An XMM Survey of SDSS Stripe 82

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With thanks to the SDSS Stripe 82 “Co-add Team”: Jim Annis, Huan Lin (Fermilab), Robert Lupton, Michael Strauss, Jim Gunn (Princeton), Linhua Jiang, Xiaohui Fan (Arizona), Edd Edmundson (Portsmouth) and the SDSS Collaboration (particularly the “ADIOS” team)

Outline

• Much of the science that can be achieved by observing a 50+ sq. deg. field for 10+ ks is generic and has already been nicely described.
• Thus, herein I will concentrate on the added benefit of having some of that area within the SDSS footprint, specifically the "Southern Equatorial Stripe (#82)" from 21-4 hrs.

- Review of SDSS
- Why optical (or large area)
- Why SDSS
- Why SDSS Stripe 82
- Some specific science

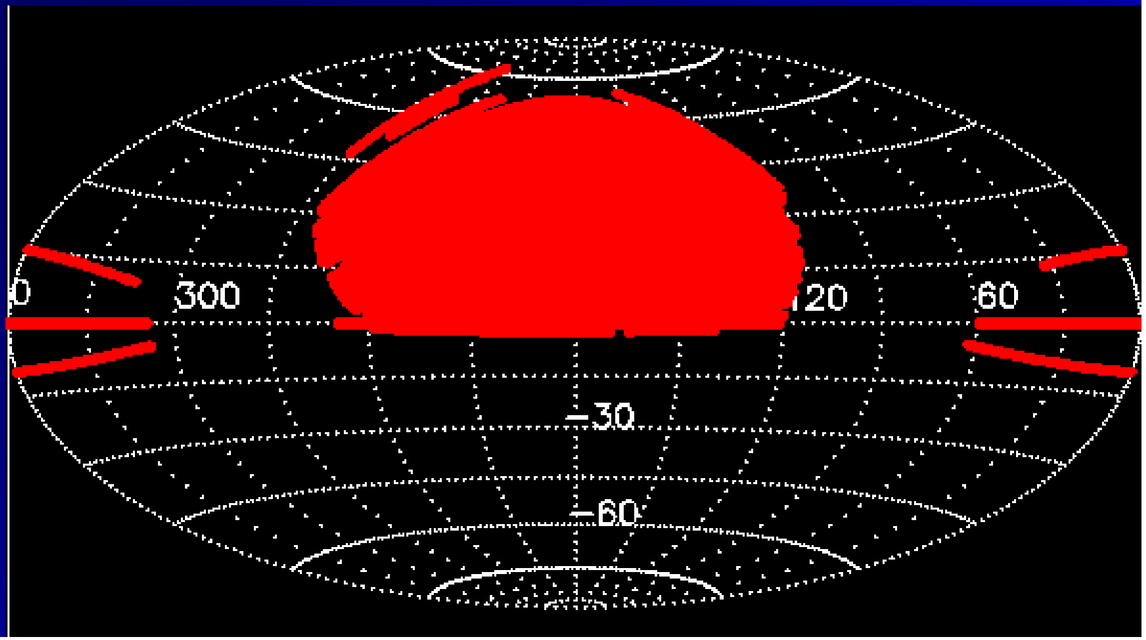
The Sloan Digital Sky Survey

Spectra of ~1,000,000 galaxies and ~100,000 quasars in ~10,000 sq. deg.

quasars: i < 19.1 (20.2) for z<3.0 (z>3.0)

galaxies :r <17.77

photometry: r<22.2



York et al. 2000
Richards et al. 2002
Schneider et al. 2007
Strauss et al. 2002

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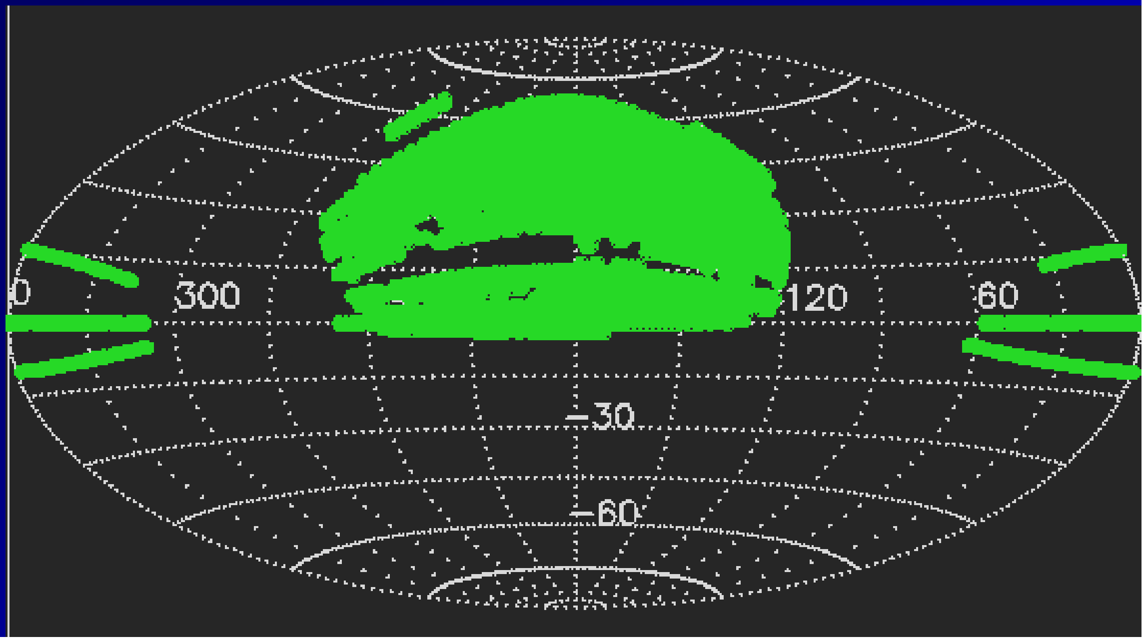

York et al. 2000
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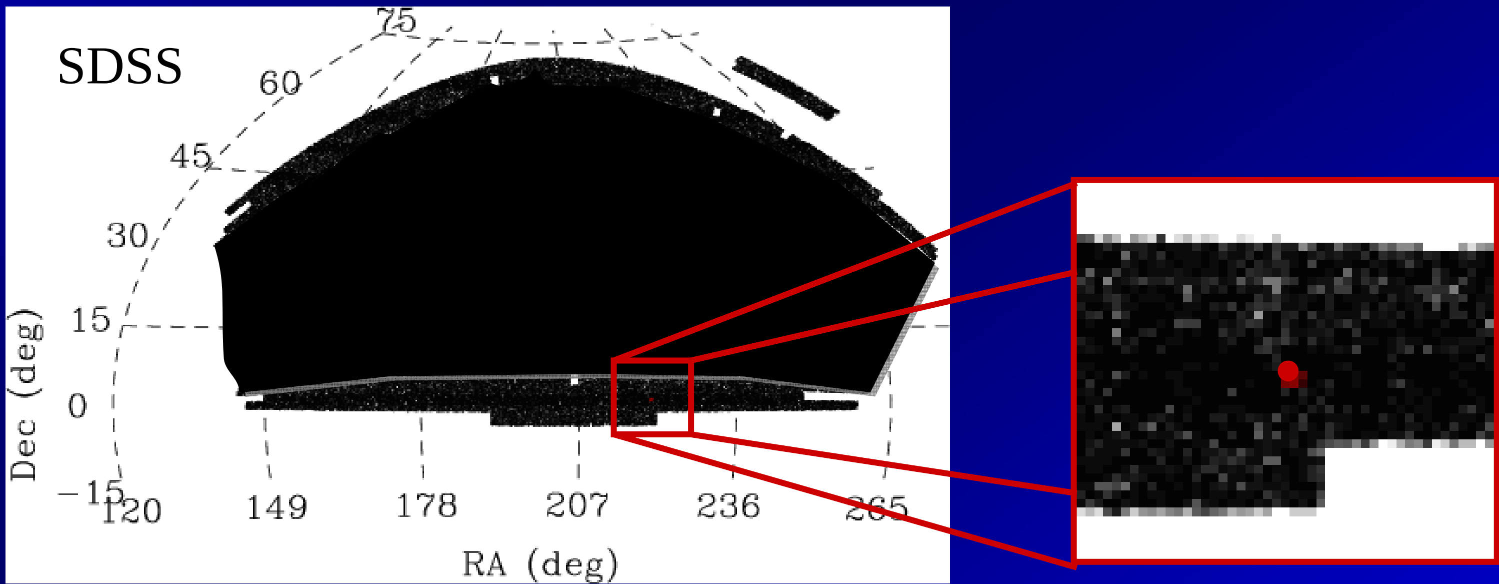
Strauss et al. 2002

Optimizing Quasar Surveys

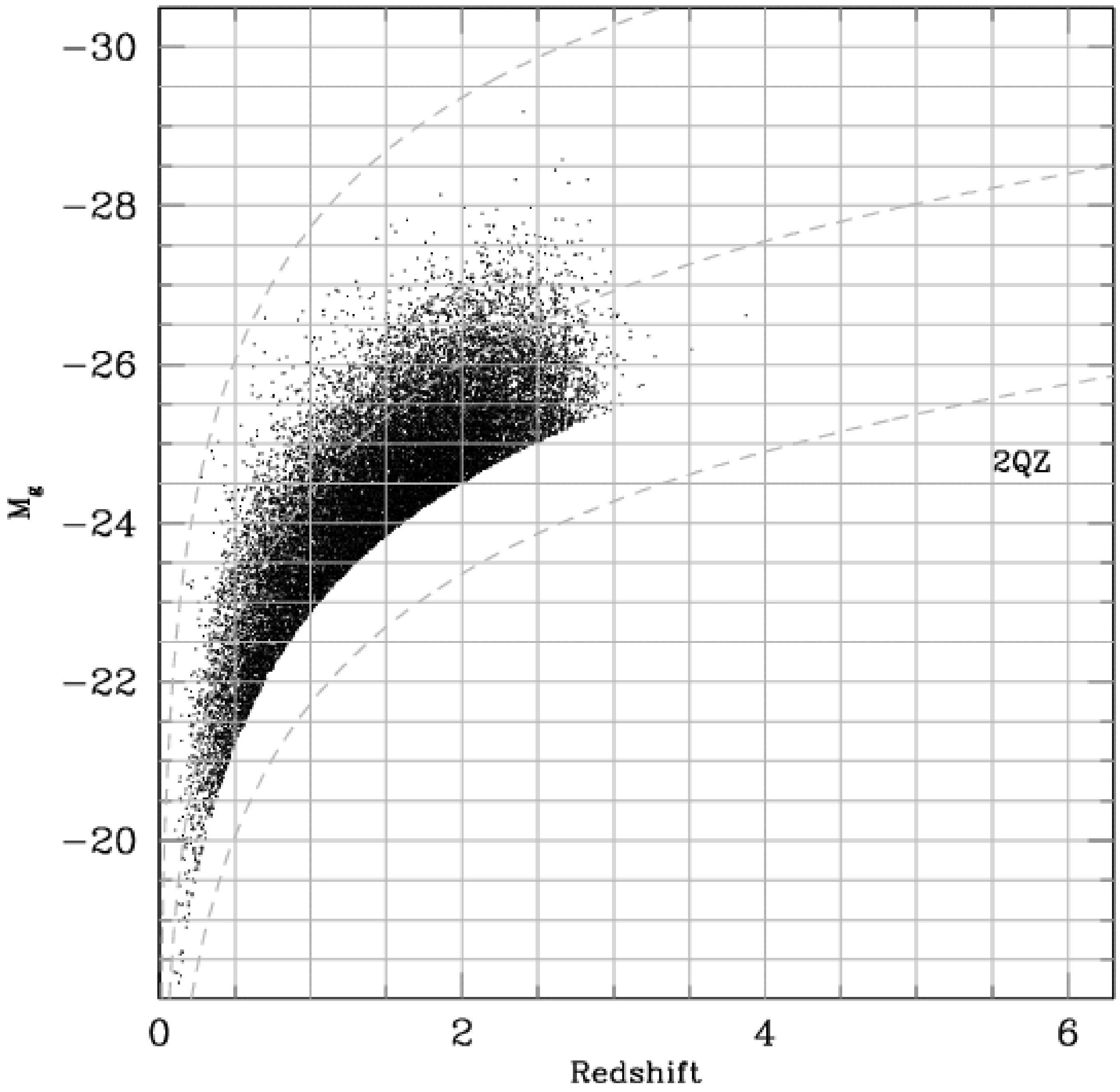
X-ray/IR surveys are deep enough (up to a few 1000 AGN/sq. deg.), but not wide enough.

Optical surveys are wide enough, but not deep enough.

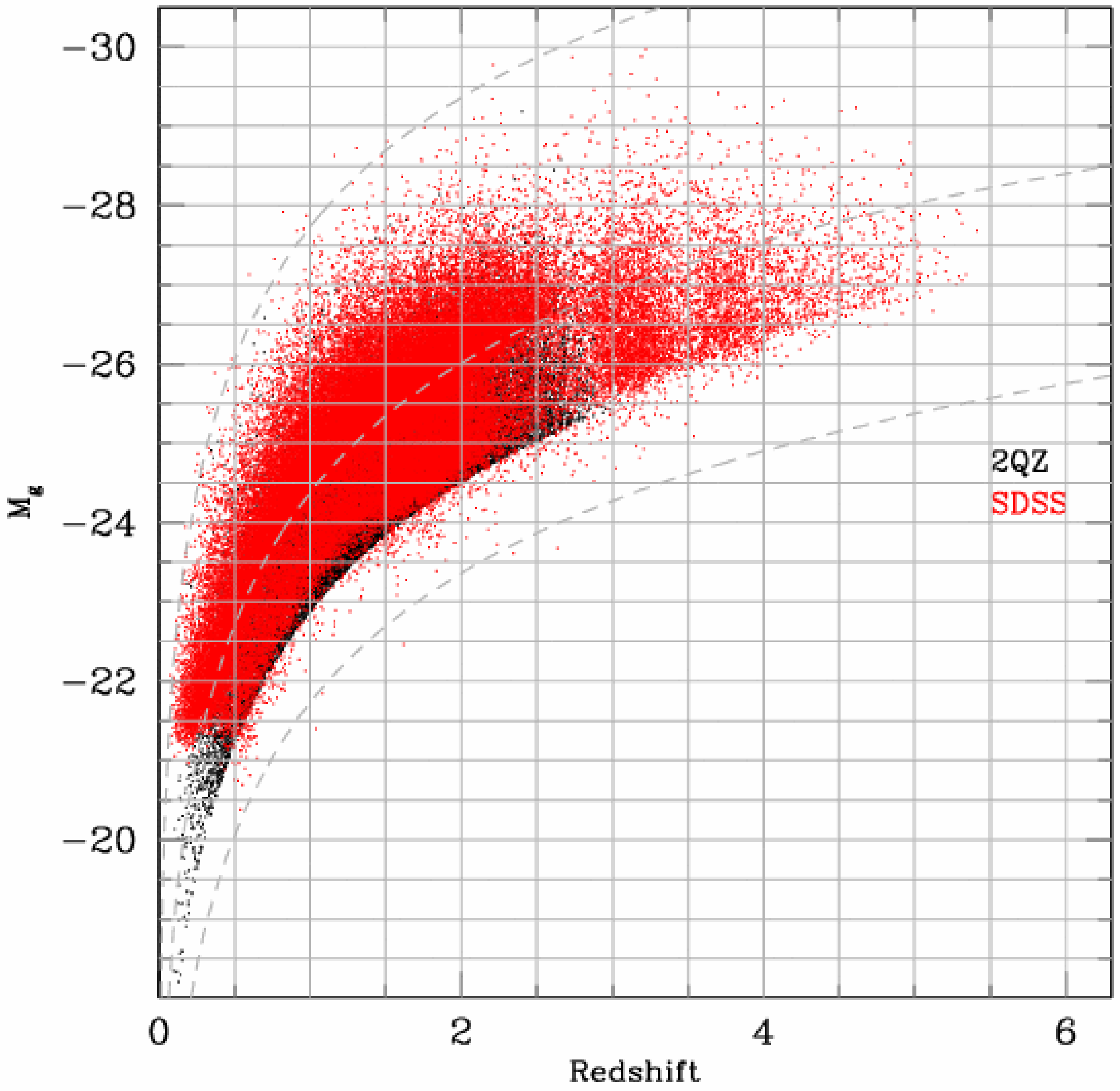


Need deeper optical surveys and/or larger area X-ray/IR surveys.

Quasar Surveys Status

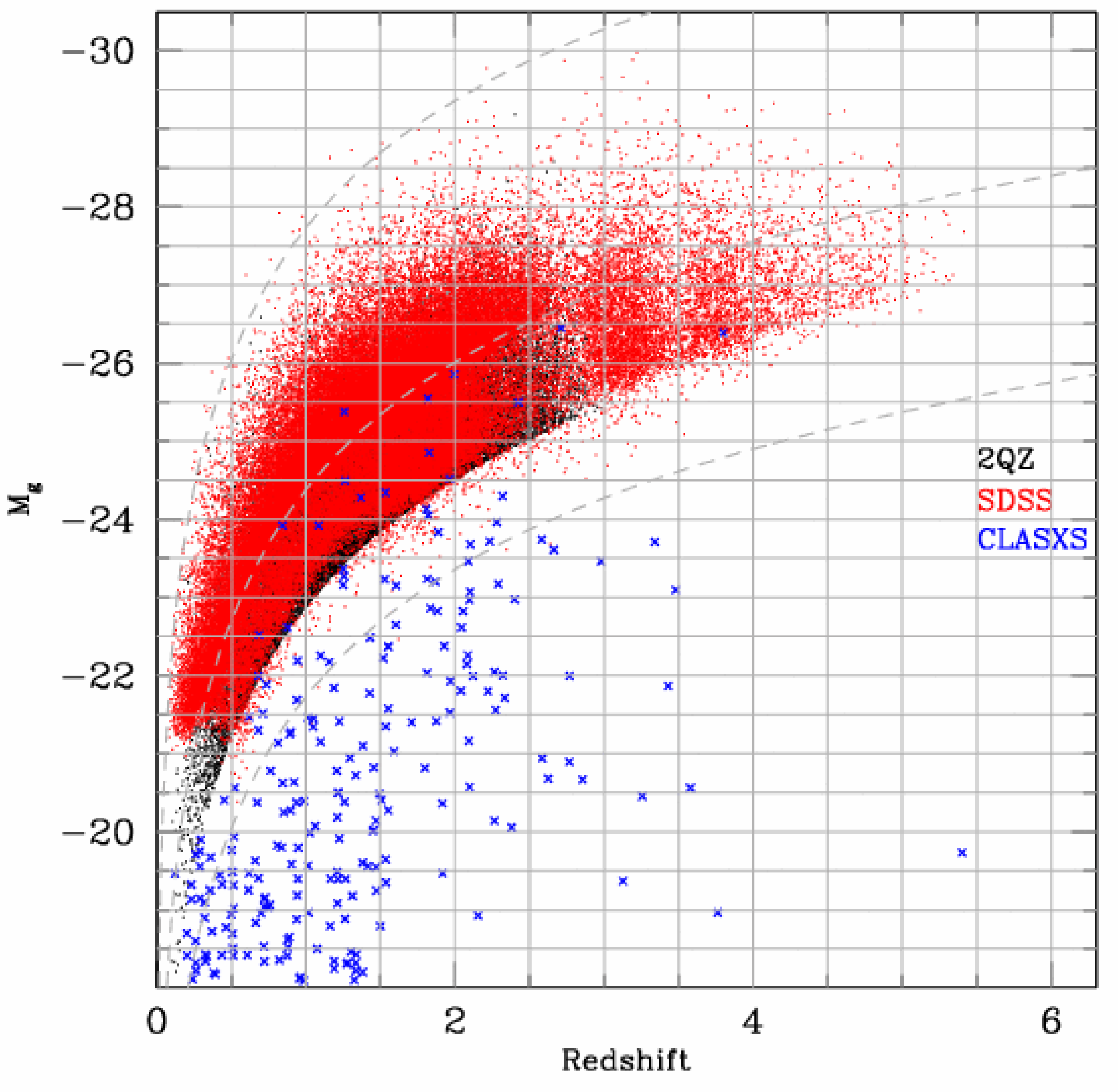


Quasar Surveys Status



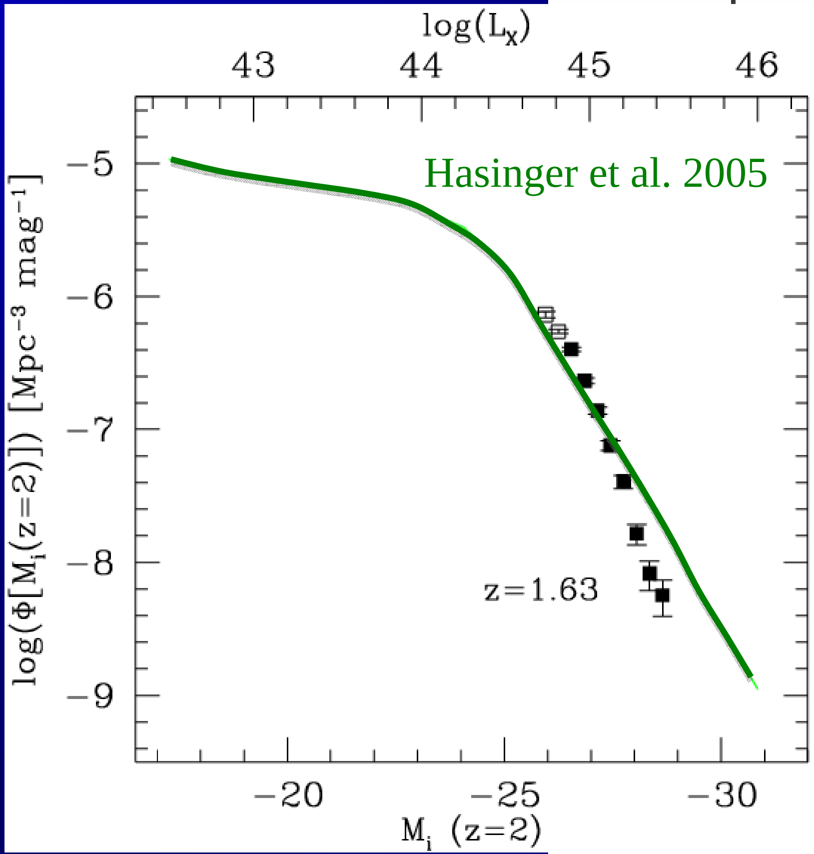
Quasar Surveys Status

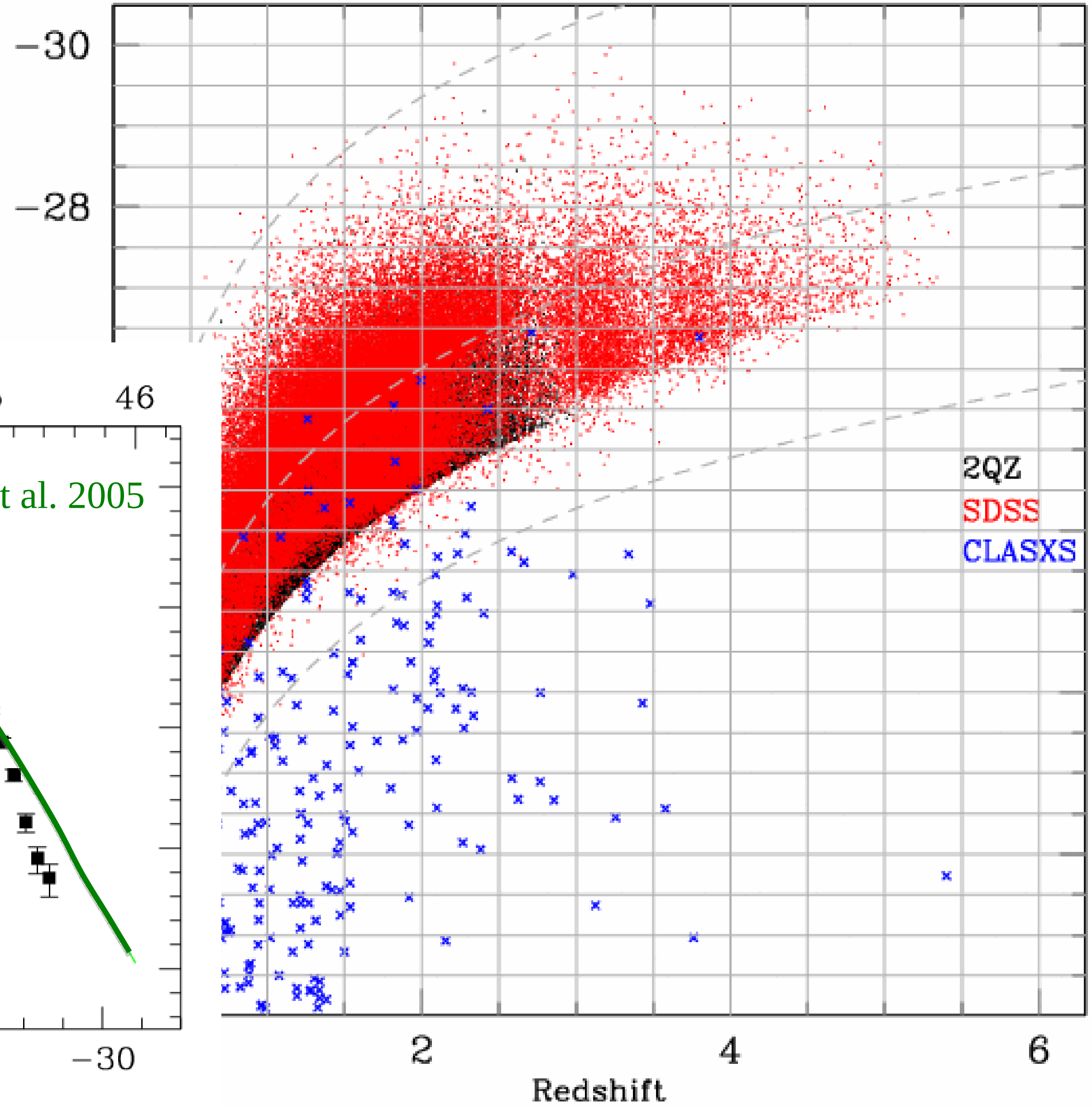
See also Steffen et al. (2006, AJ)



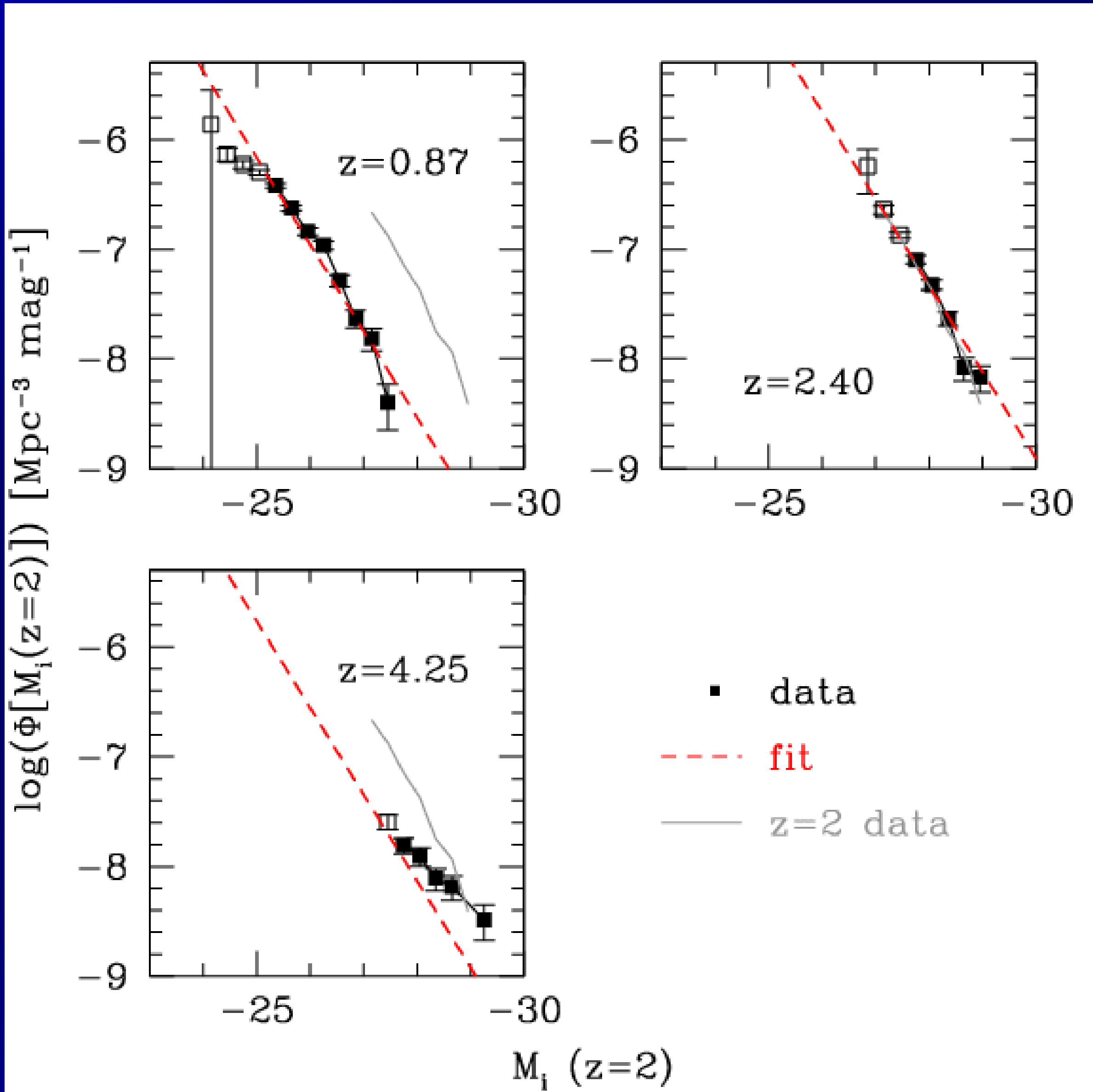
See also Steffen et al. (2006, AJ)

Quasar Surveys Status

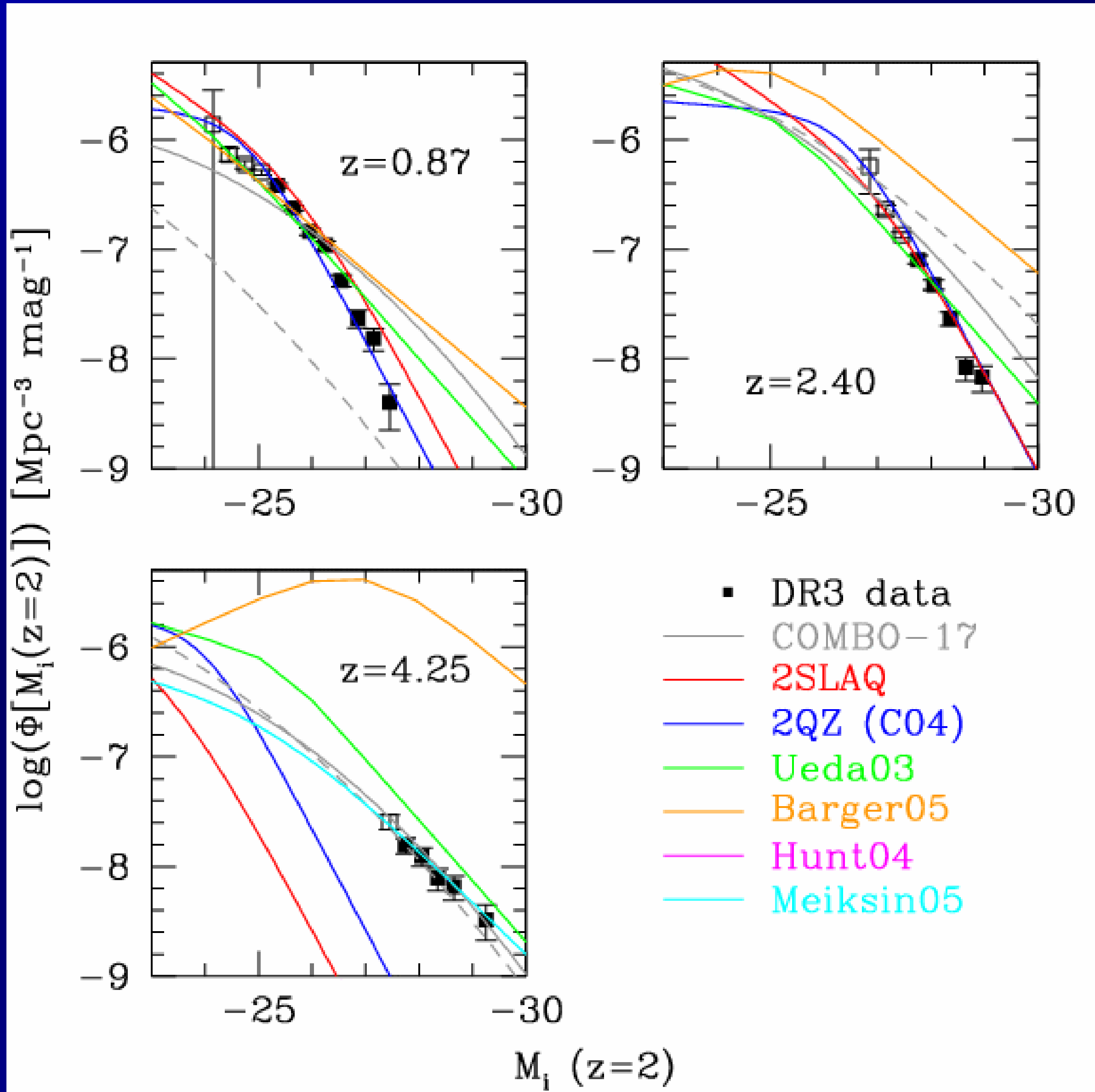




QLF Comparison

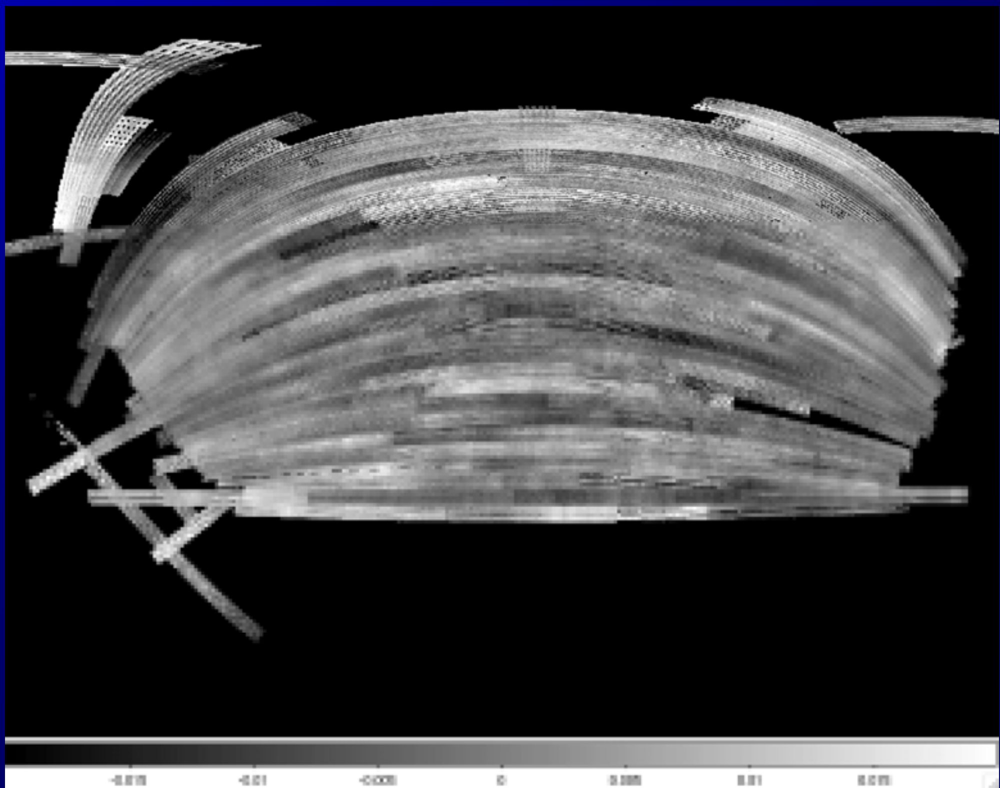


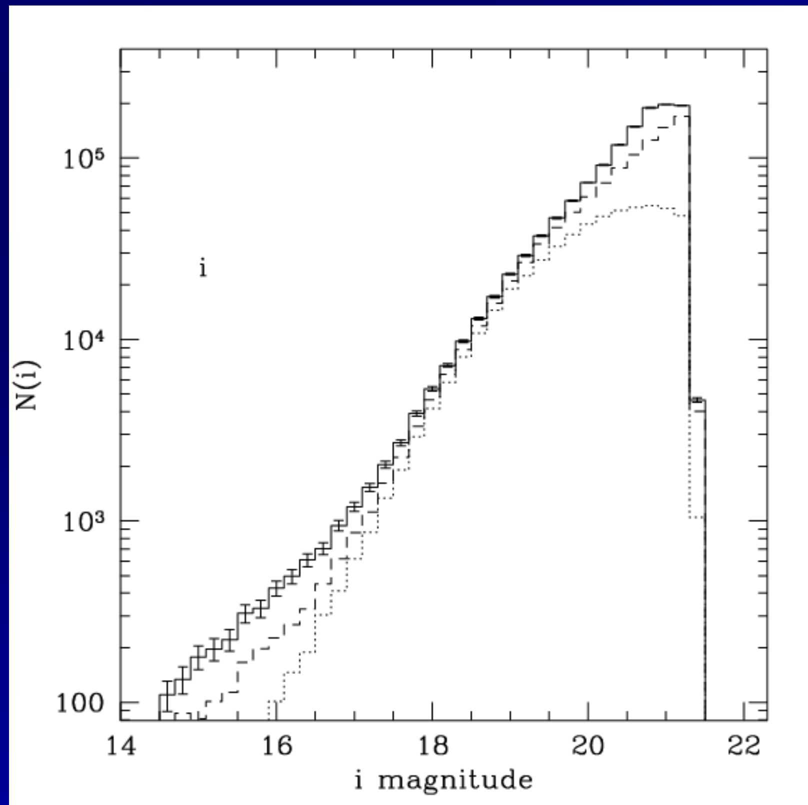
QLF Comparison



Why SDSS?

- No parallel for uniformly calibrated photometry.
- Small area can leverage training data from millions of objects.

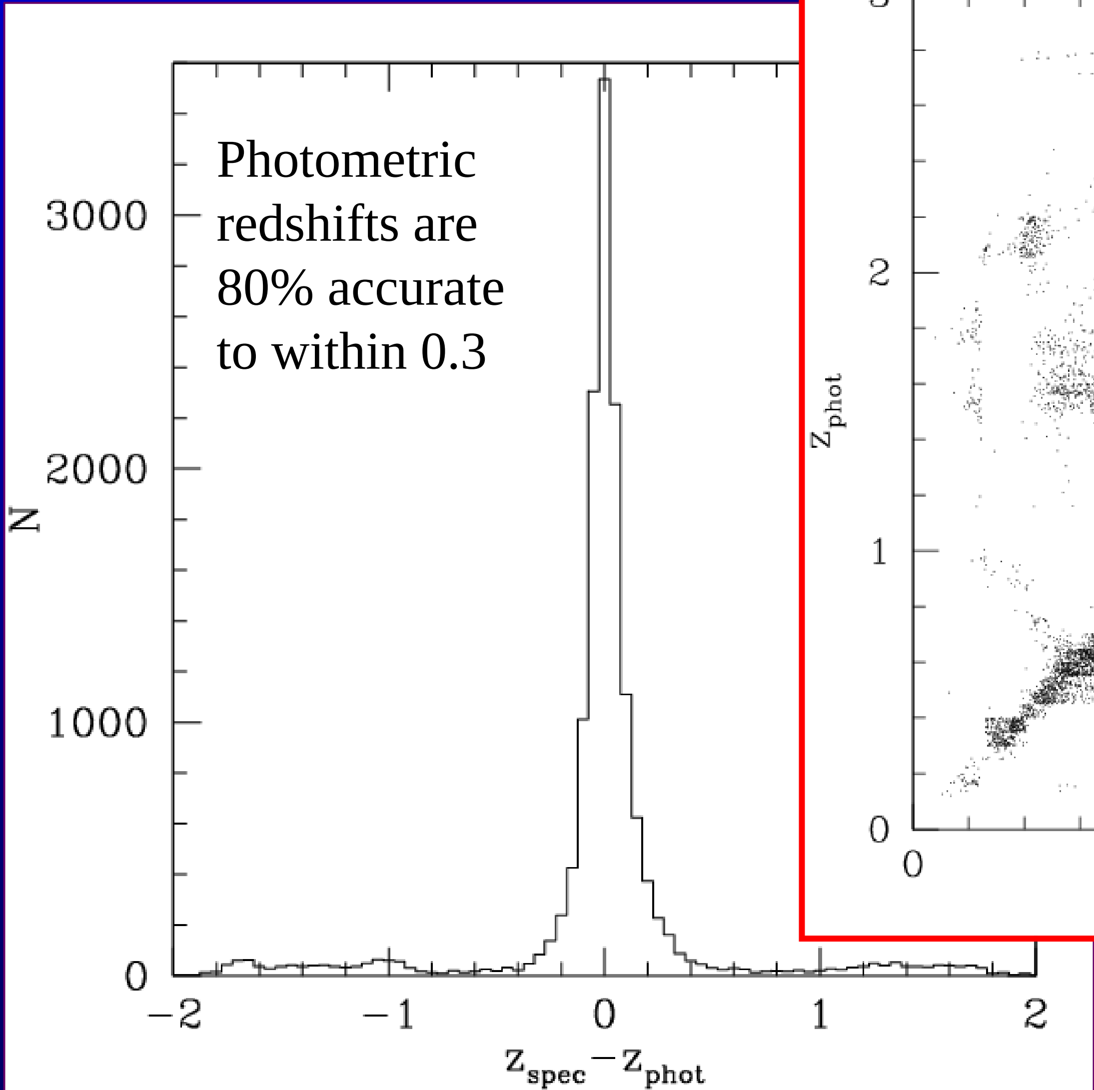


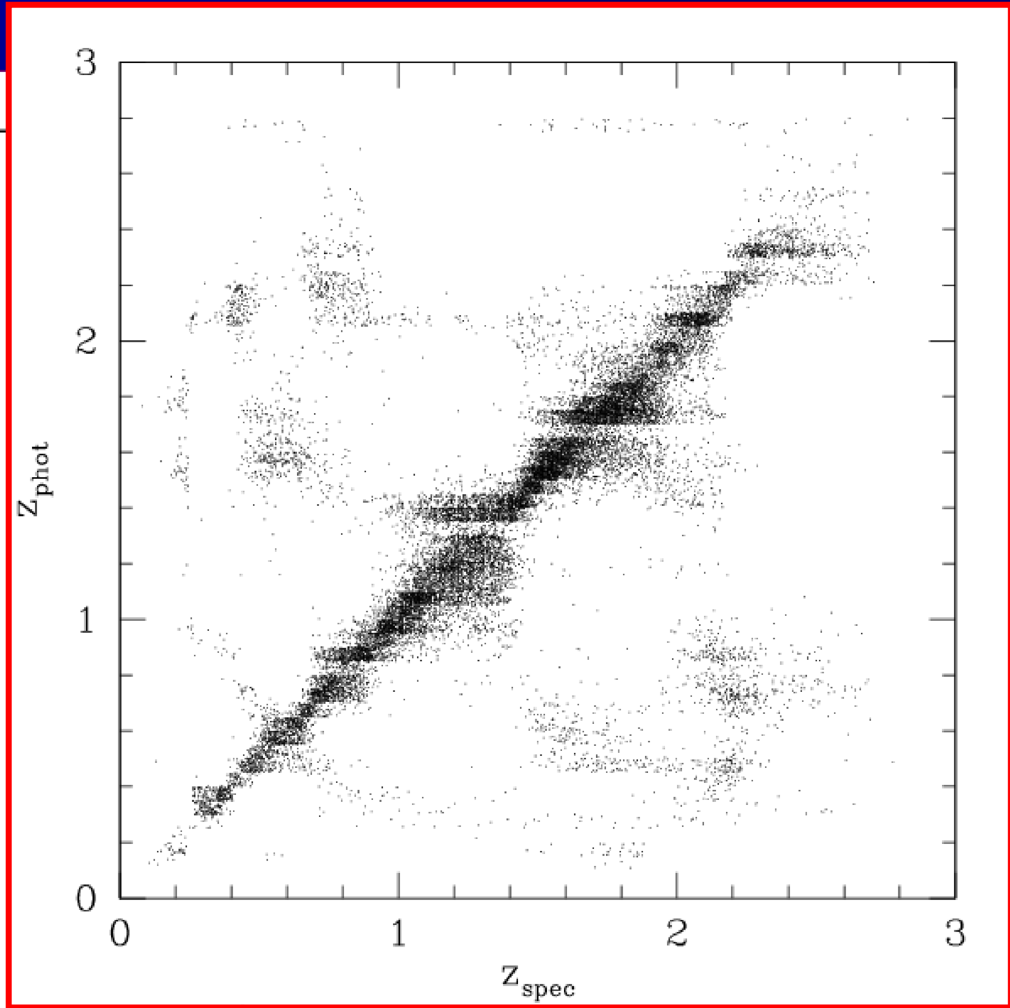


Richards et al., in prep.

Padmanabhan et al. 2008

Photometric Redshifts

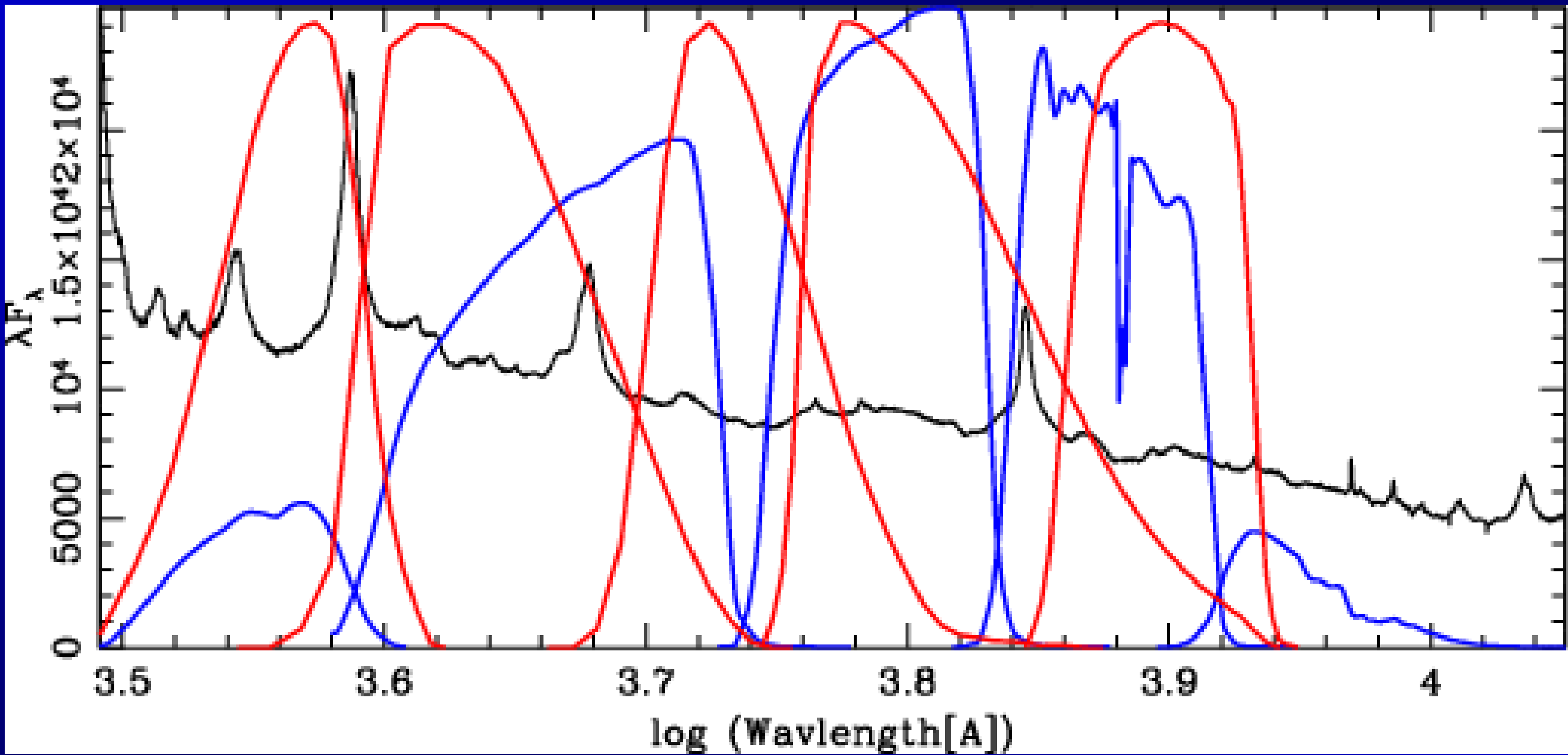




Richards et al. 2001

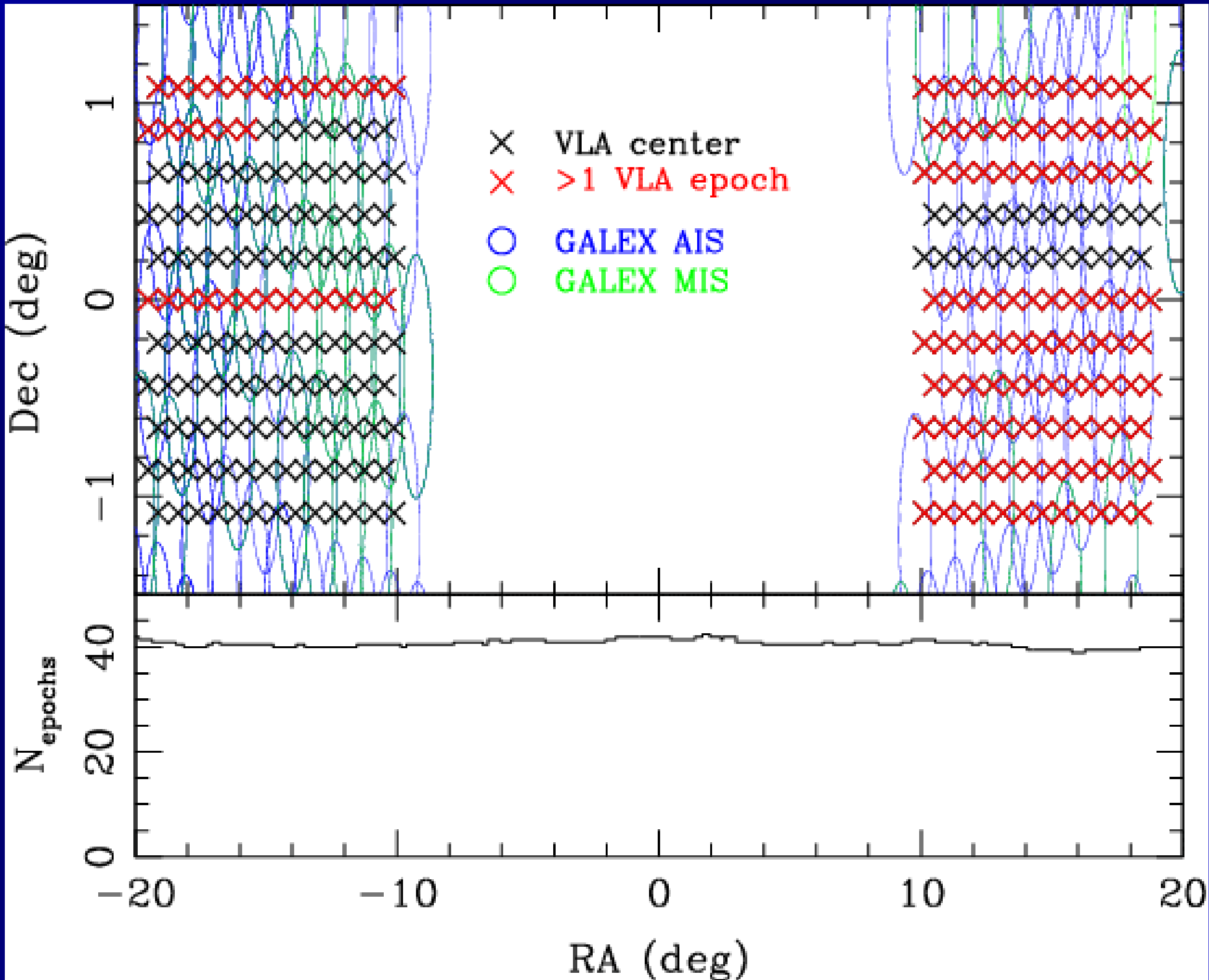
Weinstein, Richards et al. 2004

SDSS vs. Johnson-Morgan/Kron-Cousins



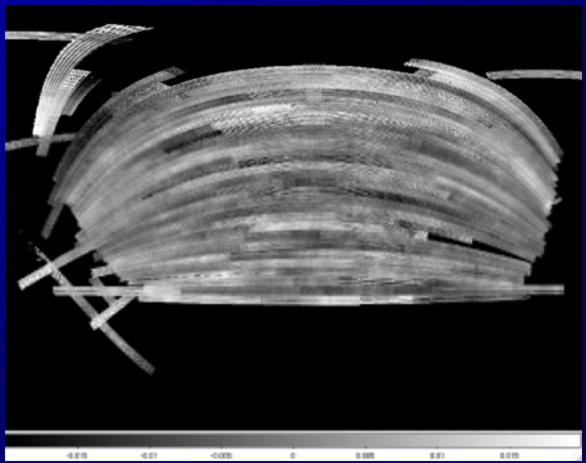
SDSS Stripe 82

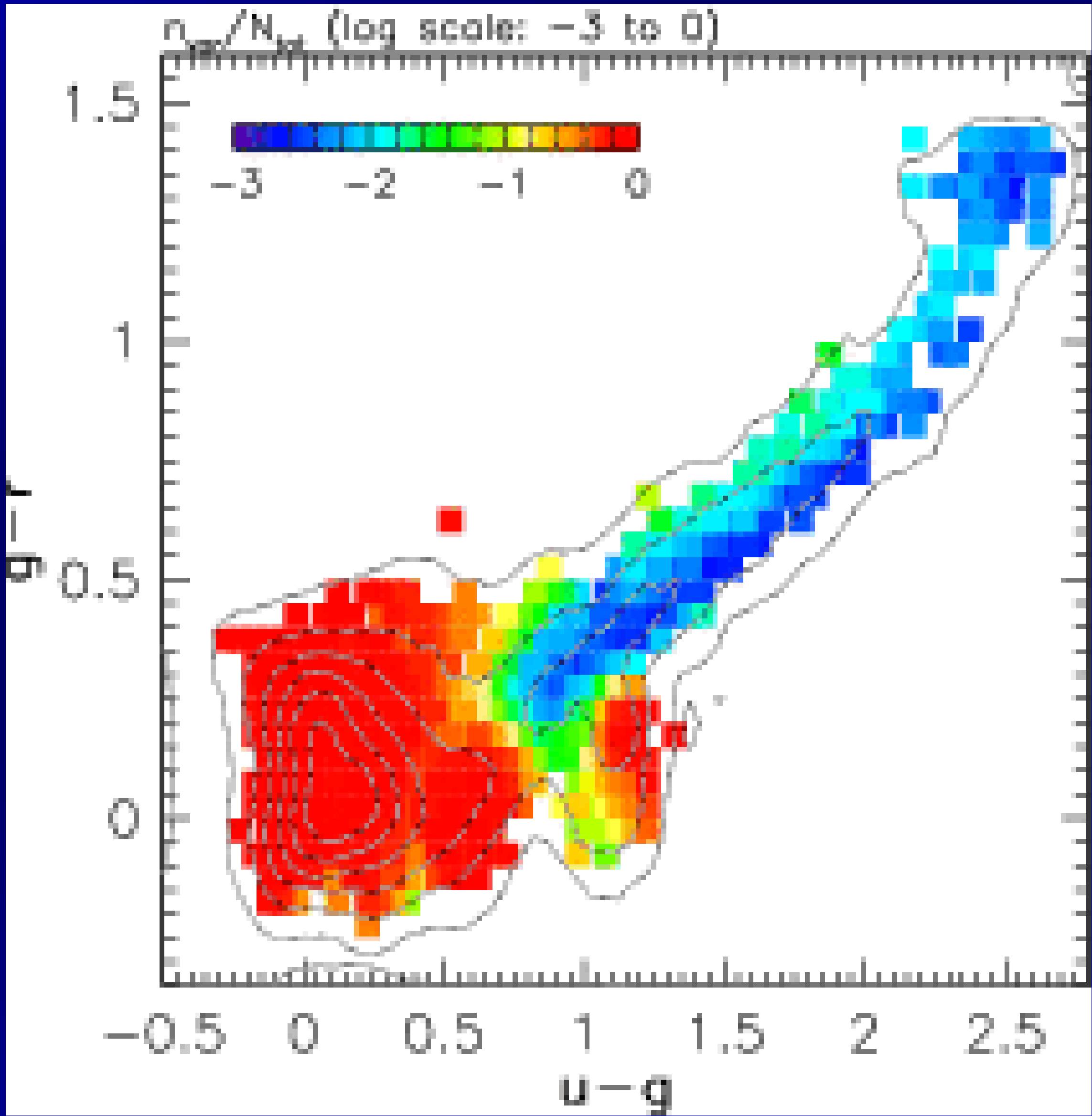
- 40+ SDSS epochs
- Deep GALEX data
- Deep VLA data
- UKIDSS coverage
- Co-added photometry to g=24.5



Variability Selection

- Like pre-LSST data
- Note that Pan-STARRS lacks a u filter.



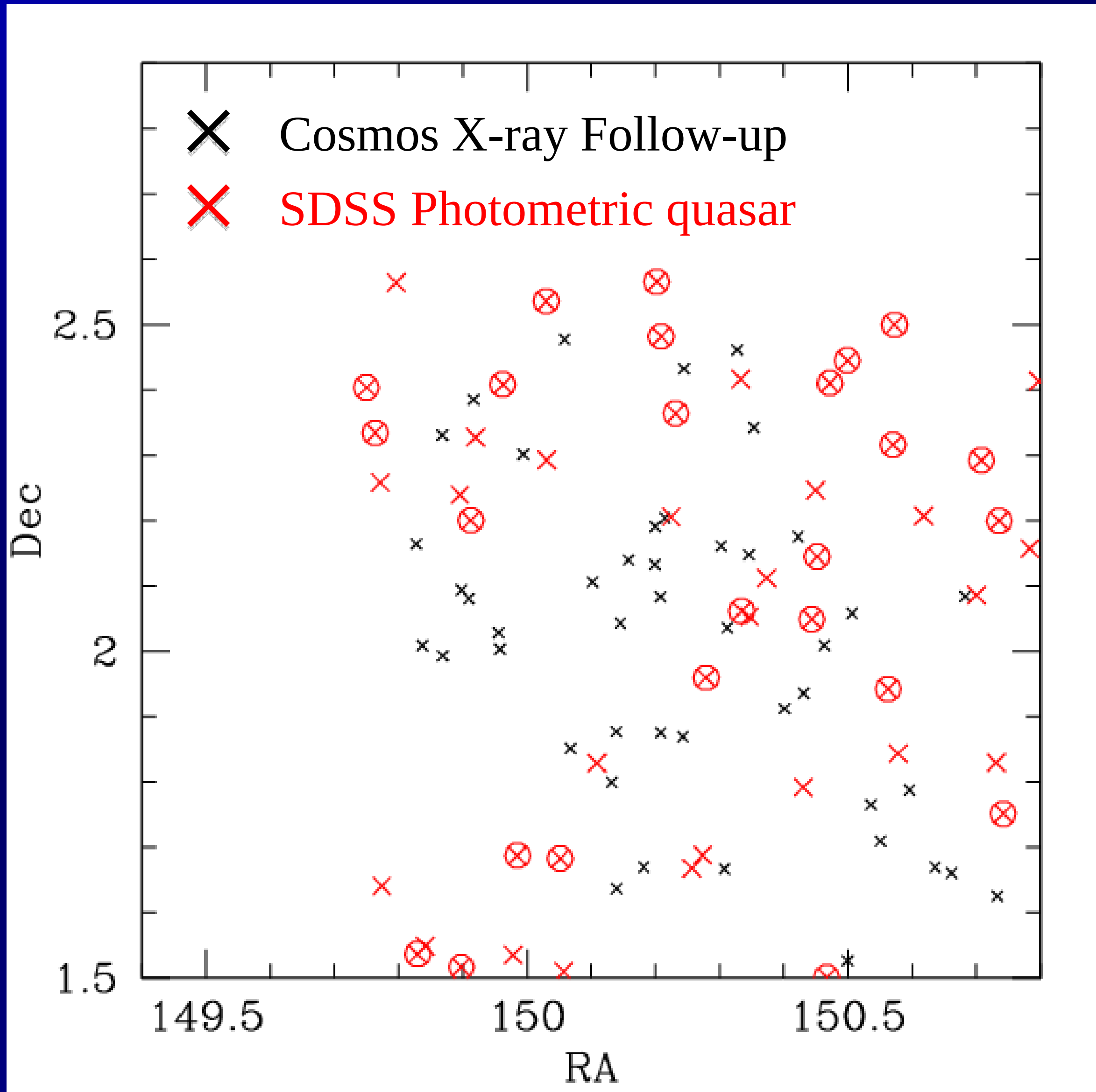


Sesar et al. (2007, AJ, 135, 2236)

COSMOS

Trump et al. 2007 used X-rays in the COSMOS field to target AGNs.

Our photometric algorithm finds another 27-69 objects that were missed. (Some missed because of coverage.)

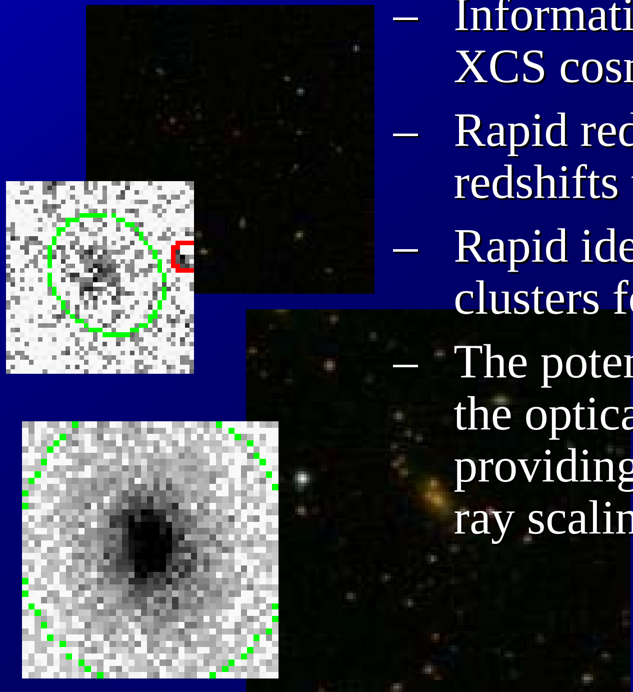


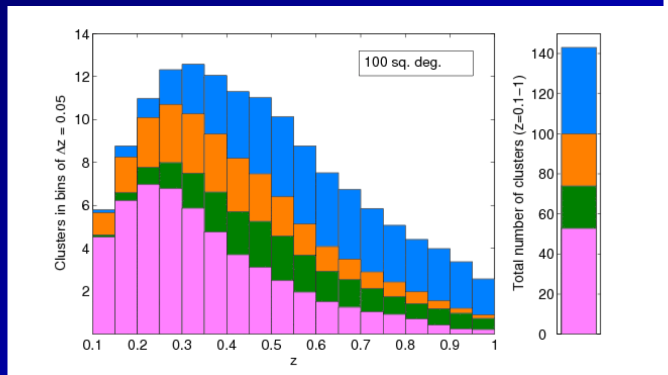
Clusters in Stripe 82:
i) SDSS will provide identifications & redshifts
ii) XCS will provide selection function
iii) Added value compared to XCS

(figures and information courtesy of XCS team; see xcs@xcs-home.org)

z=1.45 XCS cluster found in Stripe 82 depth data (Stanford et al. 0606075, Hilton et al. 0708.3258)

- 610 (of 1800) XCS cluster candidates are in the SDSS footprint
- Stripe 82 will provide:
  - Information on systematic errors in XCS cosmology
  - Rapid redshift follow-up (to higher redshifts than possible with XCS+DR5)
  - Rapid identification of potential z>1 clusters for galaxy evolution studies
  - The potential to do cluster searching in the optical (rather than X-rays); providing vital input into optical to X-ray scaling relations for DES *etc.*





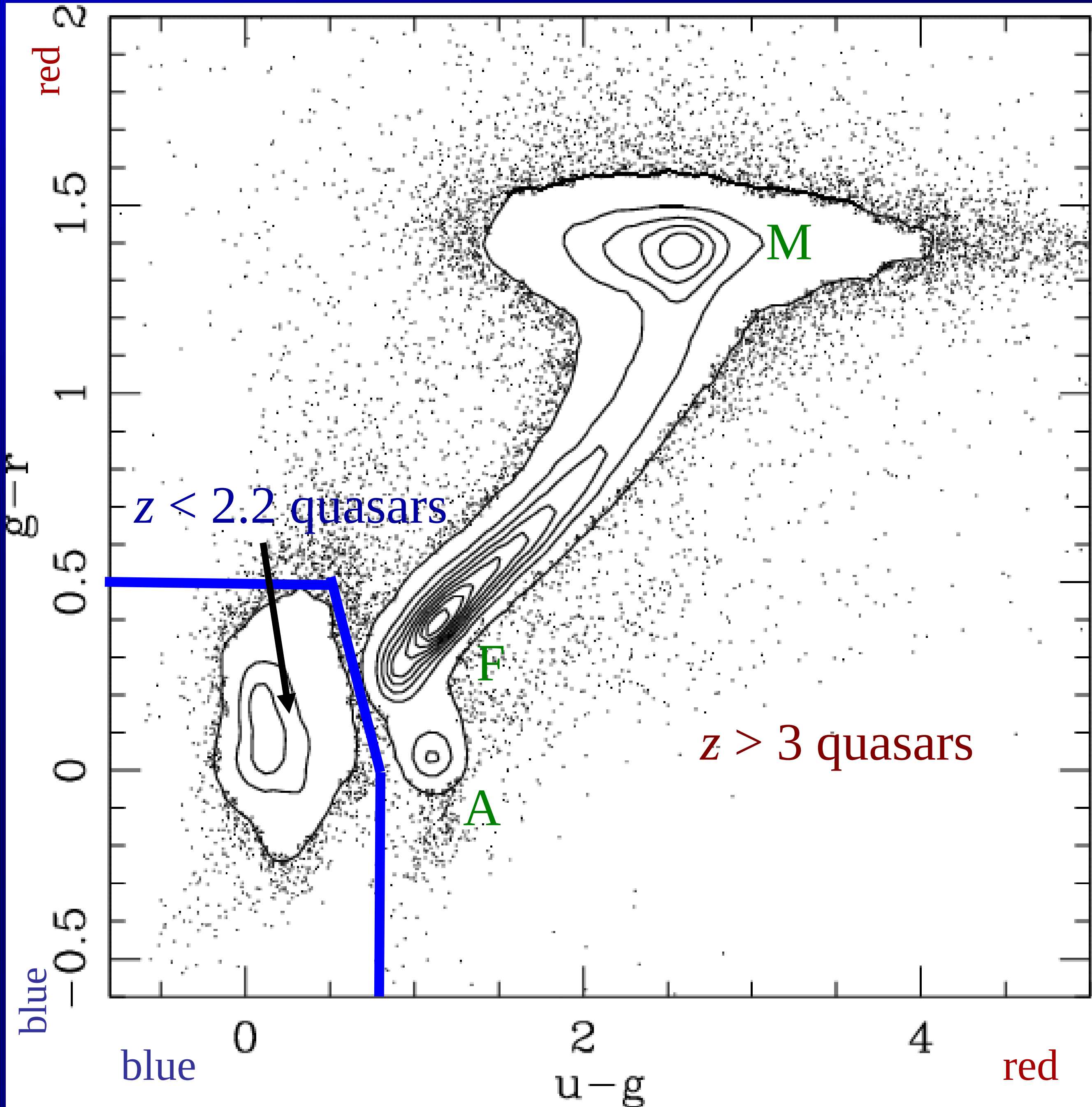
Number of XCS clusters expected in 100 square degrees (Sahlen et al. 0802.4462)

Conclusions

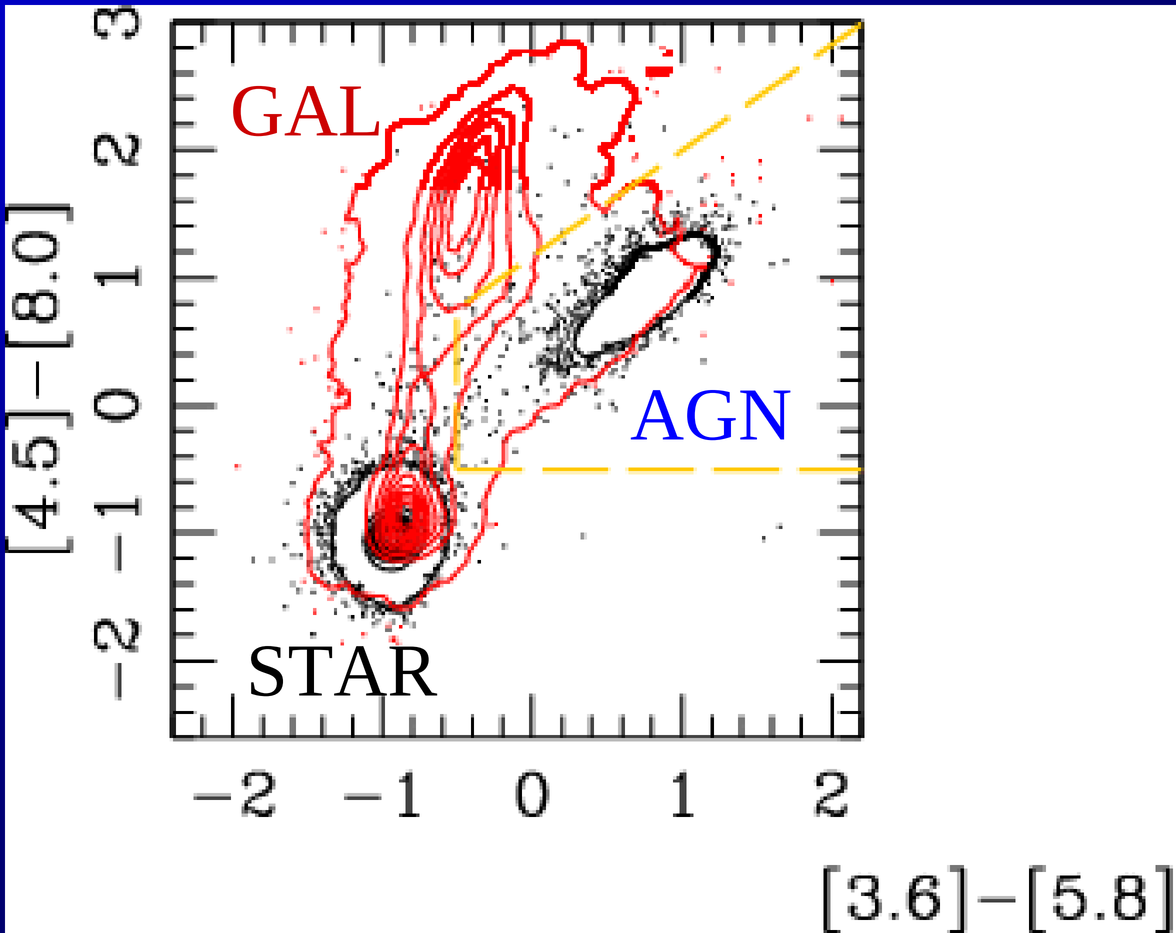
Stripe 82 offers

- significant multi-wavelength coverage
- dozens of epochs of data
- 10-m telescope follow-up depth
- considerable photometric leverage
- large, existing cluster catalogs

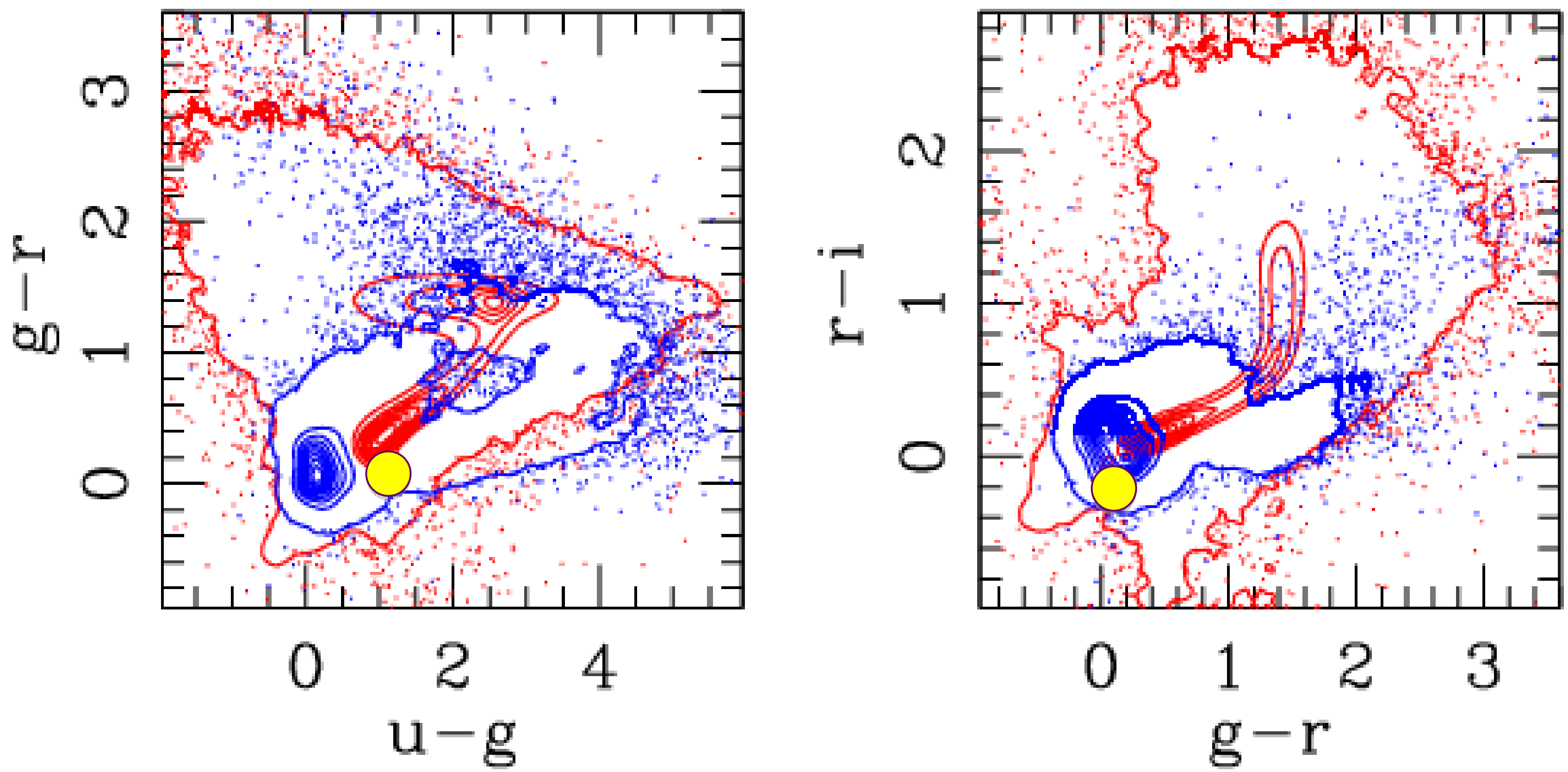
Traditional Quasar Selection



Spitzer-IRAC (Mid-IR) Selection



e.g. Lacy et al. 2004, Stern et al. 2005



Given two training sets, Here quasars and stars (non-quasars), and an unknown object, which class is more likely?

"NBC": Bayes' (1763) Rule

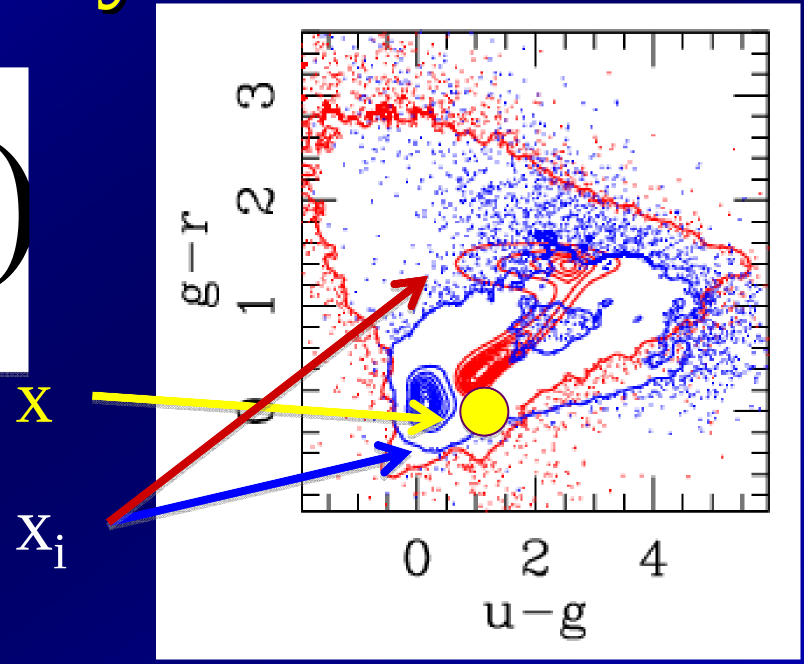
$$P(Star\,|\,x) = \frac{P(x\,|\,Star)P(Star)}{P(x\,|\,Star)P(Star) + P(x\,|\,QSO)P(QSO)}$$

Where

- x = N-D colors
- P(Star|x) = probability of being a star, given x
- P(x|Star) = probability of x, drawing from stars training set
- P(x|QSO) = probability of x, drawing from QSO training set
- P(Star) = stellar prior
- P(QSO) = quasar prior
- P(Star) + P(QSO) = 1
- Star if P(Star|x)>0.5, QSO if P(Star|x)<0.5

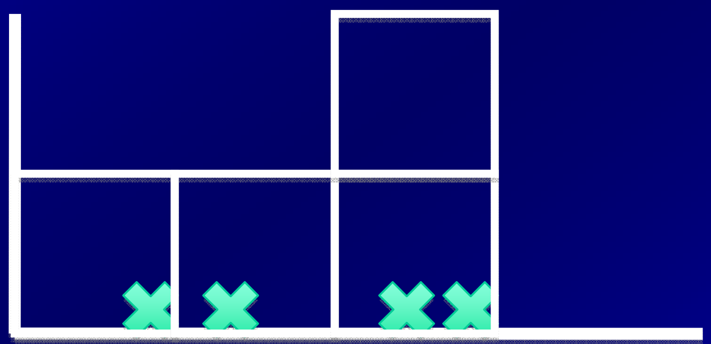
"KDE": Kernel Density Estimation

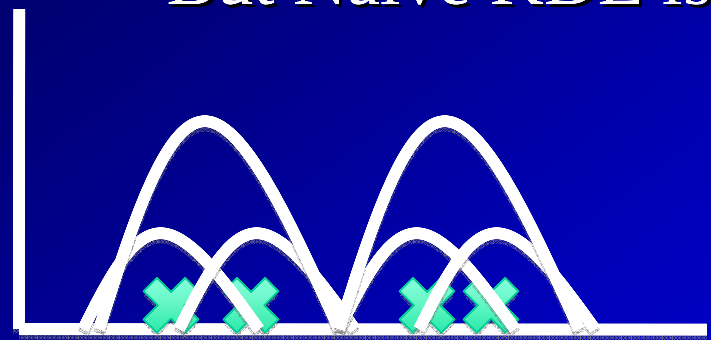
$$PDF = \frac{1}{N}\sum_{i}^{N} K_h\left(\left\| x - x_i \right\|\right)$$



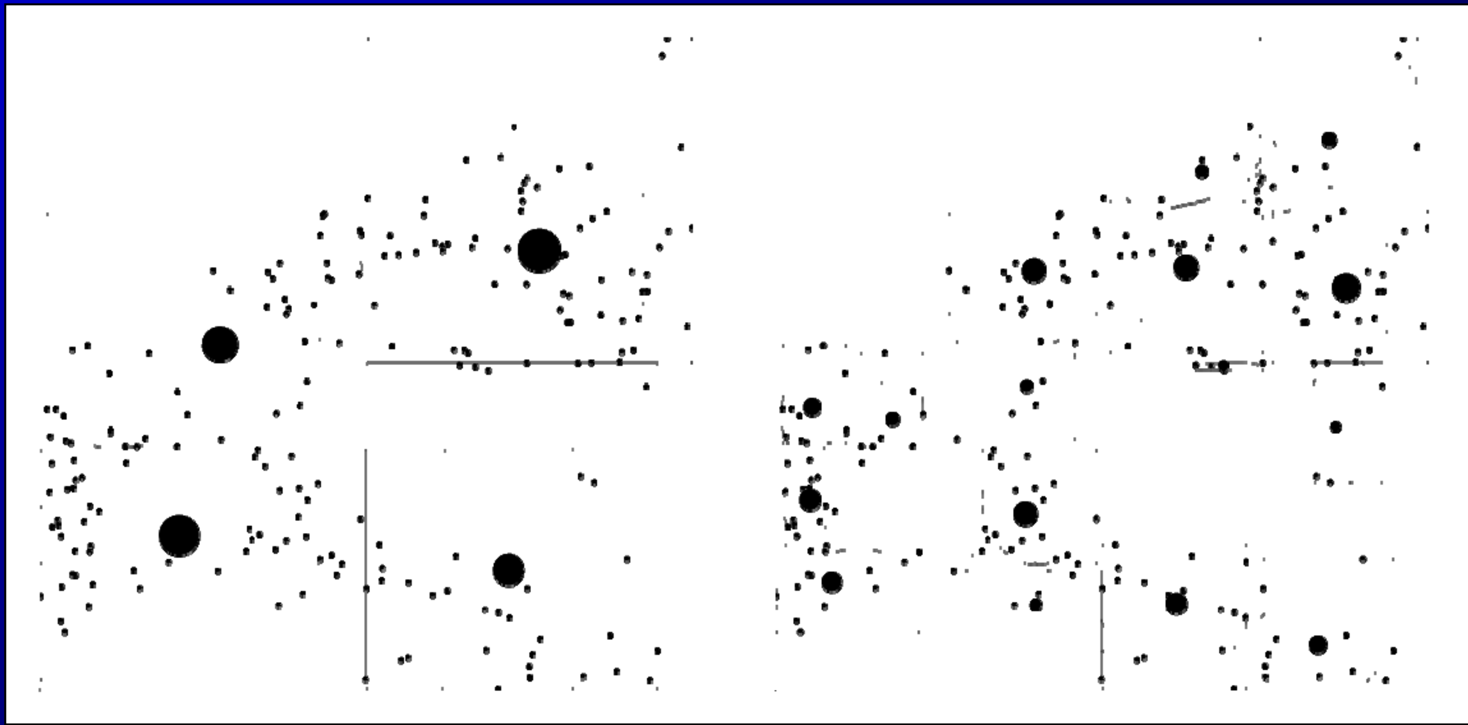
$$K_h(z) \propto \exp - \left(\frac{z^2}{2h^2}\right)$$

But Naïve KDE is $O(N^2)$



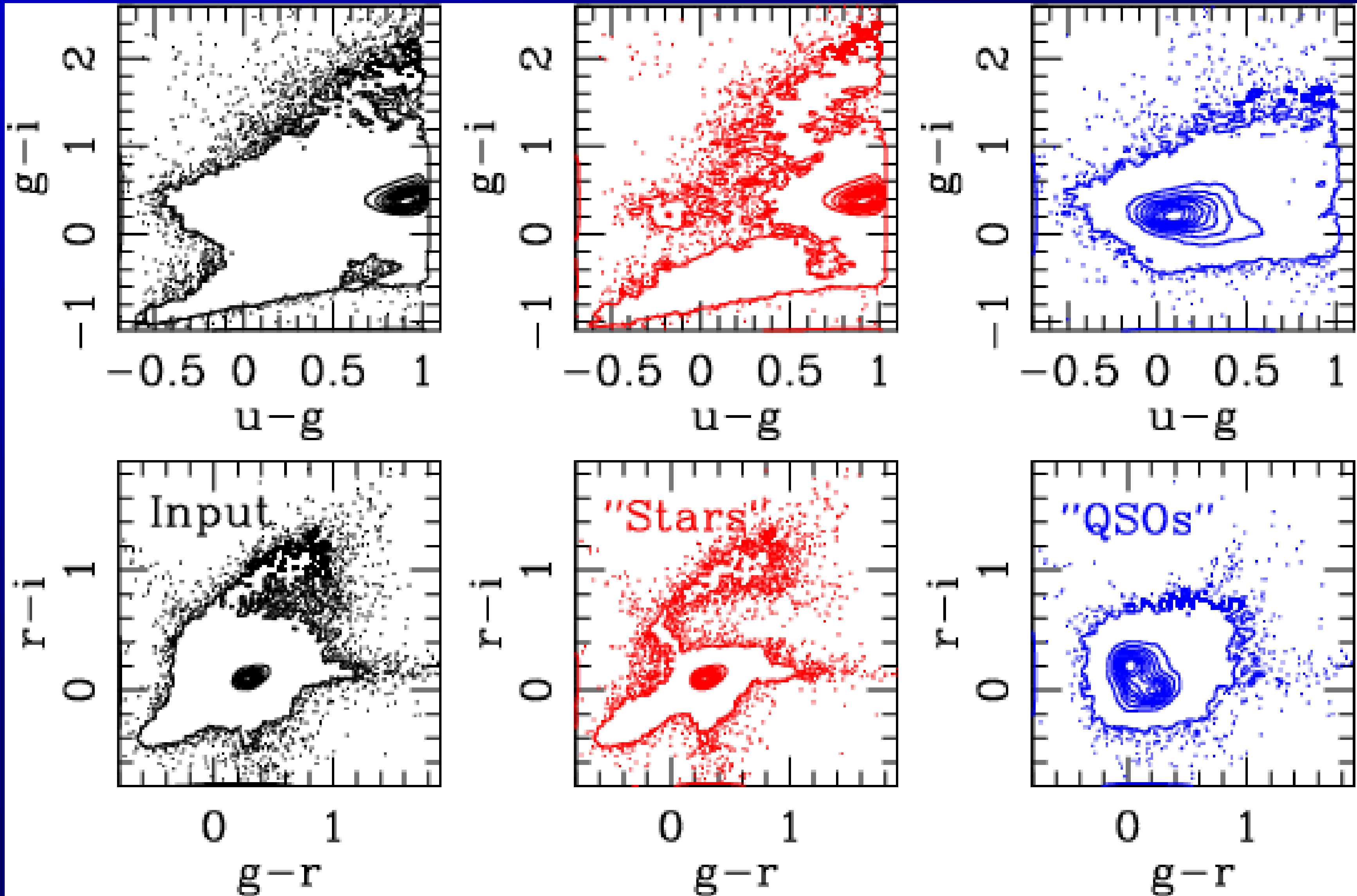


Dual-tree Method



- Tree building is $O(N \log N)$; usually fast in comparison to the rest of computation
- Classification of 500k objects in ~900 sec for reasonable bandwidths
- See Gray, Riegel in Compstat 2006

Separating Quasars from Stars

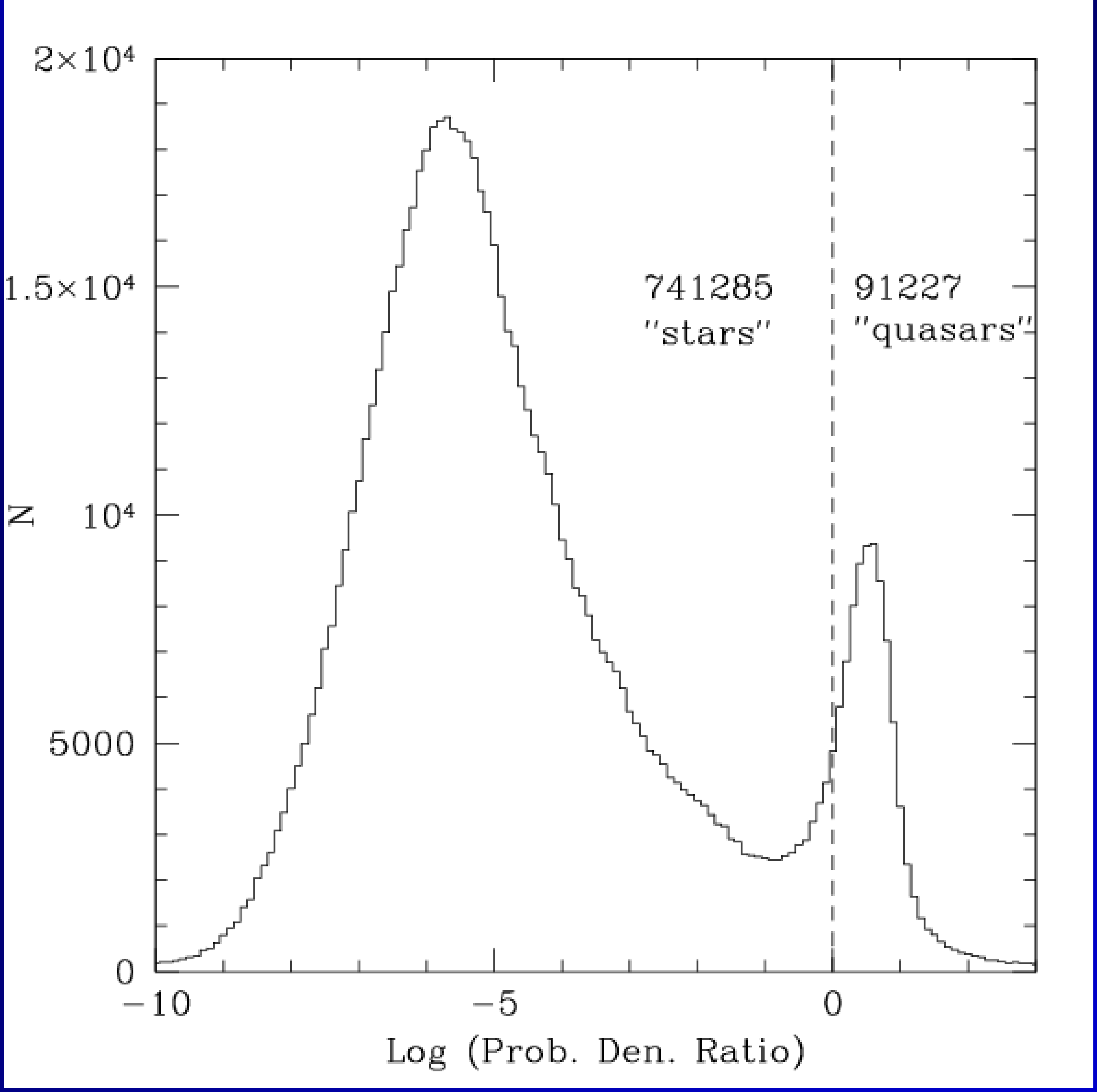


Comparing Probability Densities

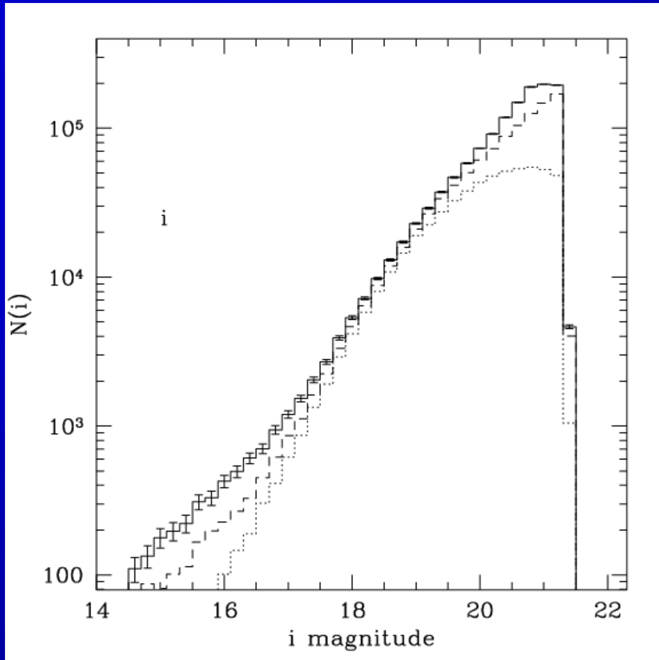
100,000 z<3 quasars in DR1 (95% efficient to g=21)

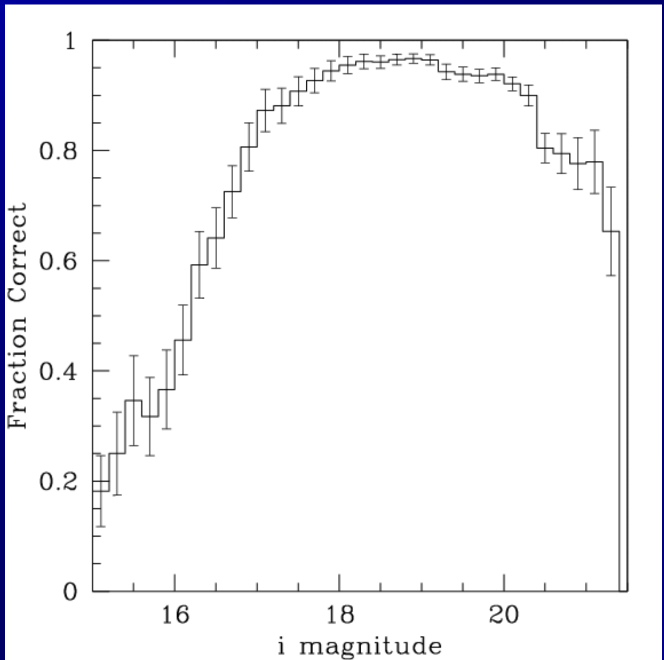
SDSS is 85% efficient to g=19

1,000,000 quasars from 0<z<5 in the whole SDSS area.



Richards et al. 2004c



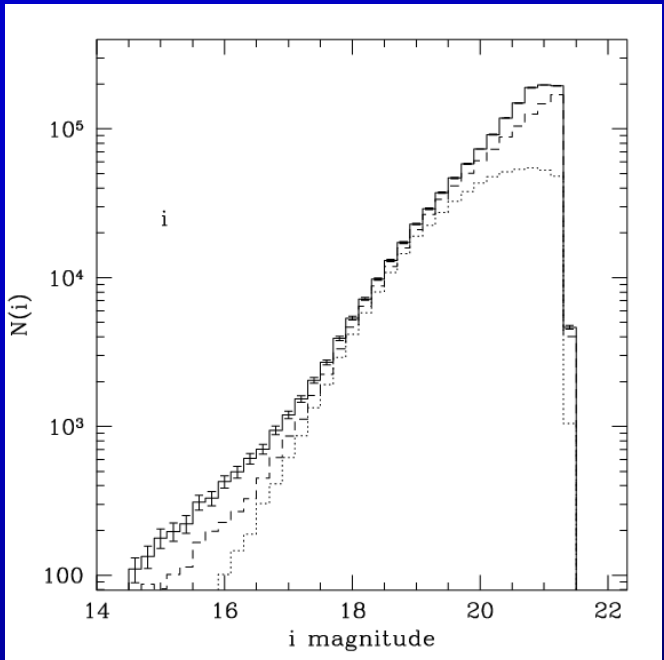


DR6 Results
including high-z

840,000 – 1,060,000 quasars

Richards et al. 2008

DR6 Results
including high-z



840,000 – 1,060,000
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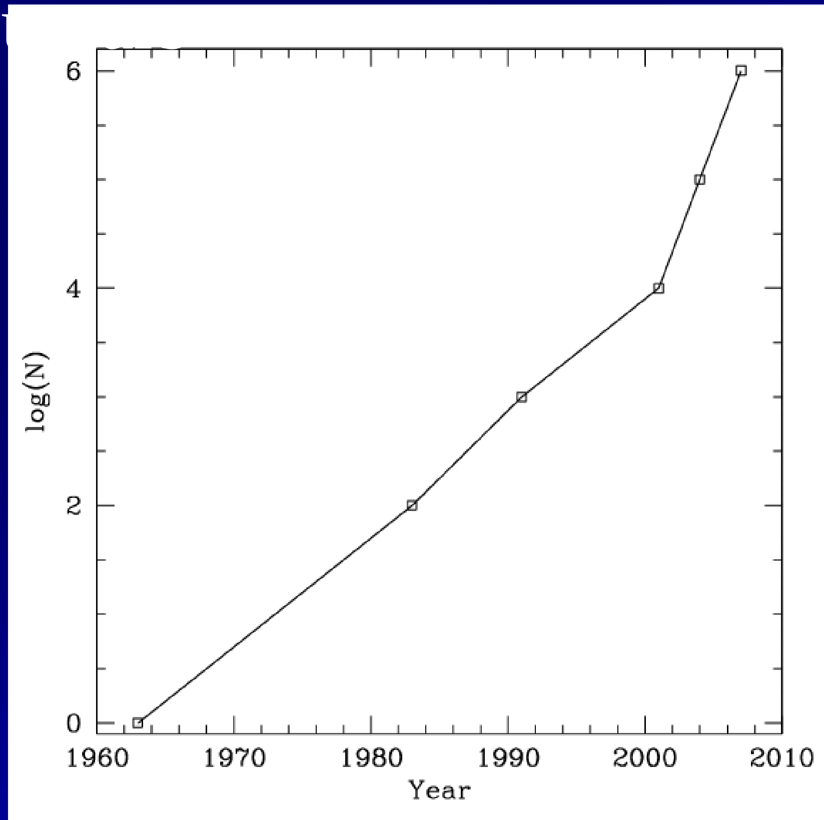
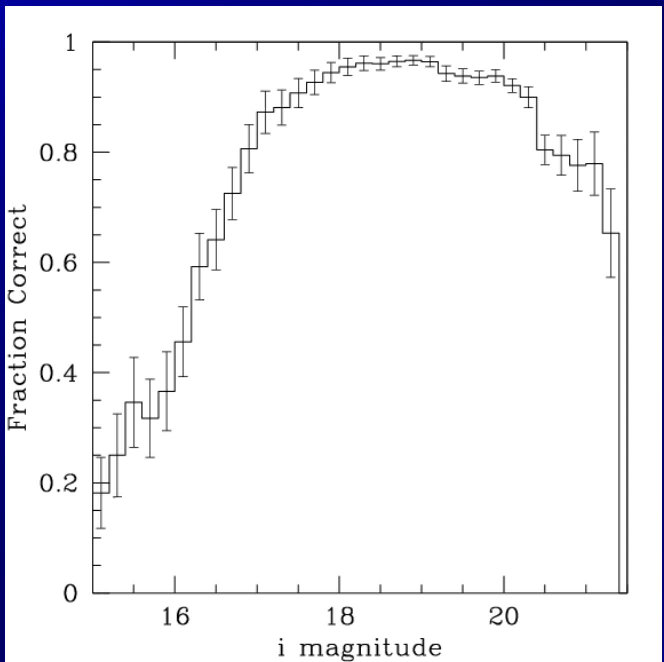
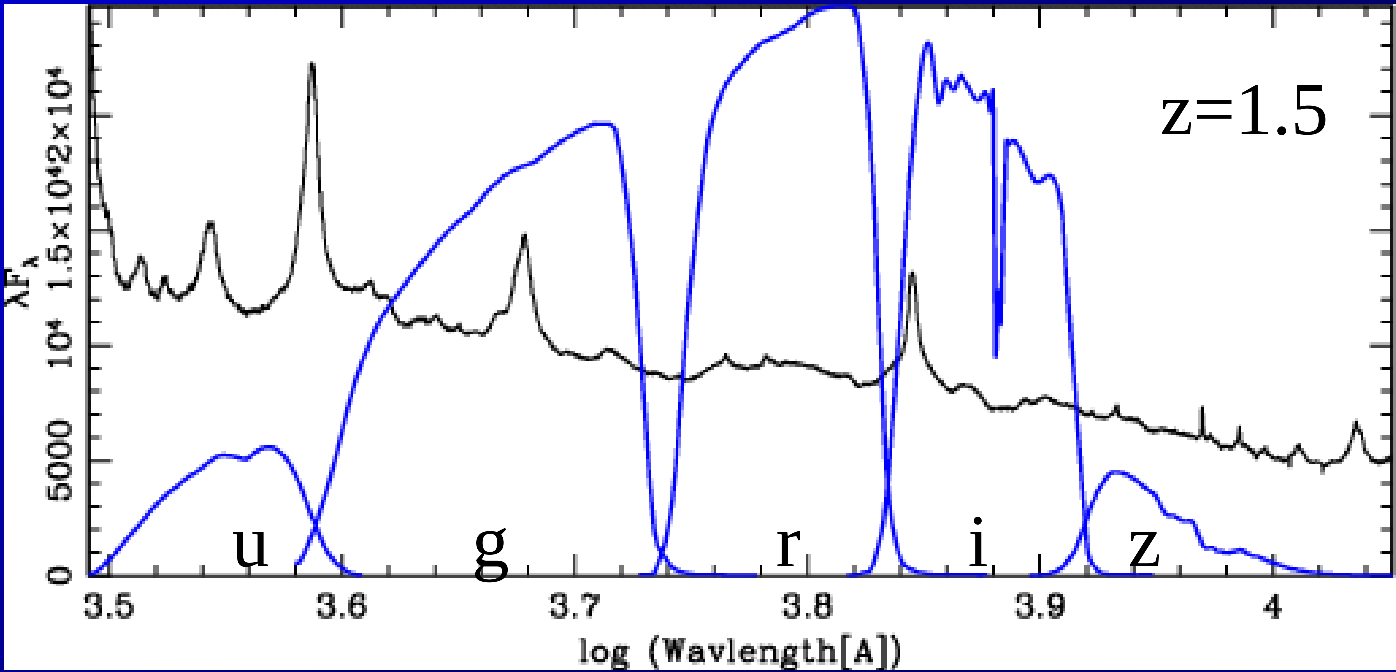
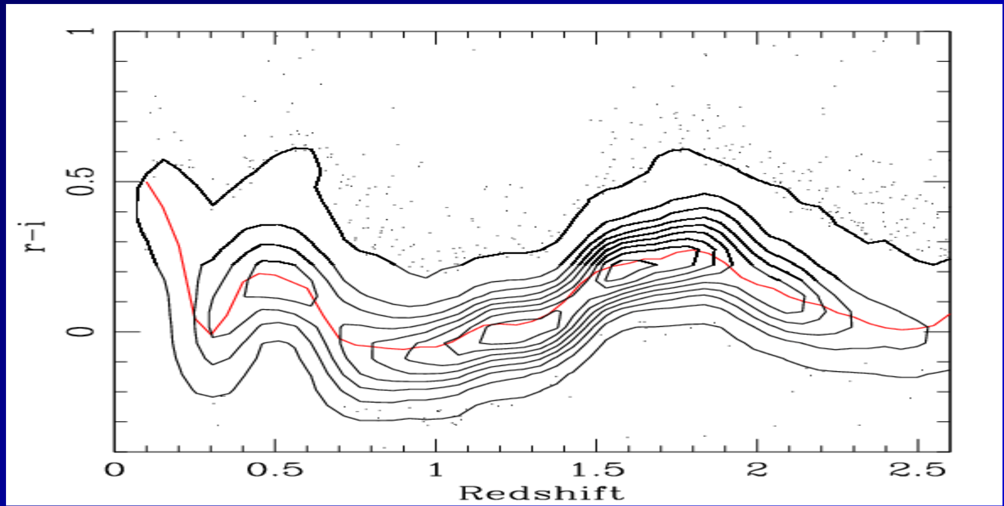




Richards et al. 2008

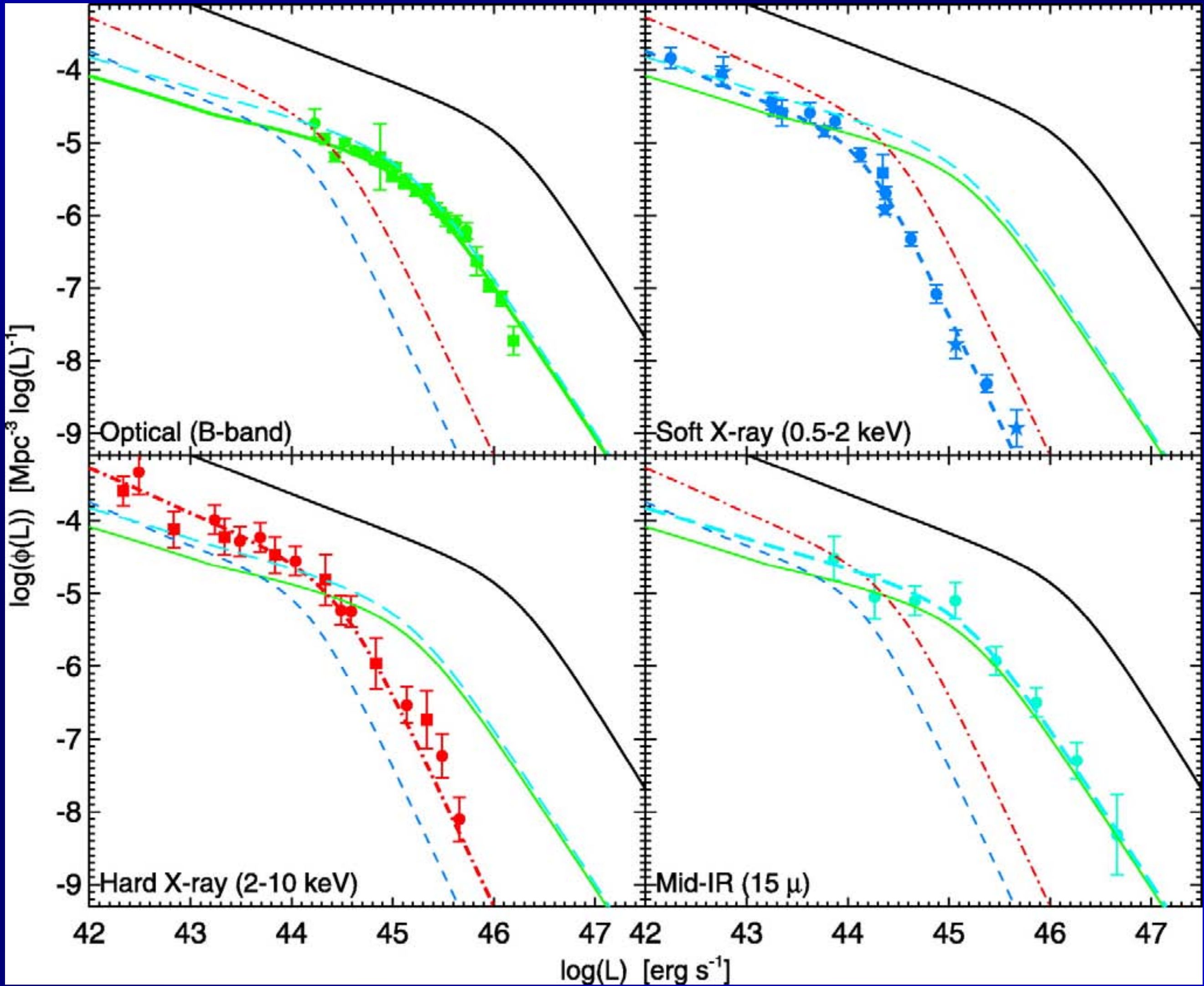
Quasar Photo-z





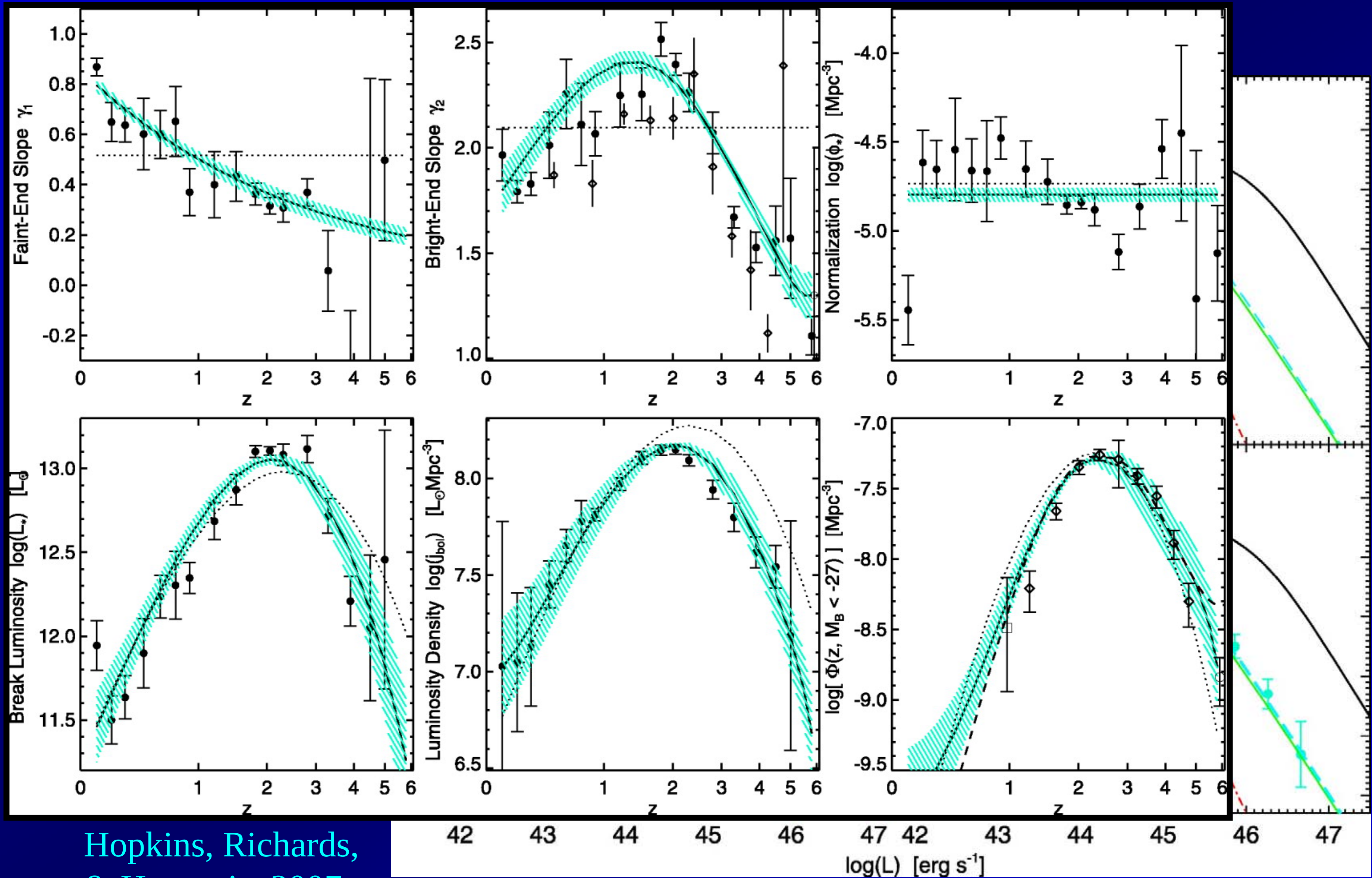
Bolometric QLF

Optical and X-ray alone may not fully describe the QLF, but combined, they do (at least the answers are consistent).



Hopkins, Richards, & Hernquist 2007

Bolometric QLF

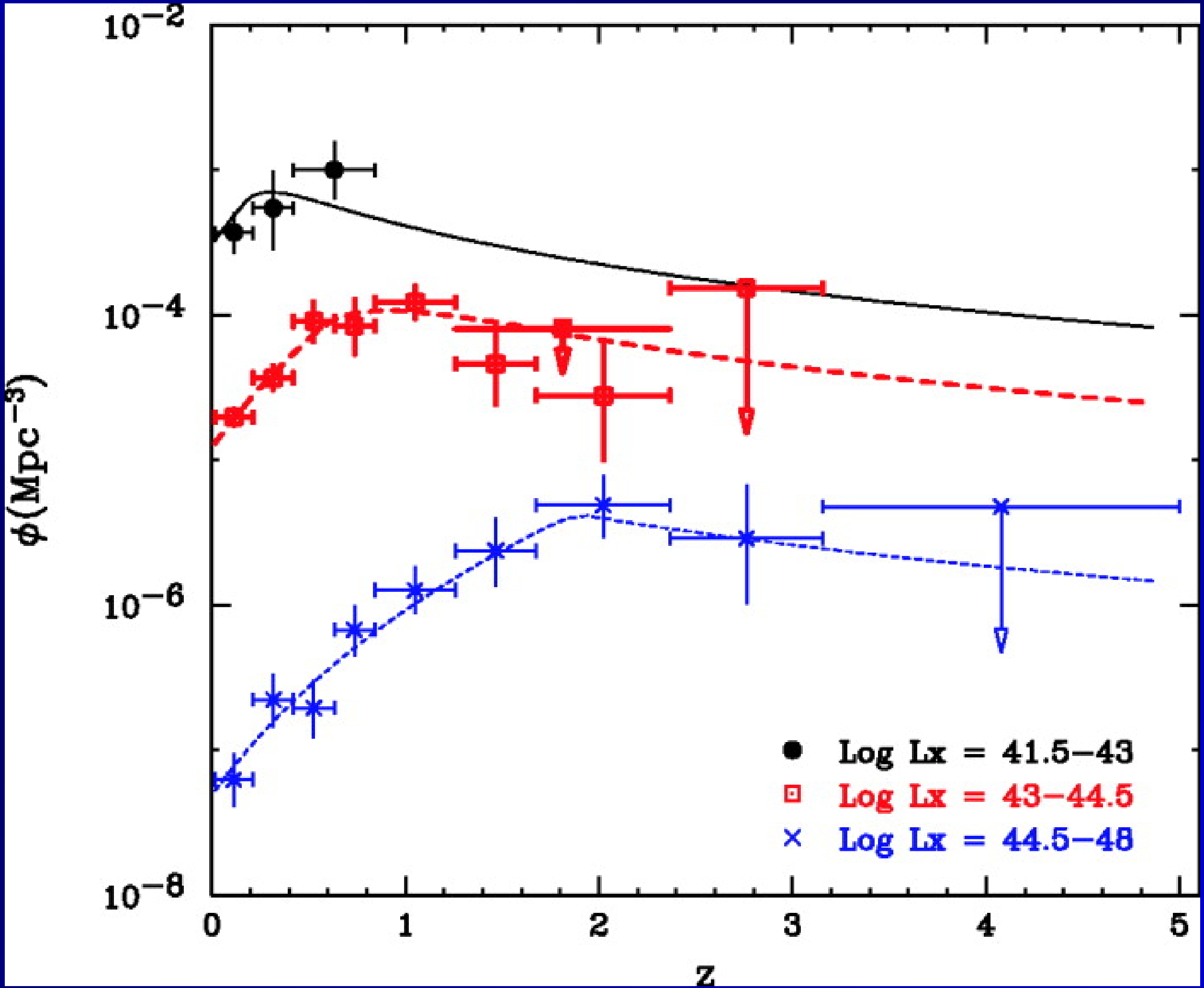


Hopkins, Richards, & Hernquist 2007

Luminosity-Dependent Density Evolution

AKA:

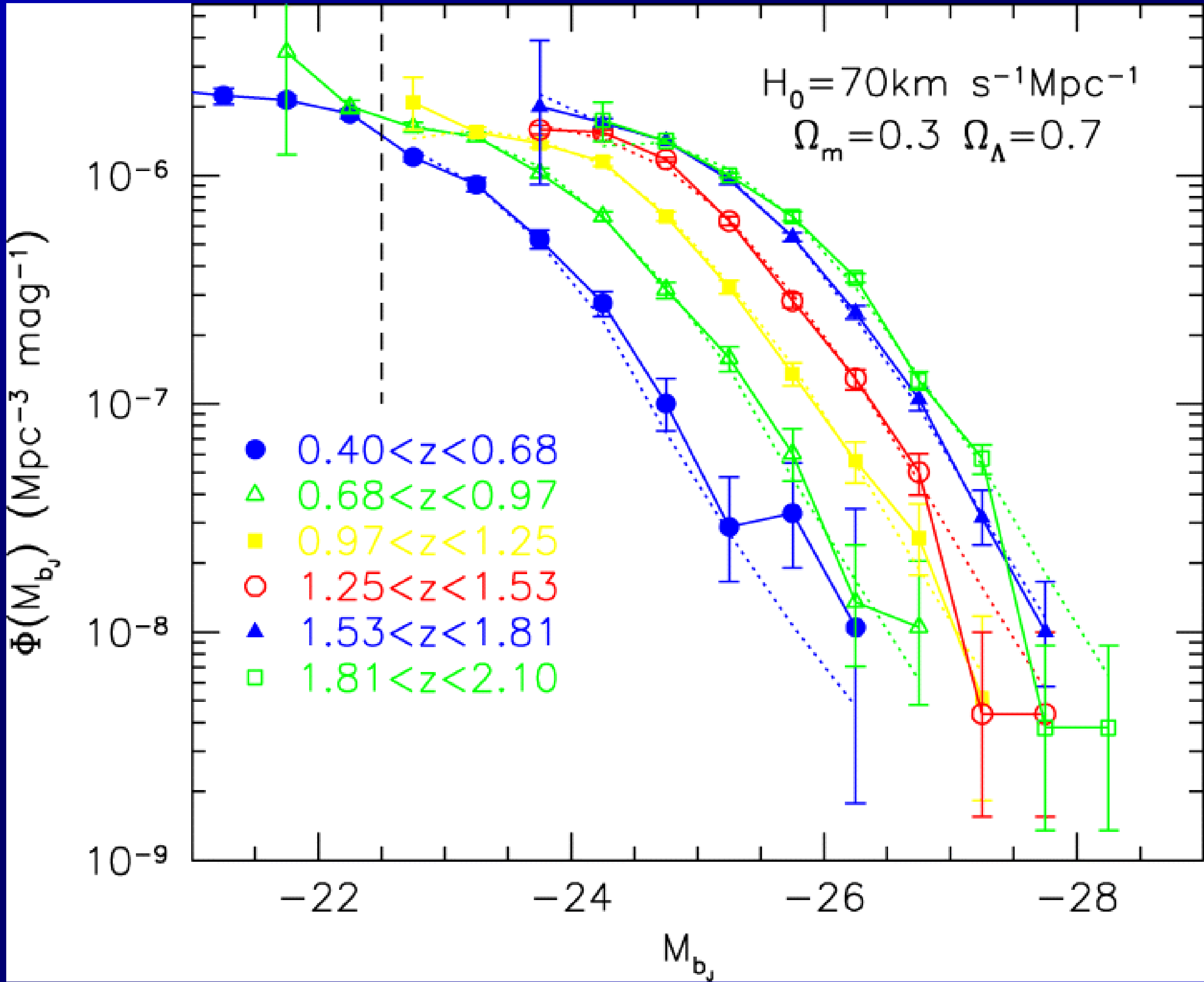
Cosmic Downsizing



Ueda et al. (2003)

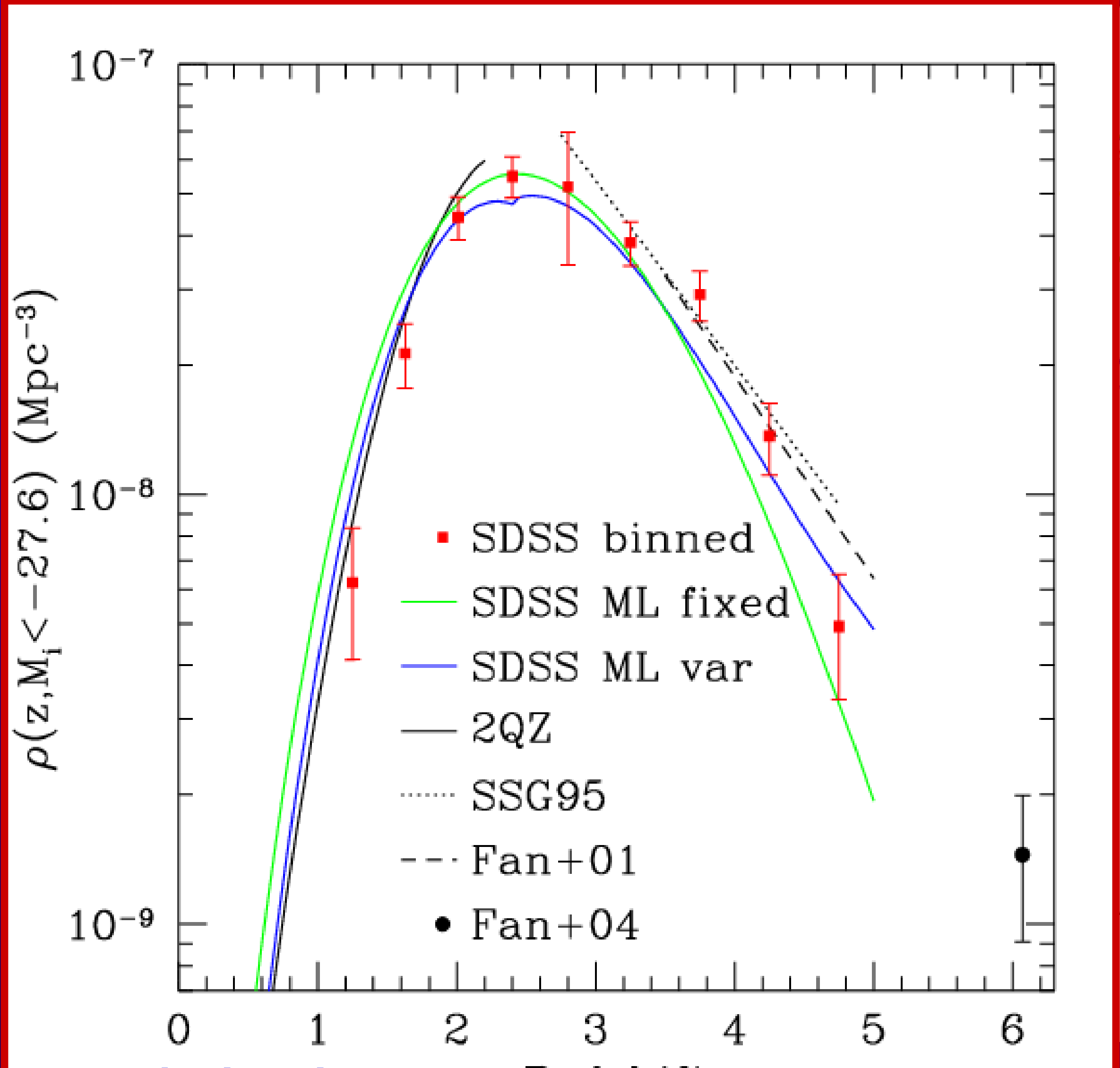
Quasar Luminosity Function

Space density of quasars as a function of redshift and luminosity

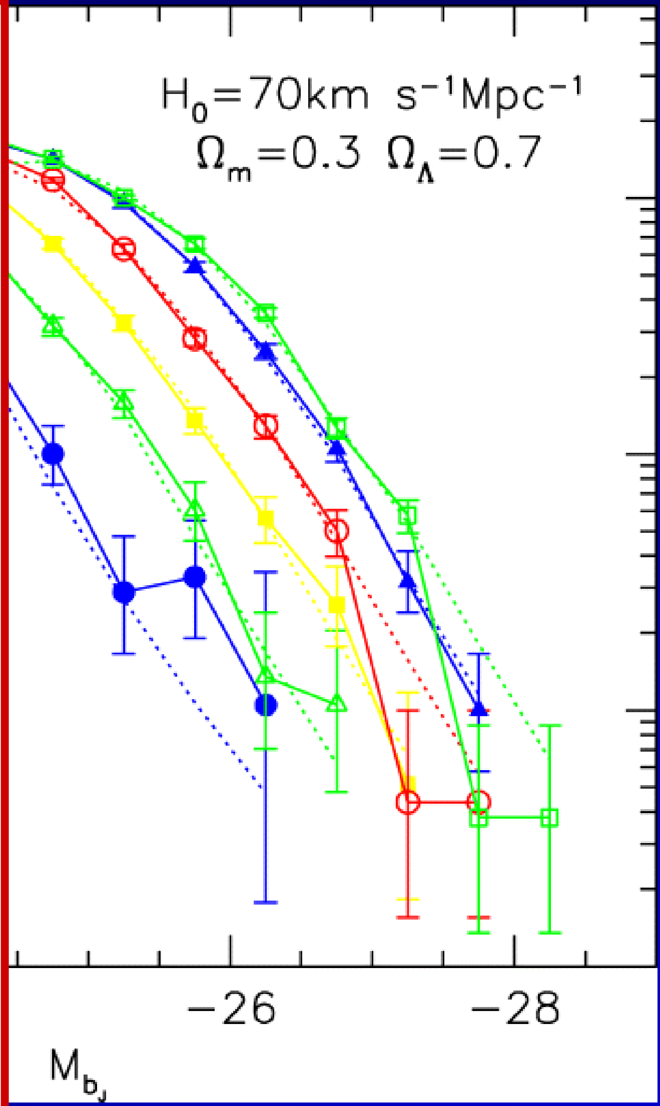


Croom et al. 2004

Quasar Luminosity Function



e.g., Richards et al. 2006

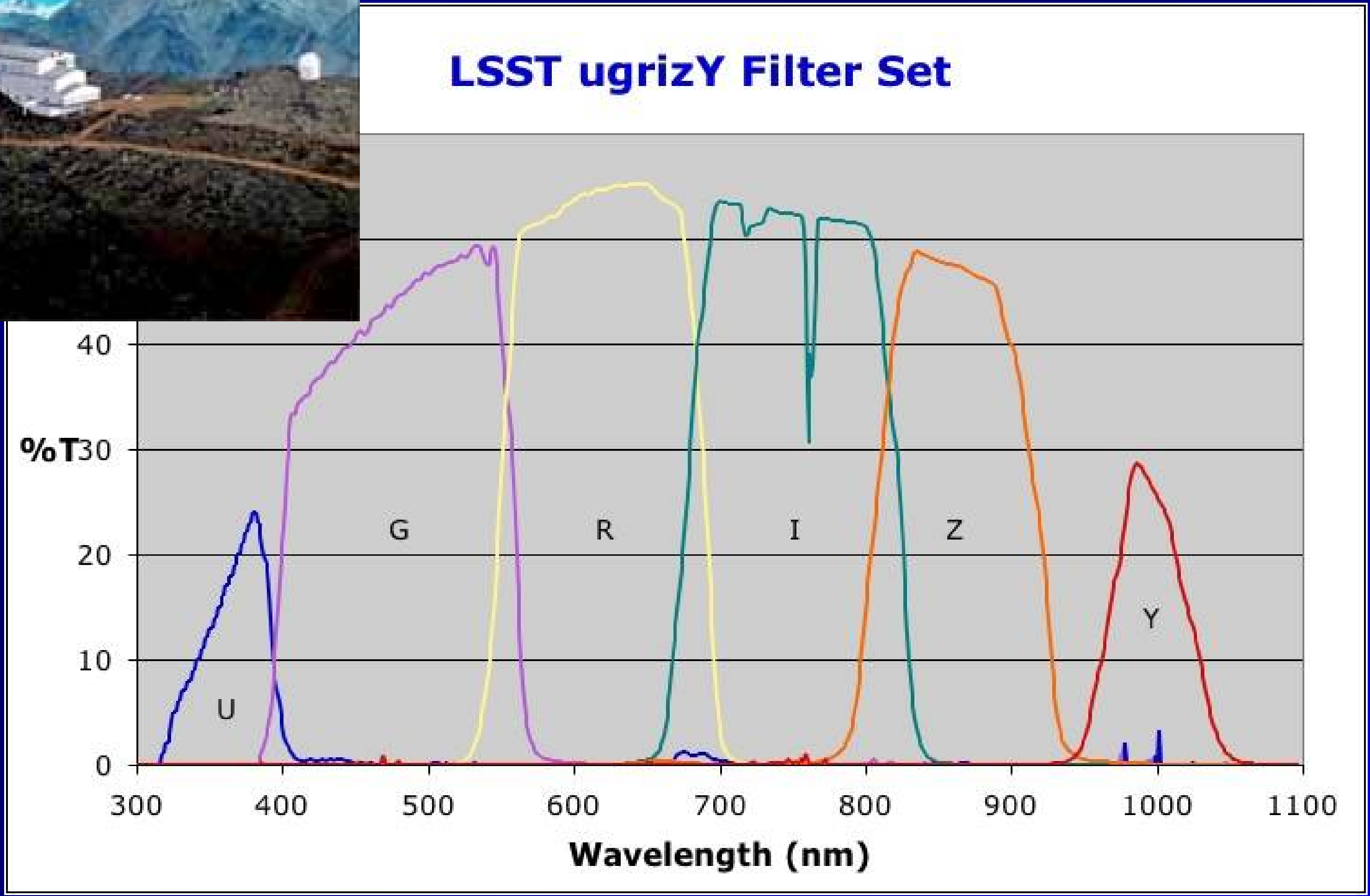


Croom et al. 2004

LSST

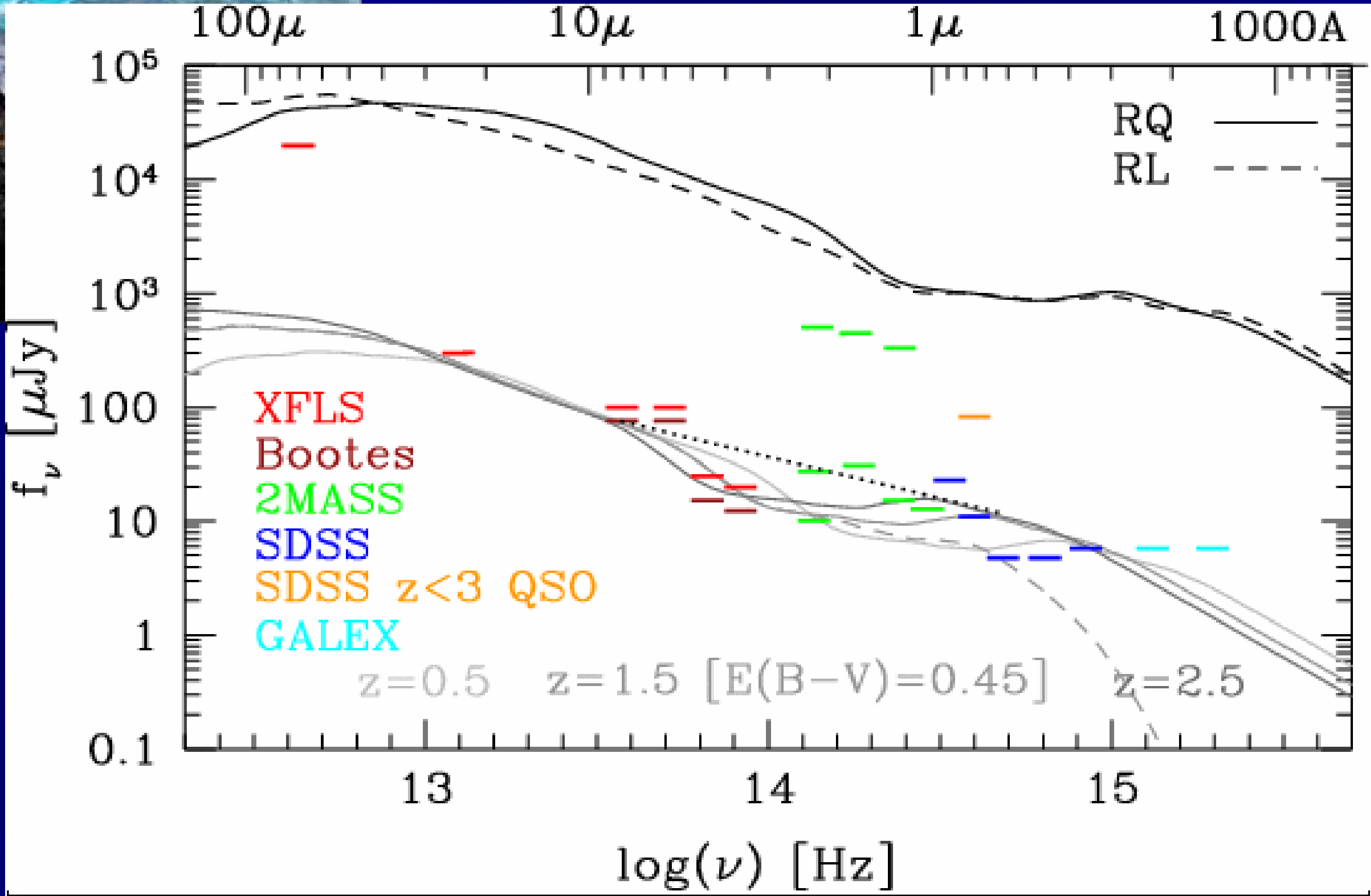
Large Synoptic Survey Telescope

LSST corp.

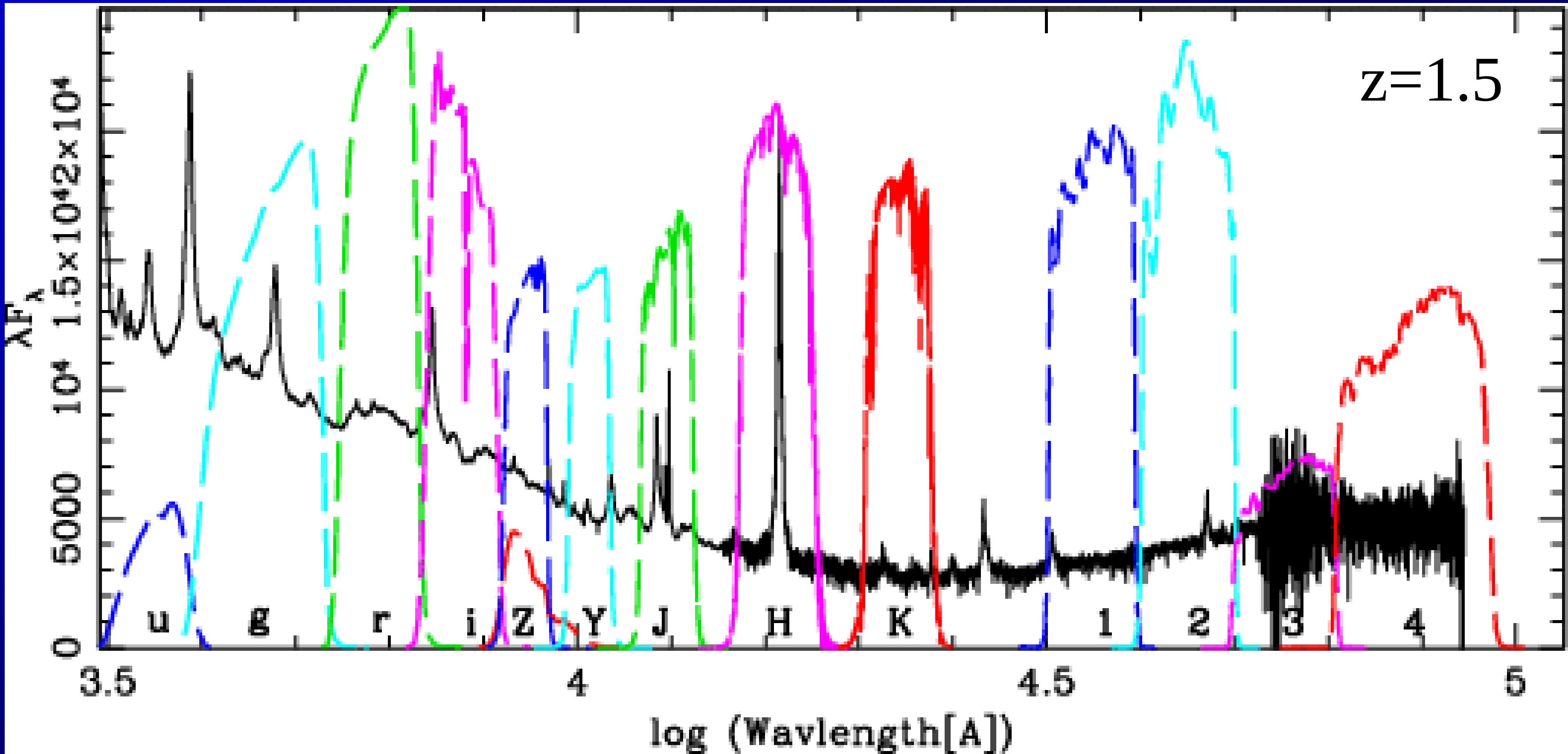


LSST

LSST corp.



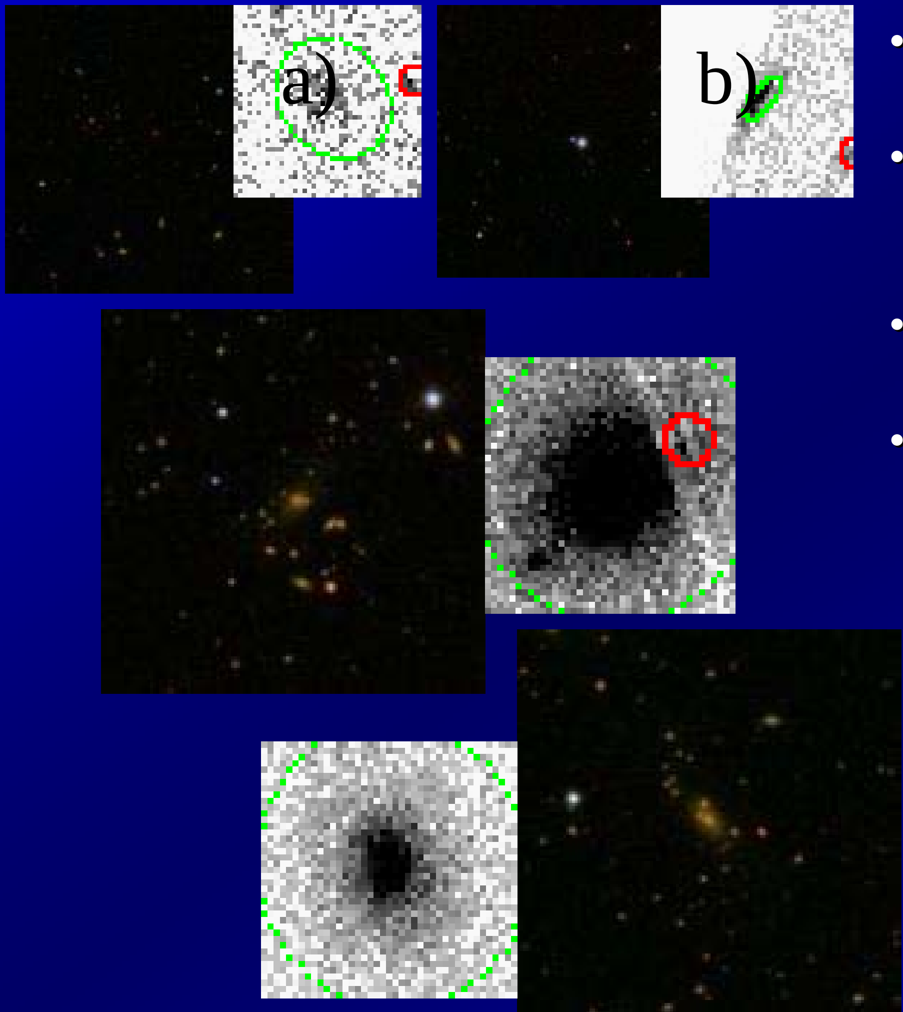
SDSS+UKIDSS+IRAC



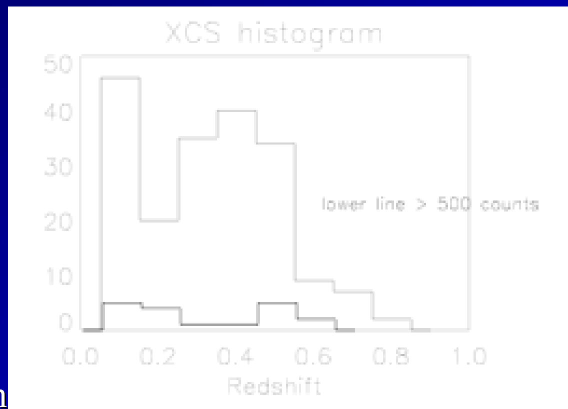
H α plus slope change makes for robust photo-z

Clusters in Stripe 82:
i) SDSS will provide identifications & redshifts

(figures and information courtesy of XCS team; xcs@xcs-home.org for more info)



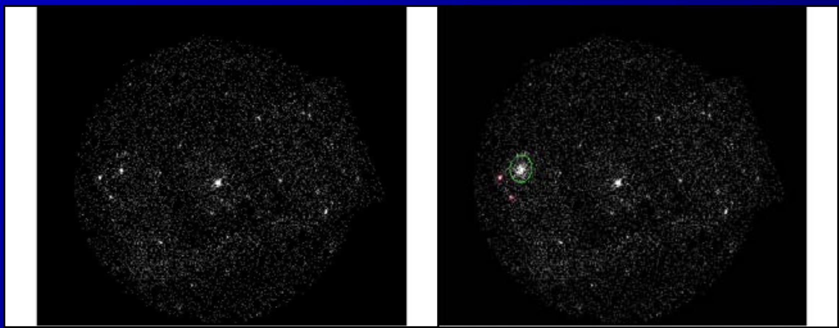
- There are currently 610 (of 1800) XCS cluster candidates* in the SDSS footprint)
- Some have been shown to be either a) non-cluster X-ray sources or b) potential high redshift clusters
- But most are clearly associated with SDSS galaxy enhancements
- Using an LRG technique, more than 200 have been assigned an SDSS redshift



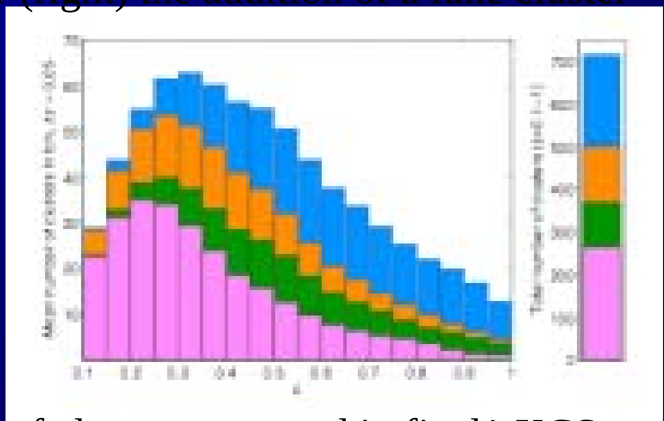
*exten

Clusters in Stripe 82:
ii) XCS will provide selection function

(figures and information courtesy of XCS team; xcs@xcs-home.org for more info)



Modelling selection function: an XCS field before (left) and after (right) the addition of a fake cluster



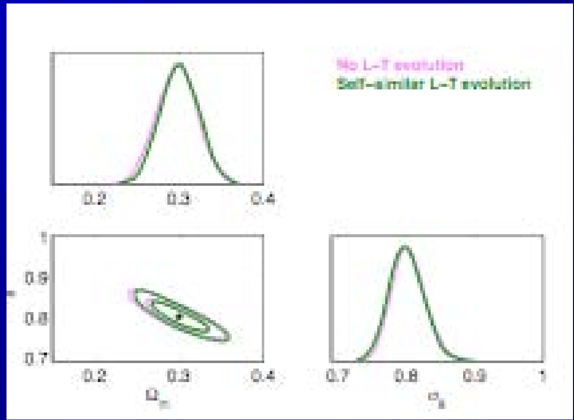
Number of clusters expected in final* XCS as a function of differing assumptions about scaling relations (Sahlen et al. 0802.4462)

*500 square degrees

- Relevant features of the XCS selection function pipeline:
  - It can be run on "beta-model" clusters or on clusters taken from hydro simulations (currently CLEF, soon Millenium gas)
  - It can be represent the entire archive (i.e. all varieties of observation and exposure) or a specific survey with a single observing mode and exposure tim
  - Combined with prescriptions for *N(m,z)*, *M-T* & *L-T*, we will have robust predictions for the proposal

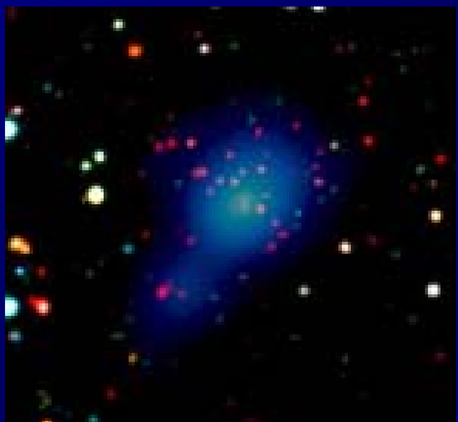
Clusters in Stripe 82:
iii) Added value compared to XCS

(figures and information courtesy of XCS team; xcs@xcs-home.org for more info)



Parameter predictions for the final* XCS (Sahlen et al. 0802.4462)

*500 square degrees and >500 count detections



This z=1.45 XCS cluster was spotted in optical data no deeper than expected from co-added Stripe 82 (Stanford et al. 0606075, Hilton et al. 0708.3258)

- XCS will cover significantly more area than the proposed Stripe 82 survey
  - XCS cosmology will be driven by the detections in non-contiguous fields
- However, Stripe 82 will still provide:
  - Information on systematic errors in XCS cosmology (varying flux limits, cluster clustering, AGN contamination *etc.)*
  - Rapid redshift follow-up (to higher redshifts than possible with XCS+DR5)
  - Rapid identification of potential z>1 clusters (before the demise of XMM & Chandra) for galaxy evolution studies
  - The potential to do cluster searching in the optical (rather than X-rays); providing vital input into optical to X-ray scaling relations for DES *etc.*