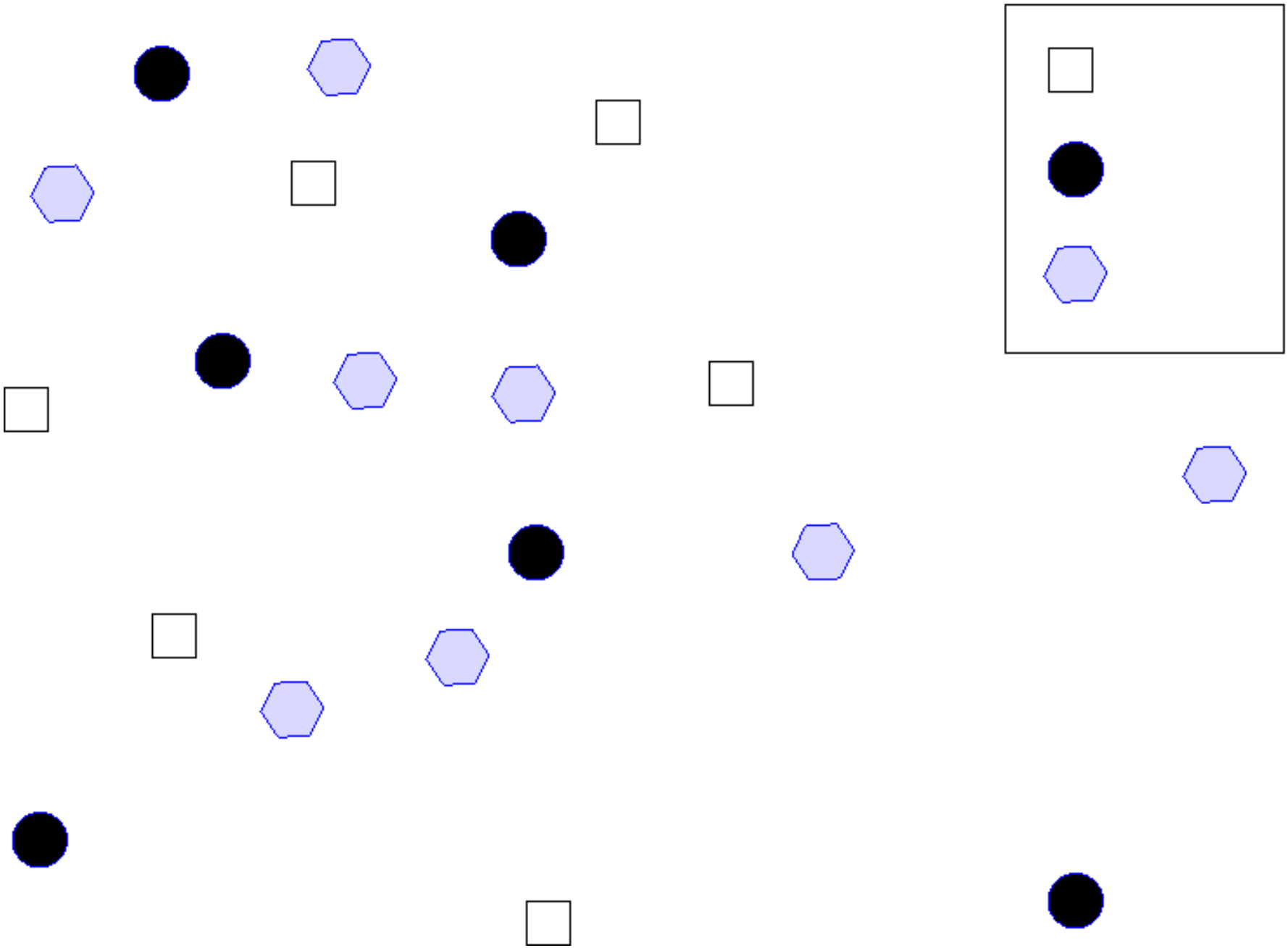
  - Different tools
  - Mining + visualization
  - Interactive steps
  - iterations

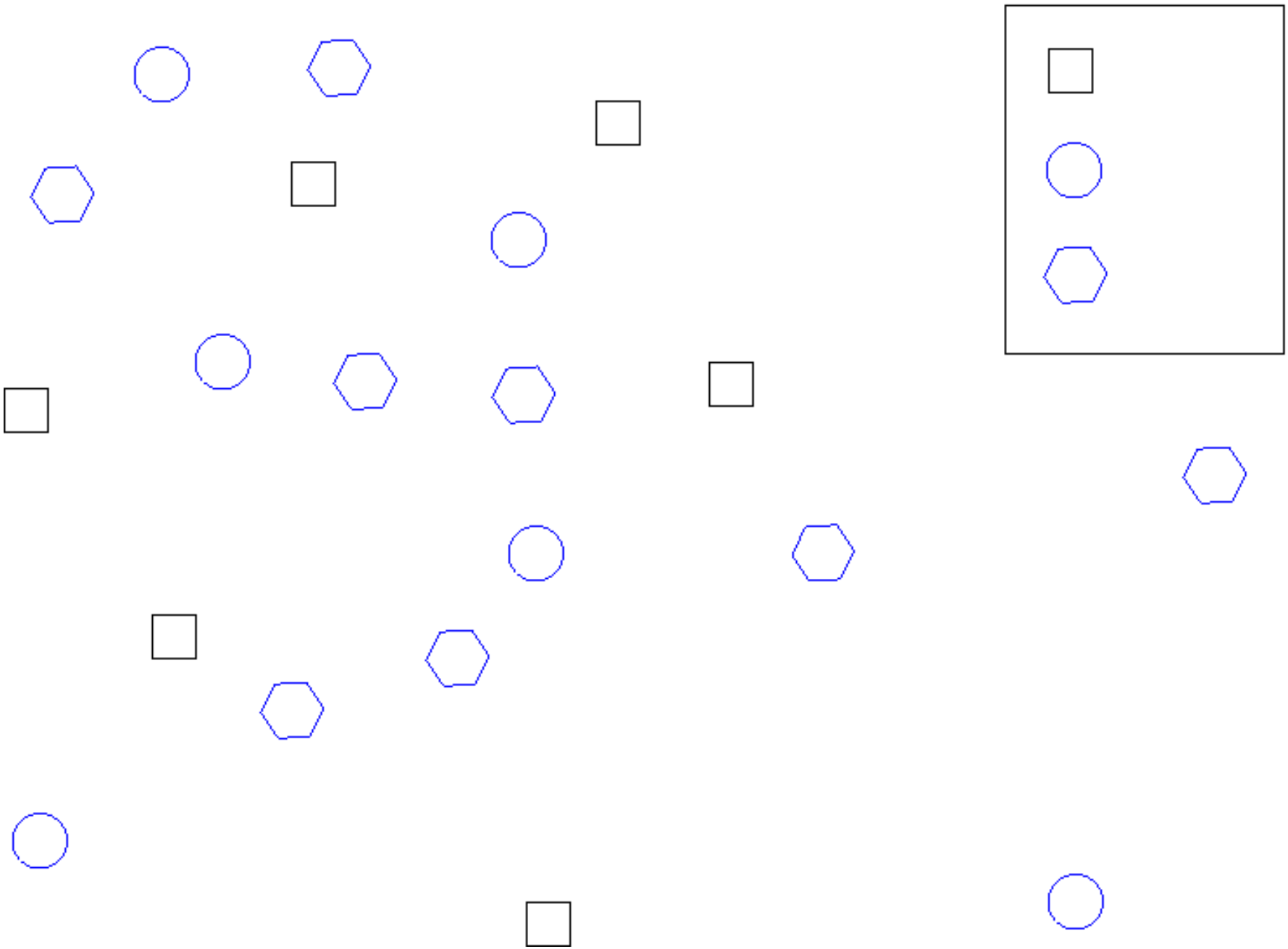
Overview

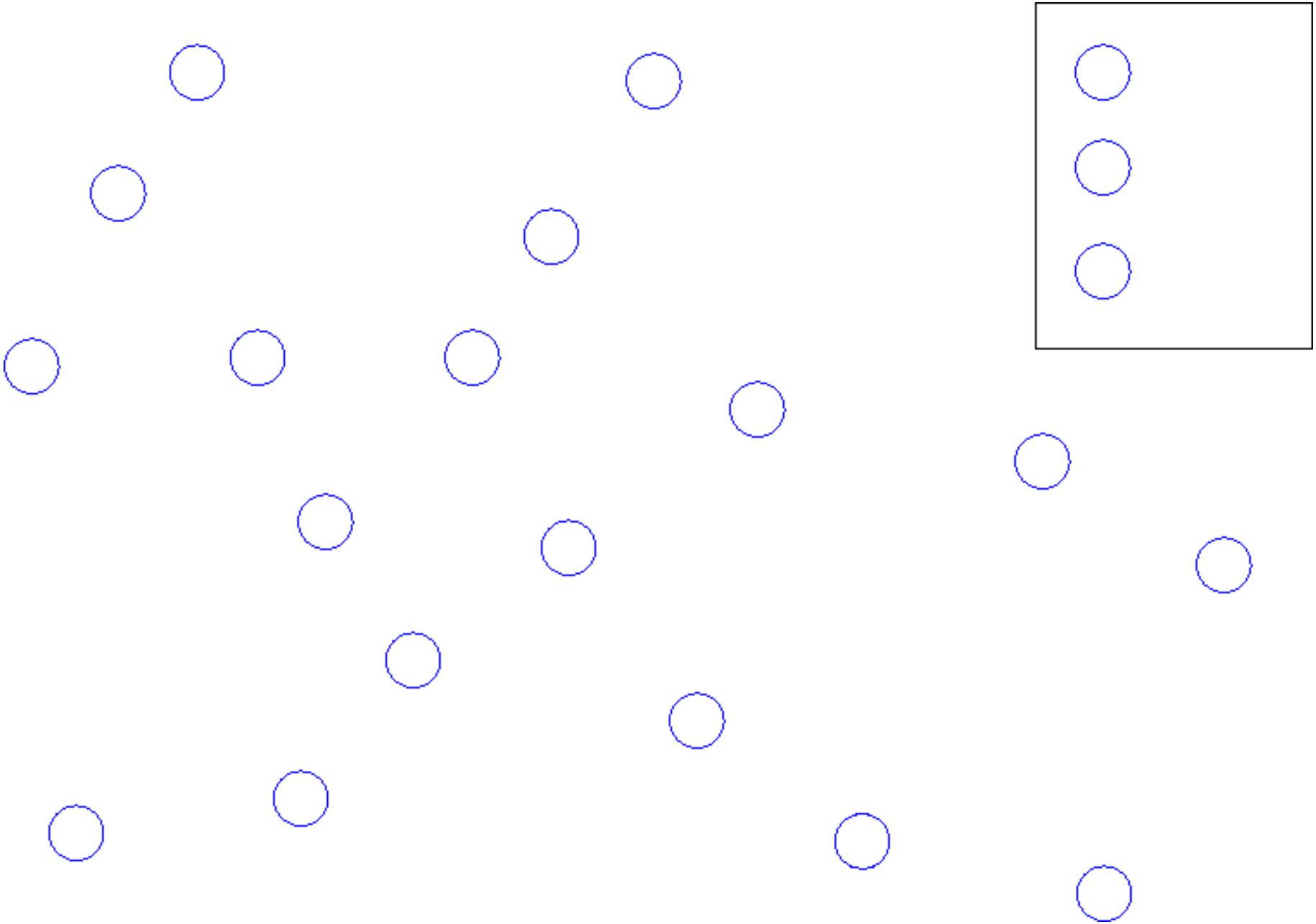
- How are quasars found (in general)
- Why are quasars interesting (or important)
- What is Palomar-QUEST survey (exactly)
- How we look for QSOs in PQ data (now)
- How (nice) it will be in (ideal) VO world

Different objects, diff. looks (if you know how to look)

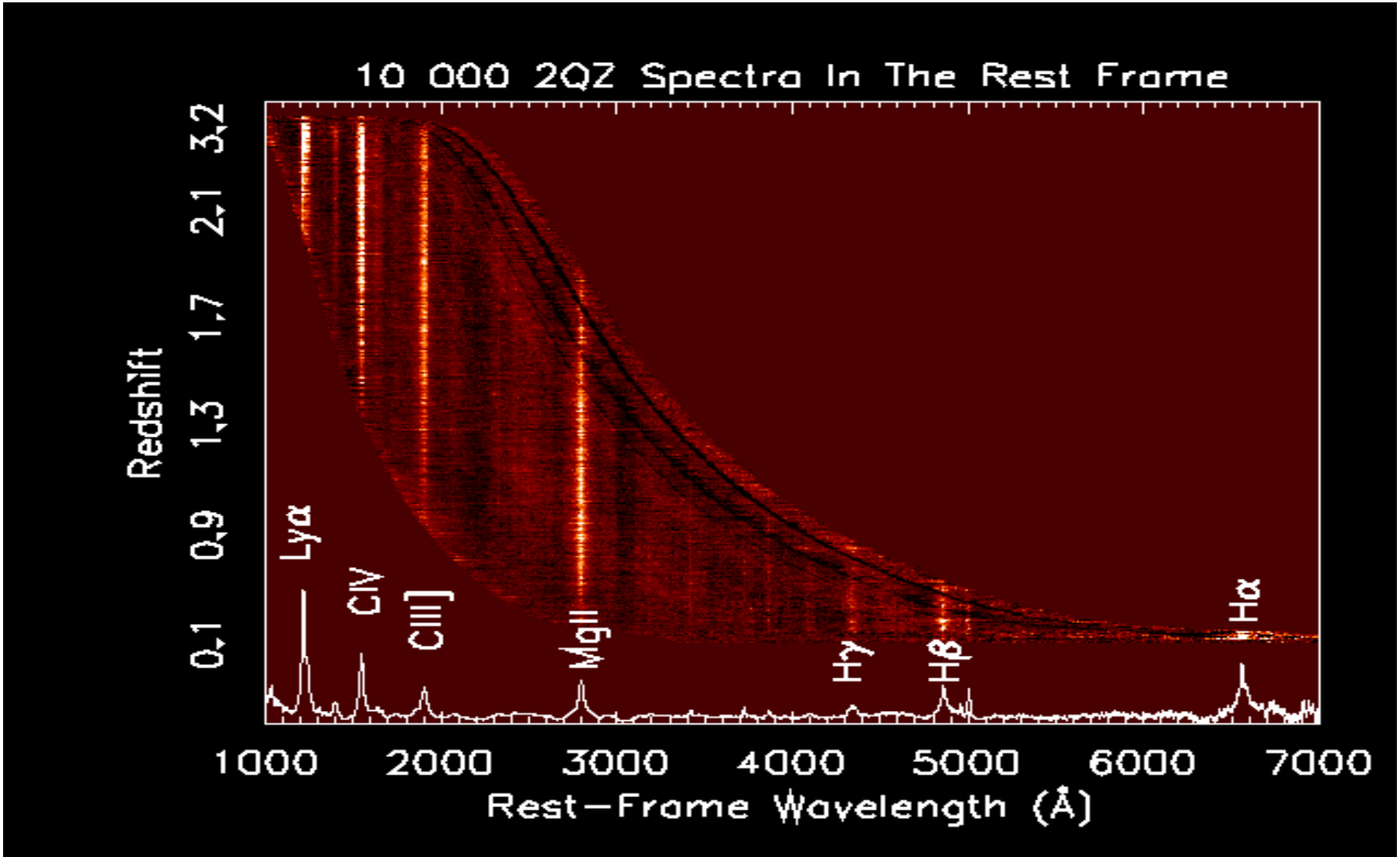




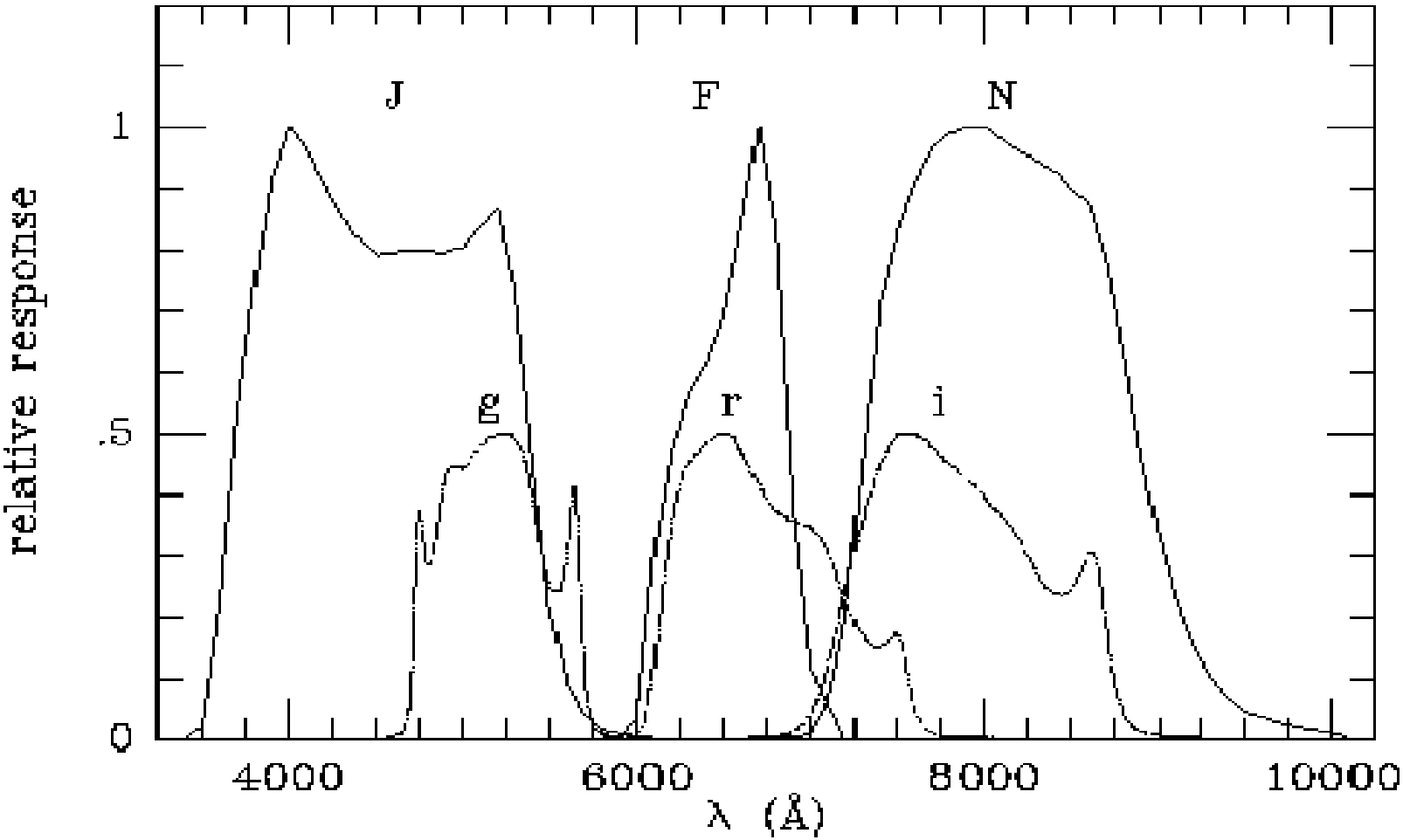




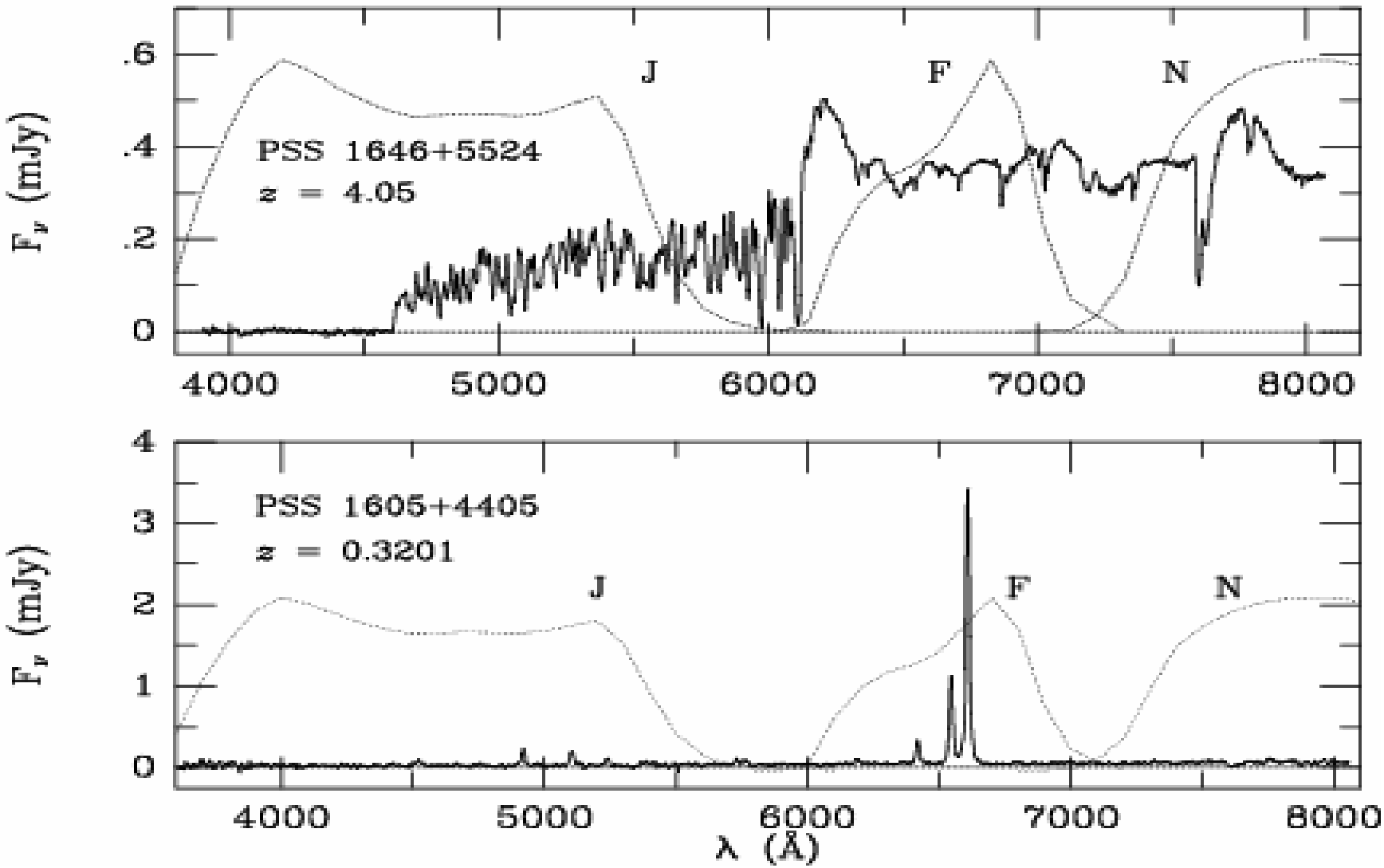
Restframe quasar spectrum (2df)



DPOSS filters



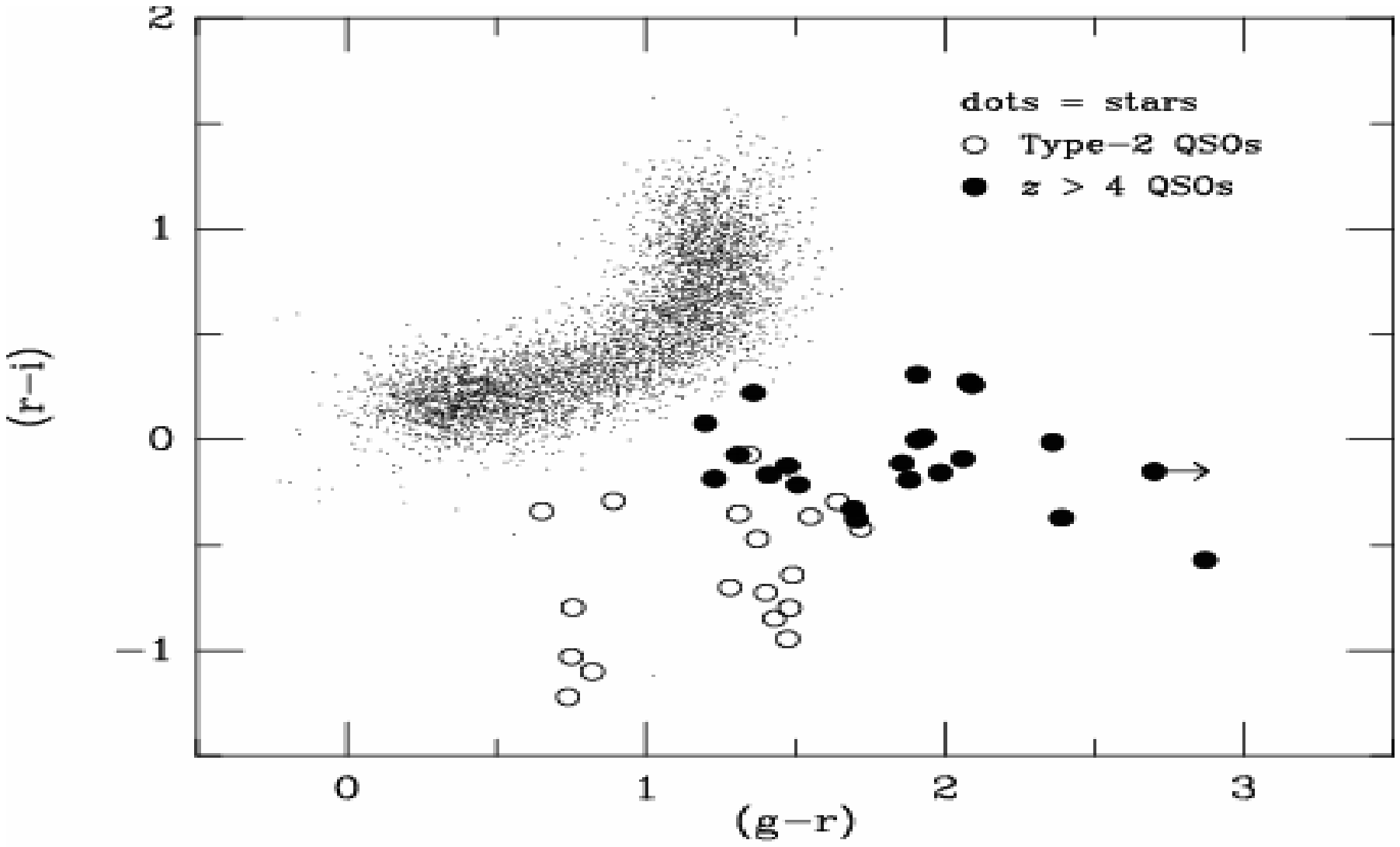
Different objects, diff. filters



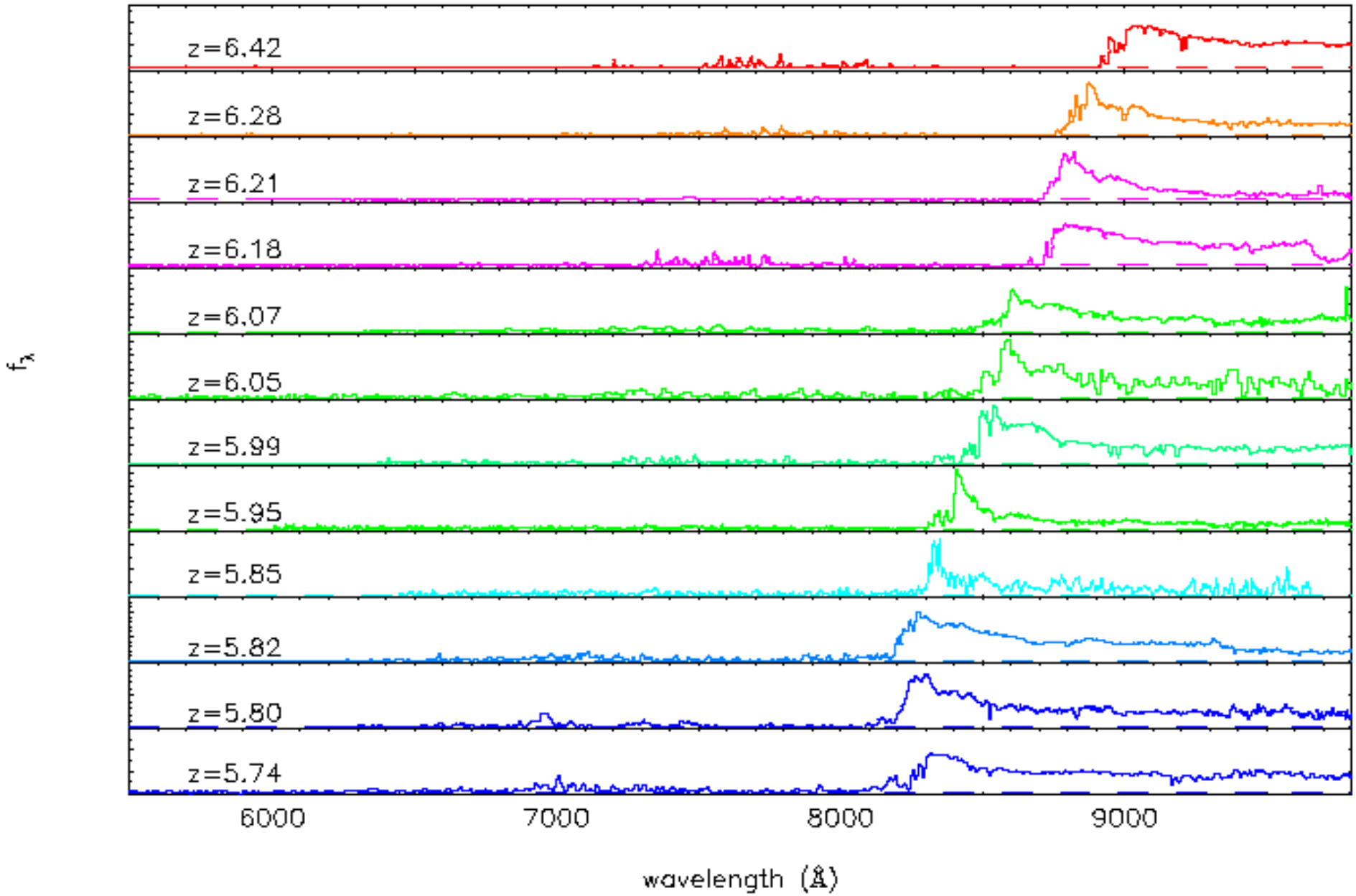
id	ra	dec	g	r	i	g-r	r-i
182394844	359.0332642	1.1372399	20.733	20.957	19.839	-0.22400093	1.118
182394838	359.0346375	1.14885	20.451	19.606	17.892	0.8449993	1.7140007
182394814	359.0388794	1.15965	20.478	20.125	19.628	0.35300064	0.49699974
182394676	359.0702515	1.16179	20.919	20.03	18.794	0.88899994	1.2360001
182394963	359.0029907	1.1695501	16.014	16.059	16.47	-0.045000076	-0.4109993
182394886	359.0227051	1.1740999	19.677	19.231	18.515	0.44599915	0.7160015
182394727	359.0571594	1.1879699	18.464	17.518	17.326	0.94600105	0.19199944
182394803	359.0411987	1.1882399	19.737	18.438	18.299	1.2989998	0.13899994
182394877	359.0254517	1.18864	16.28	16.034	16.441	0.24600029	-0.4069996
182394968	359.0023193	1.1897199	19.135	18.31	18.604	0.82500076	-0.29400063
182394684	359.0675659	1.1925501	21.402	20.771	20.24	0.6310005	0.53100014
182394947	359.0065918	1.19804	21.417	20.738	20.867	0.67899895	-0.12899971
182390652	359.0340881	1.10365	20.394	19.408	19.005	0.98599815	0.4030018
182390510	359.0679321	1.11285	19.776	18.993	18.503	0.78299904	0.48999977
182390820	359.0004272	1.1201899	20.283	19.774	19.294	0.5090008	0.47999954

It's the colors, rather than magnitudes that play an important role.

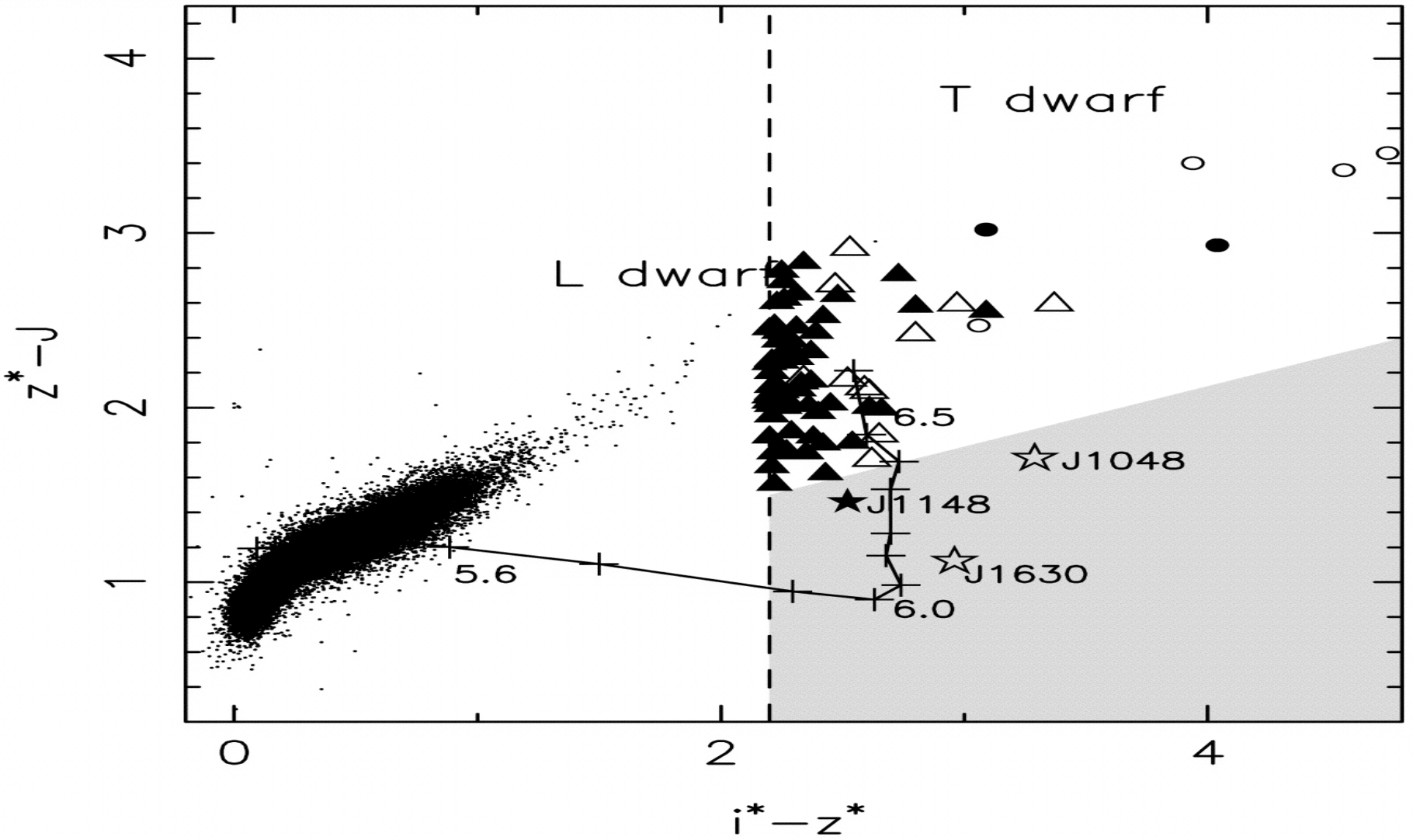
Different outliers diff. regions



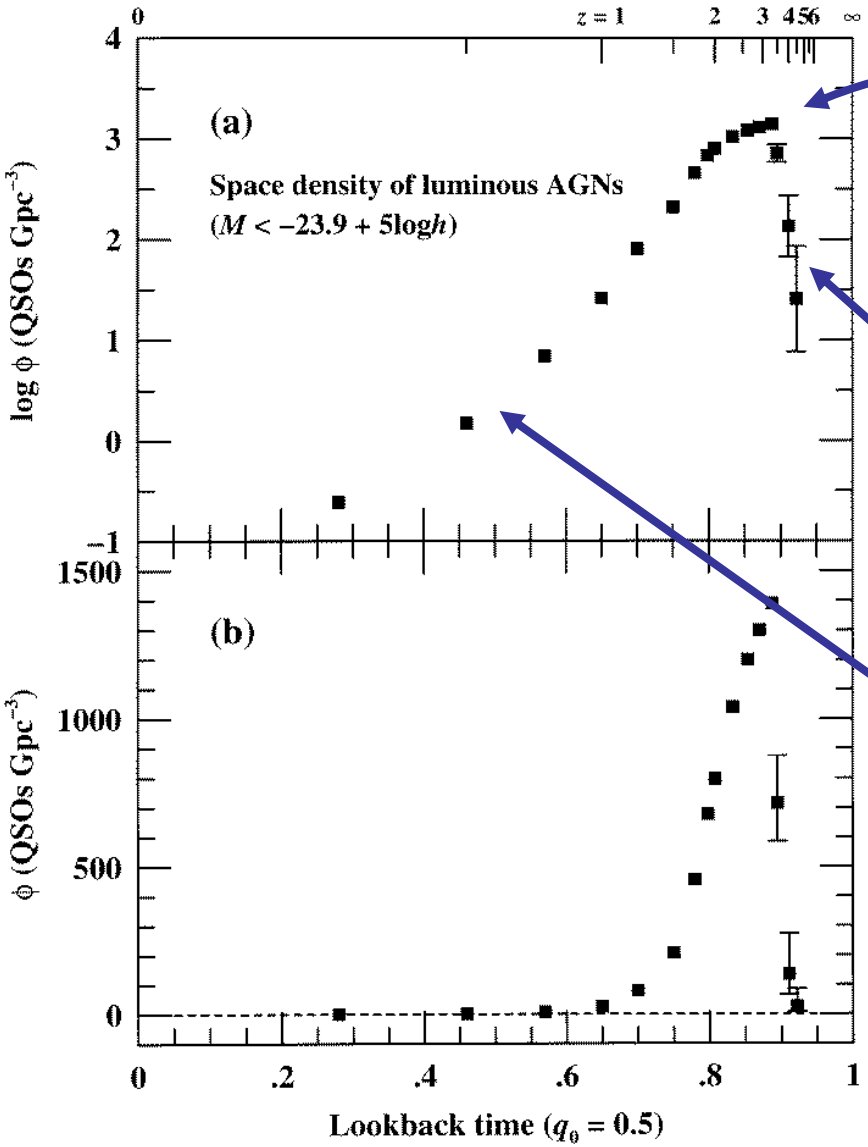
March of Ly-alpha (SDSS, Fan et al.)



Different colors, diff. Filters (Fan et. al)



Number Density of Quasars



The Peak of the Quasar Era at z ~ 2 - 3: The Maximum Merging Epoch?

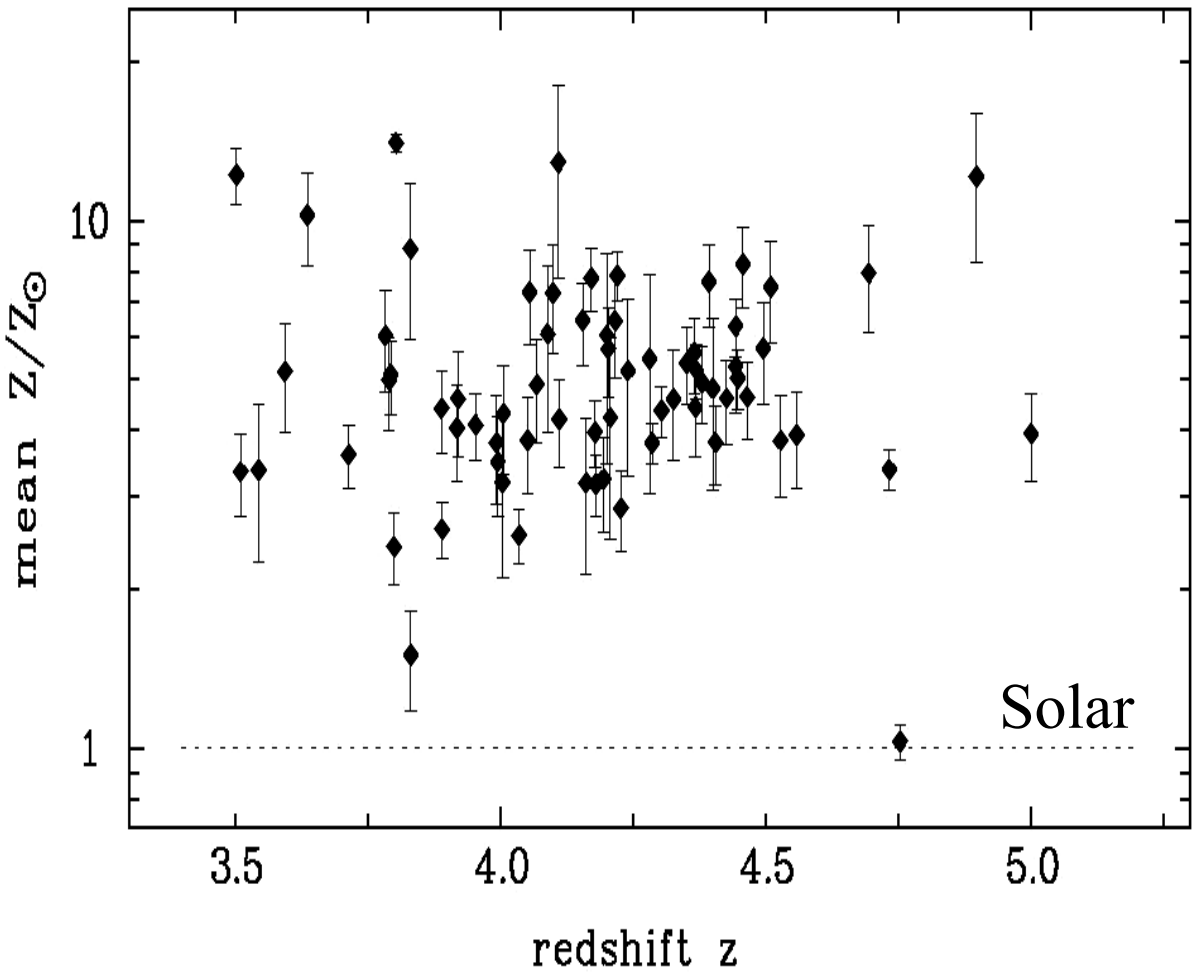
The Rise of Quasars: Initial Assembly of the Host Galaxies, Growth of the SMBHs

The Decline at Low ***z***'s: Diminishing Fueling Events

Triple trouble at higher z

- Fainter
- Rarer
- Redder

High-z QSOs Are Very Metal Rich!

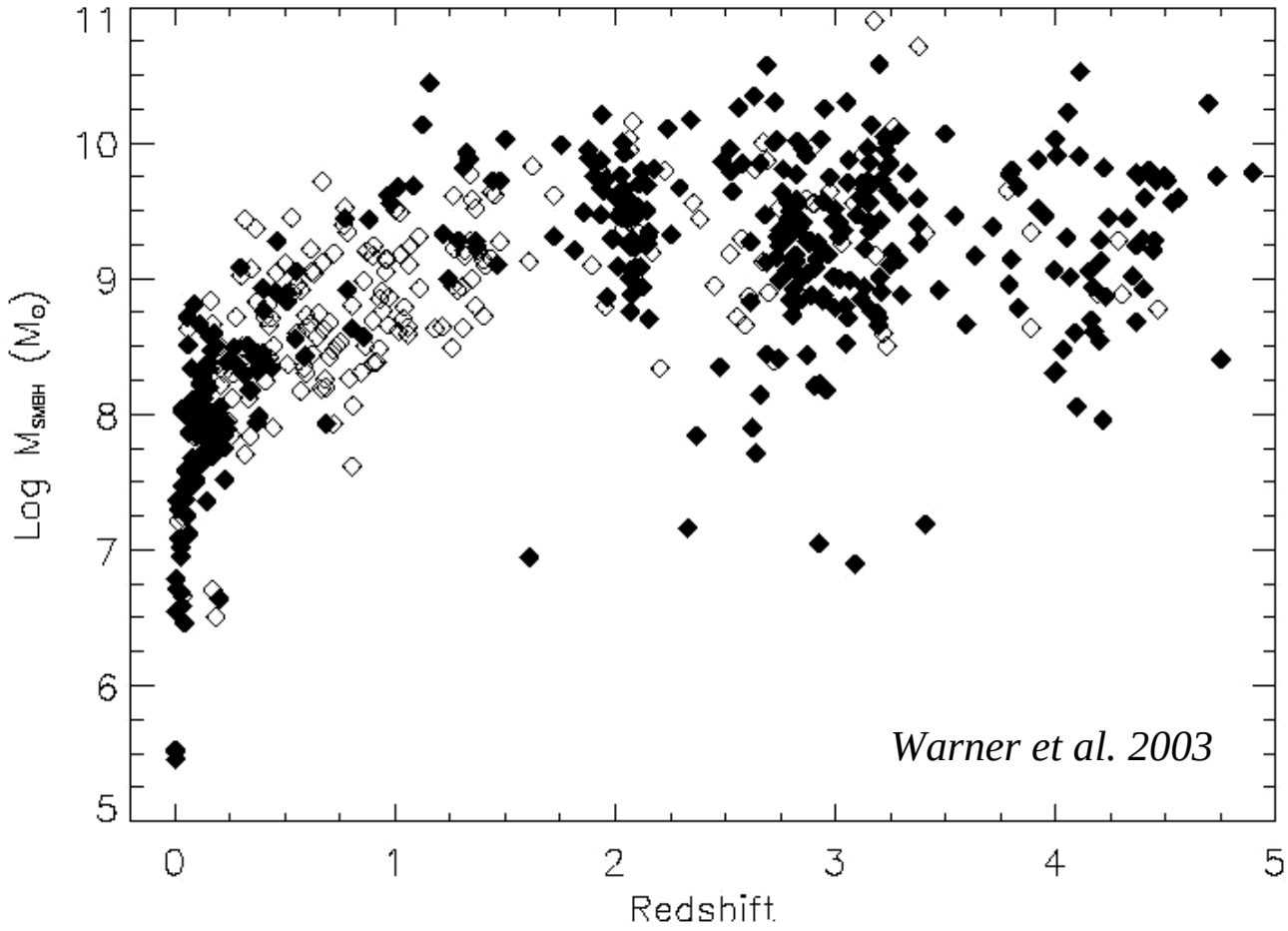


Hamman, Dietrich, et al. 2003

Much more so than the DLA absorber galaxies at comparable redshifts or even the Milky Way disk stars ***today***!

The only known stellar populations with comparable metallicities are the **cores of massive elliptical galaxies.**

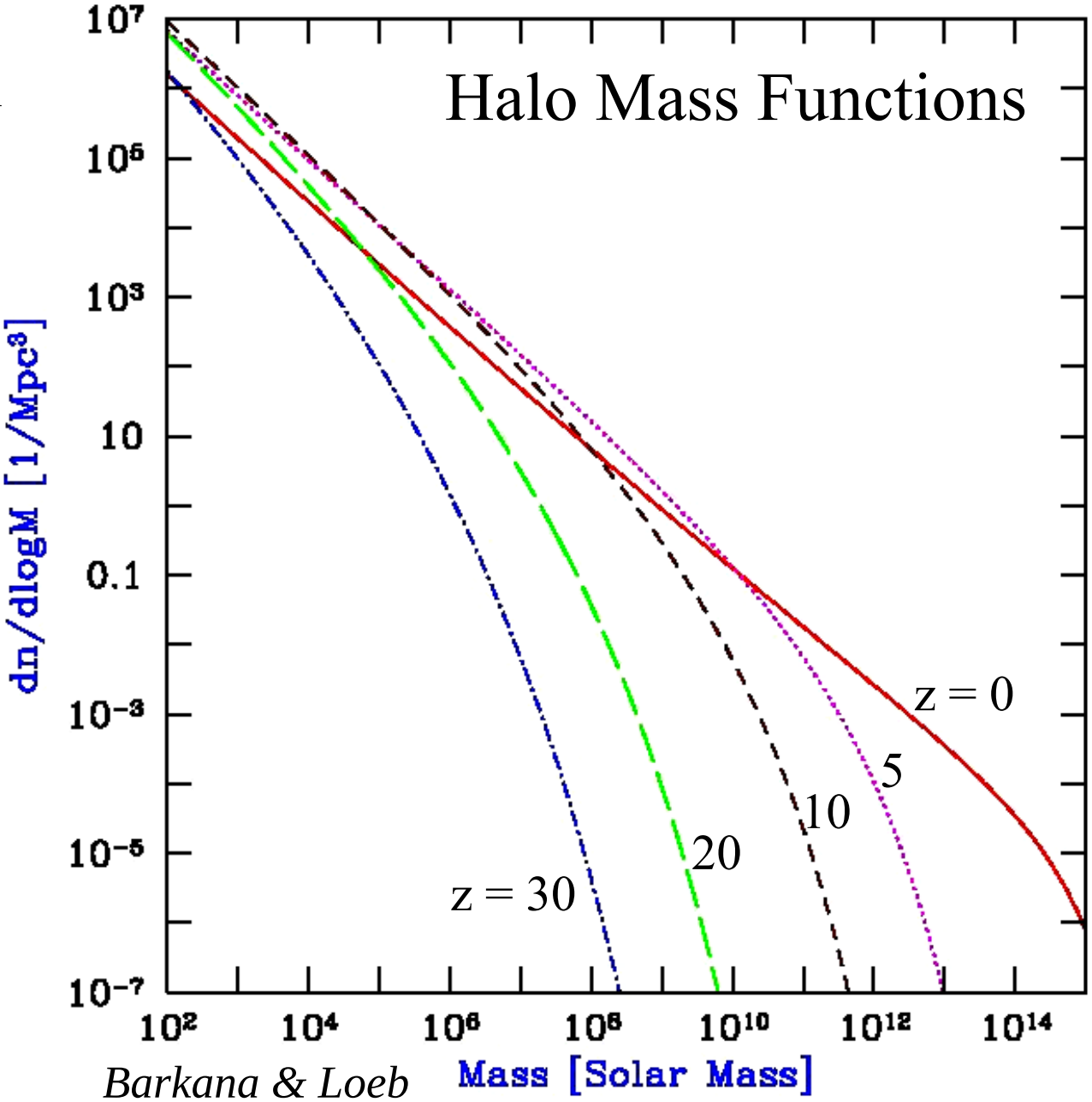
Luminous QSOs Contain SMBHs Even at High *z*'s!

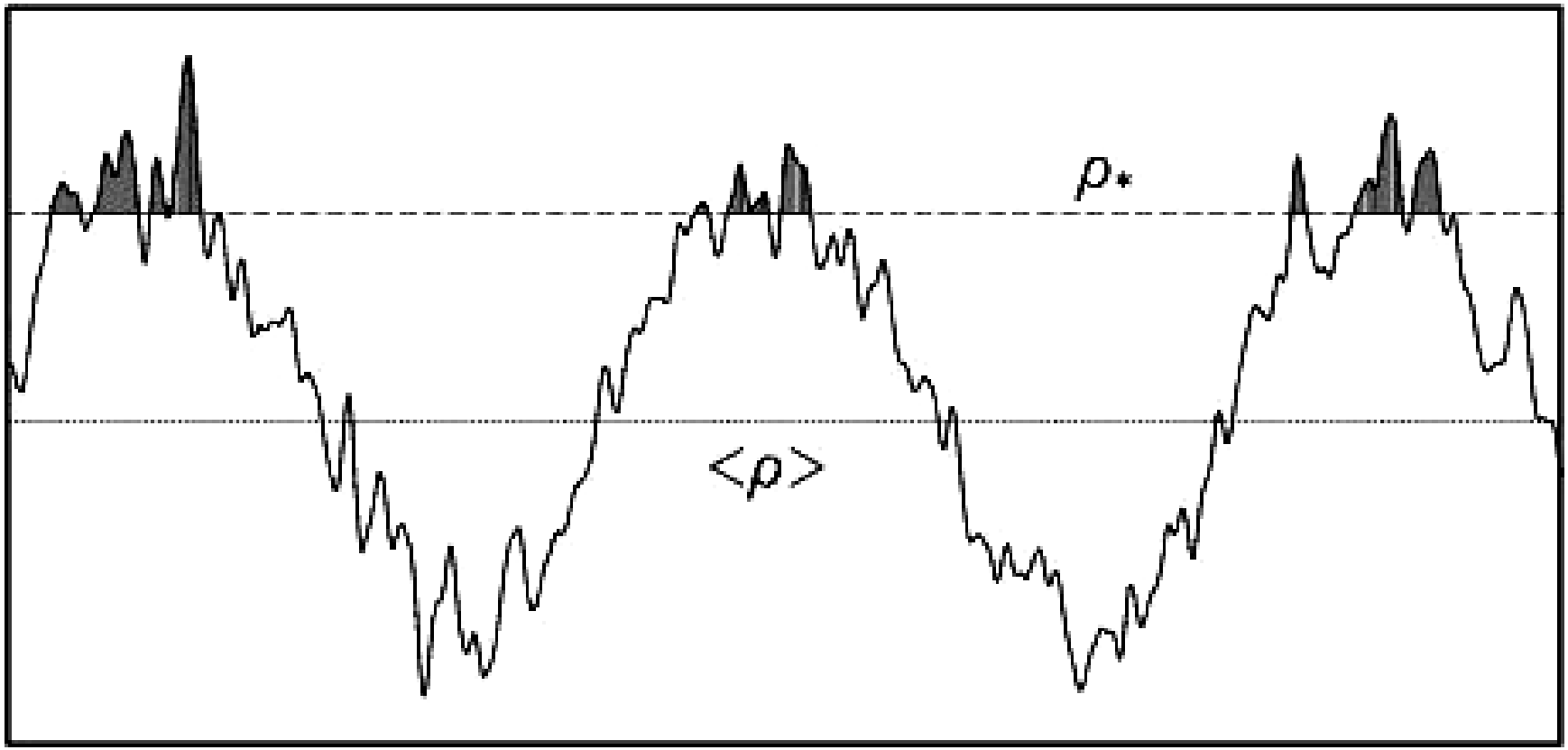


Host halos of such high mass must be **exceedingly rare** at high redshifts

(Press-Schechter)

They must correspond to the **highest peaks** of the primordial density field, and thus be **highly biased**





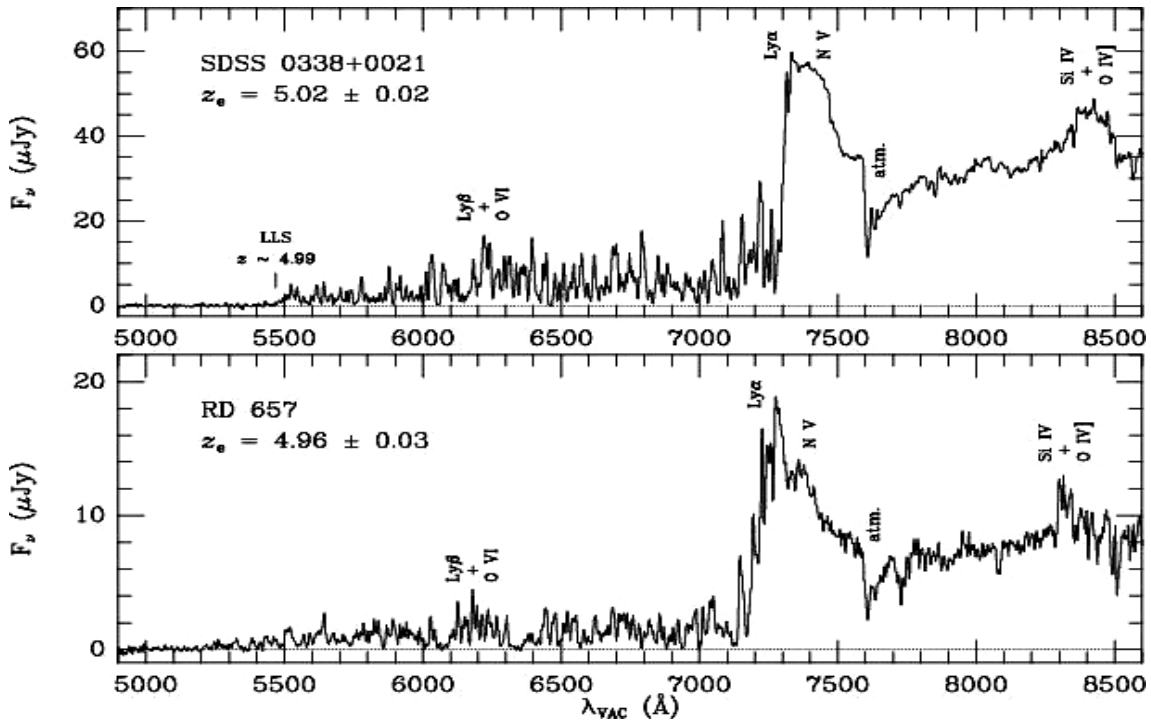
Luminous QSOs ⮝ Massive BHs ⮝ Massive host halos

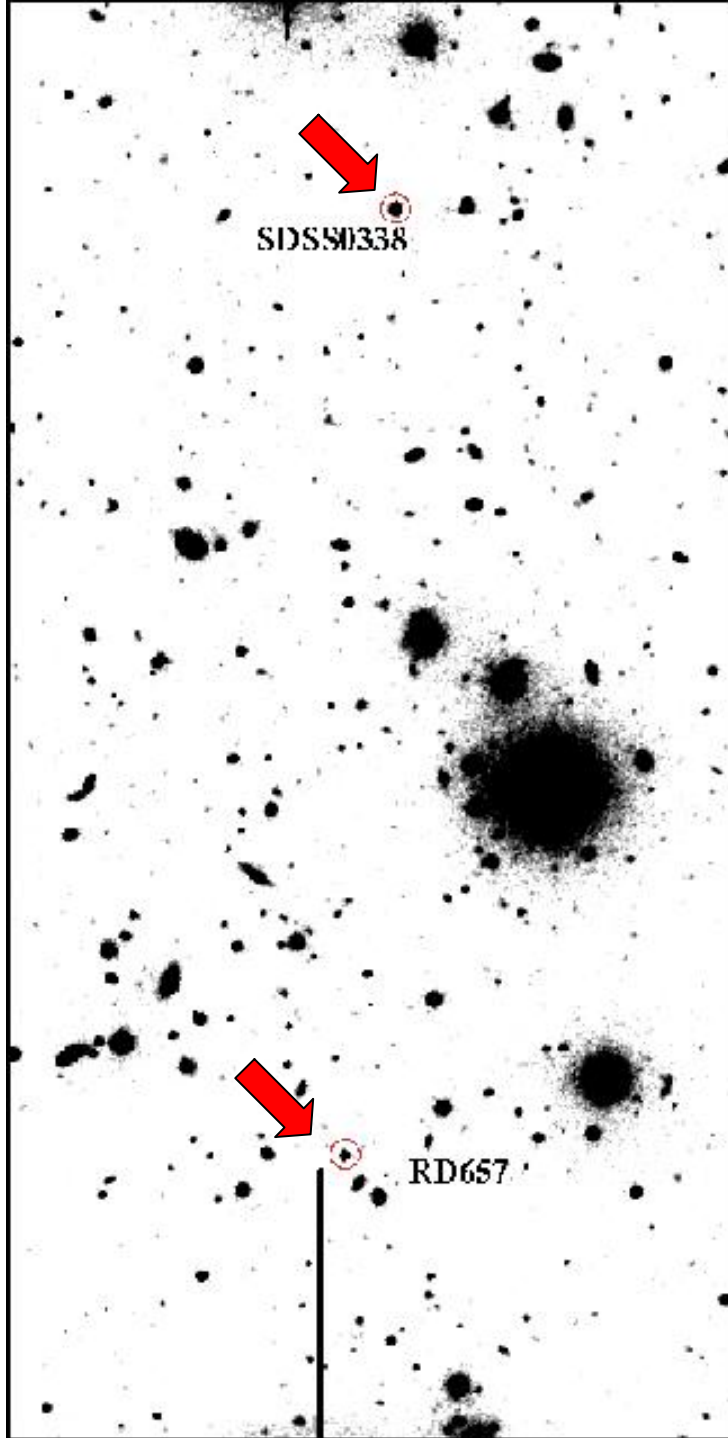
Clustering of ionizing sources ⮝ Clumpy reionization

A QSO Pair at z = 5:

Biased peaks marking an early large-scale structure (a protocluster?)

(Djorgovski, Stern, Mahabal, Castro 2003)

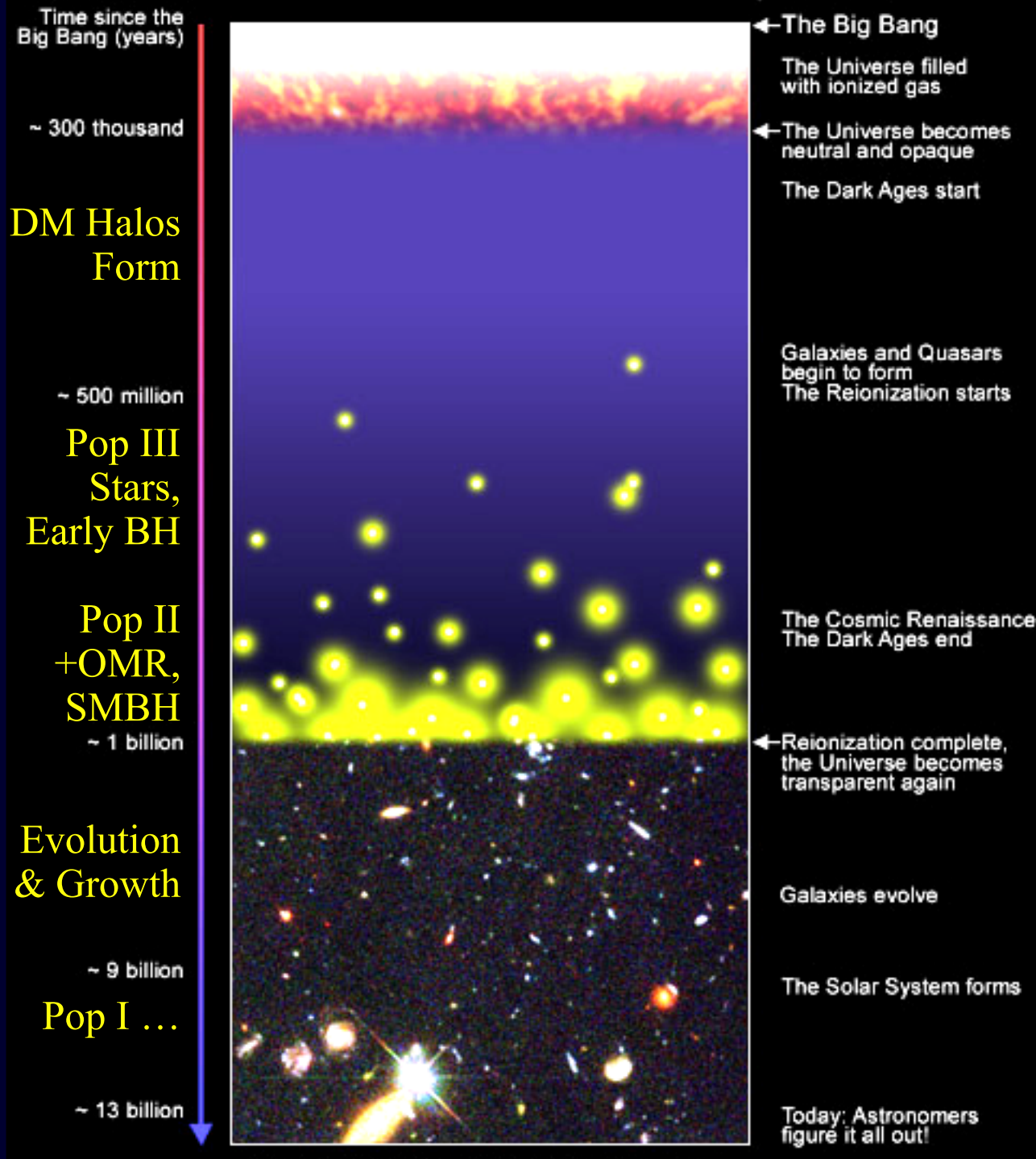




The New Frontier:

Exploring the Reionization Era

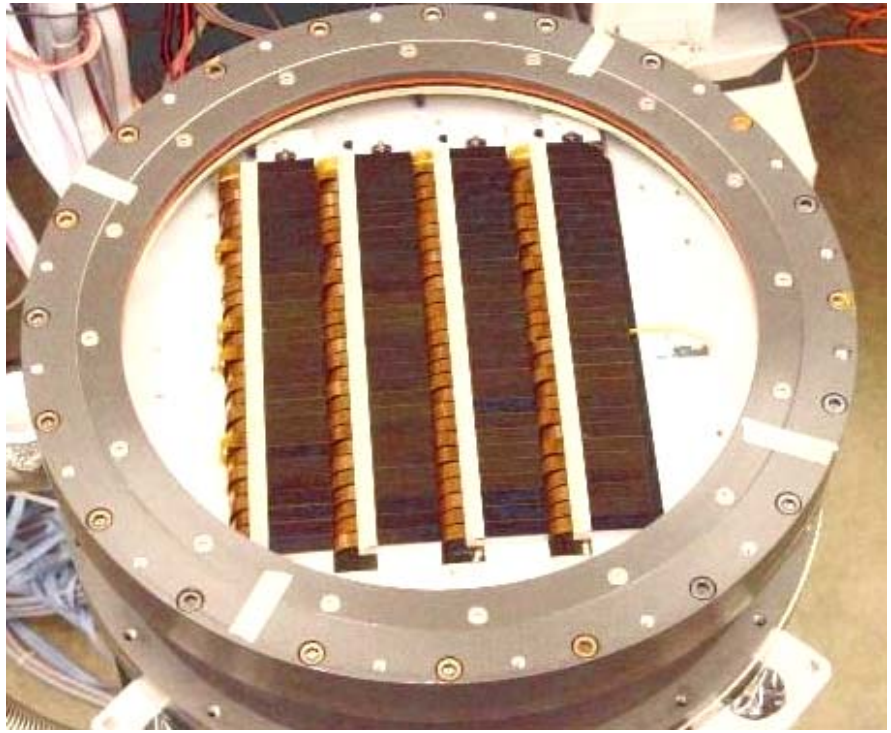
(The Cosmic Renaissance)



High-redshift quasars provide a powerful probe of:

- ✓ formation of massive galaxies
- ✓ primordial large-scale structure
- ✓ end of the reionization

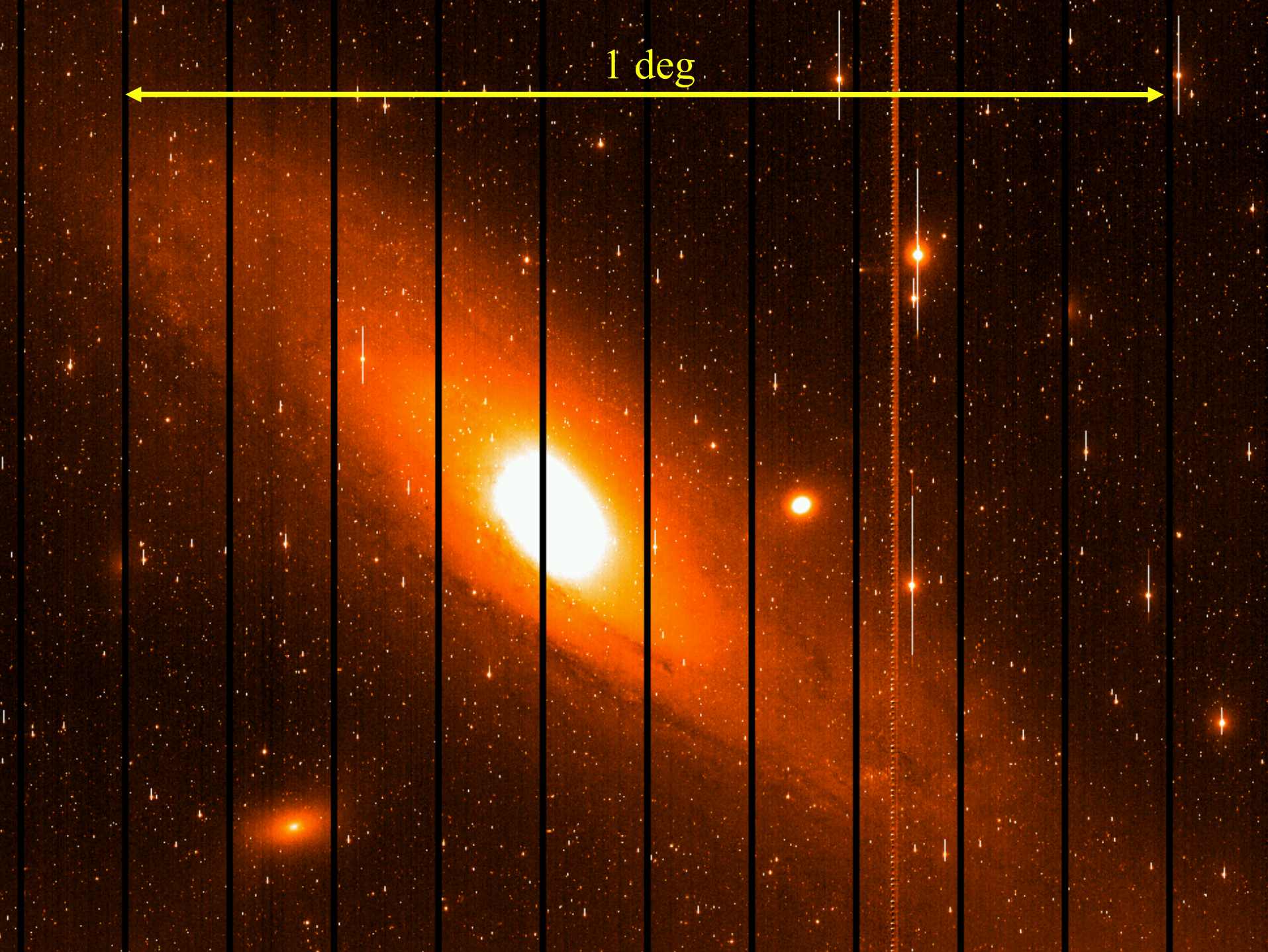
The Palomar-Quest (PQ) Survey
(aka the Third Palomar Sky Survey)



A new, digital, synoptic sky survey done with the the Yale/IU Quest-2 112-CCD camera at the Palomar 48” Oschin Schmidt telescope

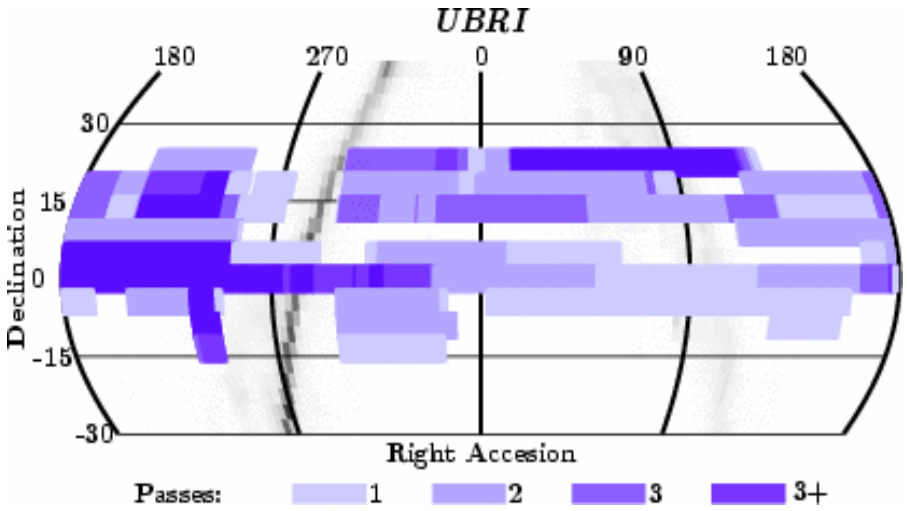
The Palomar-Quest Survey

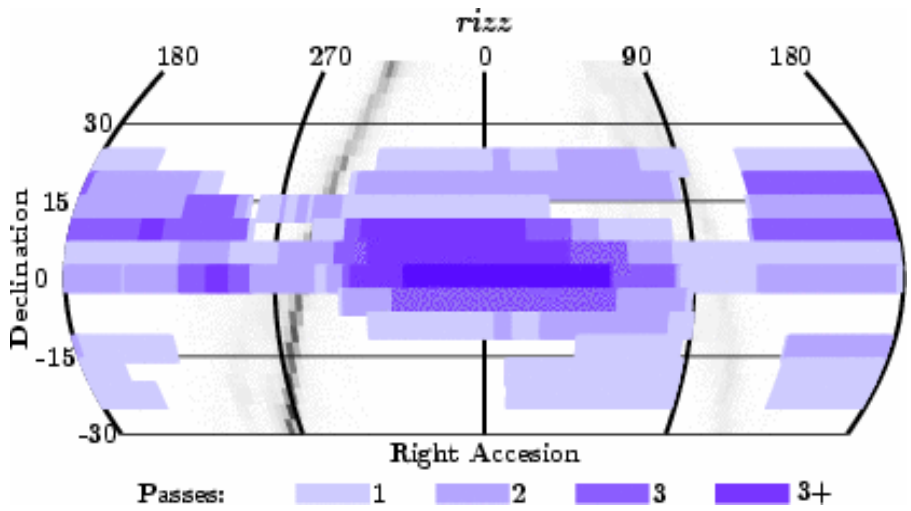
- A collaboration between Caltech, Yale/Indiana U., and JPL; plus collaborations with other groups (NCSA, INAOE, LBL)
- Using the refurbished 48" Palomar Oschin Schmidt telescope, and the new 112-CCD, 161-Megapixel camera
- Point & track (snapshot area 9.2 deg^2) or driftscan mode in Dec strips 4.6º wide
- Data rate ~ 1 TB/month; next-day processing ⌫ real-time
- Started in summer of 2003
- NVO connections and standards built in from the start
- Repeated observations, time baselines minutes to years
- **A science and technology precursor/testbed for the LSST and other major synoptic sky surveys in the future**


1 deg

Sky Coverage (as of June 2004)

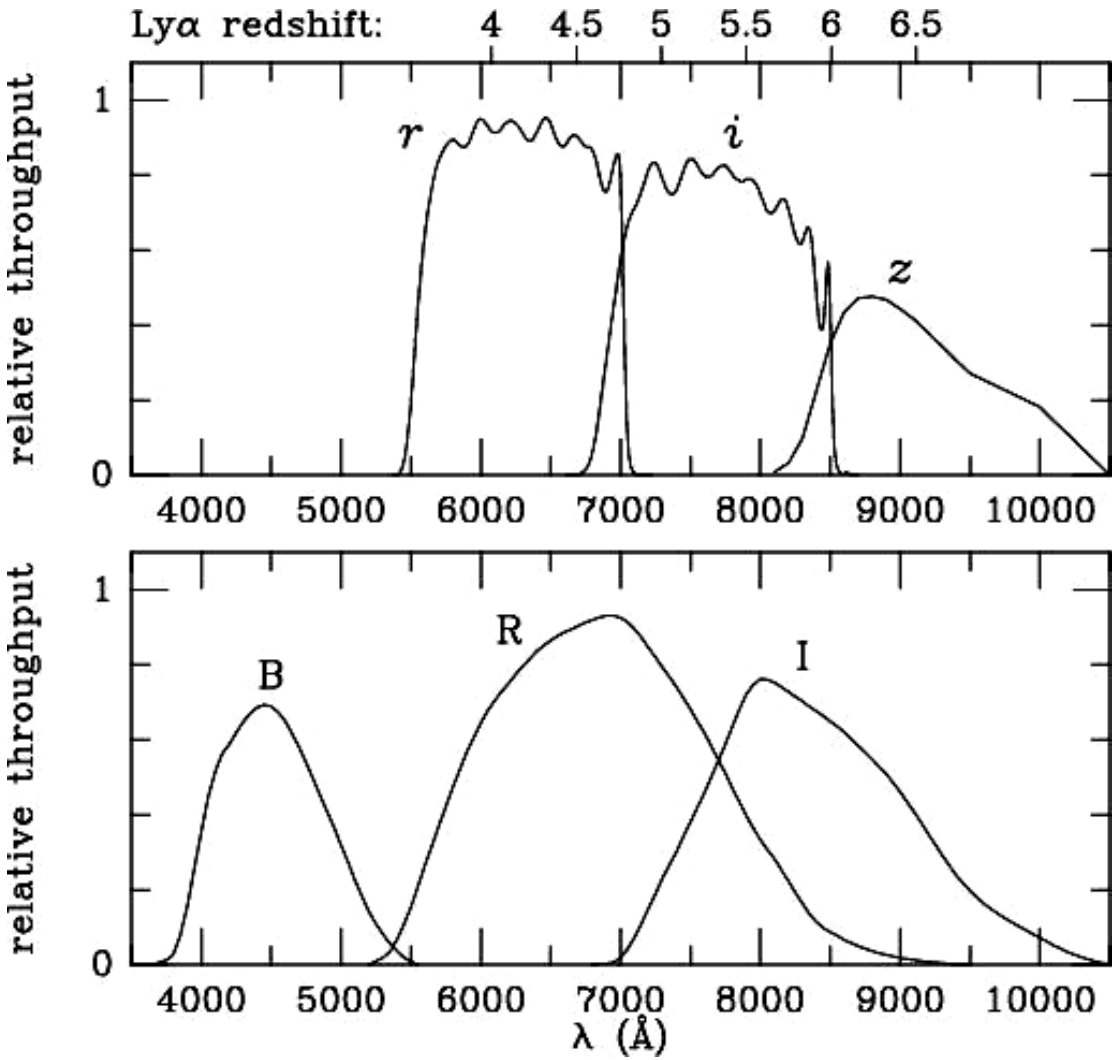
- Range -25°< δ < +30°, excluding the Galactic plane
- Ultimately cover ~ 12,000 - 15,000 deg^2
- Rate ~ 500 deg^2/night in 4 bands
- As June'04, covered ~ 10000 deg^2 in *UBRI*, of which ~ 7000 deg^2 at least twice; and ~ 10500 deg^2 in *rizz*, of which ~ 5500 deg^2 at least twice





Bandpasses and Depth

Typical limiting magnitudes in a single pass:



$r_{\rm lim} \approx$ 21.5 mag

$i_{\rm lim} \approx$ 20.5 mag

$z_{\rm lim} \approx$ 19.5 mag

$R_{\rm lim} \approx$ 22 mag

$I_{\rm lim} \approx$ 21 mag

In 4 passes (2 *UBRI* + 2 *rizz*), yearly:

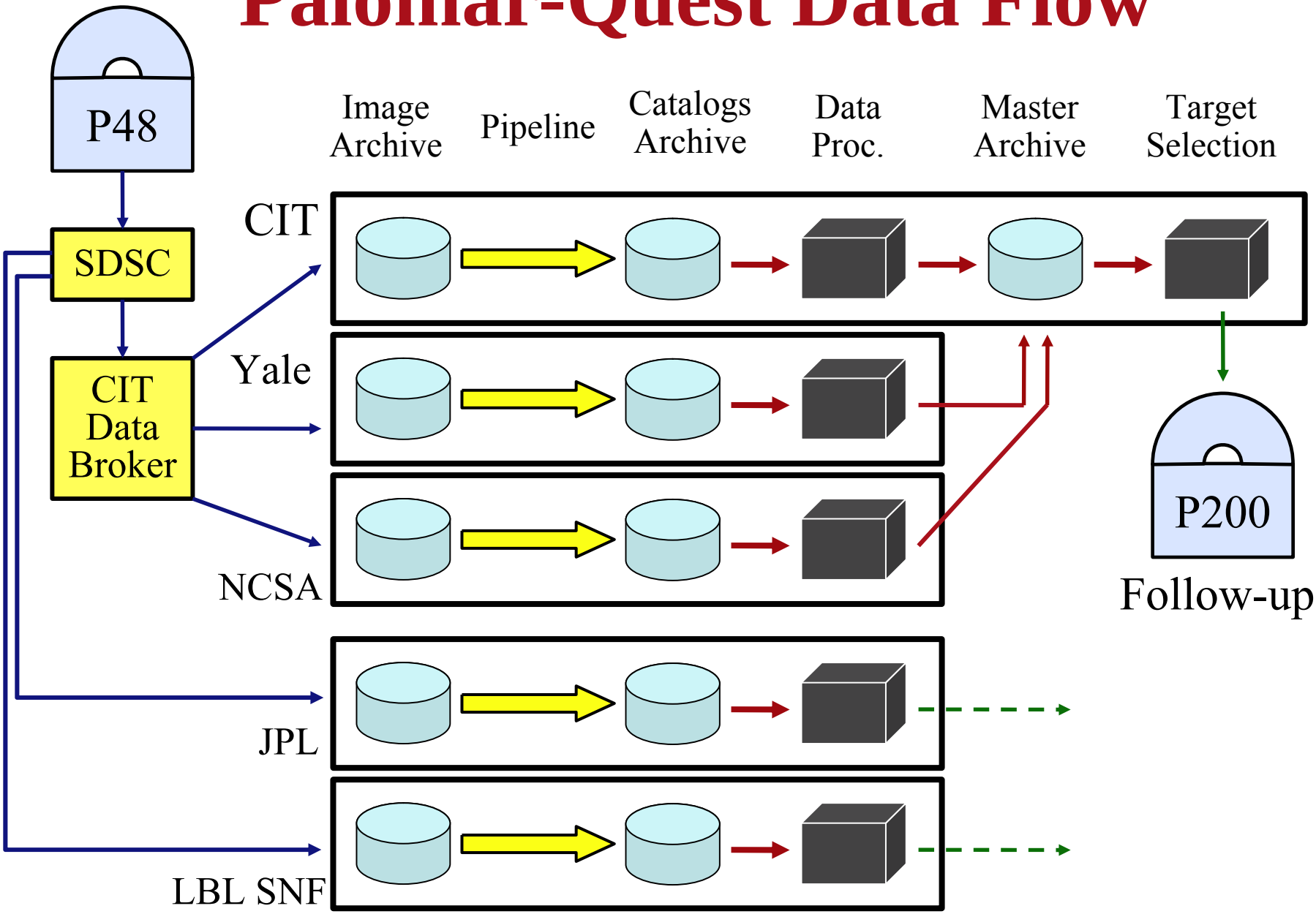
$r_{\rm lim} \approx$ 22.5 mag

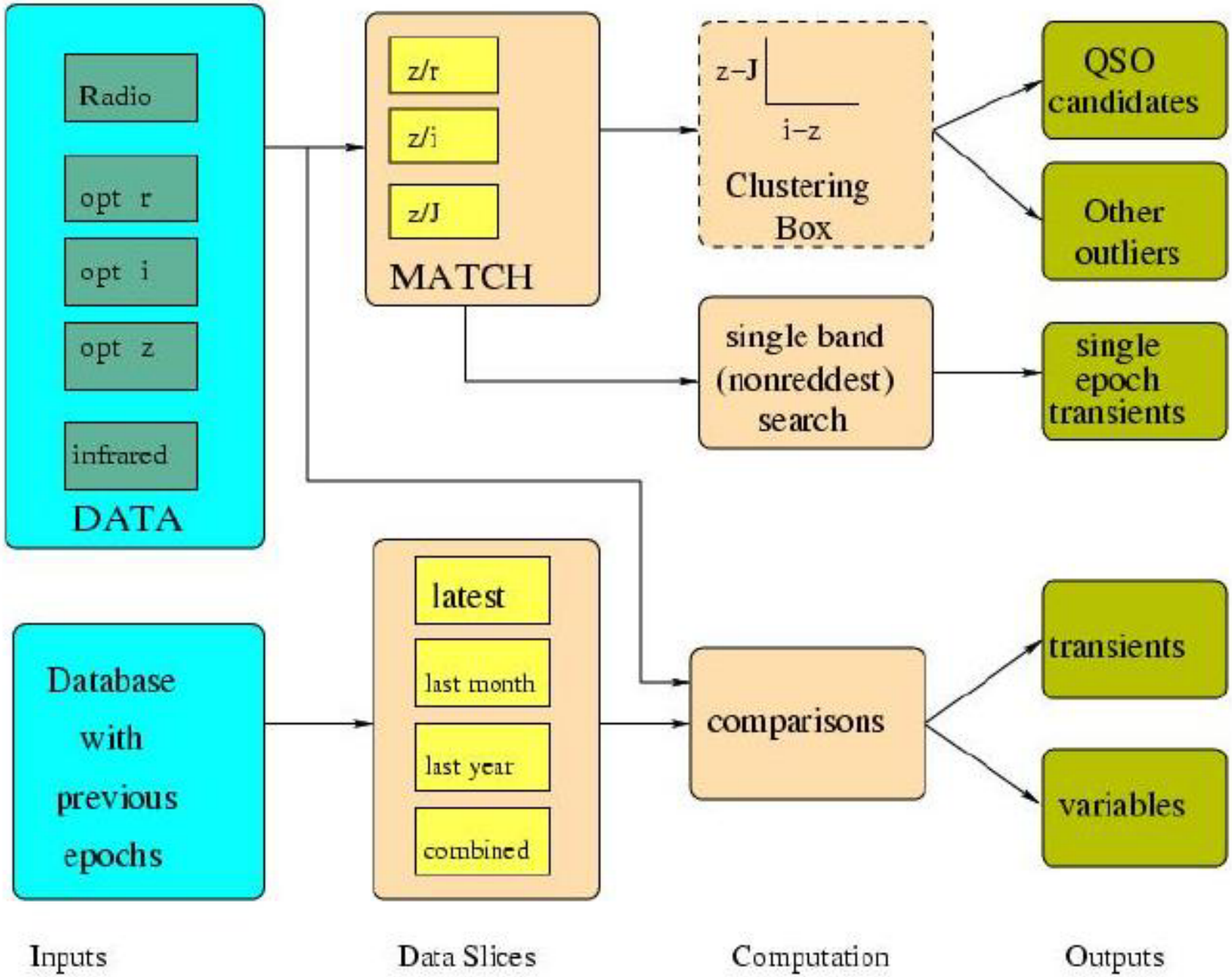
$i_{\rm lim} \approx$ 21.5 mag

$z_{\rm lim} \approx$ 20.25 mag

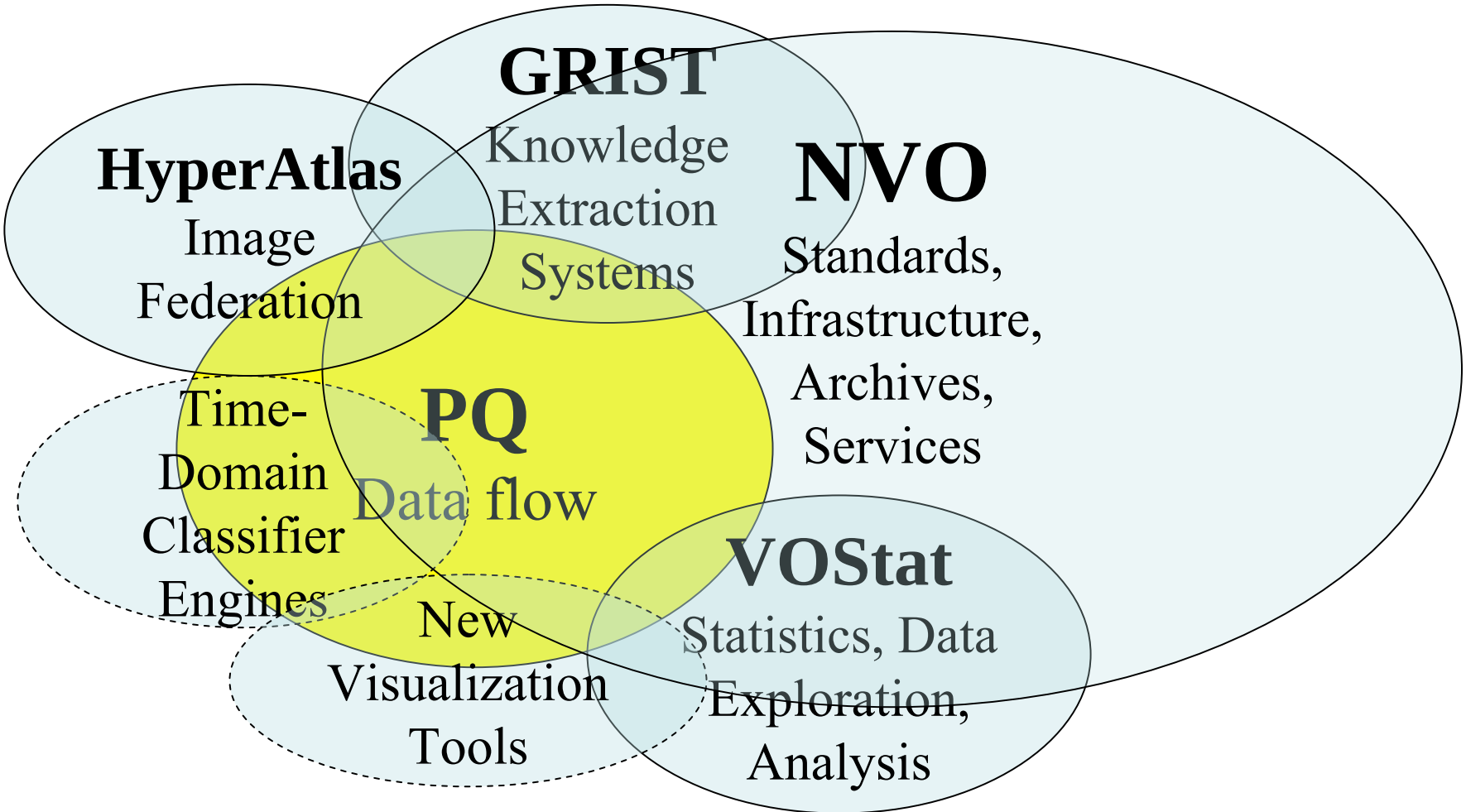
In 5 years, ~ 0.8 mag deeper …

Palomar-Quest Data Flow




Radio
opt r
opt i
opt z
infrared
DATA
z/r
z/i
z/J
MATCH
z–J
i–z
Clustering Box
QSO candidates
Other outliers
single band (nonreddest) search
single epoch transients
Database with previous epochs
latest
last month
last year
combined
comparisons
transients
variables
Inputs
Data Slices
Computation
Outputs

Coping with the Data Flow in the PQ Survey: a Federation of Projects

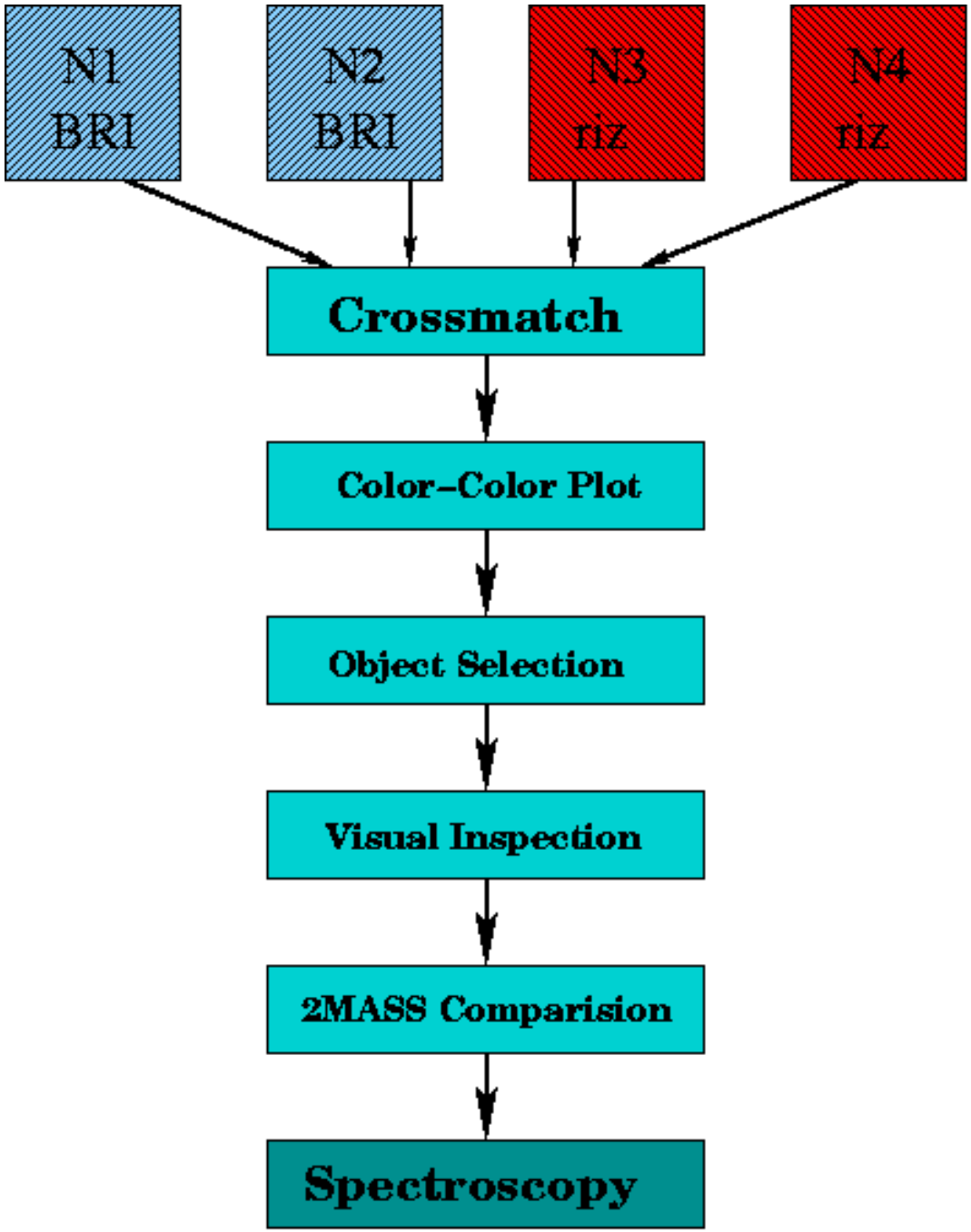


The PQ Survey Science

- Large QSO and gravitational lens survey
  - Tests of the concordance cosmology
  - Dark mattter distribution
  - AGN physics and evolution
- **High-redshift ($z \sim 4$ - 6.5) QSO survey**
  - Probes of reionization and early structure formation
- **Exploring the time domain**
  - Supernovae, GRBs, transients
  - Variable stars, AGN
  - Surprizes and new phenomena?
- Galactic structure and stellar astrophysics
- Multiwavelength (VO) astronomy
- Solar system: Earth-crossing asteroids, Kuiper Belt

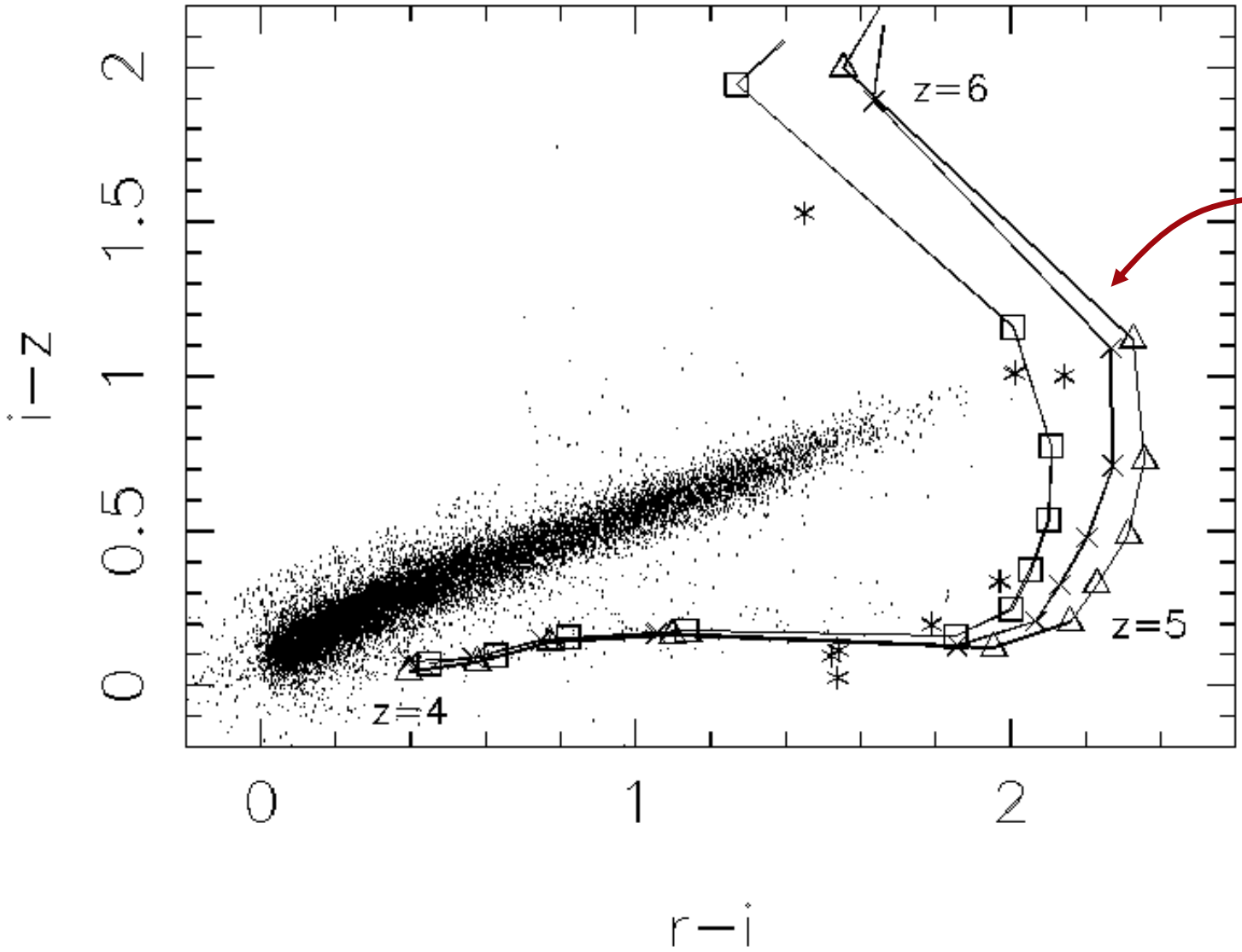
The PQ High-Redshift QSO Survey

- ***New probes of the reionization era, early structure formation and biasing,*** and the first QSOs (infall, enrichment, LF, MBH mass func.)
- Similar in scope and methodology to SDSS: same depth, comparable or larger area coverage (some overlap for healthy mutual cross-checks, some new)
- Expect to discover **~ 20 QSOs at z ~ 5.5 - 6.5** (reionization probes), **~ 100 QSOs at z ~ 4.5 - 5.5**, and **~ 200 - 300 QSOs at z ~ 4 - 4.5**
- Possible basis for a z > 7 QSO survey in NIR



- Multiple passes
- Virtual Ids
- More colors

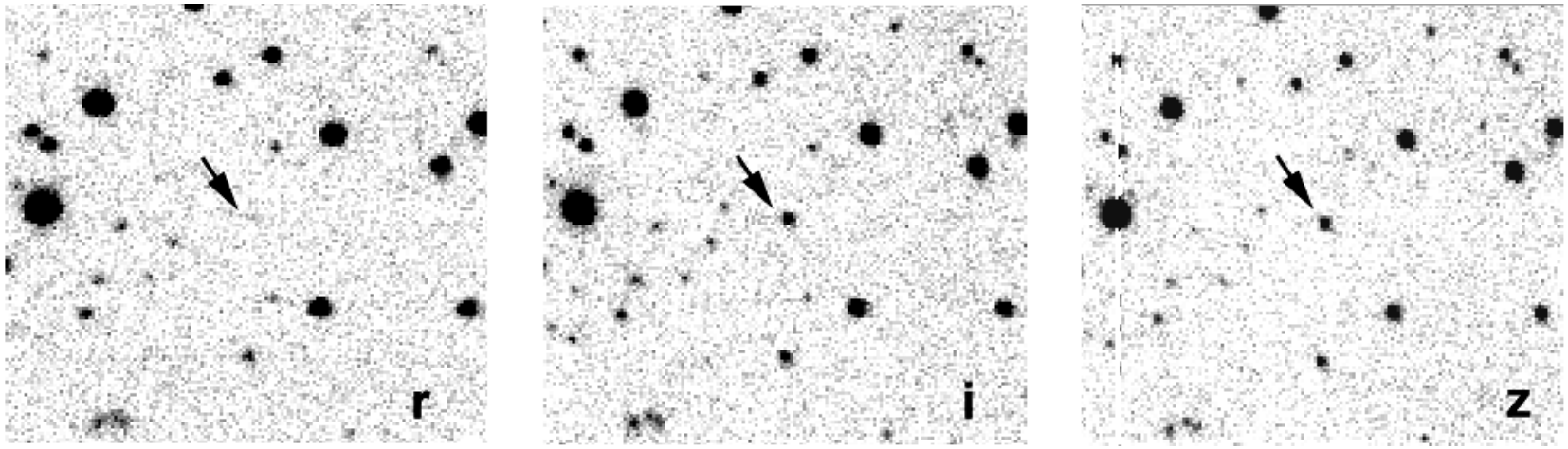
Color Selection of High-z QSO Candidates



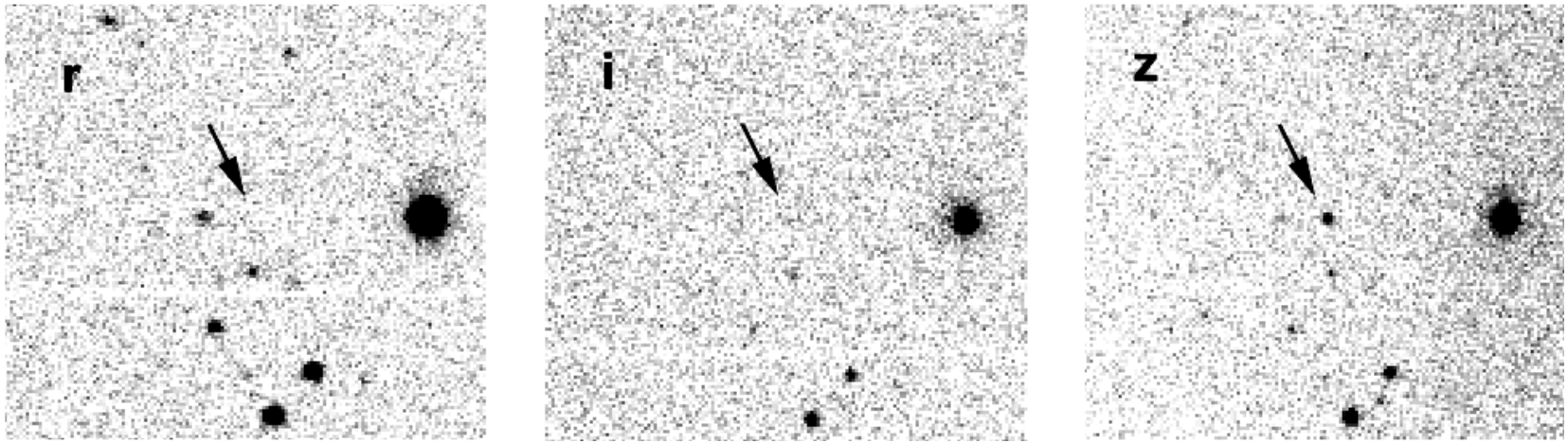
QSO redshift tracks in the *riz* color space

Examples of Color-Selected Candidates

QSO at z > 4.7 ?

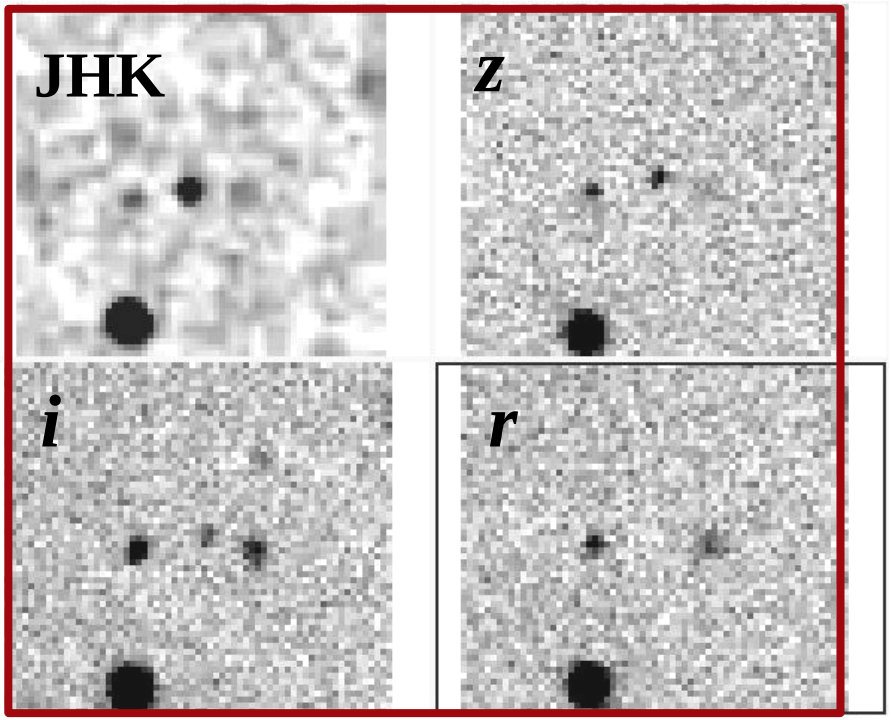


QSO at z > 5.7 ? Or a brown dwarf?

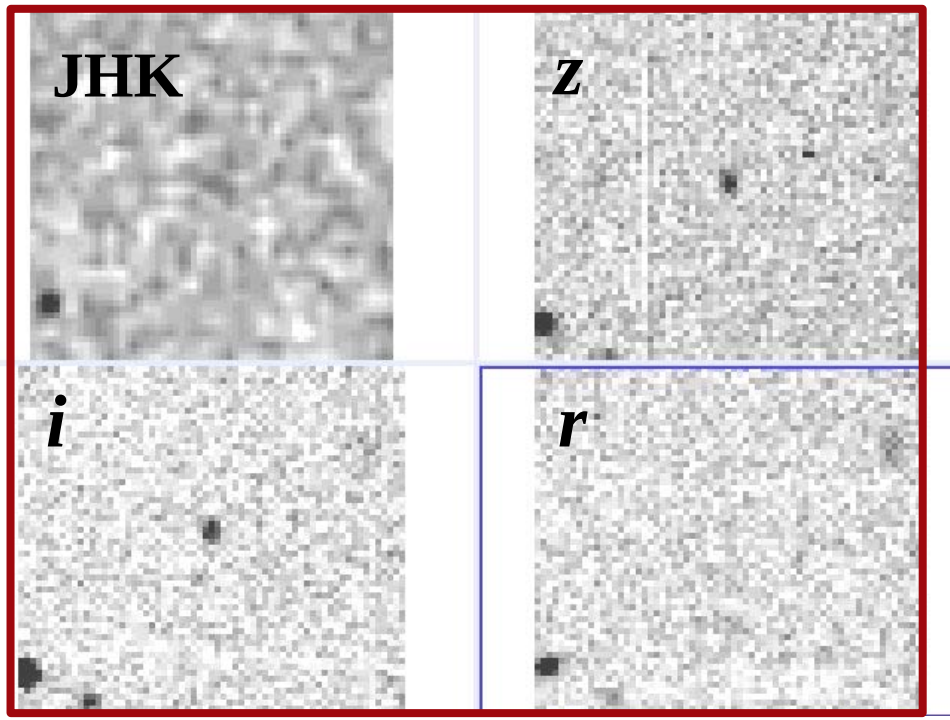


Using 2MASS Coadds to Eliminate (Some) Brown Dwarf Contamination

Probable Brown Dwarf

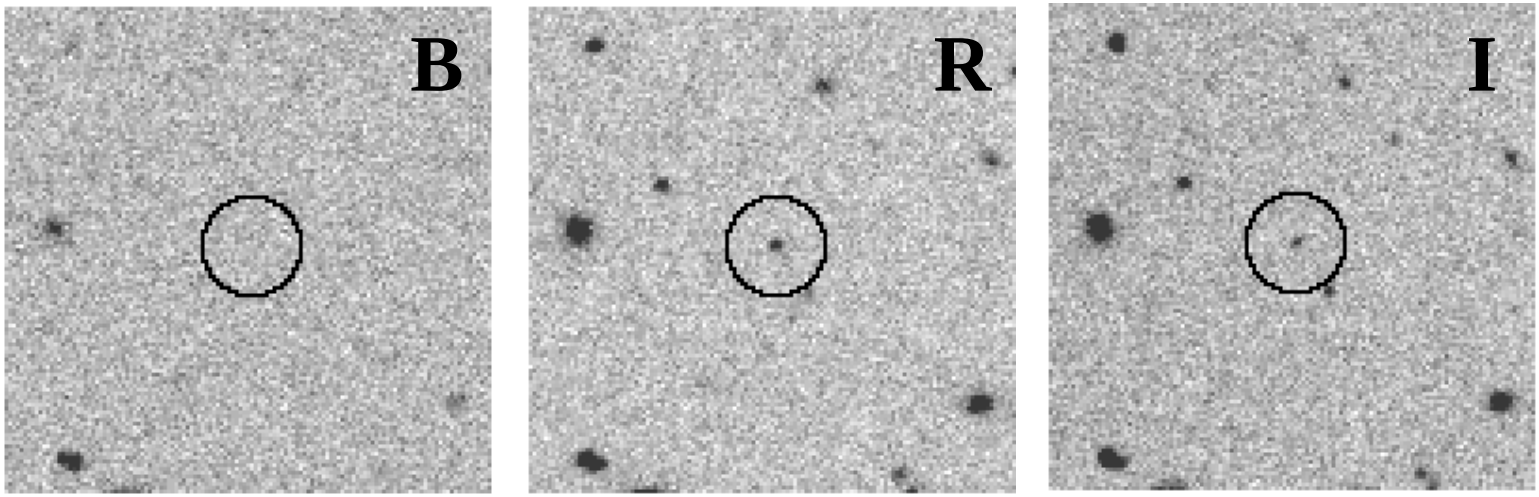


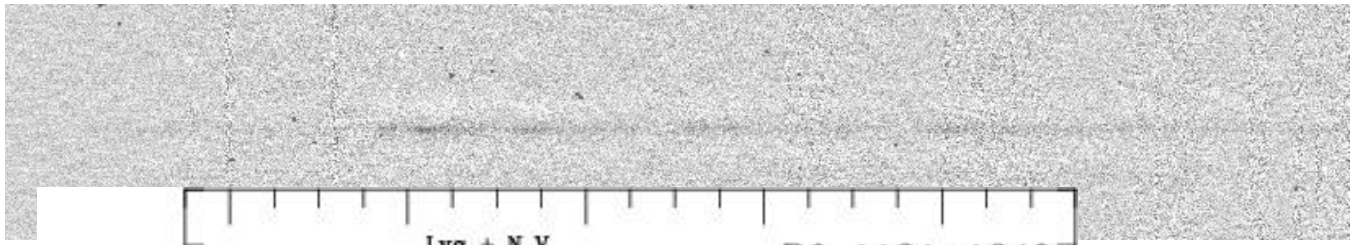
Possible High-z QSO

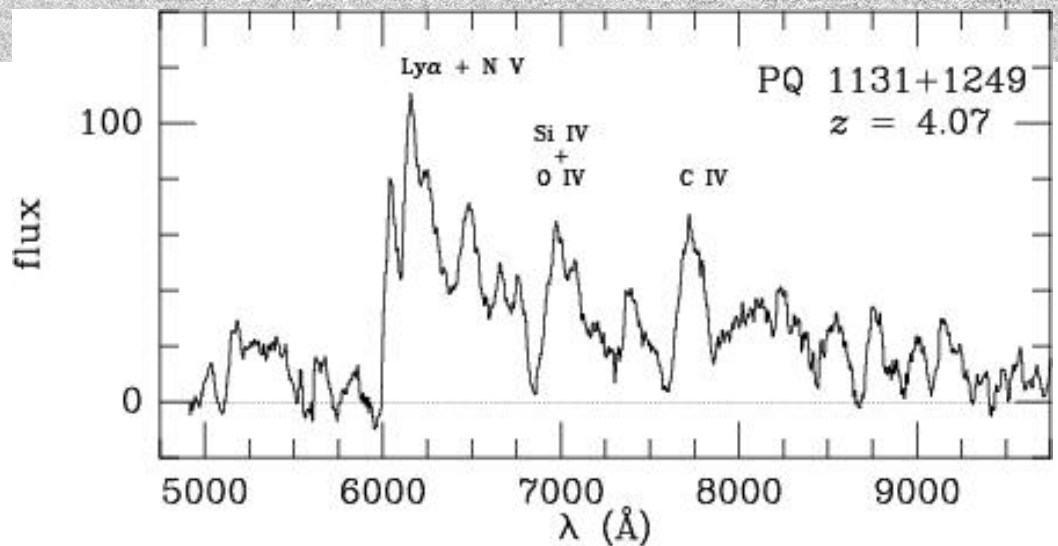


To be supplemented with our own IR observations from Yale telescopes at CTIO, from Cananea (Mexico), and possibly Palomar

Our First High-z QSO: PQ 1131+1249



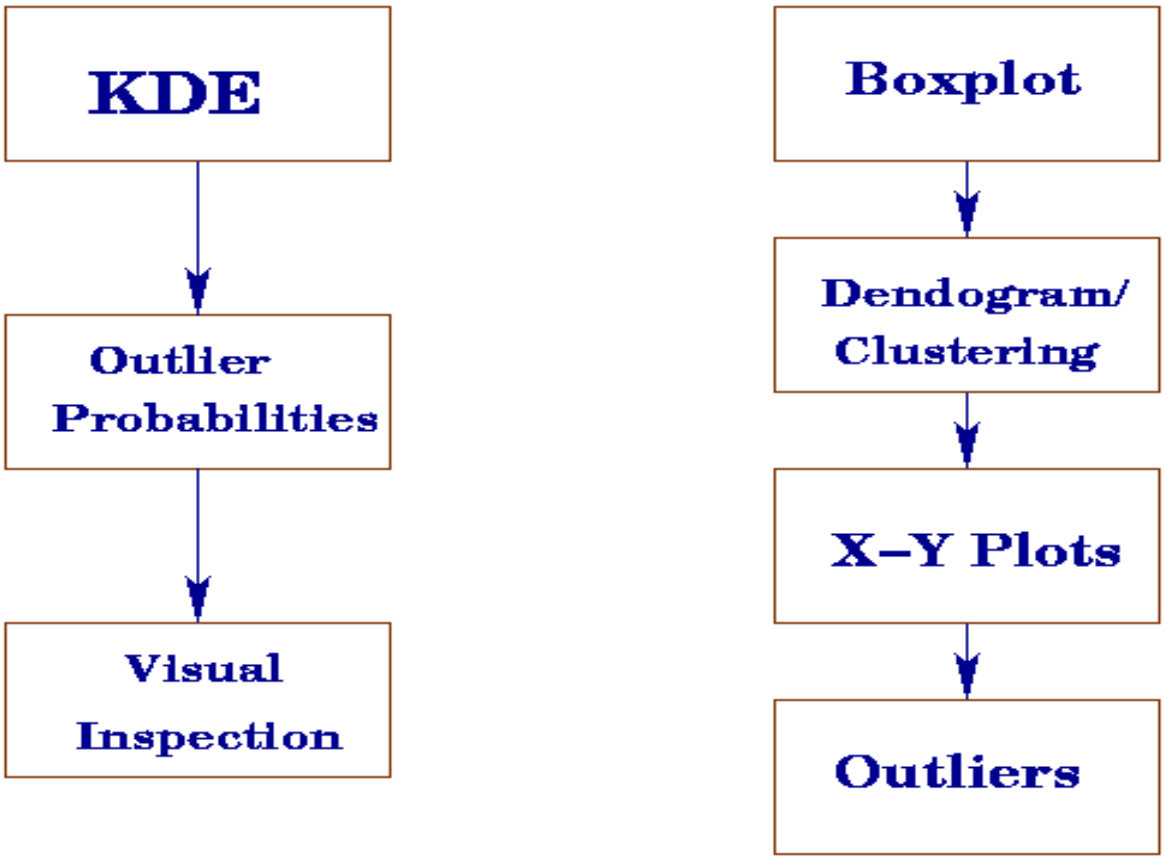




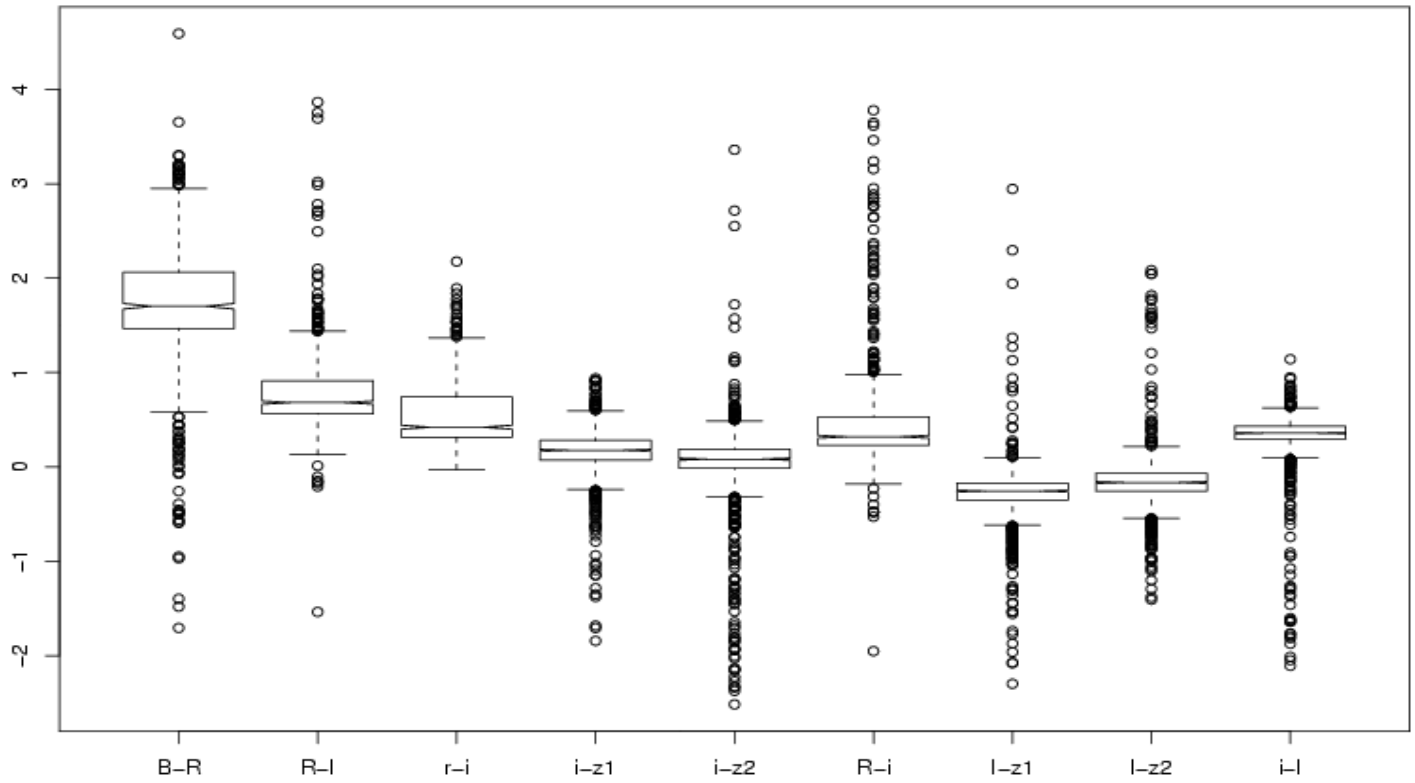
Discovery spectrum

Using VOSTAT

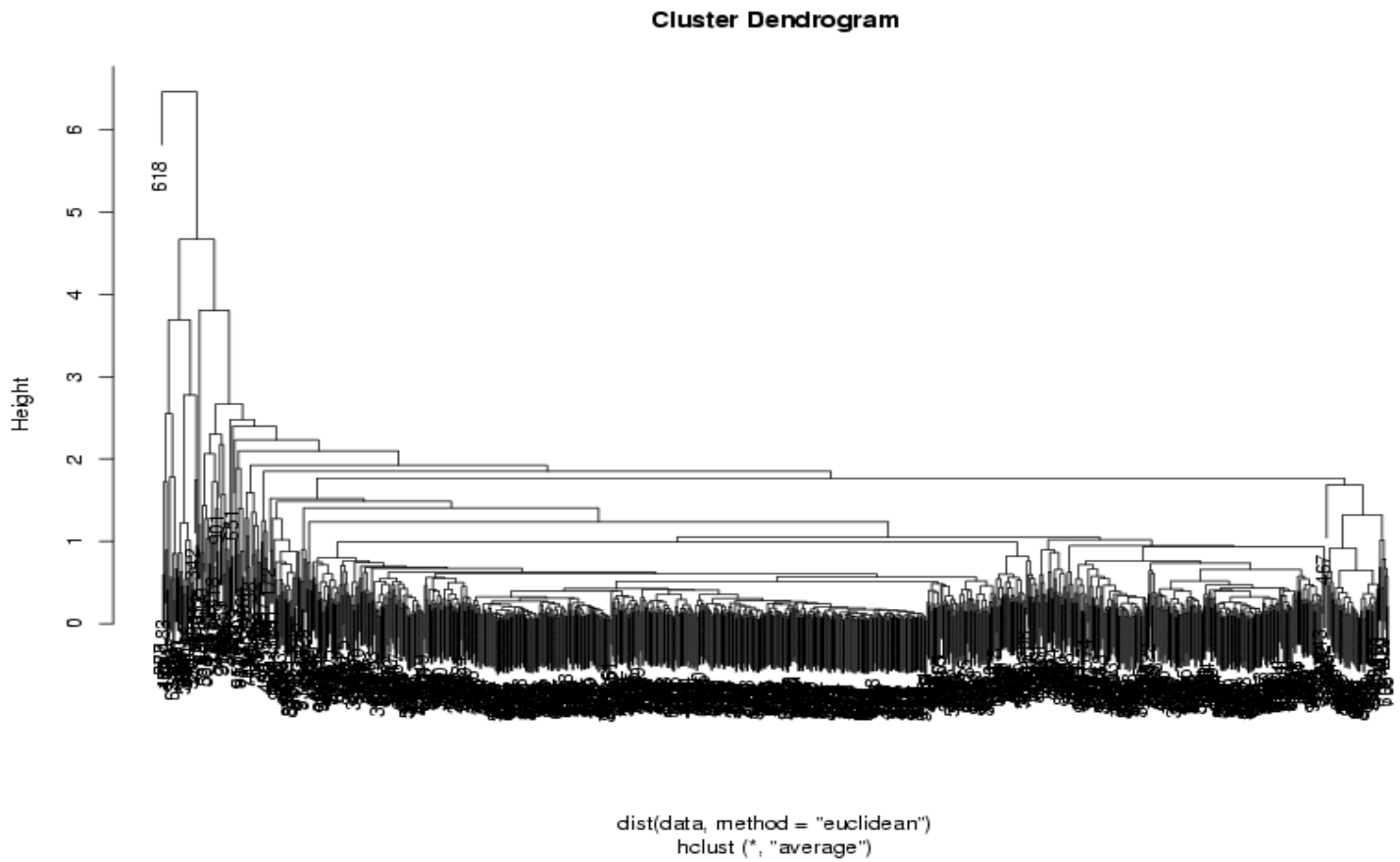
http://vostat.org



Boxplot (simple way for outliers)



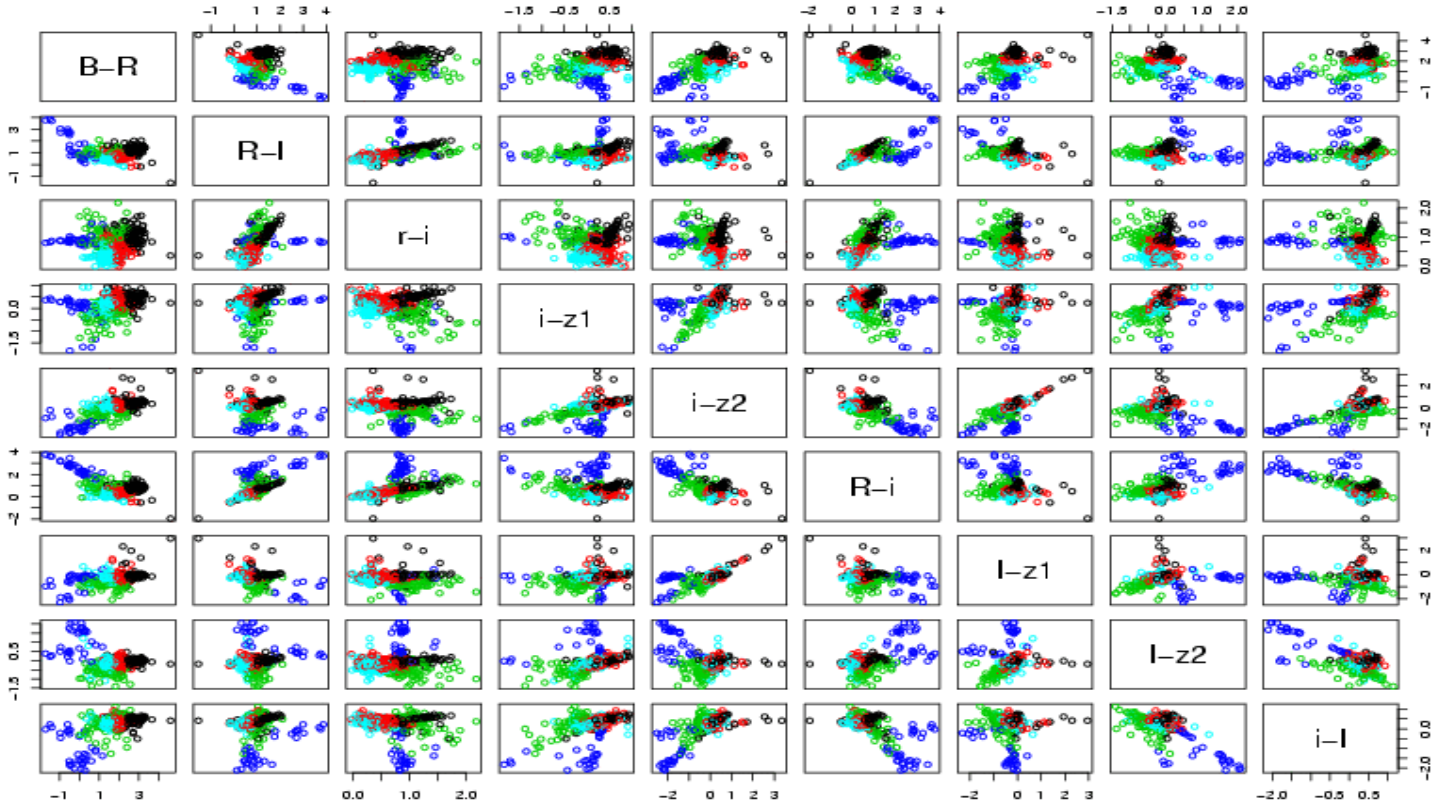
Dendograms (estimating clusters)



Cluster details

```
> print(cl$size)
[1]  75 122 480 289  33
> print(cl$centers)
     X2.1553   X0.8833    X0.563     X0.2347     X0.1909   X0.5069    X.0.1855
1  1.4074840 0.9671000 1.0442640 -0.29106000 -0.51805867 0.7100160 -0.77514267
2  2.6638713 1.1741434 0.9580811  0.40006393  0.39761967 0.7380221 -0.03850164
3  1.5062098 0.5789365 0.3302465  0.12387542  0.05890729 0.2437696 -0.27625958
4  2.0228934 0.7910471 0.5455412  0.24857820  0.15998754 0.4003003 -0.23075917
5 -0.1626848 1.5104515 0.8905485 -0.08033333 -1.67197273 2.5554939 -0.62693030
     X.0.1417    X0.3764
1 -0.54814400  0.2570840
2 -0.03605738  0.4361213
3 -0.21129146  0.3351669
4 -0.14216851  0.3907467
5  0.96470909 -1.0450424
> print(cl$withinss)
[1] 118.08204 126.88979  95.40461  87.19068 142.91592
> print(cl$cluster)
  [1] 1 4 3 2 3 3 3 4 3 3 3 3 3 3 3 4 4 3 3 4 3 3 3 3 3 4 5 3 3 3 3 3 3 3 3 3 5
```

X-Y plots (clusters brushed)



Probabilities reflected as scatter

BRI

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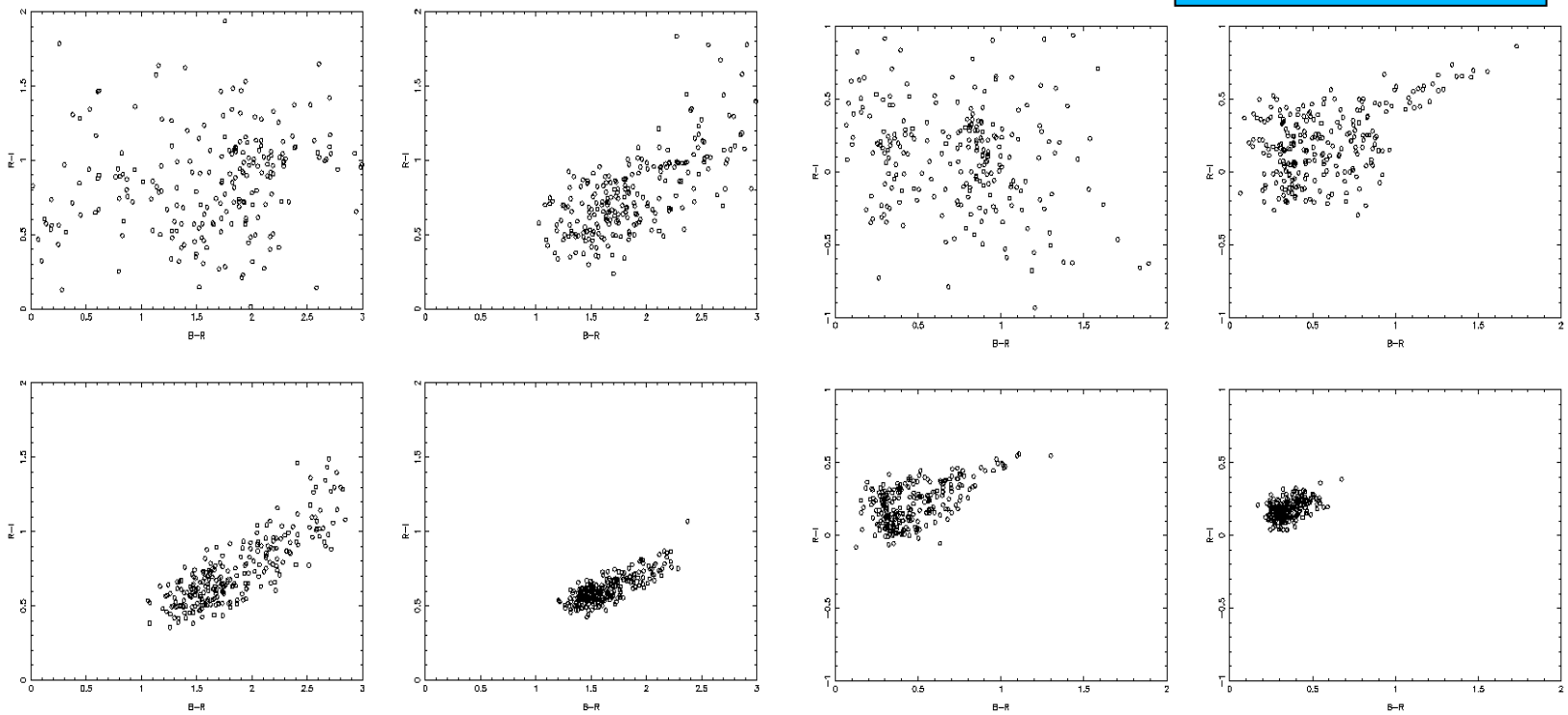

RIB images