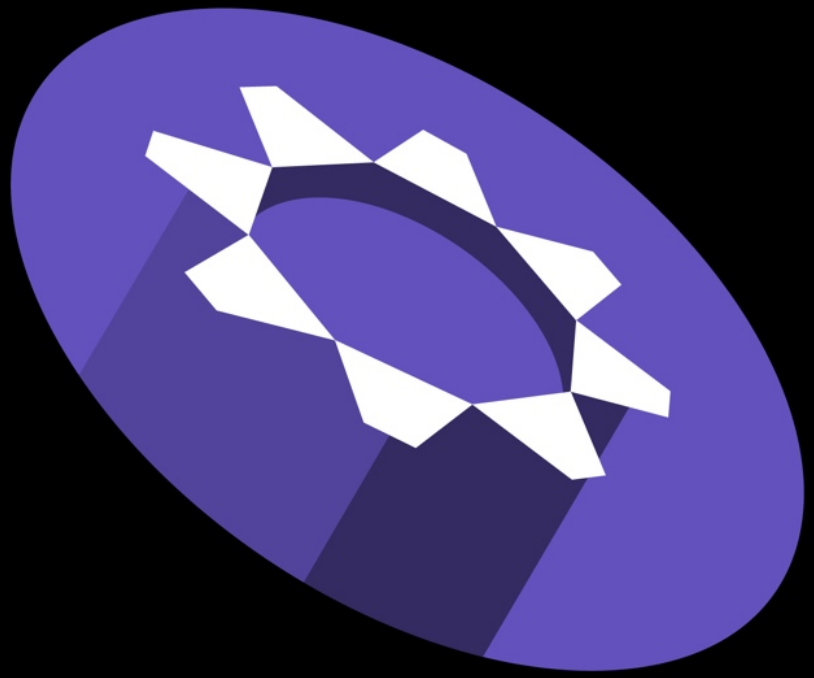
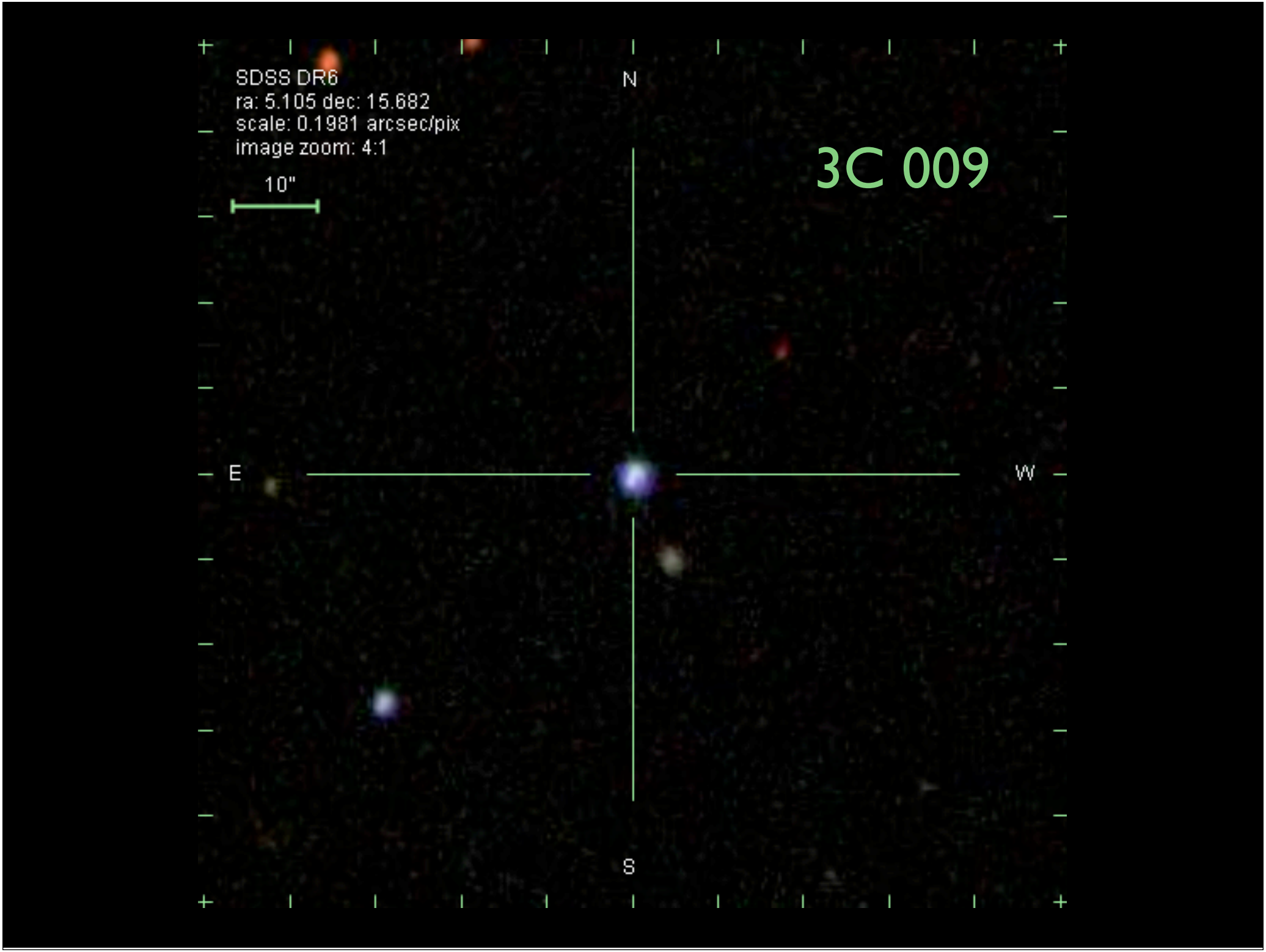


SDSSIII


SDSS DR6
ra: 5.105 dec: 15.682
scale: 0.1981 arcsec/pix
image zoom: 4:1
10"
N
E
W
S
3C 009

BOSS and the Height of the Quasar Empire

Nic Ross (LBNL)

INPA Journal Club

Lawrence Berkeley National Lab

27 May 2011

Overview

1. Yesterday (pre-2009)

2. Today
    i. Early 2011
    ii. Late 2011

3. Tomorrow (post-mid 2014)

The BOSS Quasar Working Group

Scott Anderson, Eric Aubourg, Jill Bechtold, Niel Brandt, Bill Carithers, Aldo Dall'Alglio, Xiaohui Fan, Nurten Filiz Ak, Andreau Font, Rob Gibson, Joe Hennawi, Shirley Ho, Jessica Kirkpatrick, Britt Lundgren, Marcio Maia, Ian McGreer, Jordi Miralda-Escudé, Adam Myers, Nathalie Palanque-Delabrouille, Isabelle Paris, Changbom Park, Ismael Perez-Fournon, Patrick Petitjean, Jim Rich, Nic Ross, David Schlegel, Don Schneider, Erin Sheldon, Yue Shen, John Silverman, Ramin Skibba, Anže Slosar, Michael Strauss, Shailendra Vikas, David Weinberg, Anja Weyant, Martin White, Michael Wood-Vasey & Christophe Yeche

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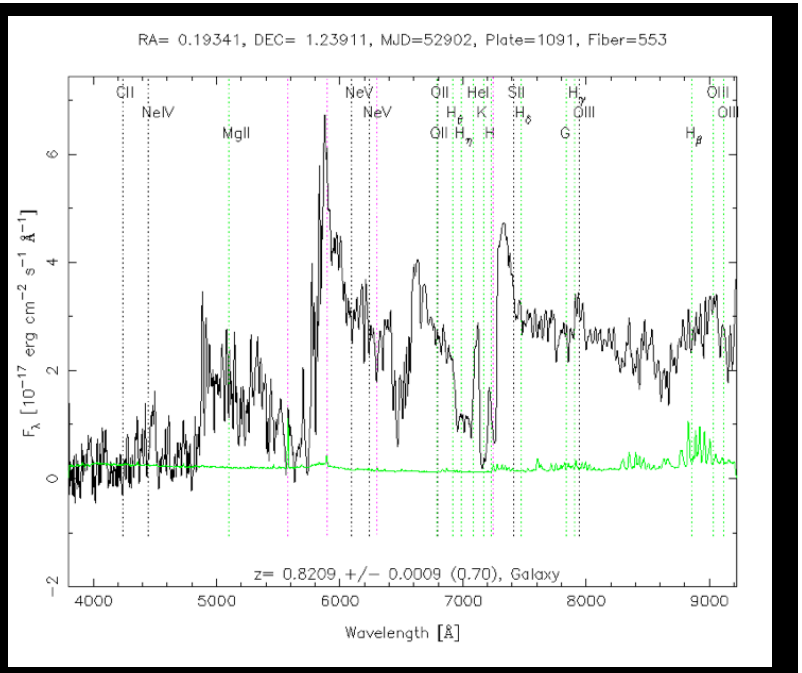
1. Yesterday (pre-2009)

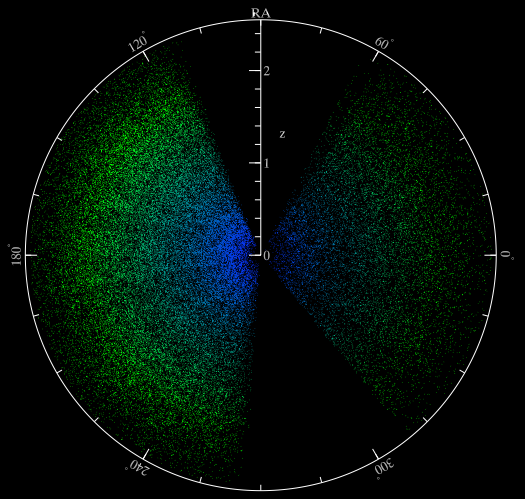
Quasars are… (1)

- **energetic / extreme physics**
  - Broad Absorption Lines (BALs) >2000 km s^{-1}, accelerated to 0.1**c** and **vary** (e.g. Gibson et al. 2009)



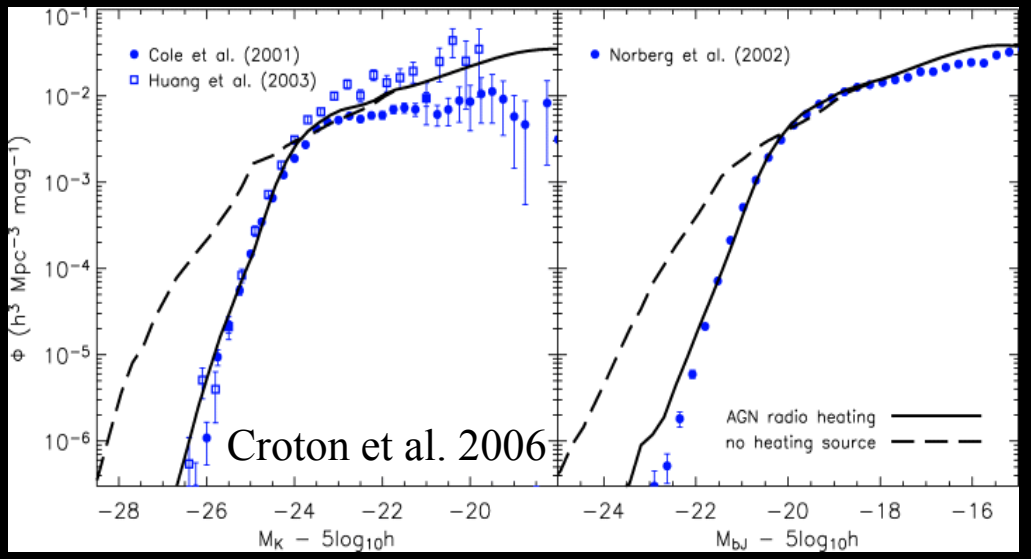
- **very luminous**
  - L_{bol} ~ several 10^{12} $L_{\odot}$
    ~ few 10^{46} erg s^{-1}

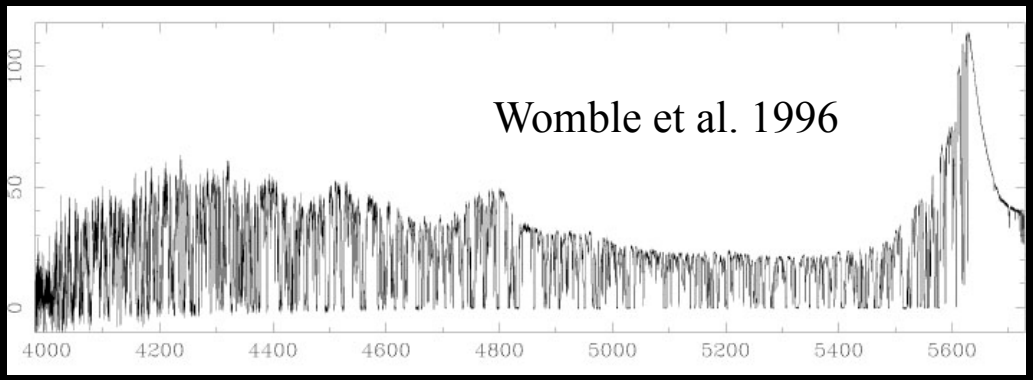
- **tracers of large scale structure**
  - e.g. Hawkins&Reddish'75; Osmer'81; Shanks et al.'83, Porciani'04; Croom'05; Ross'09
- **distant (evolution of LSS)**
  - $\langle z \rangle_{SDSS}$=1.3 ⇒ 4000 Mpc

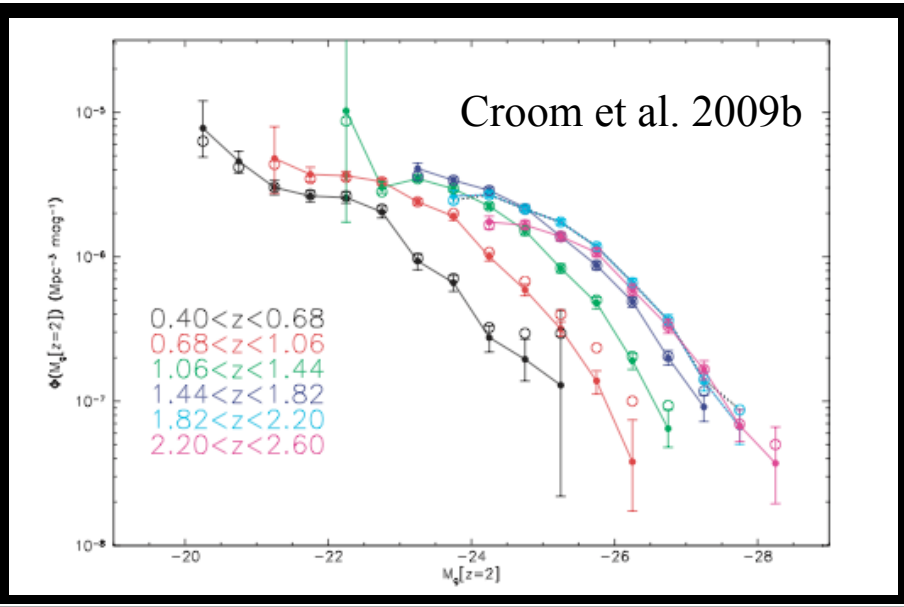


Quasars are... (2)

- **(maybe) connected to galaxy mergers and evolution**
  - "AGN Feedback" (e.g. Cattaneo et al. 2009)
- **backlights**
  - Lyman alpha forest (LyaF, e.g. Rauch'98)
- **rare**
  - n~10^{-7} Mpc^{-3} for M_g=-27 at z=2 (e.g. Croom et al. 2009b)







Large (optical) area surveys

- Quasars rare objects, need to cover large areas of the sky

- Mid-1990s, largest quasar samples $\approx 10^3$ objects

- Need: clean photometry, multiplexing instrument, large FoV

The Dawn of Statistical QSO Surveys

- Two major optical quasar surveys over 1998-2008:
  - 2dF QSO Redshift (2QZ; 23,660 QSOs, Croom et al. 2004)
  - SDSS Quasar Survey (105,783 QSOs; Schneider'10)

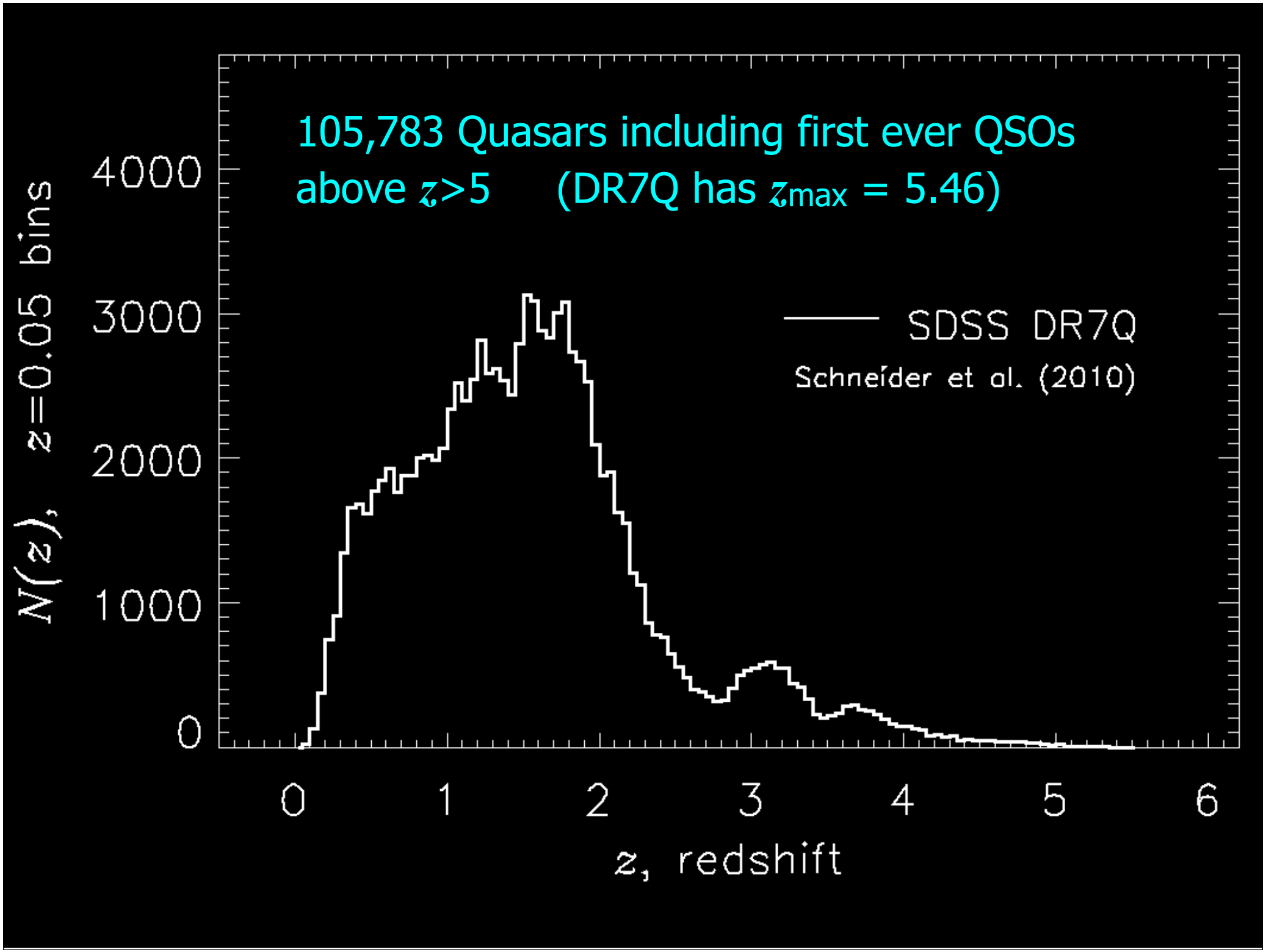
- SDSS ideal for large quasar survey:
  - High quality 5-band photometry, select targets
  - Very large area coverage (1000s deg^2)
  - Multi-fibre spectroscopic follow-up, moderate resolution spectra

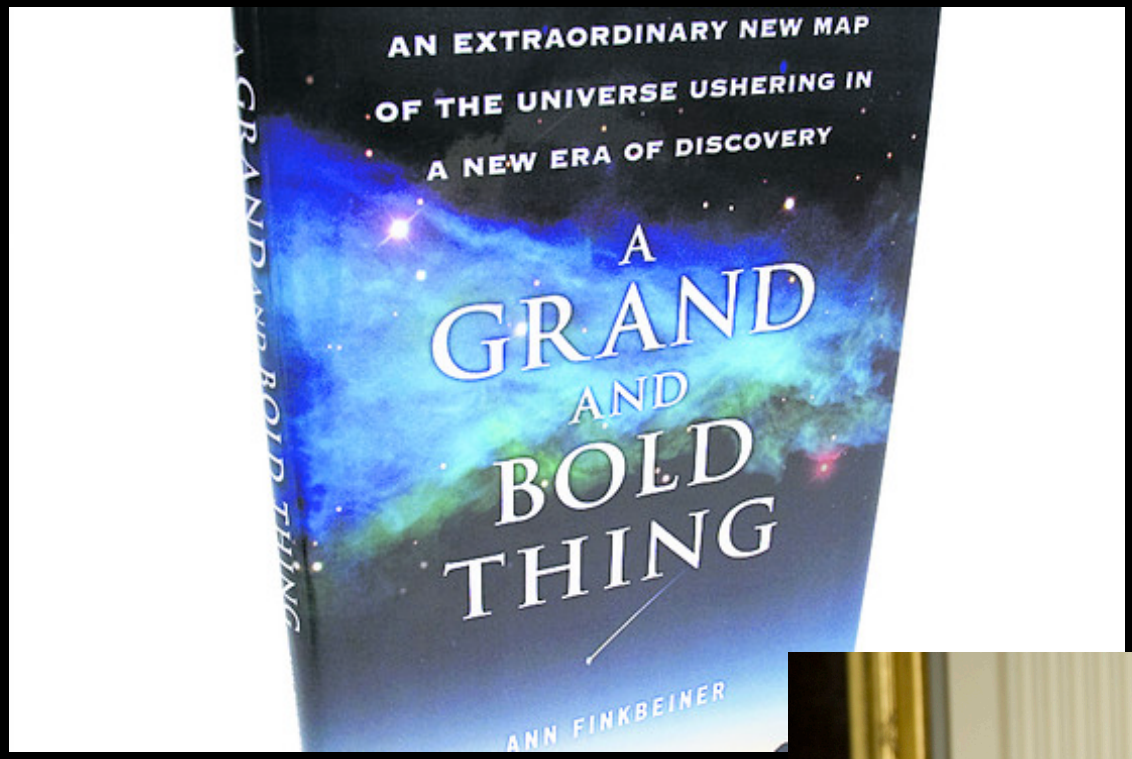
- 2.5m (100 inch) primary
- Wide Field of view, 7 deg^2
- Imaging and Spectroscopy
- 640 x 3” fibers for spectroscopy
- 10^6 galaxy redshifts, $z<0.3$
- **10^5 quasar redshifts $0<z<2$**
- **2000-2008**

- 2.5m (100 inch) primary
- Wide Field of view, 7 deg^2
- Imaging and Spectroscopy
- 640 x 3” fibers for spectroscopy
- 10^6 galaxy redshifts, $z<0.3$
- **10^5 quasar redshifts $0<z<2$**
- **2000-2008**

- 2.5m (100 inch) primary
- Wide Field of view, 7 deg^2
- Imaging and Spectroscopy
- 640 x 3" fibers for spectroscopy
- 10^6 galaxy redshifts, $z<0.3$
- **10^5 quasar redshifts $0<z<2$**
- **2000-2008**

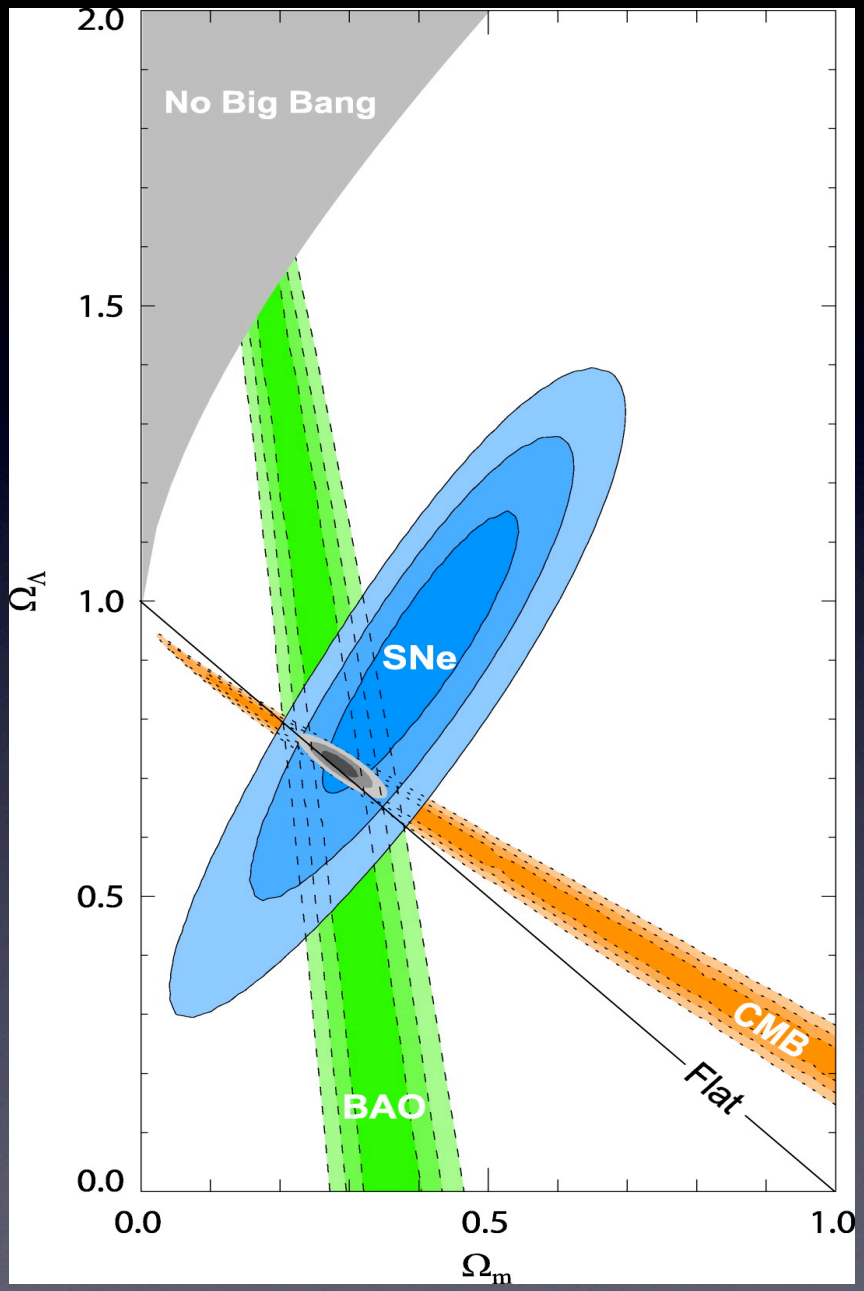
- 2.5m (100 inch) primary
- Wide Field of view, 7 deg^2
- Imaging and Spectroscopy
- 640 x 3" fibers for spectroscopy
- 10^6 galaxy redshifts, $z<0.3$
- **10^5 quasar redshifts $0<z<5$**
- **2000-2008**


105,783 Quasars including first ever QSOs
above z>5 (DR7Q has zmax = 5.46)
SDSS DR7Q
Schneider et al. (2010)
N(z), z=0.05 bins
4000
3000
2000
1000
0
0
1
2
3
4
5
6
z, redshift


AN EXTRAORDINARY NEW MAP
OF THE UNIVERSE USHERING IN
A NEW ERA OF DISCOVERY
A GRAND AND BOLD THING
ANN FINKBEINER


2. i Today: Early 2011

Cosmic Energy Inventory

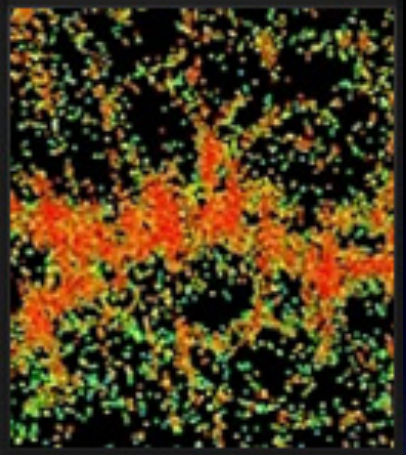


Parameter	Ω/Ω_{crit}
Dark Sector	0.954 ± 0.003
Dark energy	0.72 ± 0.03
Dark (cold) matter	0.23 ± 0.03
Baryon rest mass	0.045 ± 0.003
Warm IG plasma	0.040
Stars	0.024
IGM	0.016
neutrinos, ν	<0.004
Black holes	$\sim 10^{-5}$

Kowalski et al. (2008)

Fukugita & Peebles (2004)

BOSS



APOGEE

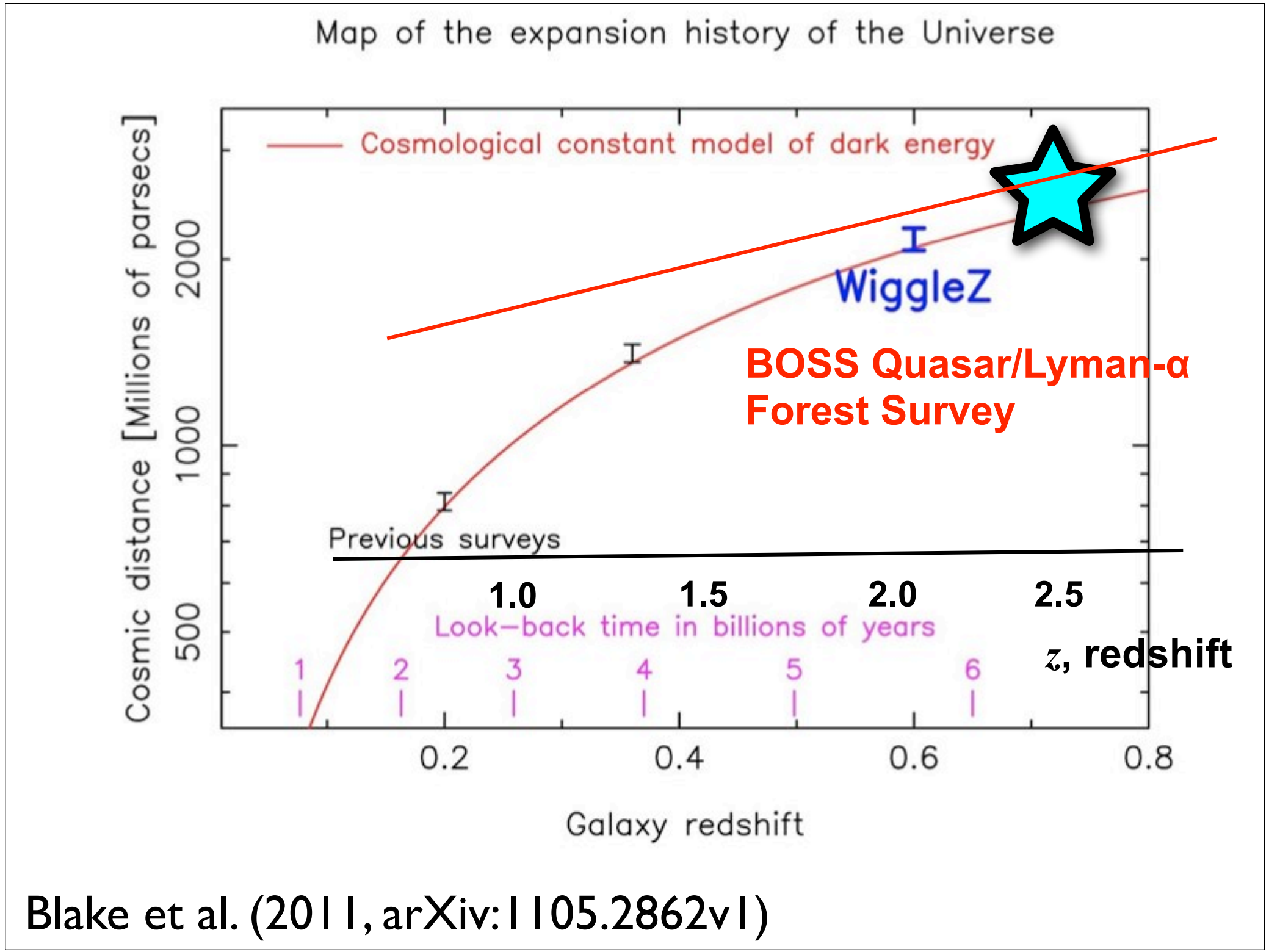
SDSSIII

SEGUE-2

MARVELS

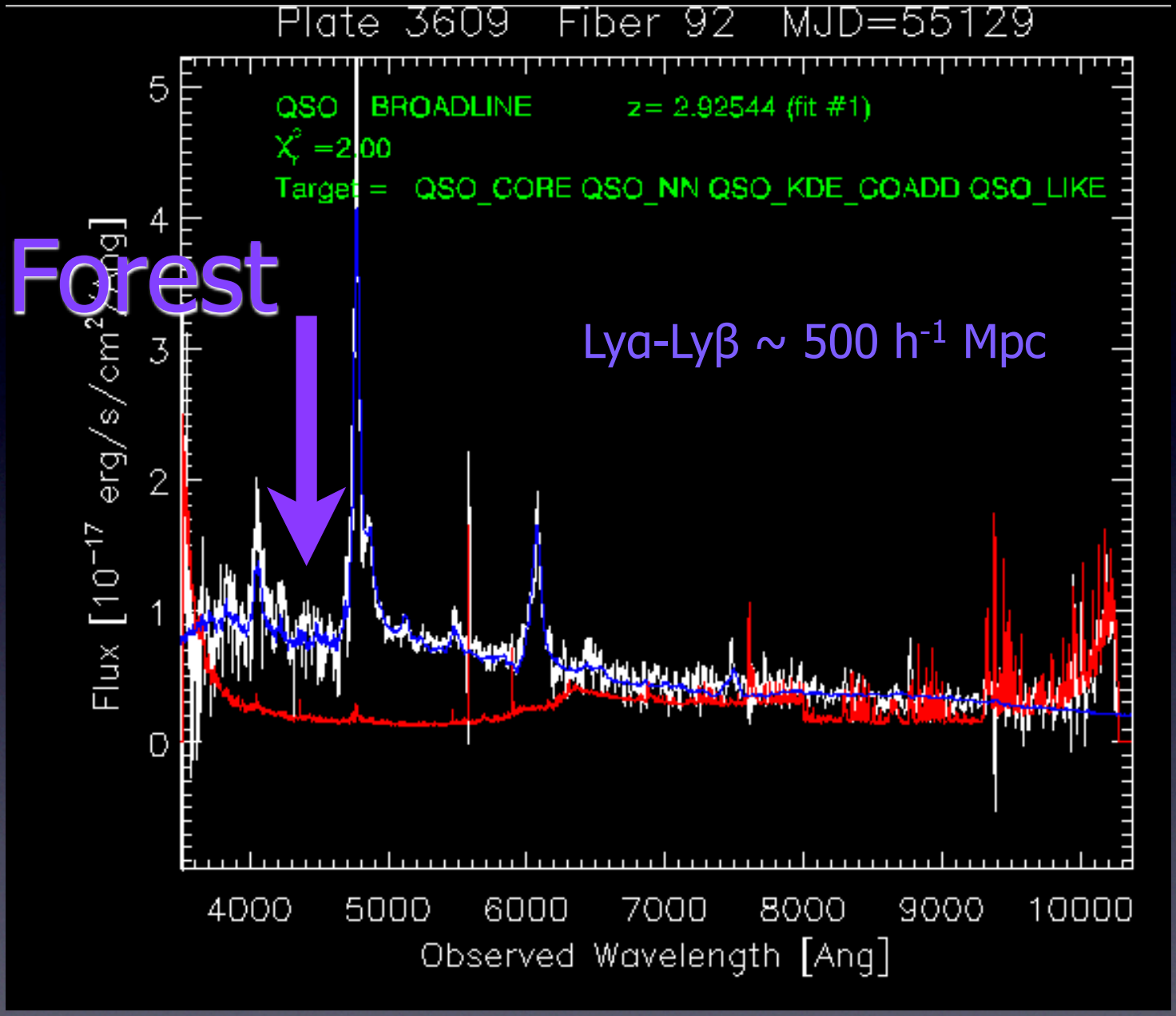
www.sdss3.org

Eisenstein et al.
arXiv:1101.1529v1



Blake et al. (2011, arXiv:1105.2862v1)

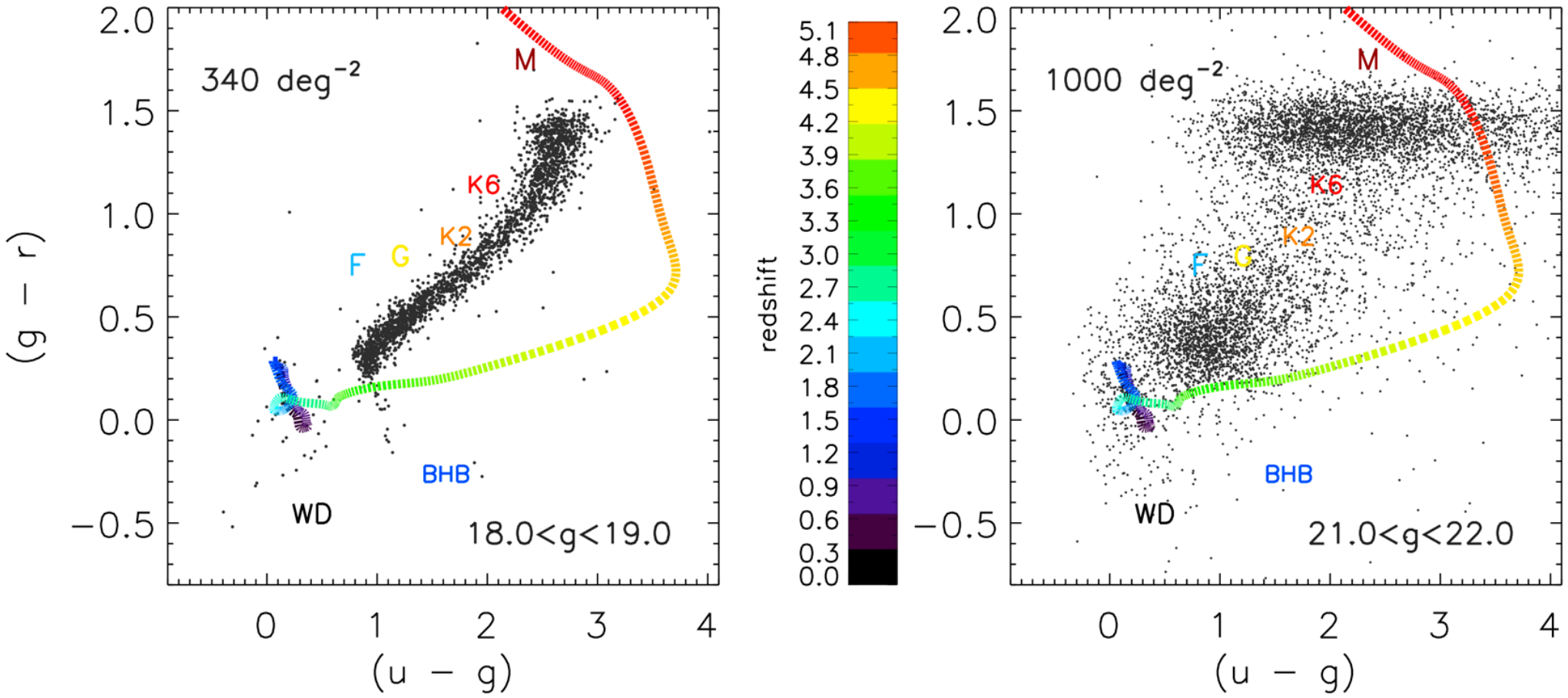
Lyα Forest



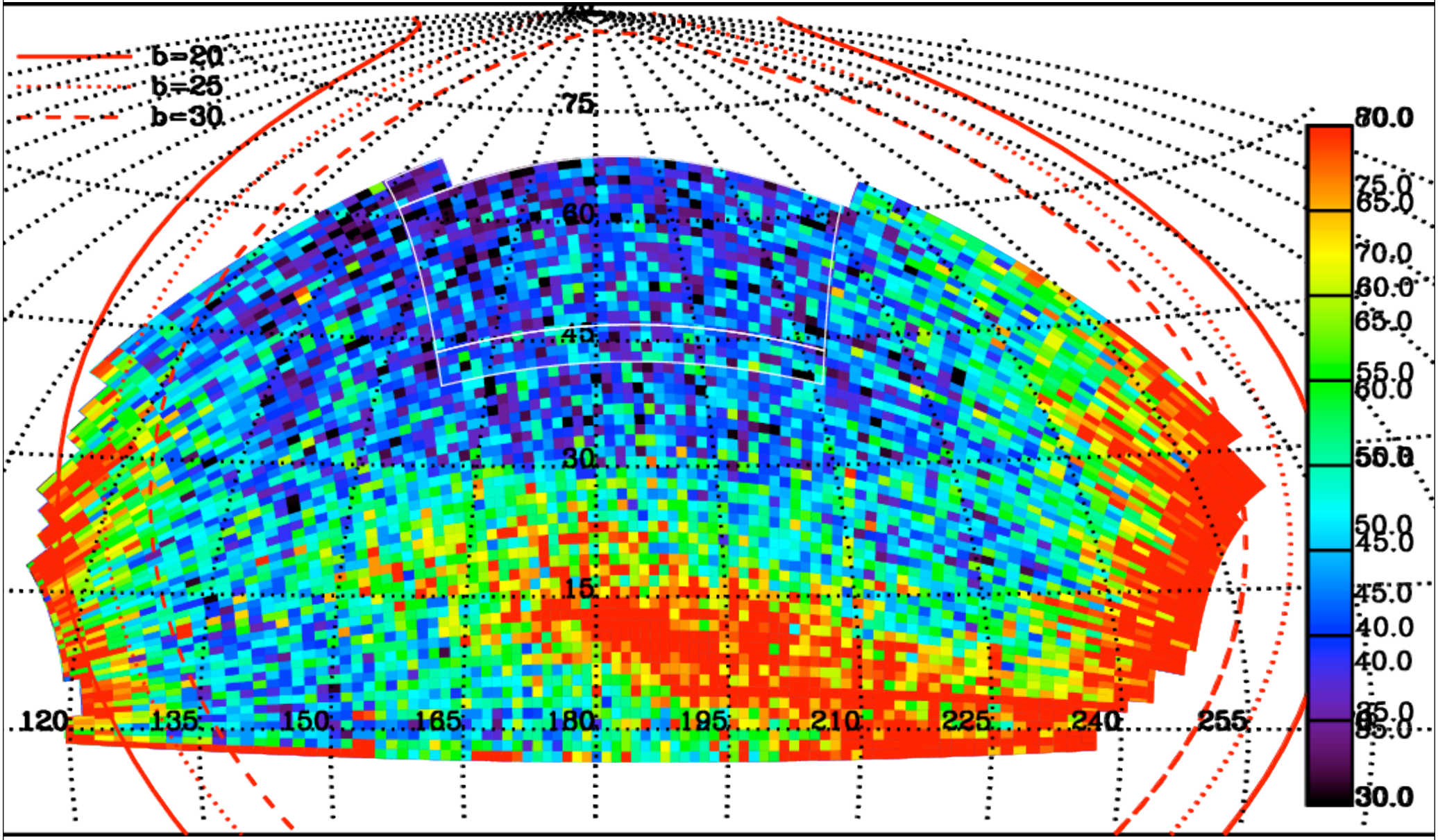
M. White (0305474, 2010); Seljak et al. (2005) McDonald & Eisenstein (2007); Slosar et al. (2010,2011), McQuinn&White (2011)

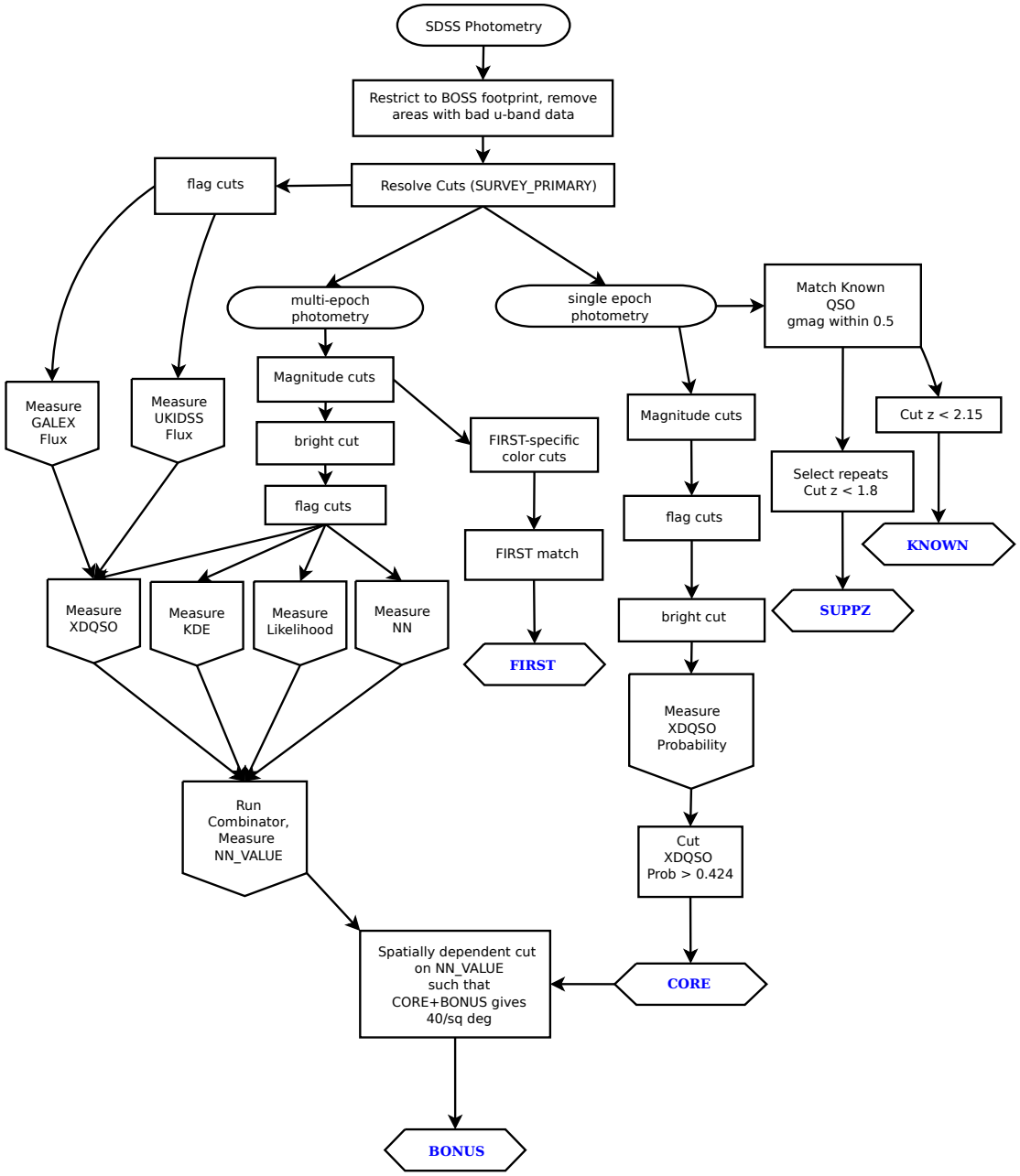
- 2.5m (100 inch) primary
- Wide Field of view, 7 deg^2
- (mainly) Just Spectroscopy
- **1000** x 2" fibers
- $10^{6.2}$ galaxy redshifts, $0.3<z<0.75$
- **$10^{5.2}$ quasar redshifts $z>2.2$**
- **2009-2014**
- Schlegel, Dawson, Roe, White
- Eisenstein et al. arXiv:1101.1529v1

Telling the difference between stars and galaxies...



Ross et al. (arXiv:1105.0606v1)


b=20
b=25
b=30
75
60
45
30
15
120
135
150
165
180
195
210
225
240
255
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0



Complicated!

Several methods:

Kirkpartick et al. (2011)
Bovy et al. (2011)
Yeche et al. (2010)
Richards et al. (2009)

Four main quasar targets:

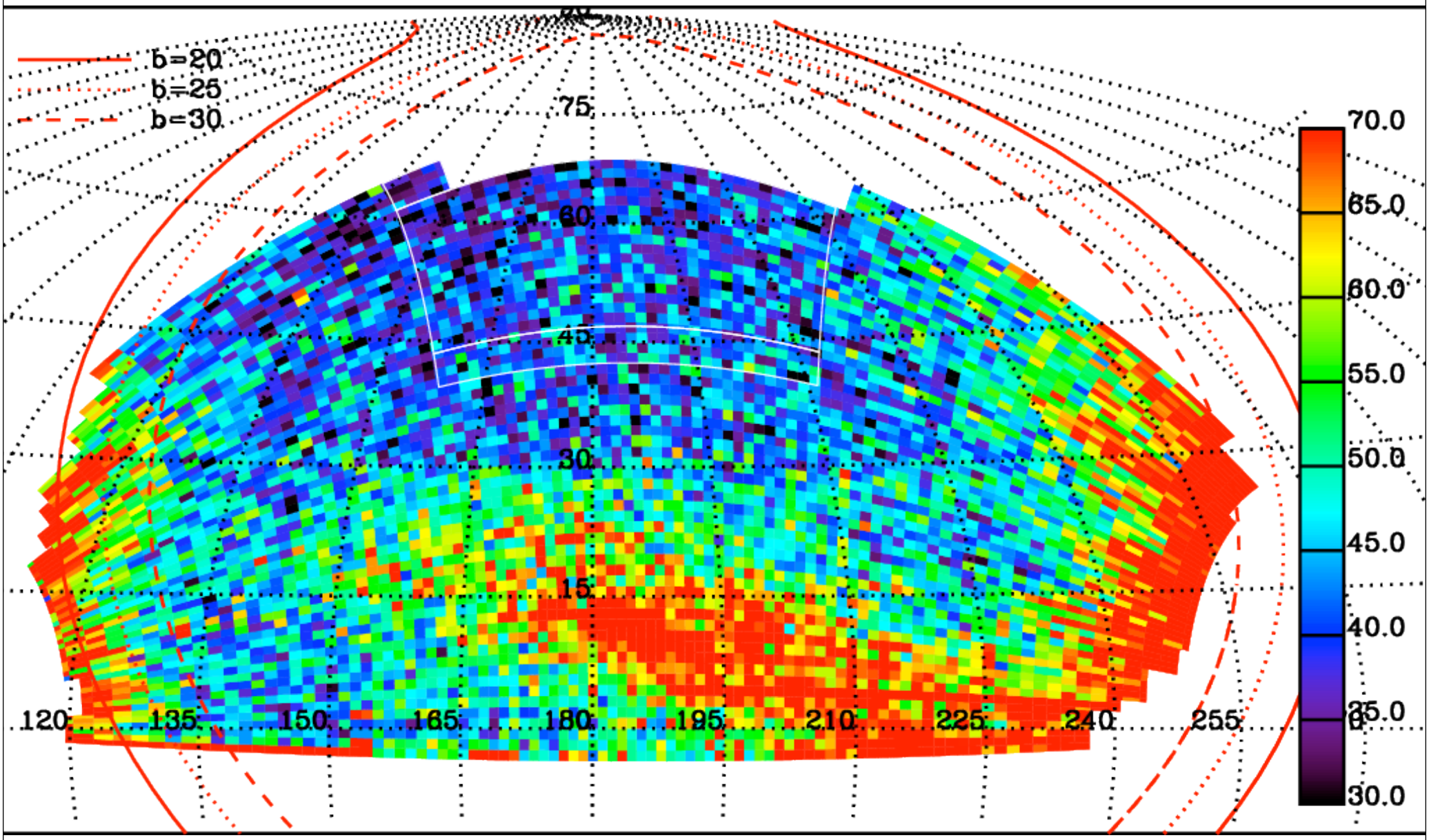
KNOWN (e.g. from SDSS)
FIRST (radio sources)
CORE (optical, 1 method)
BONUS (multi-λ, multi-method)

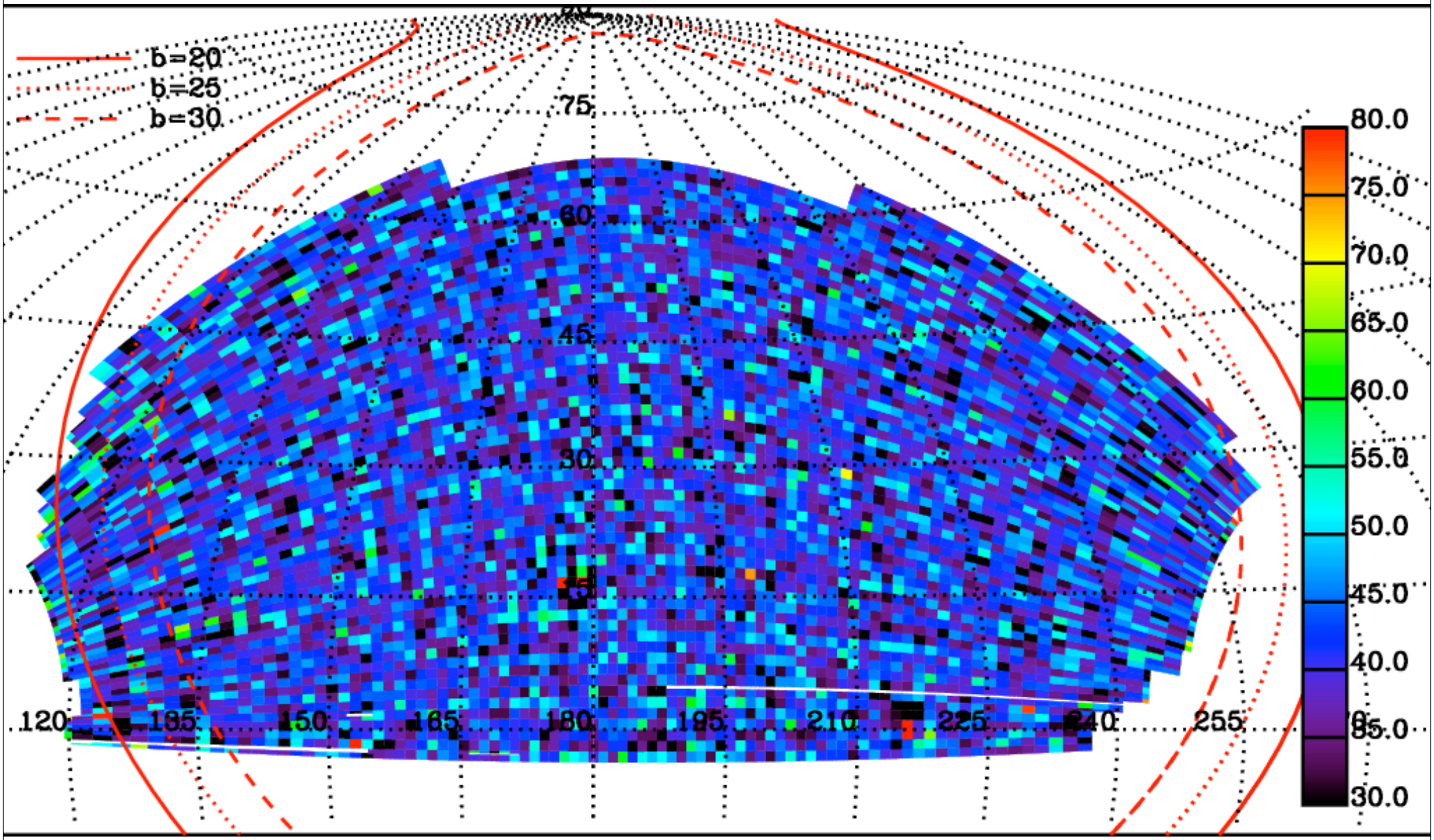
Produces:

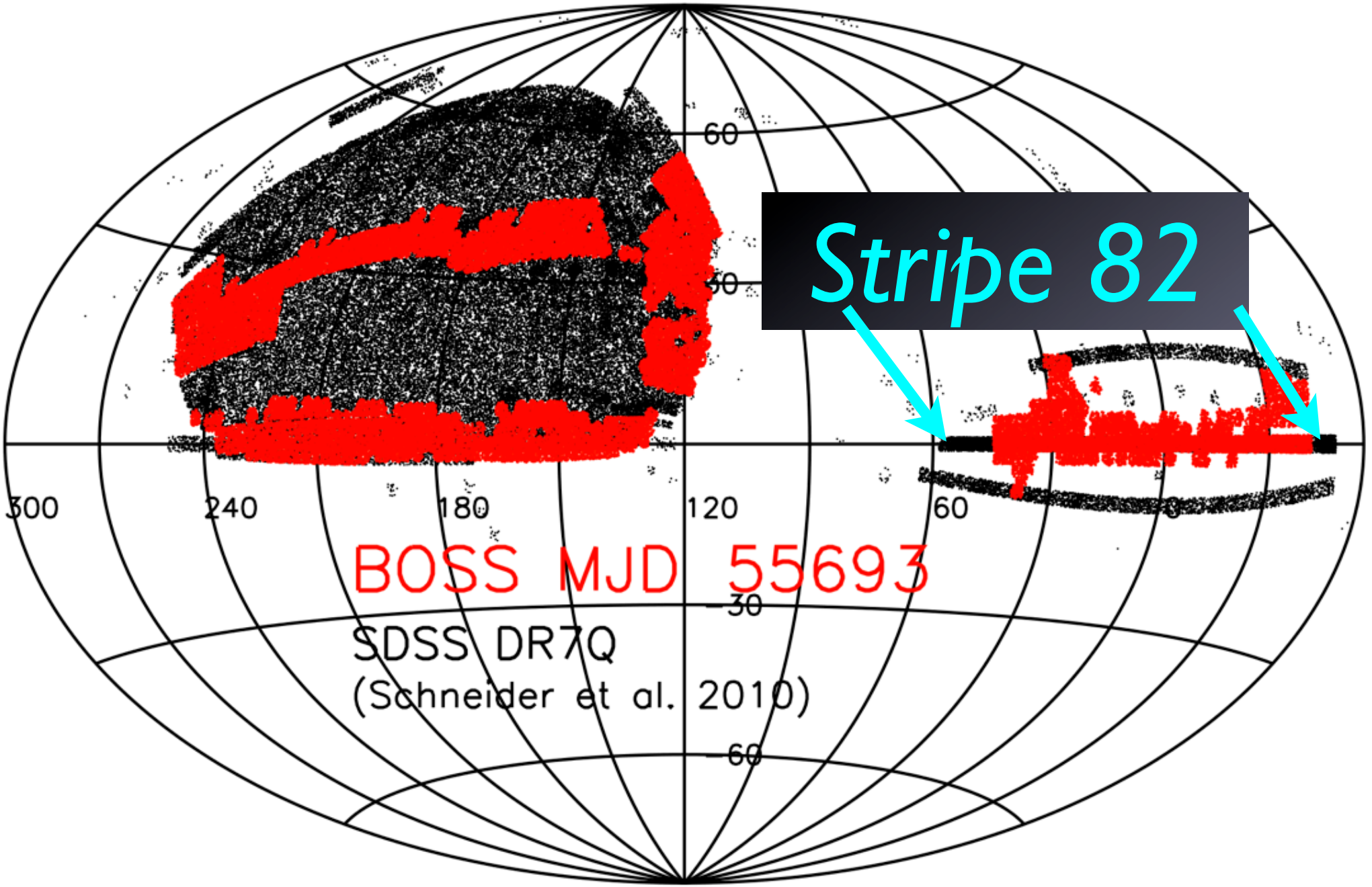
just under *430,000 targets*
across
10,200 deg^2 of sky

20 deg^2 from **CORE**
~20 deg^2 from **BONUS**
~2 deg^2 from **FIRST**/**KNOWN**

Ross et al. (arXiv:1105.0606v1)


b=20
b=25
b=30
75
60
45
30
15
120
135
150
165
180
195
210
225
240
255
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0


b=20
b=25
b=30
75
60
45
30
15
120
135
150
165
180
195
210
225
240
255
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0


Stripe 82
60
30
300
240
180
120
60
BOSS MJD 55693
SDSS DR7Q
(Schneider et al. 2010)
-30
-60

MJD 55693

MJD 55693

164,370 QSO target spectra

MJD 55693

164,370 QSO target spectra

113,490 with reliable redshifts

MJD 55693

164,370 QSO target spectra

113,490 with reliable redshifts

81,280 with reliable redshifts and are quasars

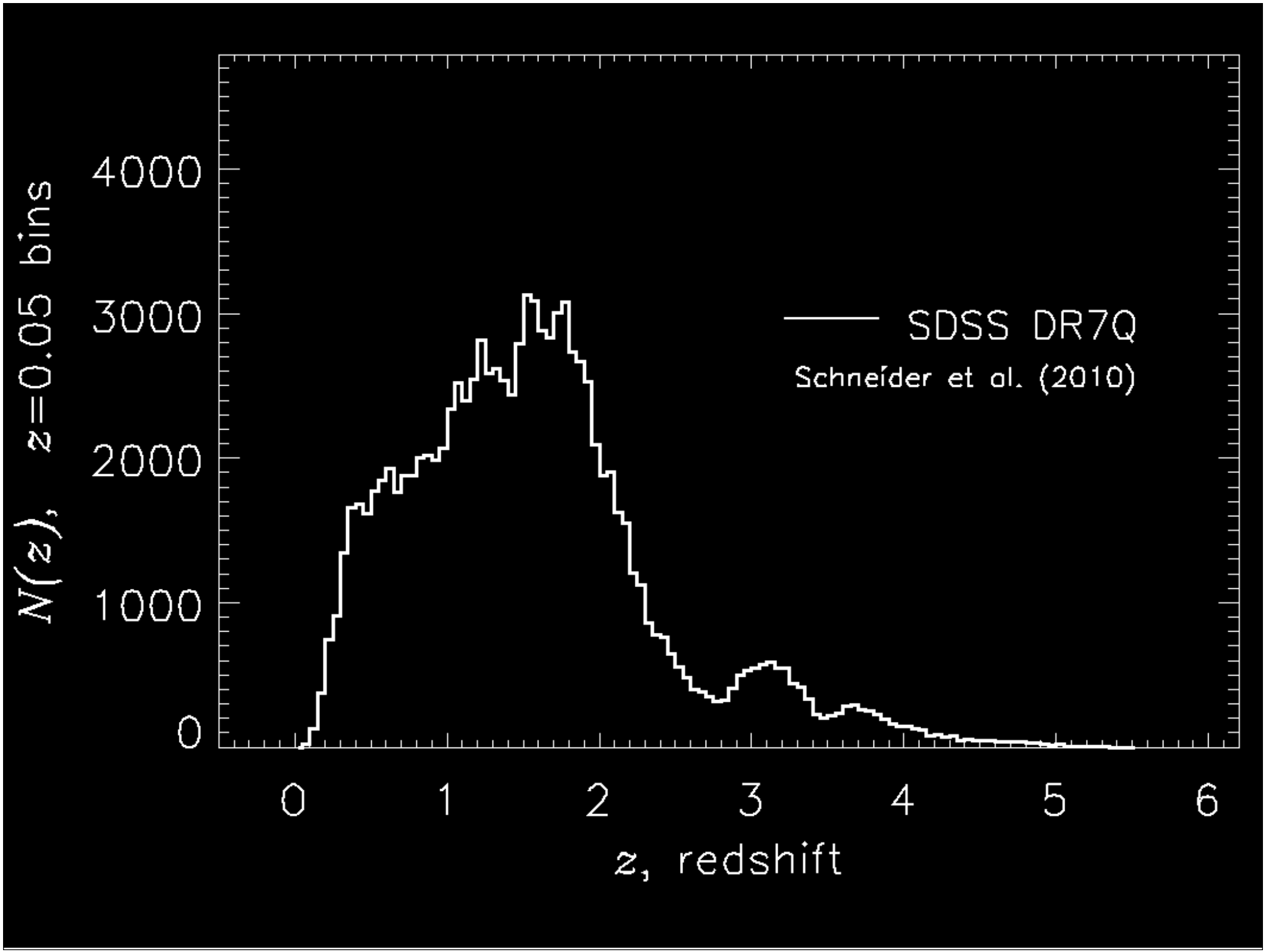
MJD 55693

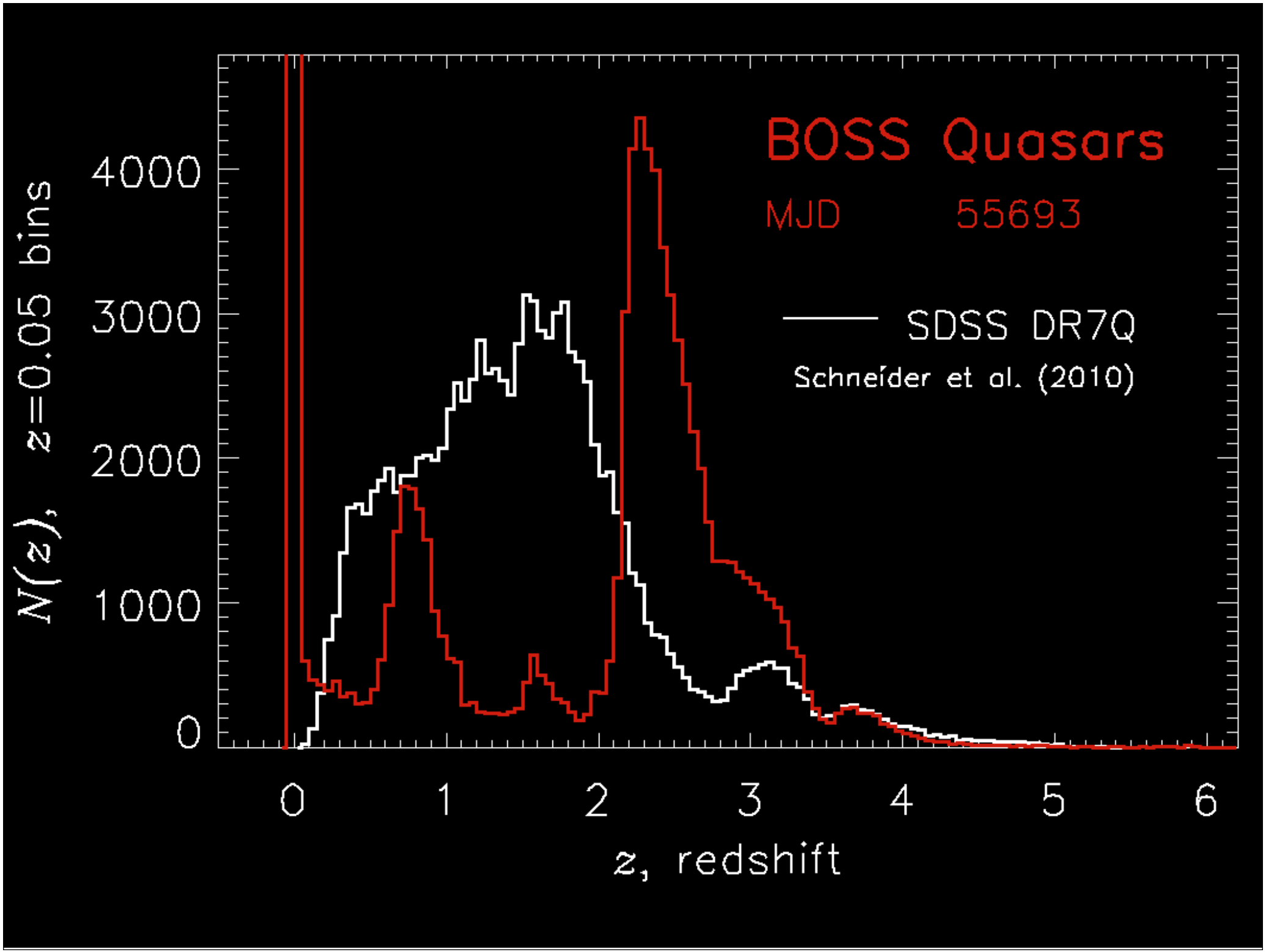
164,370 QSO target spectra

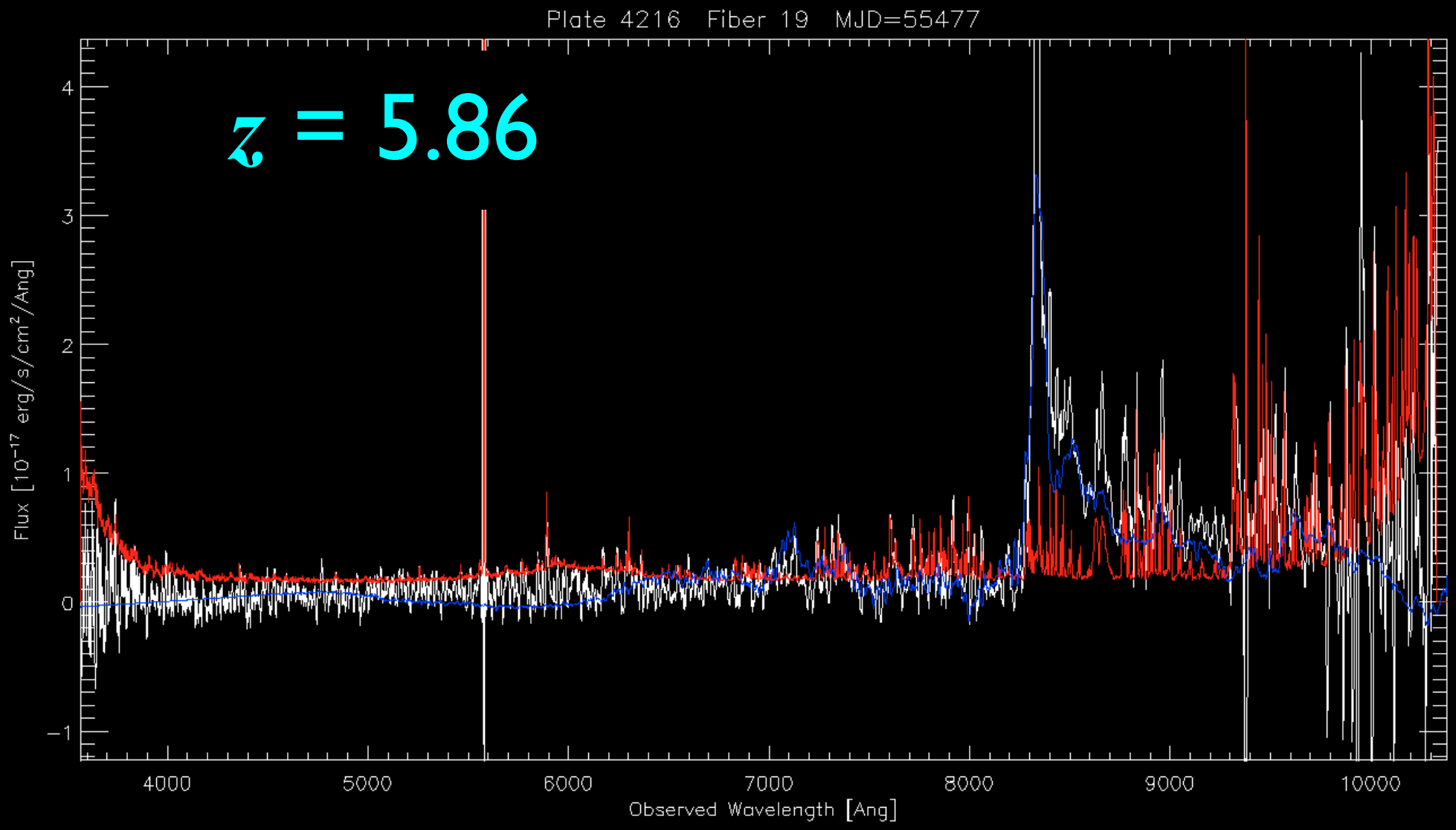
113,490 with reliable redshifts

81,280 with reliable redshifts and are quasars

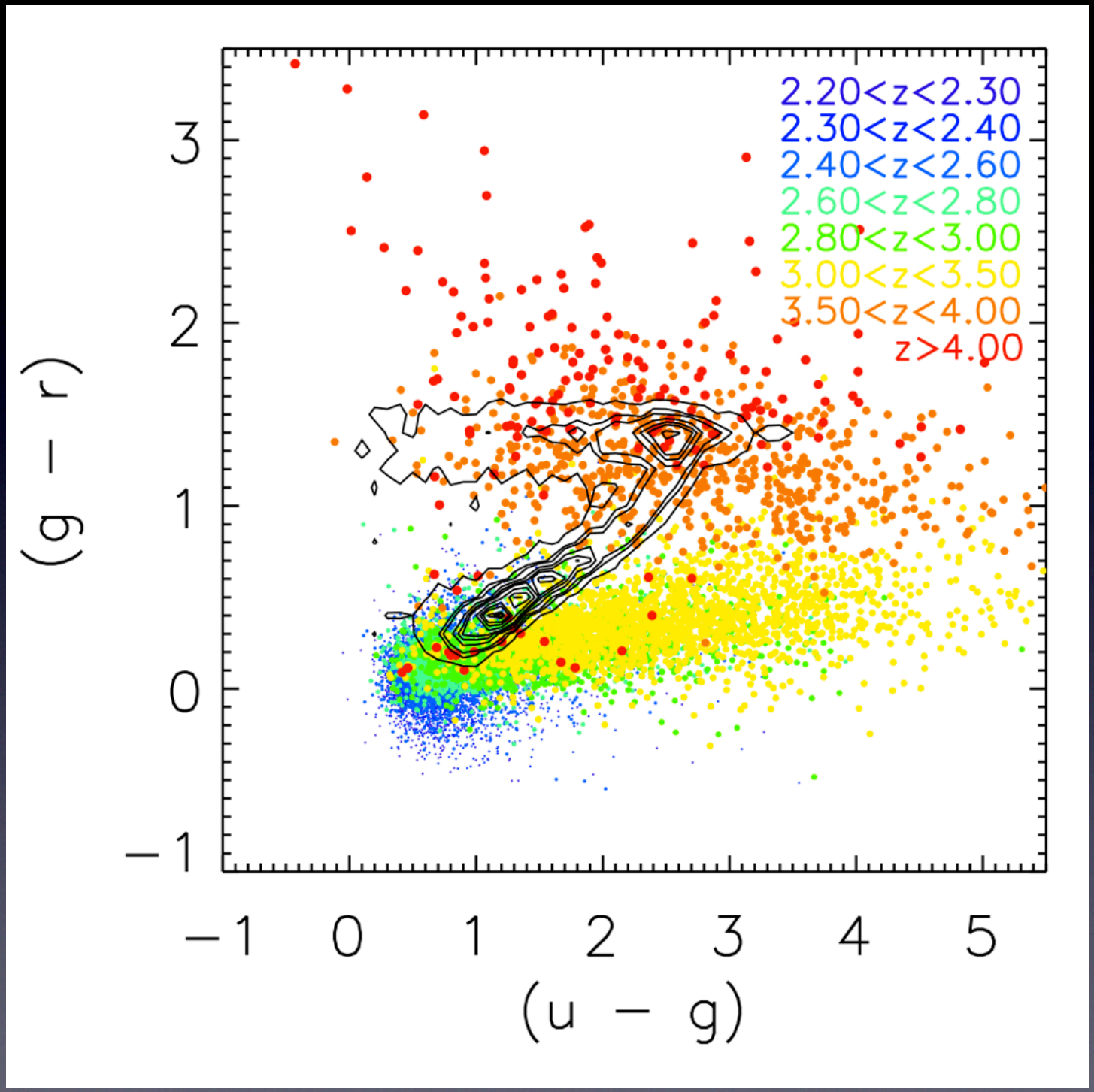
55,626 quasars with z>2.20


4000
3000
2000
1000
0
N(z), z=0.05 bins
SDSS DR7Q
Schneider et al. (2010)
0
1
2
3
4
5
6
z, redshift


BOSS Quasars
MJD 55693
SDSS DR7Q
Schneider et al. (2010)
N(z), z=0.05 bins
0
1000
2000
3000
4000
0
1
2
3
4
5
6
z, redshift



McGreer, Fan, Jiang *et al.* for the BOSS Quasar team


2.20<z<2.30
2.30<z<2.40
2.40<z<2.60
2.60<z<2.80
2.80<z<3.00
3.00<z<3.50
3.50<z<4.00
z>4.00
(g − r)
(u − g)
3
2
1
0
−1
−1
0
1
2
3
4
5


2. ii Today: Late 2011

The Quasar Luminosity Function

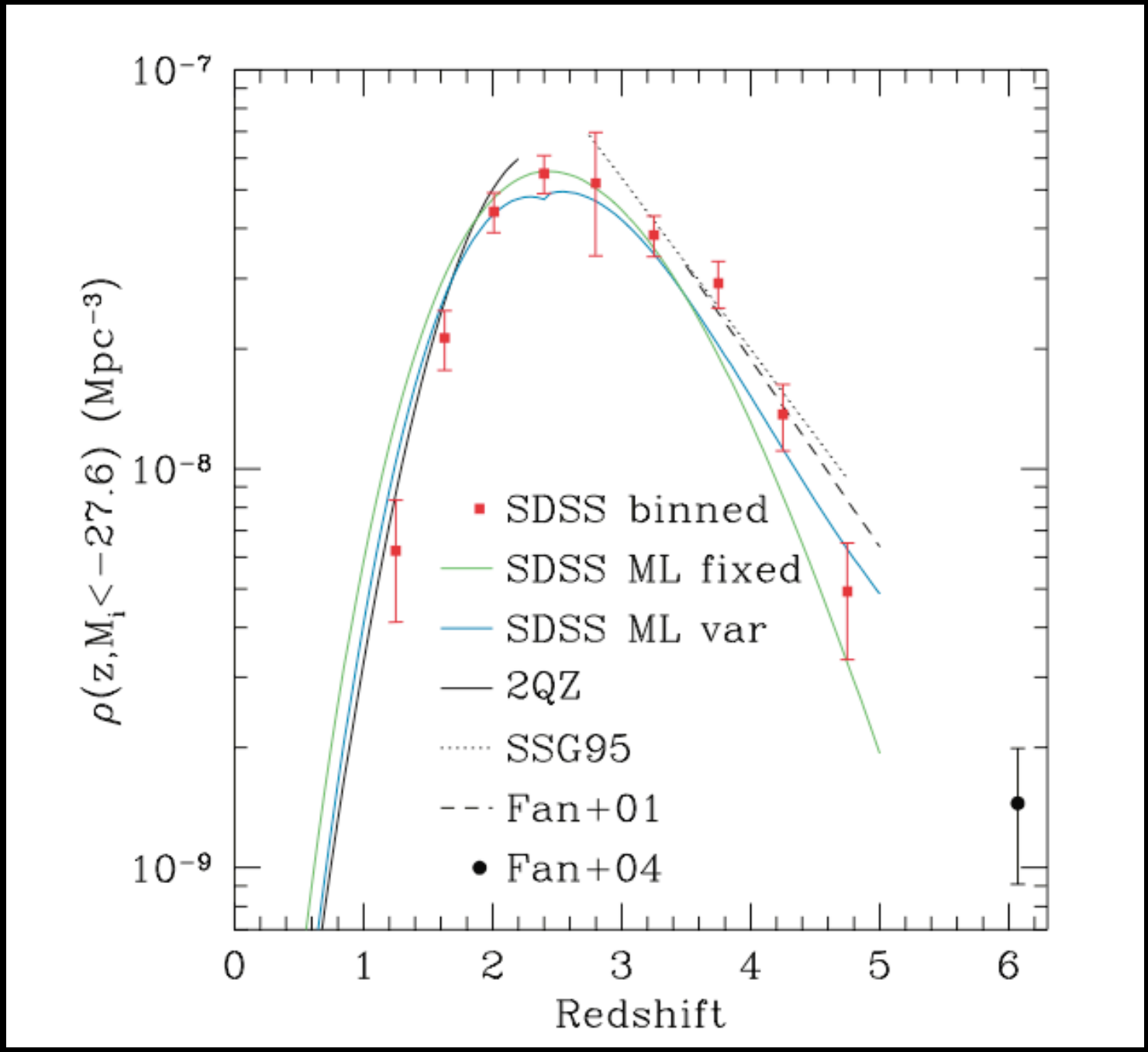
Formation History and Evolution of SMBHs

Cosmic backgrounds (UV, IR, X-ray)

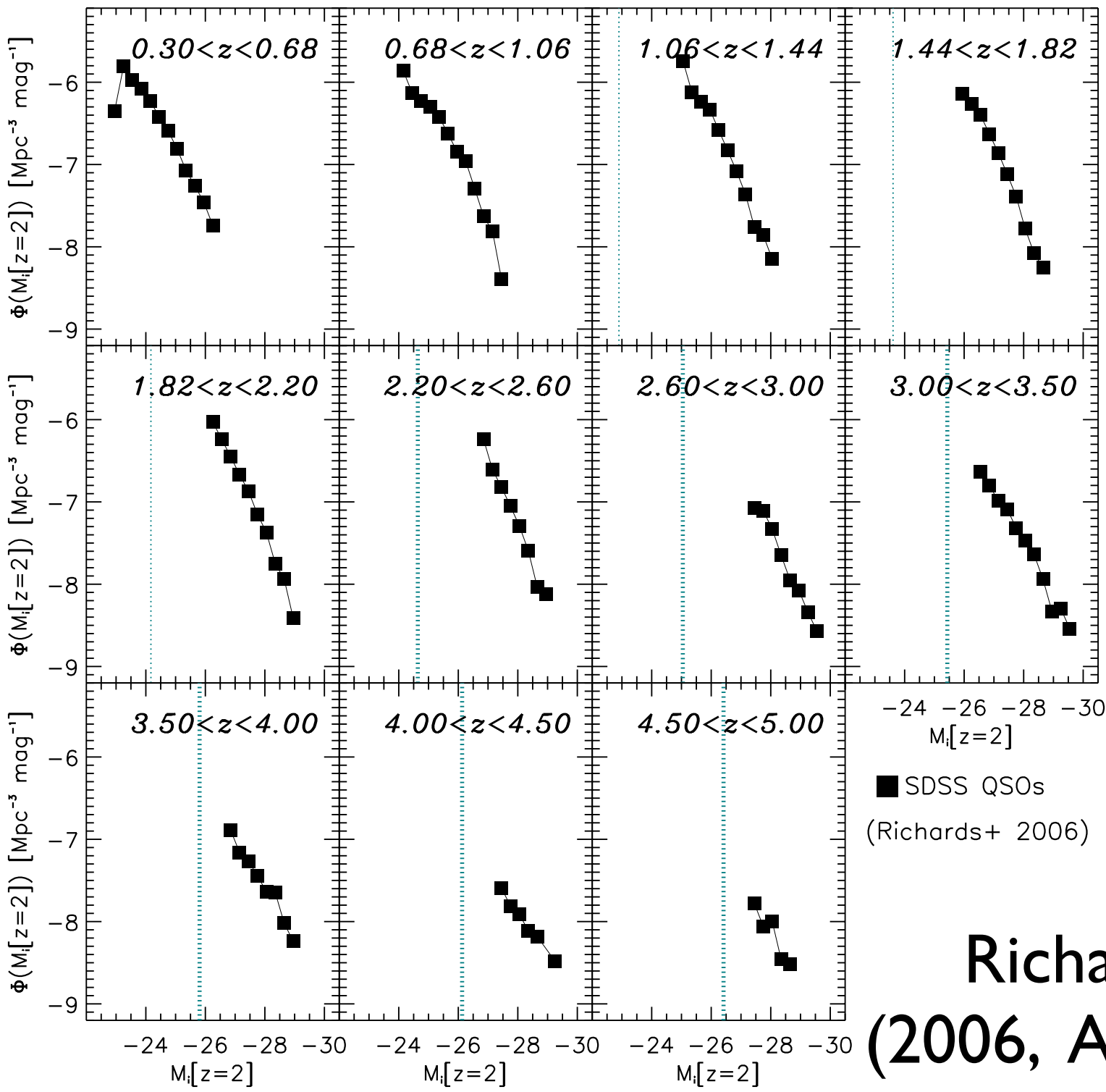
The Quasar Luminosity Function

BH-Spheroid connection

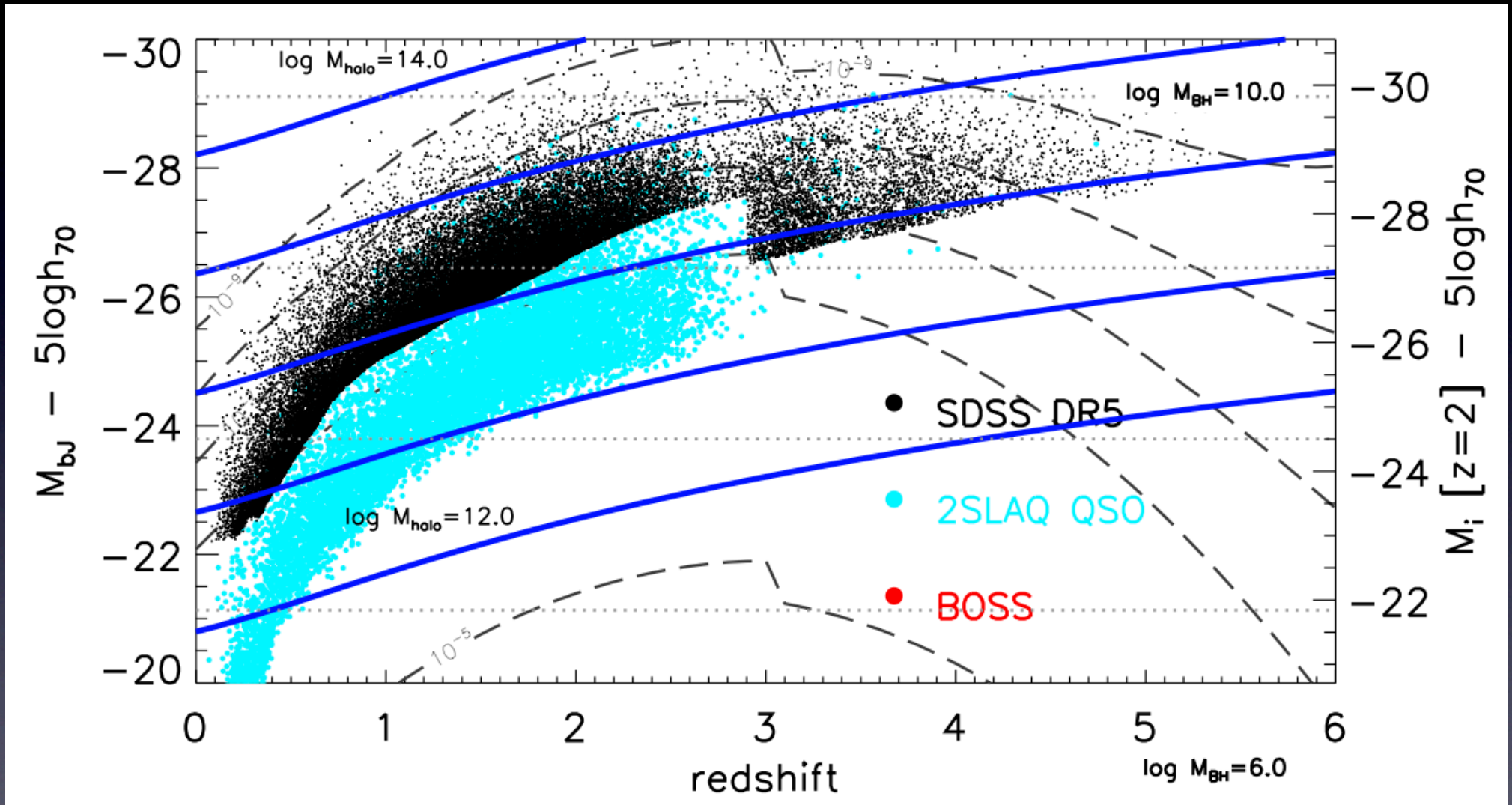
Estimates for LyAF surveys



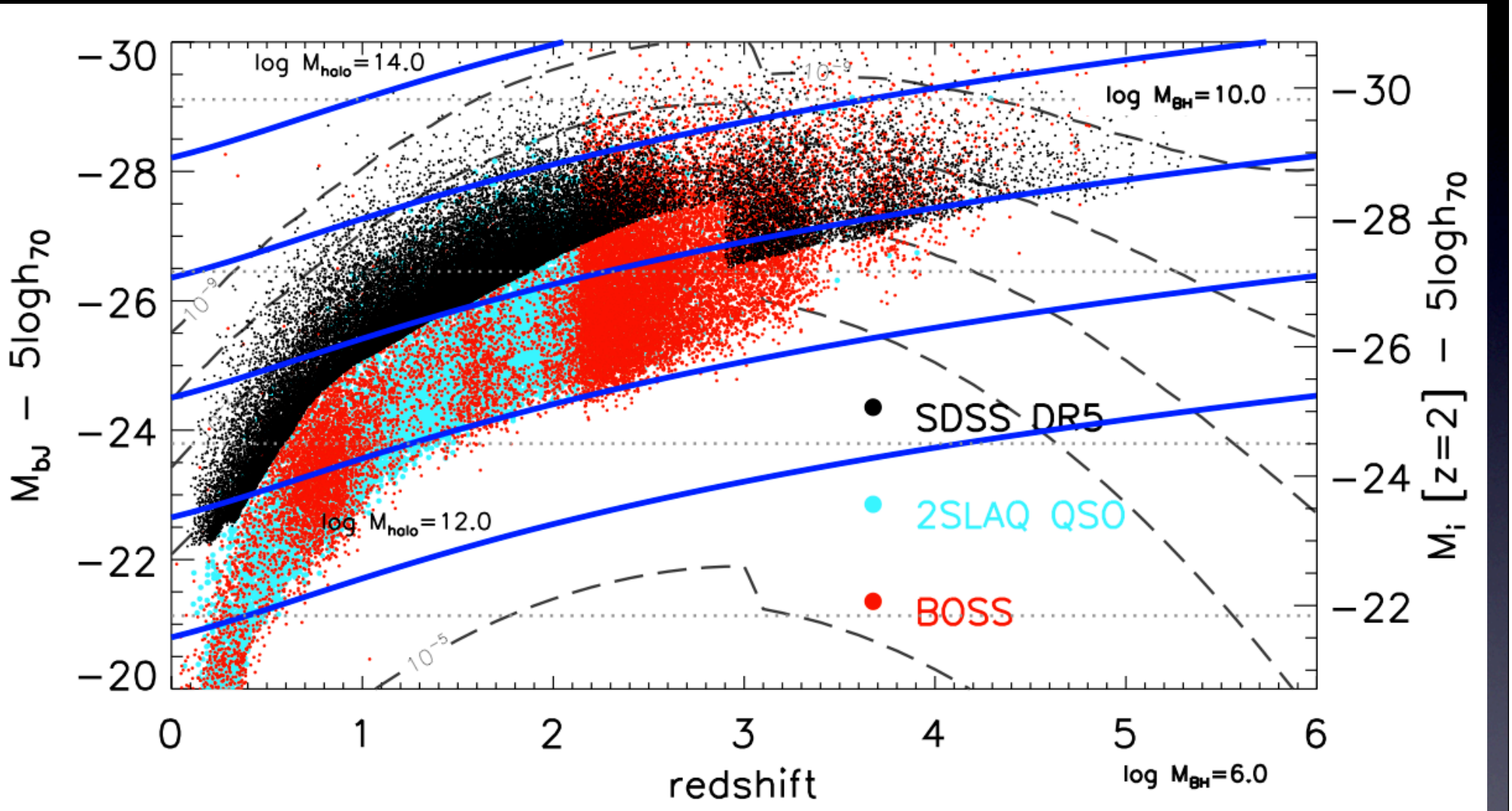
Richards et al. (2006, AJ, 131, 2766)



Richards et al.
(2006, AJ, 131, 2766)



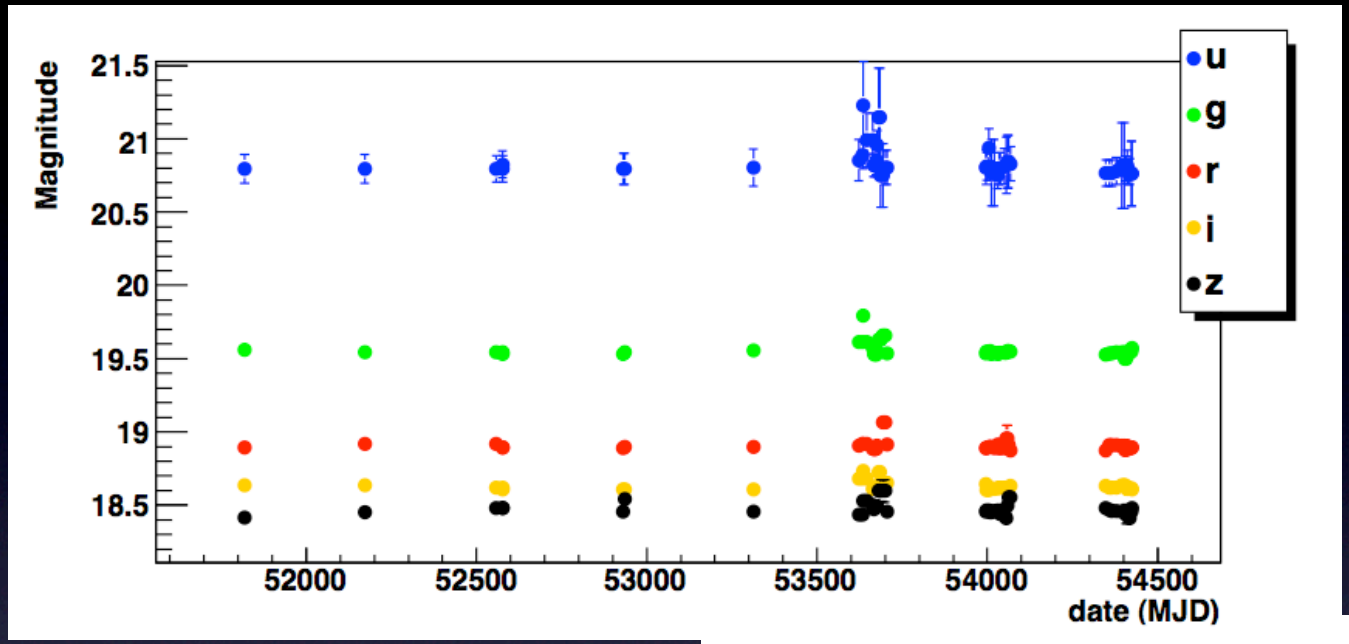
Ross et al. (2011b, in prep)



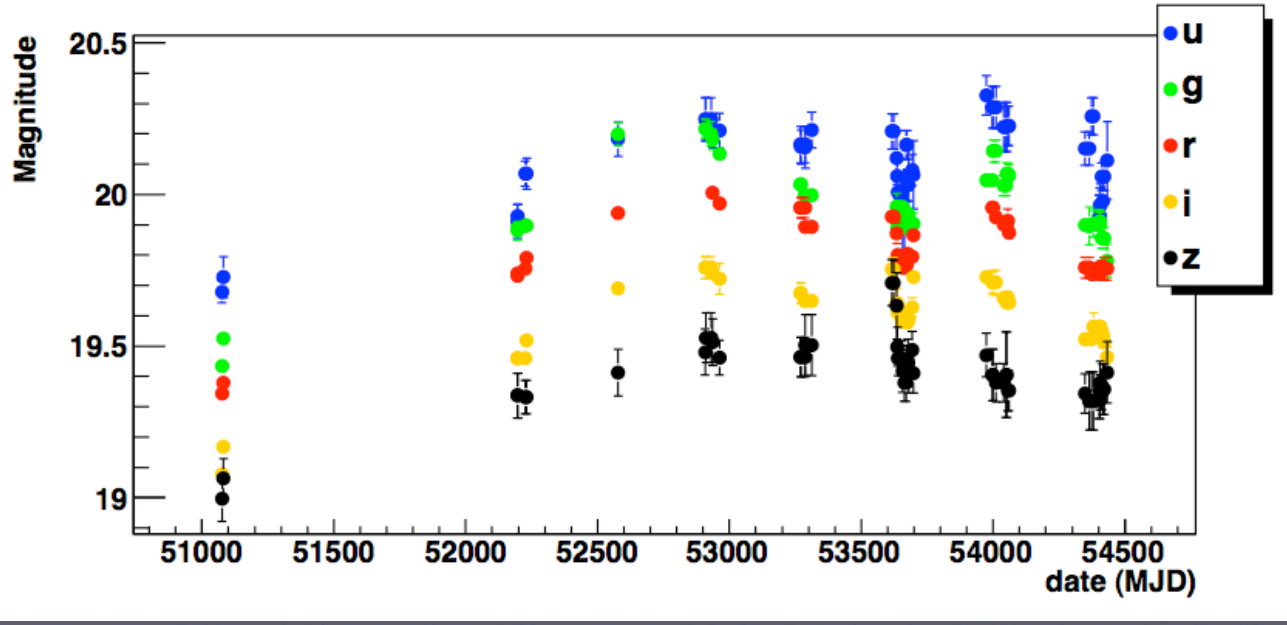
Ross et al. (2011b, in prep)

Stripe 82

Variability Selection



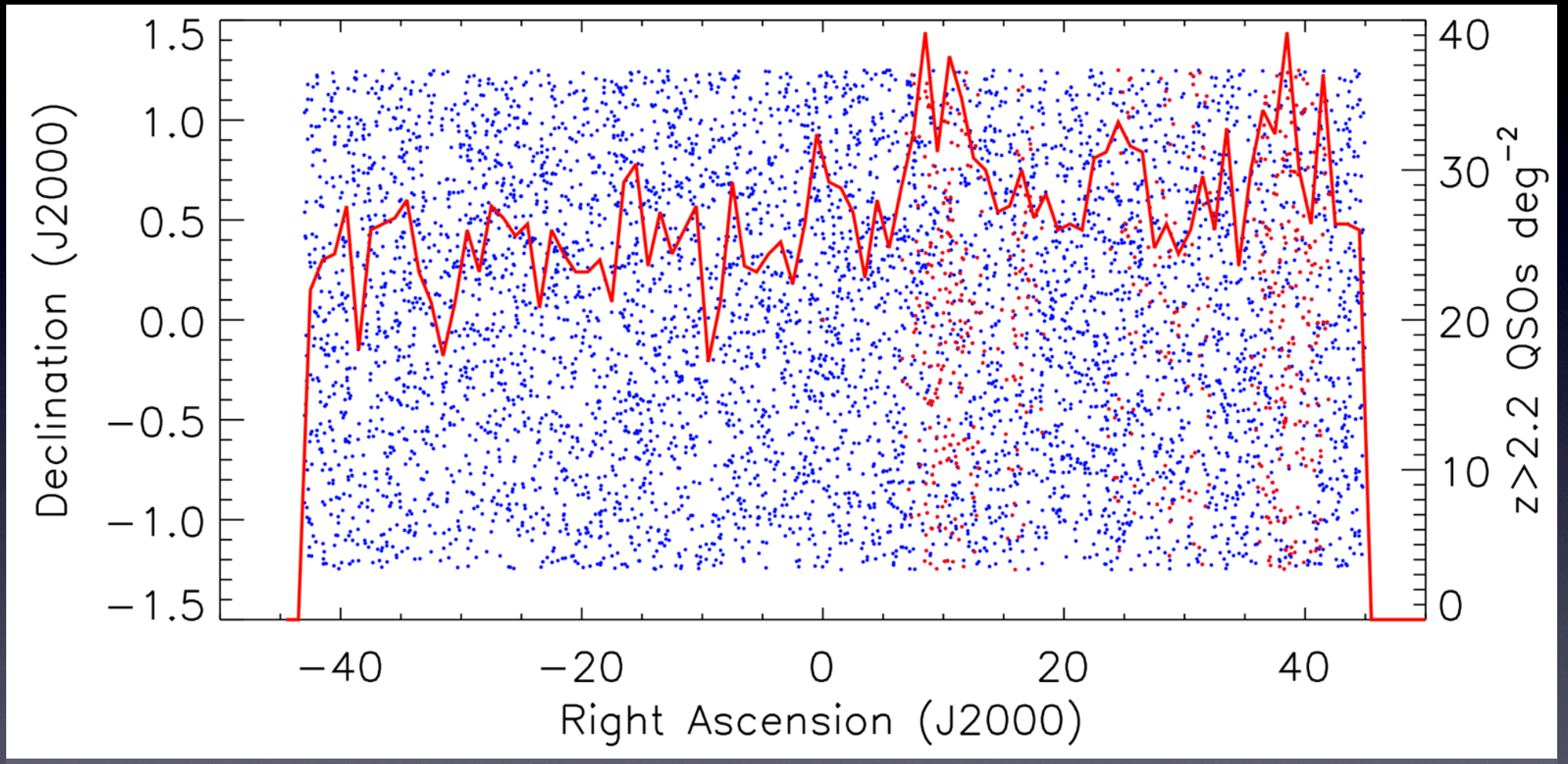
star



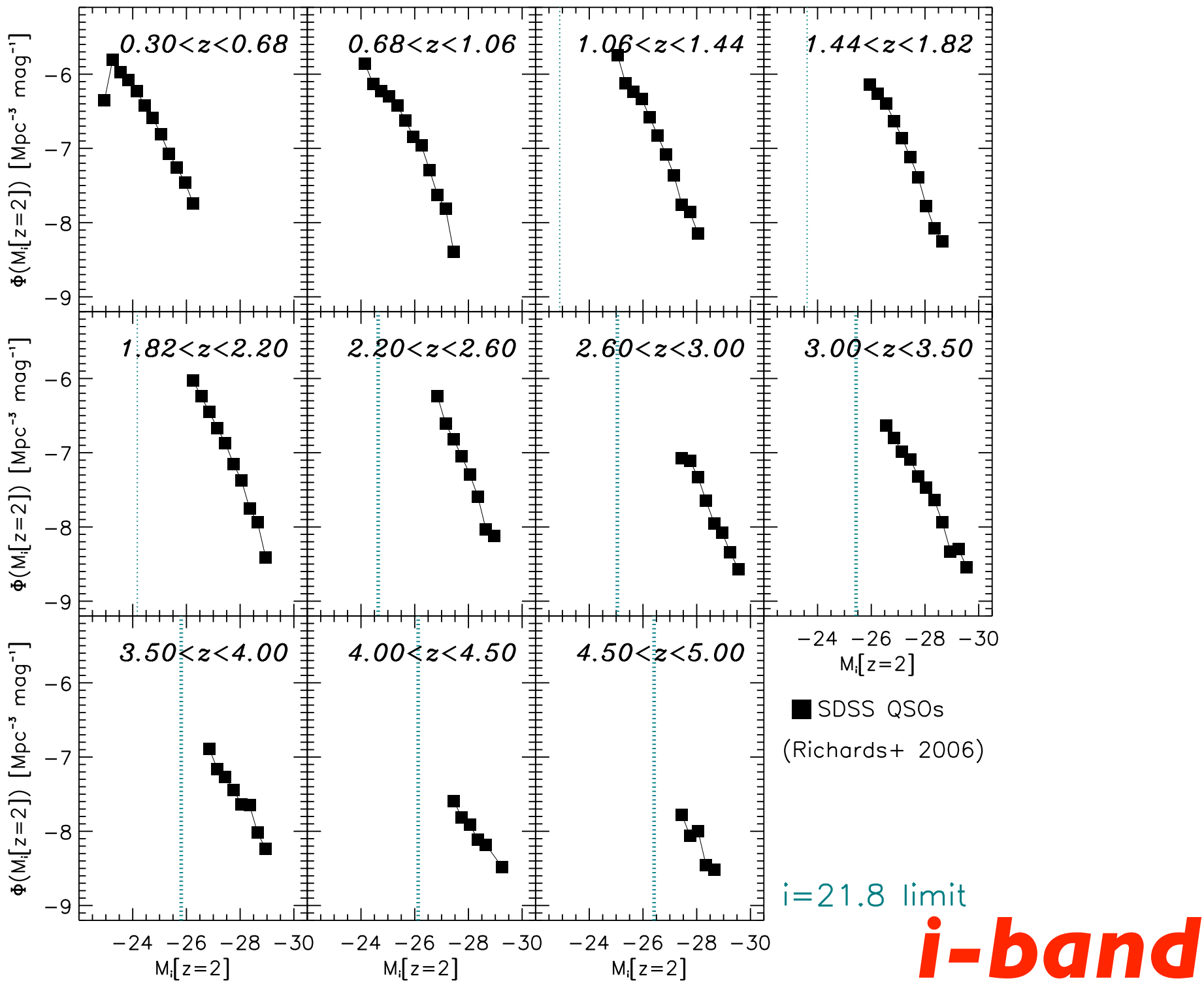
Quasar

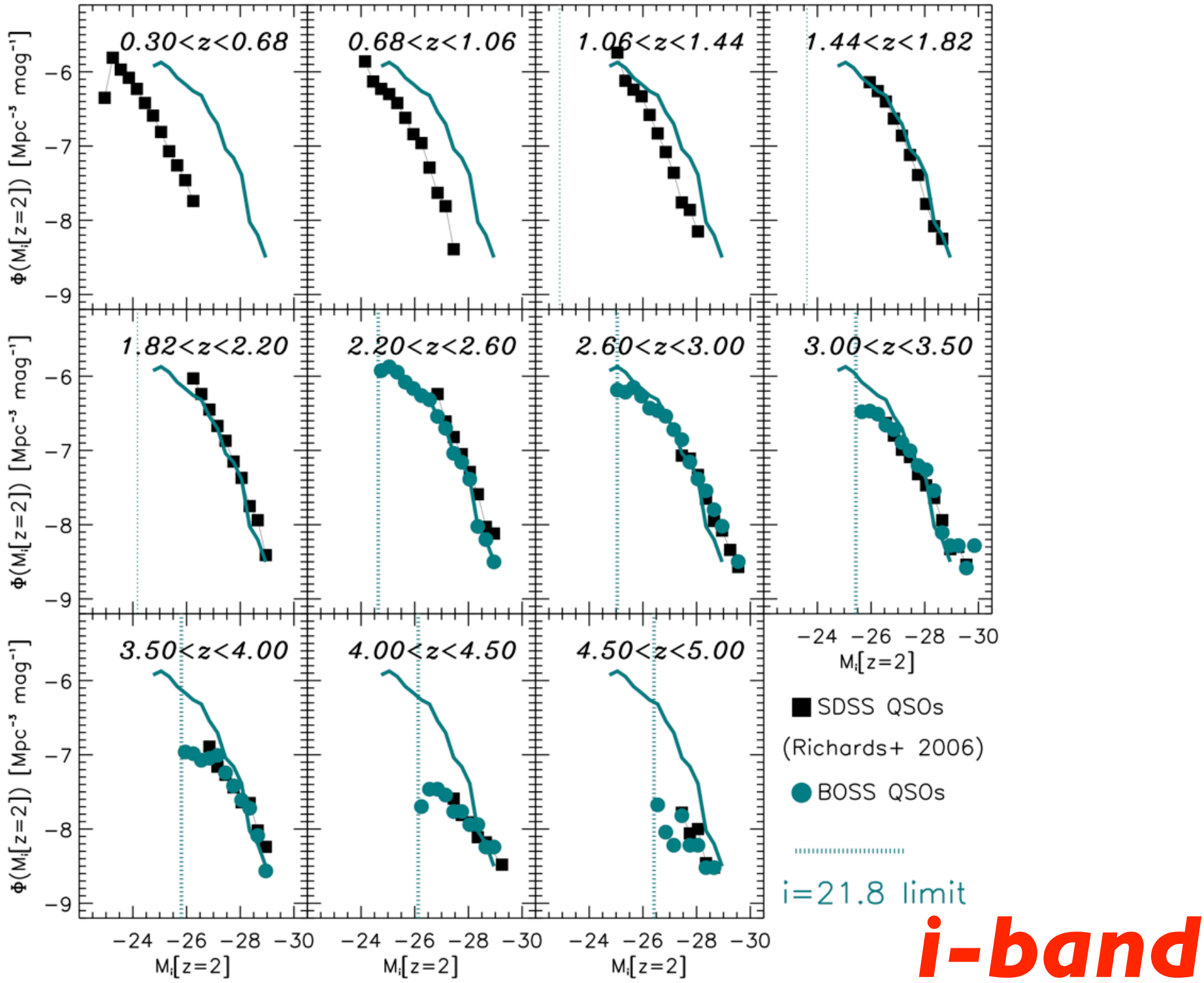
Palanque-Delabrouille et al. (2011)

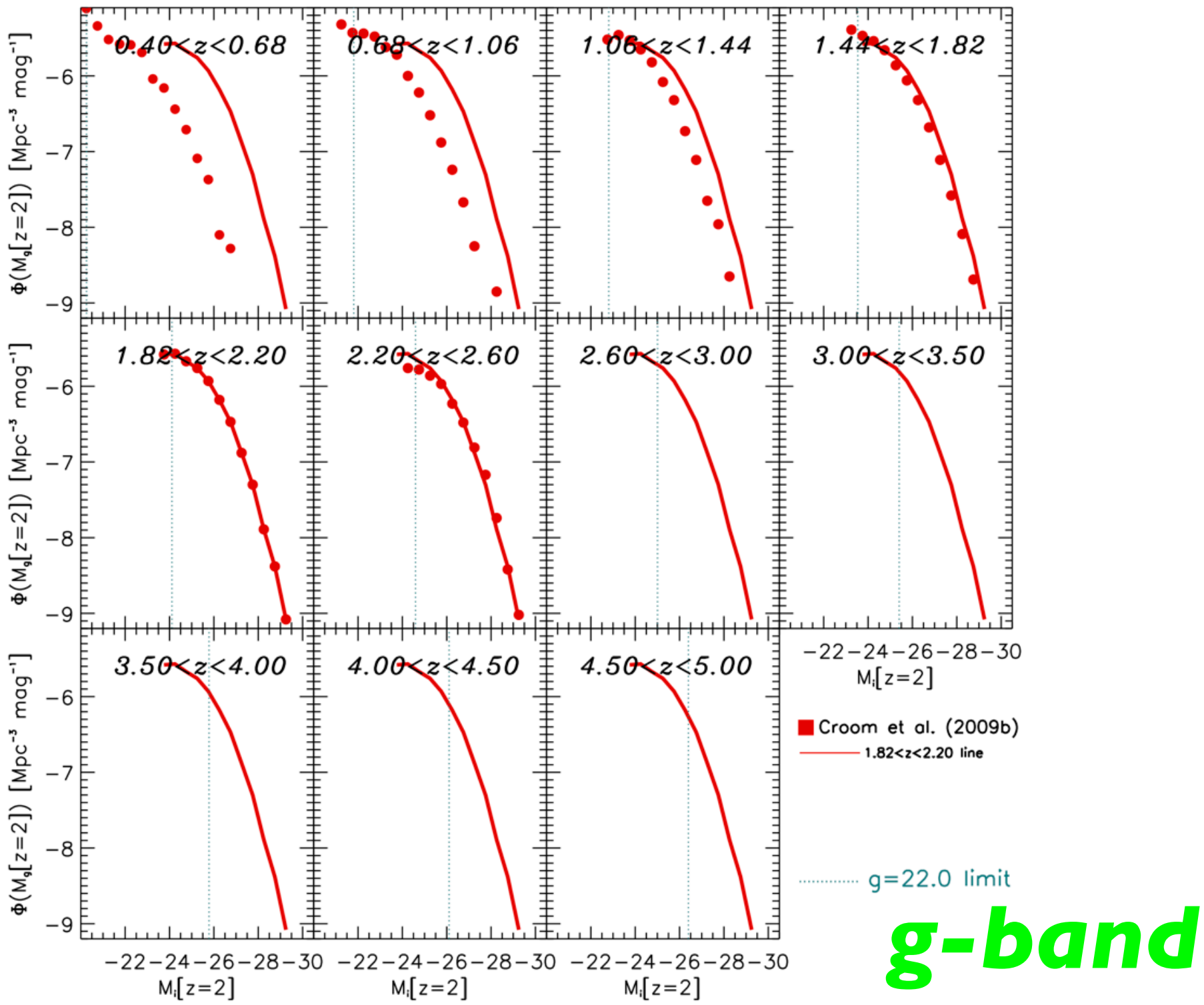
Variability Selection Stripe 82

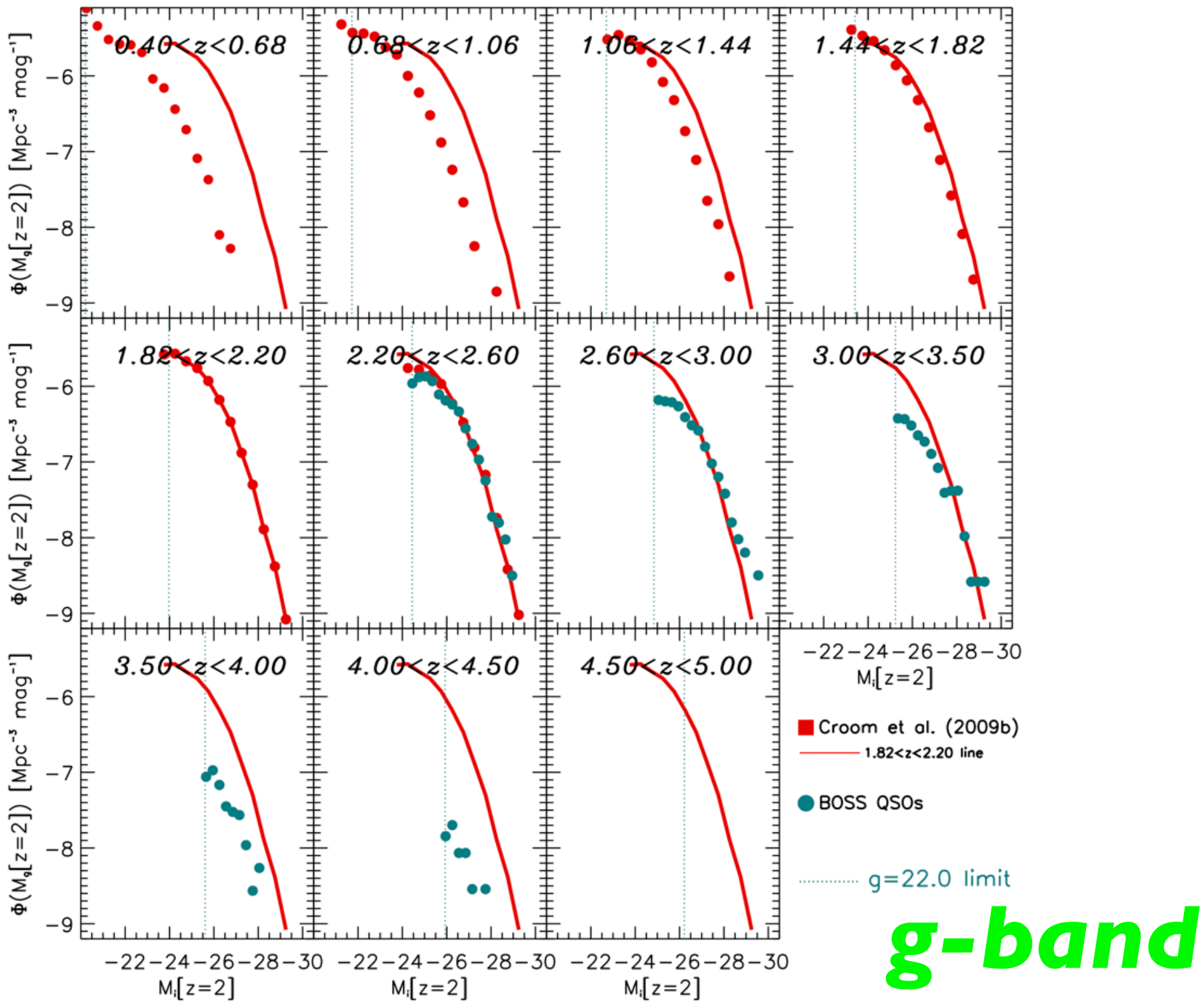


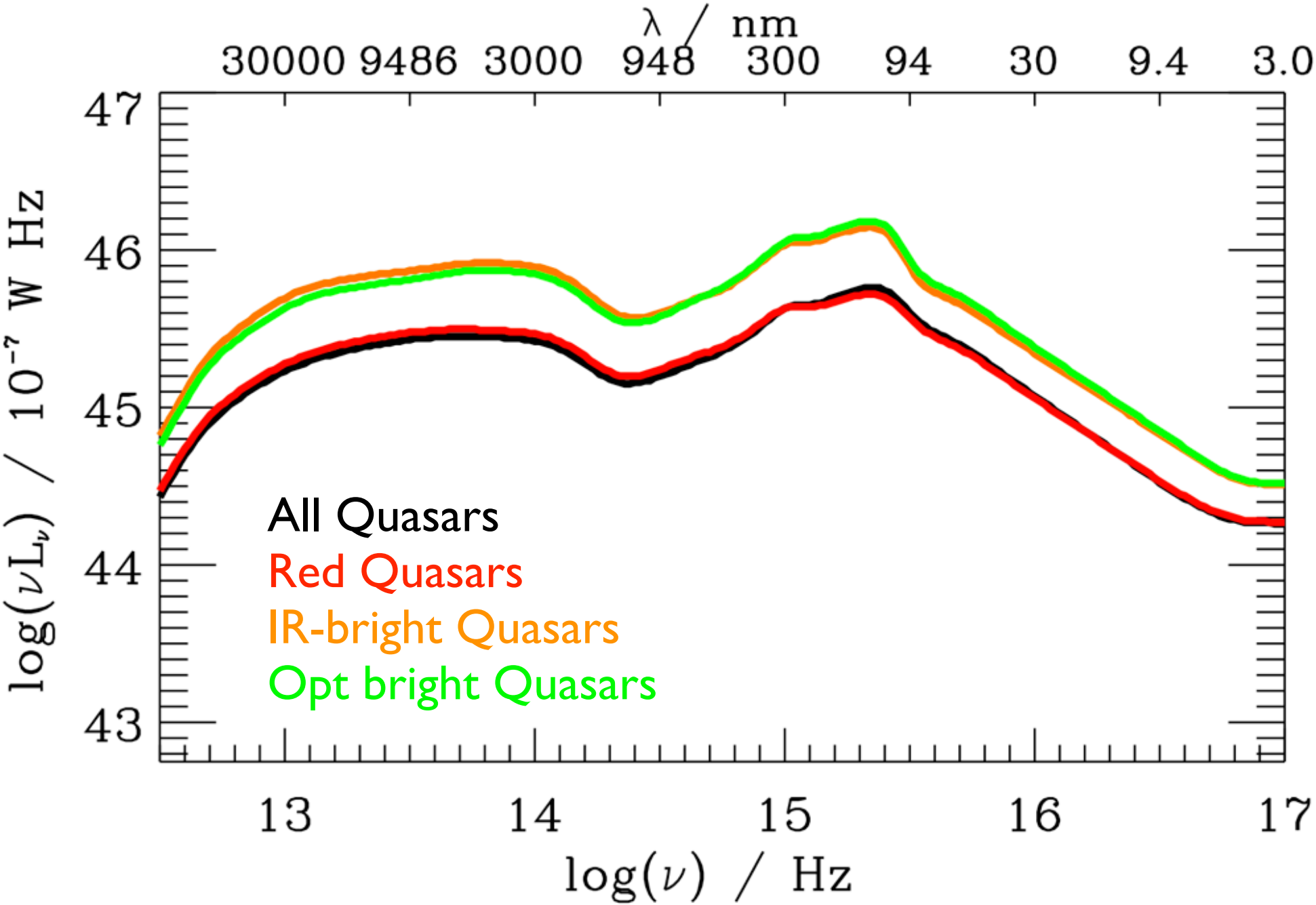
Palanque-Delabrouille et al. (2011)


0.30<z<0.68
0.68<z<1.06
1.06<z<1.44
1.44<z<1.82
1.82<z<2.20
2.20<z<2.60
2.60<z<3.00
3.00<z<3.50
3.50<z<4.00
4.00<z<4.50
4.50<z<5.00
Φ(M_i[z=2]) [Mpc^-3 mag^-1]
M_i[z=2]
−6
−7
−8
−9
−24
−26
−28
−30
SDSS QSOs
(Richards+ 2006)
i=21.8 limit
i-band

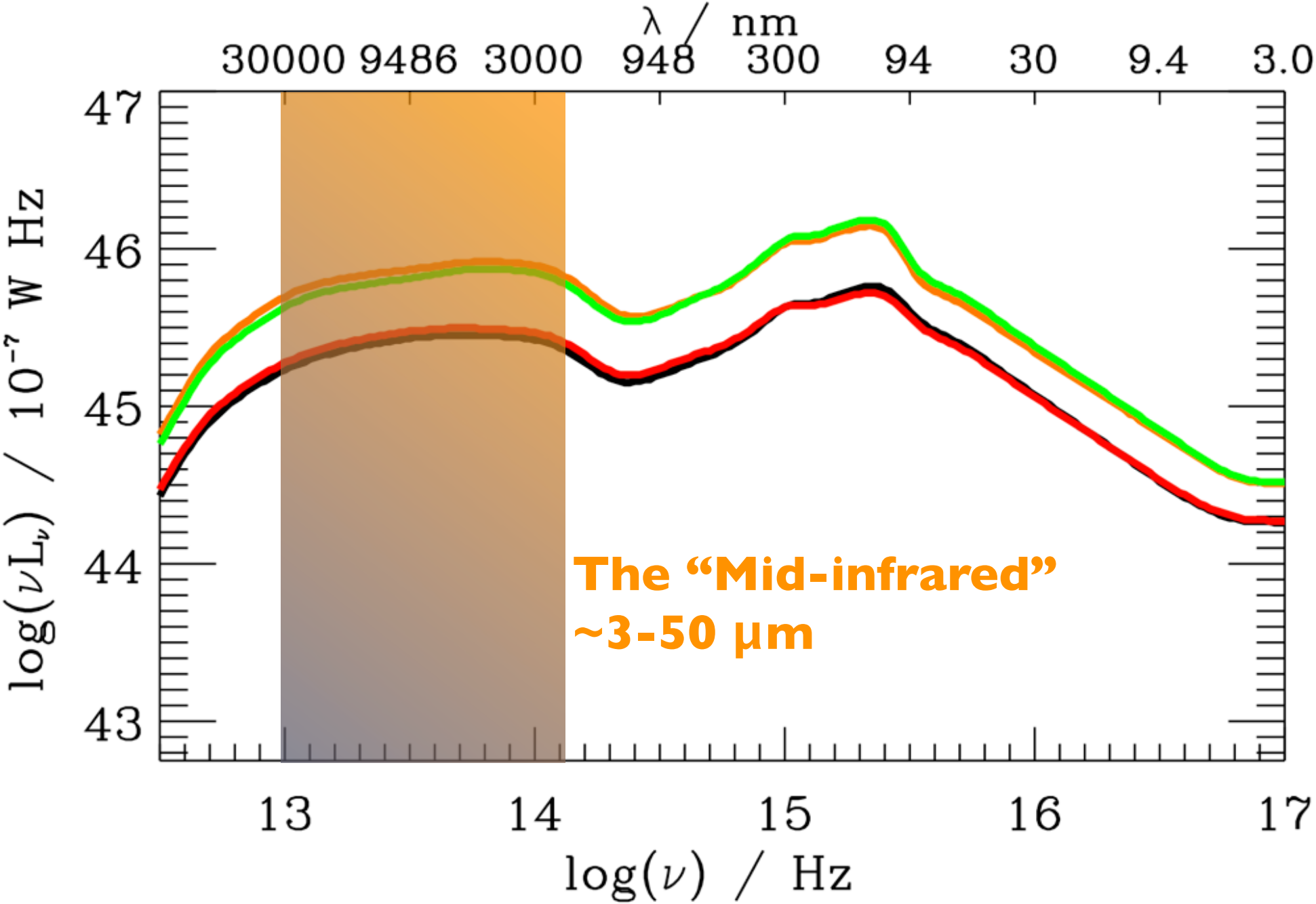

0.30<z<0.68
0.68<z<1.06
1.06<z<1.44
1.44<z<1.82
1.82<z<2.20
2.20<z<2.60
2.60<z<3.00
3.00<z<3.50
3.50<z<4.00
4.00<z<4.50
4.50<z<5.00
Φ(M_i[z=2]) [Mpc^-3 mag^-1]
M_i[z=2]
SDSS QSOs
(Richards+ 2006)
BOSS QSOs
i=21.8 limit
i-band


0.40<z<0.68
0.68<z<1.06
1.06<z<1.44
1.44<z<1.82
1.82<z<2.20
2.20<z<2.60
2.60<z<3.00
3.00<z<3.50
3.50<z<4.00
4.00<z<4.50
4.50<z<5.00
Φ(M_g[z=2]) [Mpc^-3 mag^-1]
M_i[z=2]
−22 −24 −26 −28 −30
−6 −7 −8 −9
Croom et al. (2009b)
1.82<z<2.20 line
g=22.0 limit
g-band


0.40<z<0.68
0.68<z<1.06
1.06<z<1.44
1.44<z<1.82
1.82<z<2.20
2.20<z<2.60
2.60<z<3.00
3.00<z<3.50
3.50<z<4.00
4.00<z<4.50
4.50<z<5.00
Φ(M_g[z=2]) [Mpc^-3 mag^-1]
M_i[z=2]
−22 −24 −26 −28 −30
−6 −7 −8 −9
Croom et al. (2009b)
1.82<z<2.20 line
BOSS QSOs
g=22.0 limit
g-band

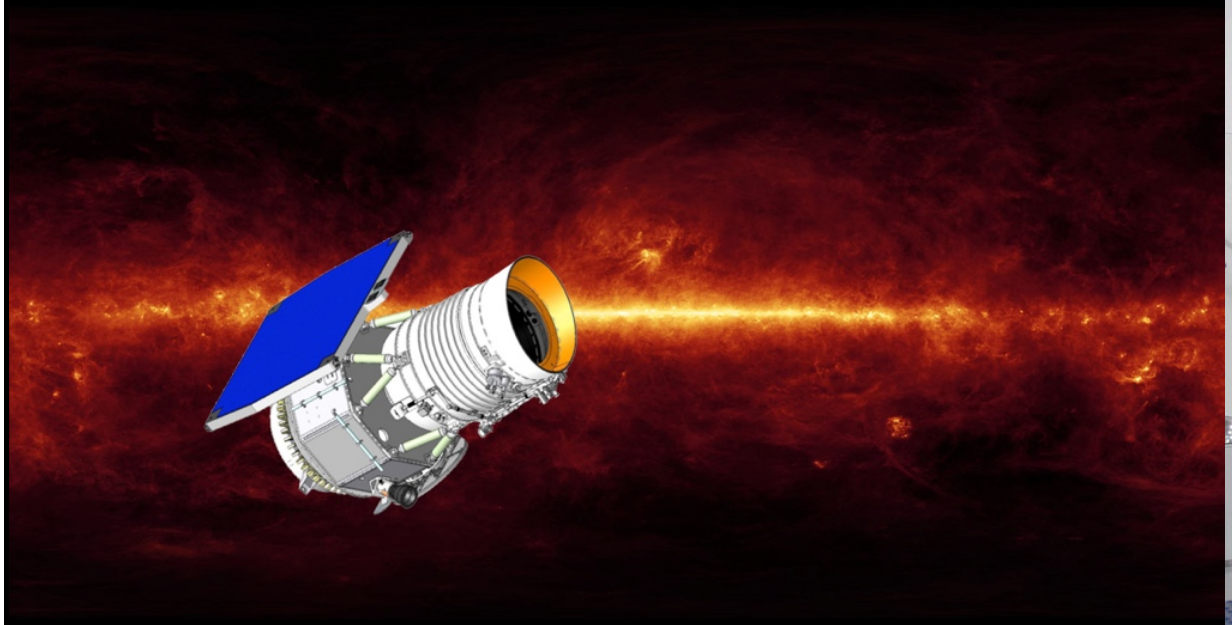


Richards et al. (2006, ApJS, 166, 470, and Refs. therein)



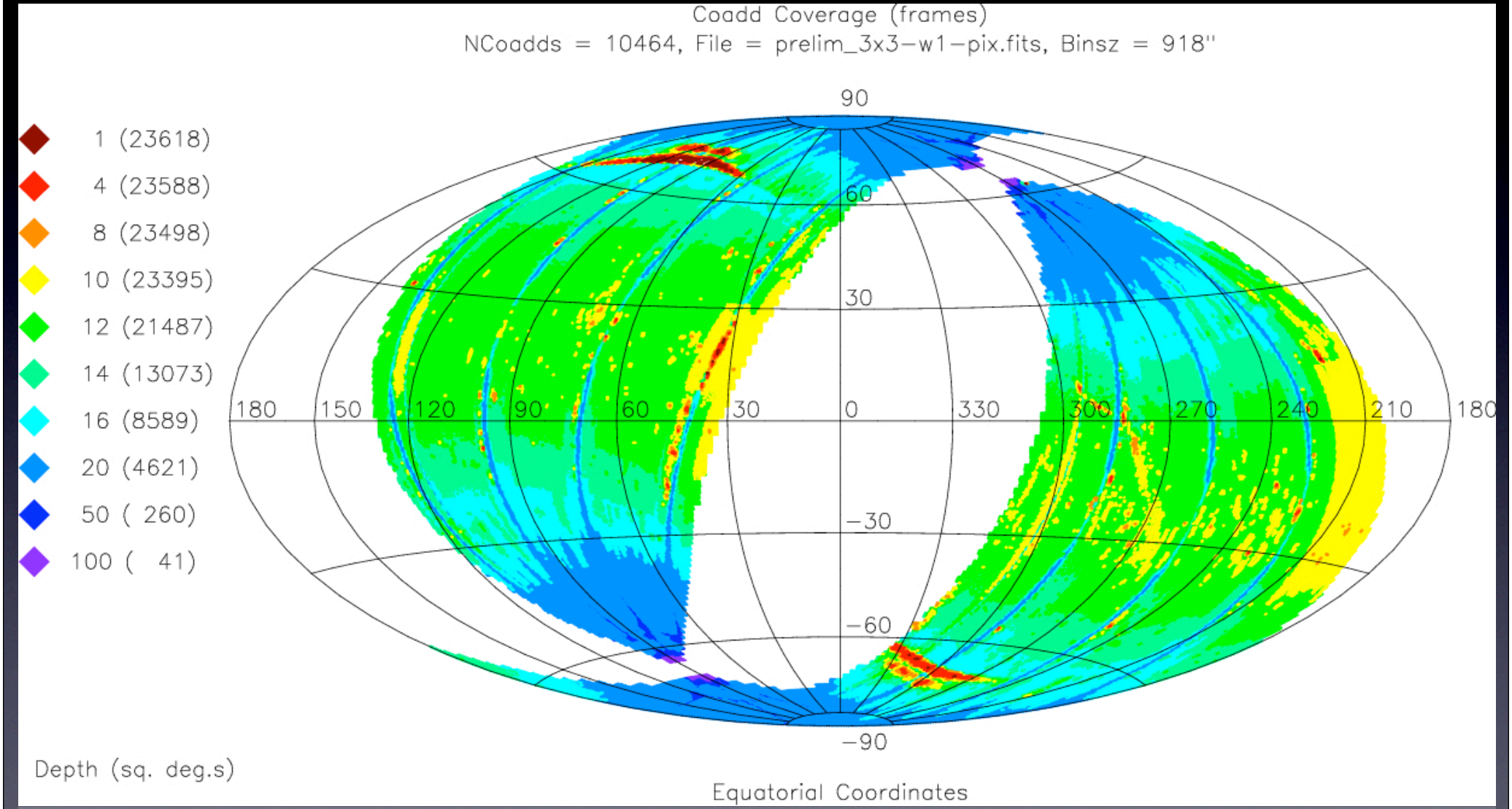
Richards et al. (2006, ApJS, 166, 470, and Refs. therein)

Wide Infrared Survey Explorer (WISE)

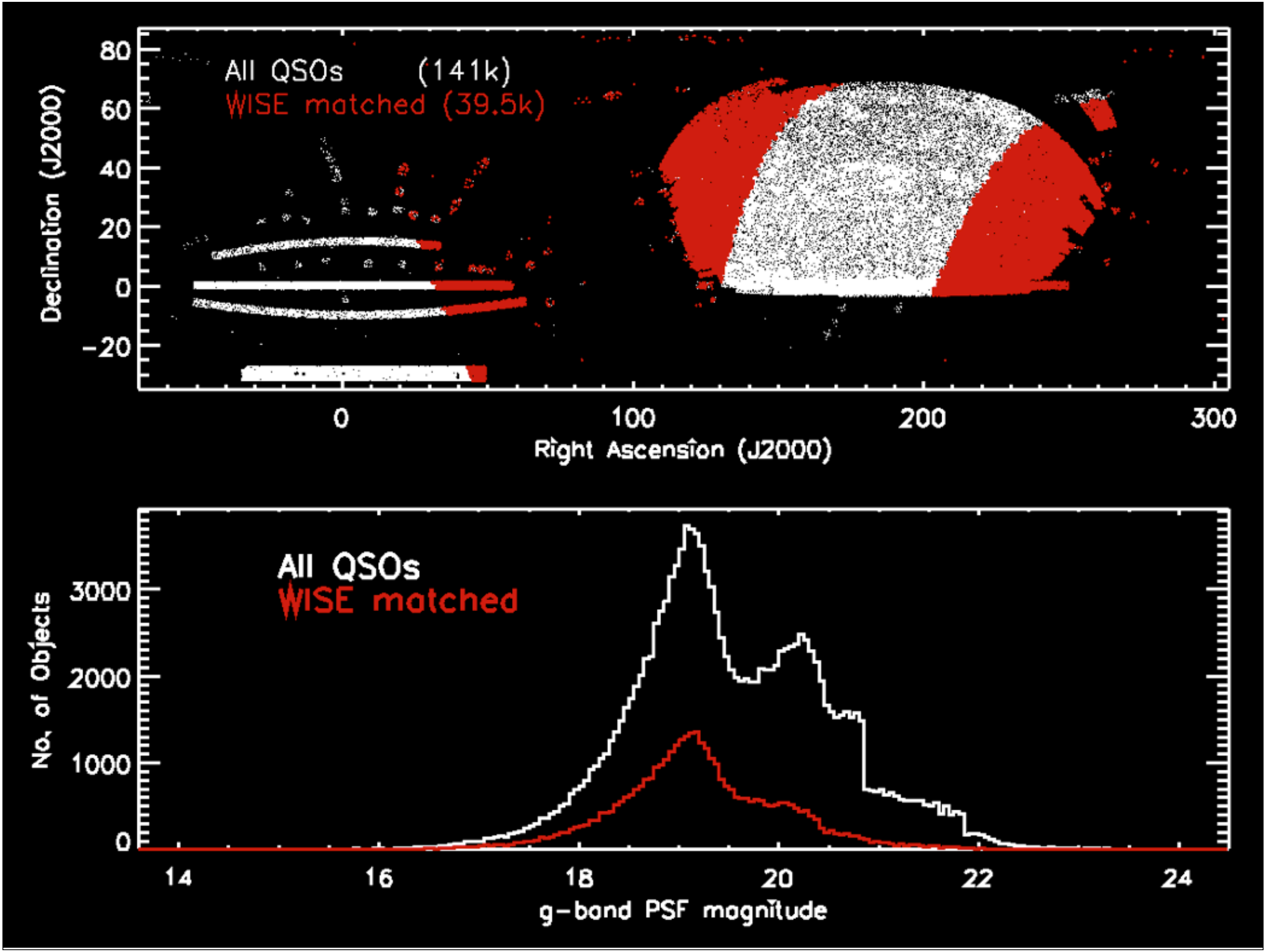


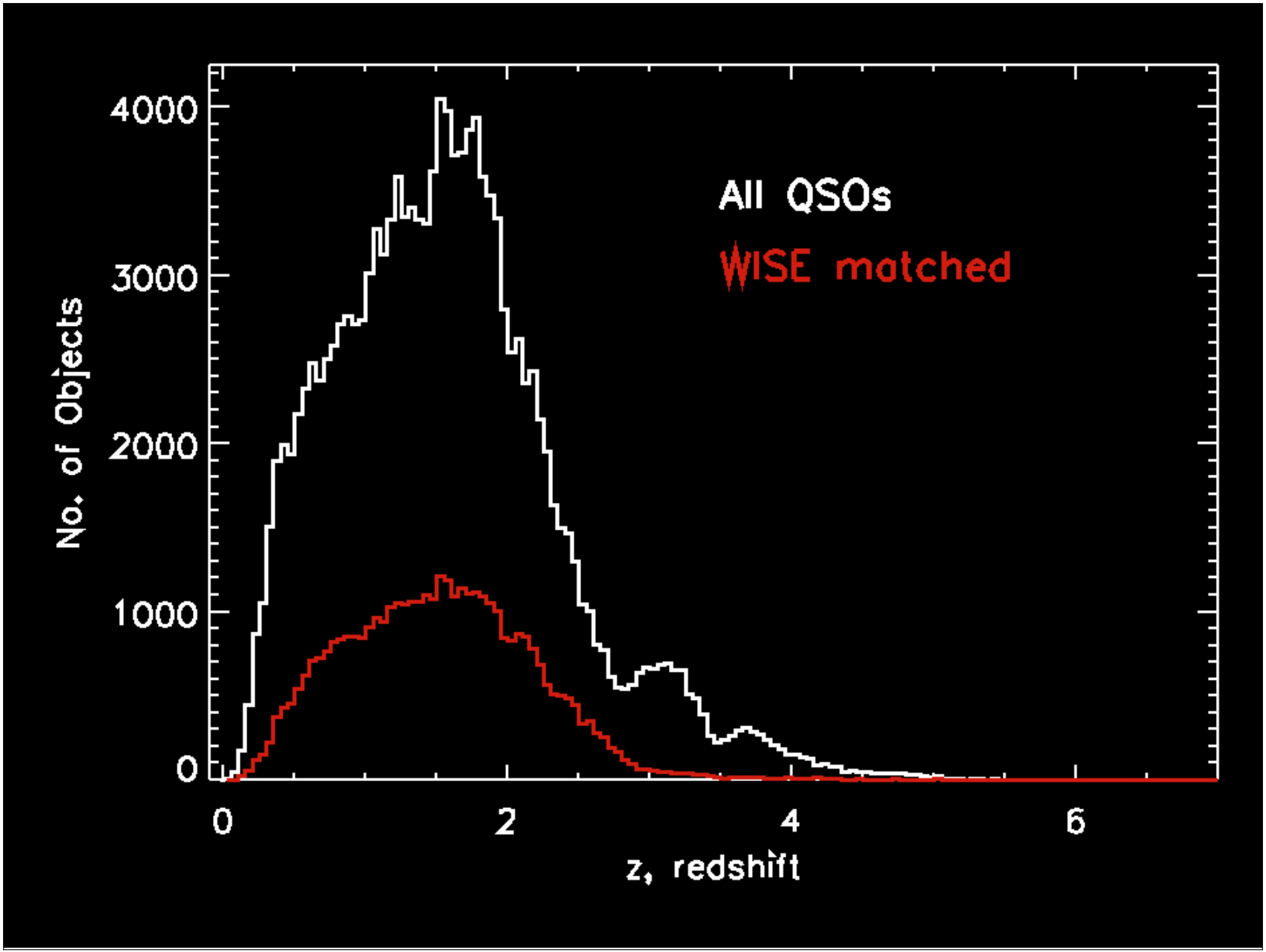
3.4, 4.6, 12, 22μm
0.08, 0.11, 1, 6 mJy
All-sky

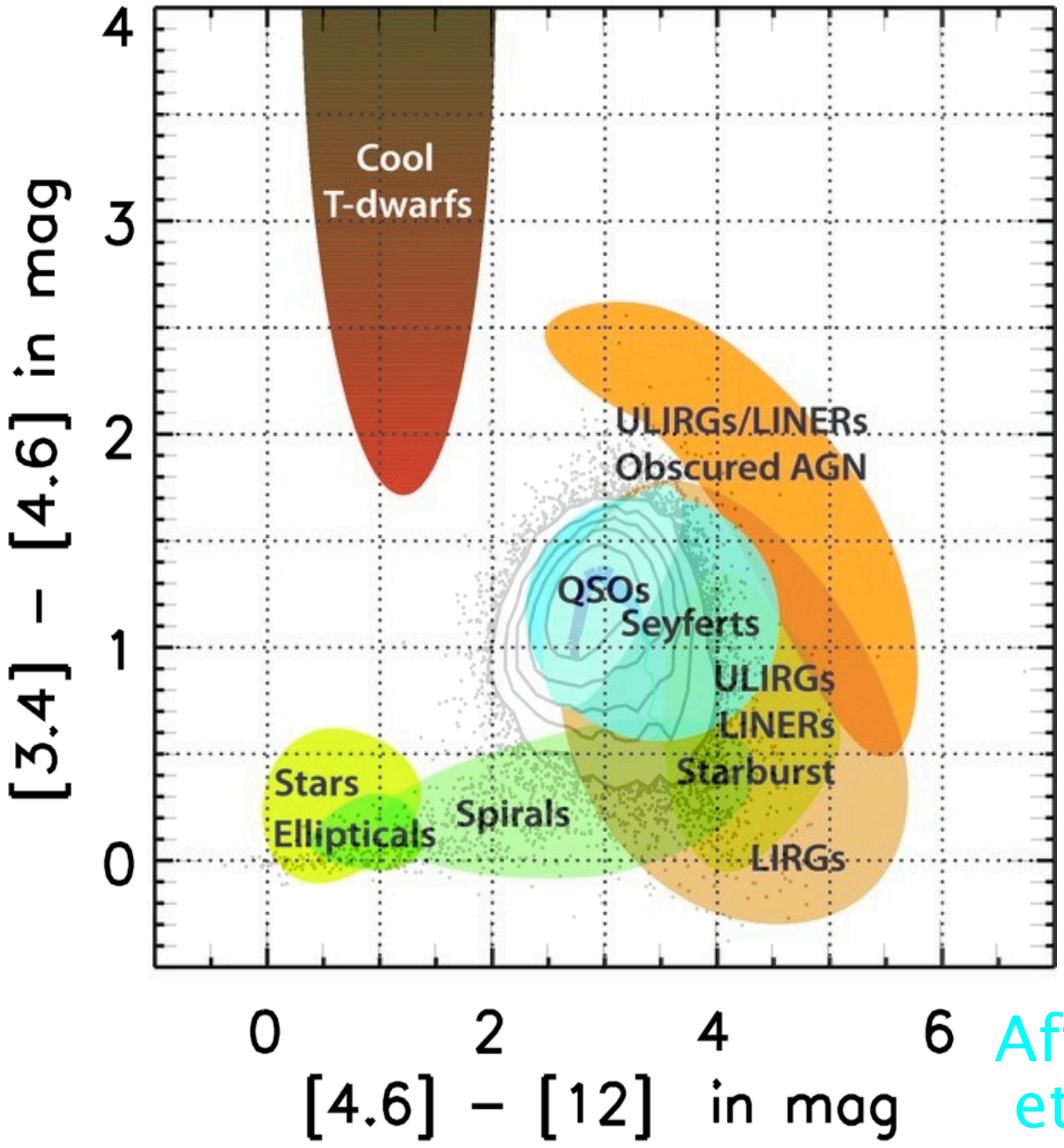
Wright et al. (2010)
wise.ssl.berkeley.edu



http://wise2.ipac.caltech.edu/docs/release/prelim/


All QSOs (141k)
WISE matched (39.5k)
Declination (J2000)
80
60
40
20
0
−20
0
100
200
300
Right Ascension (J2000)
All QSOs
WISE matched
No. of Objects
3000
2000
1000
0
14
16
18
20
22
24
g−band PSF magnitude


All QSOs
WISE matched
No. of Objects
z, redshift
0
1000
2000
3000
4000
0
2
4
6



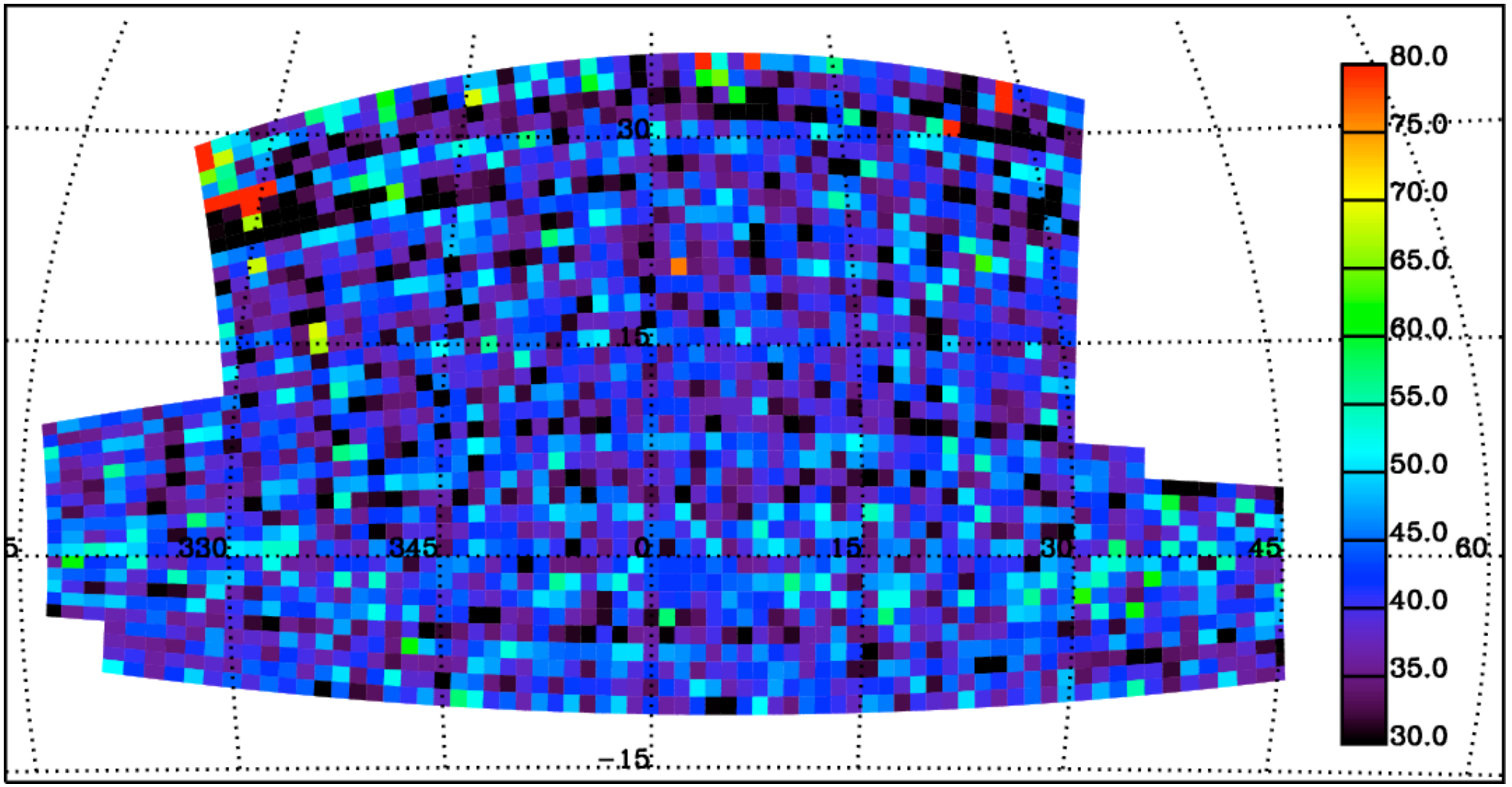
After: Wright et al. (2010)


1. Future (post-mid 2014)

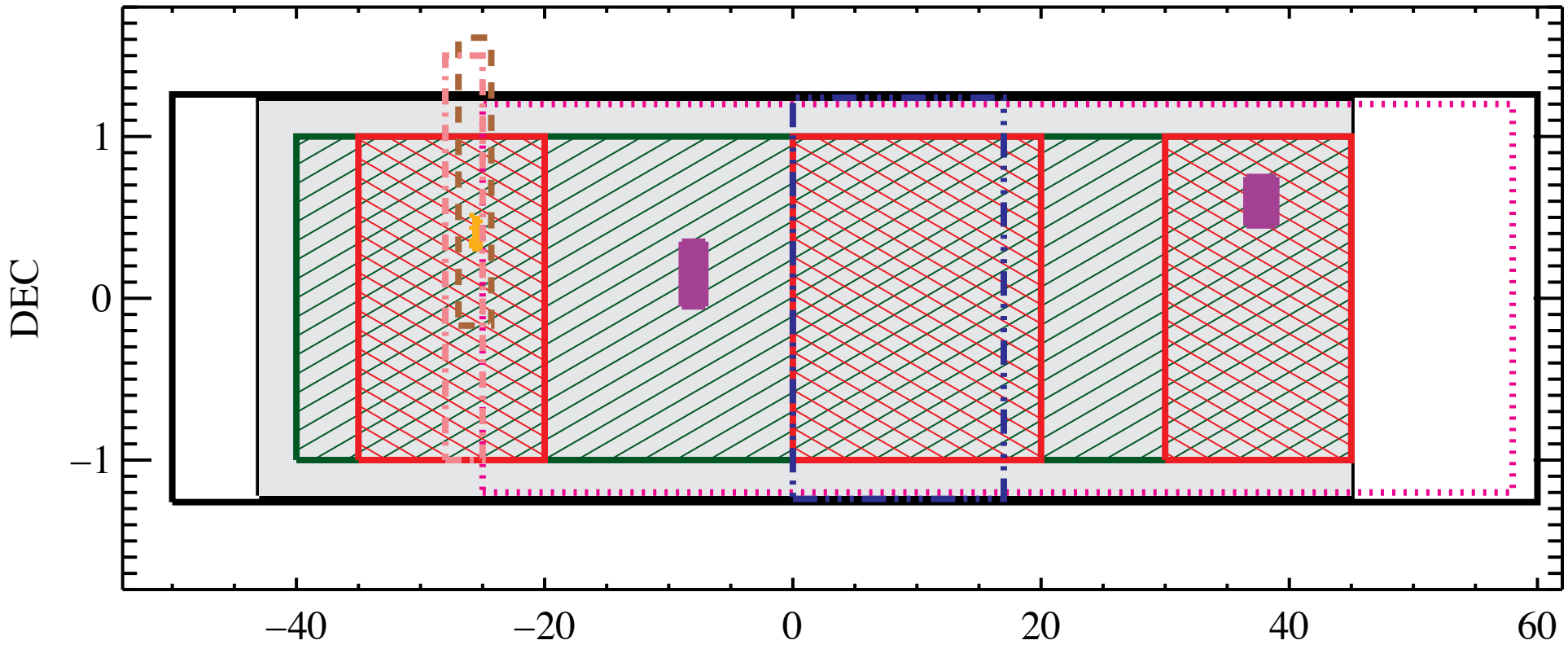
After Sloan 3: BOSS+

Eric Aubourg (APC), Niel Brandt (Penn State), Kevin Bundy (UC, Berkeley), Xiaohui Fan (Arizona), Richard McMahon (Cambridge), Adam Myers (U. Illinois), Bob Nichol (Portsmouth), Nathalie Palanque-Delabrouille (CEA-Saclay), Patrick Petitjean (IAP), Gordon Richards (Drexel), Emmanuel Rollinde (IAP), Nic Ross (LBNL), Don Schneider (Penn State), Scott Anderson (U. Washington), Anze Slosar (BNL), Michael Strauss (Princeton), Martin White (UC, Berkeley/LBNL) and Christophe Yeche (CEA-Saclay).

3,000 deg^2 in the Southern Galactic Cap...



...1/10th survey by SDSS-I/II



Imaging :

- Stripe 82 SDSS imaging (ugriz, i<22.75, 270 deg^2)
- CFHT imaging for lensing (170 deg^2, i<23.5) (this team)
- UKIDDS LAS, K_{vega}=18.4
- UKIDSS: DXS Field 4
- CFHTLS W4
- NESSIE (this proposal), K_{vega}=20

Spectroscopy :

- BOSS (220 deg^2, 40,000 redshifts)
- DEEP2 and PRIMUS
- VVDS
- Wiggle−z

+ deep VLA, ACT (SZ)

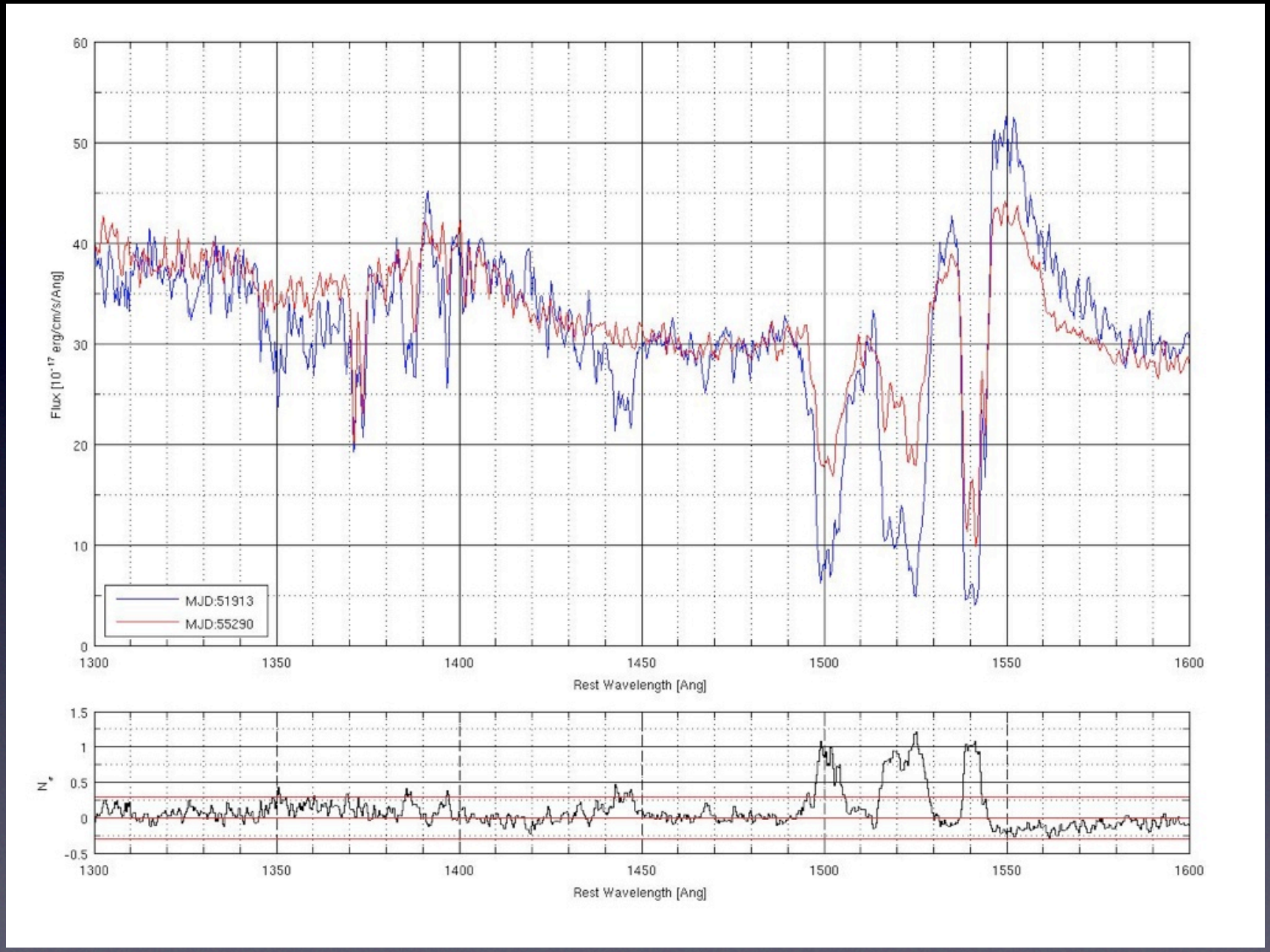
+ DES (*grizy*)

+ *Herschel*

Science Goals

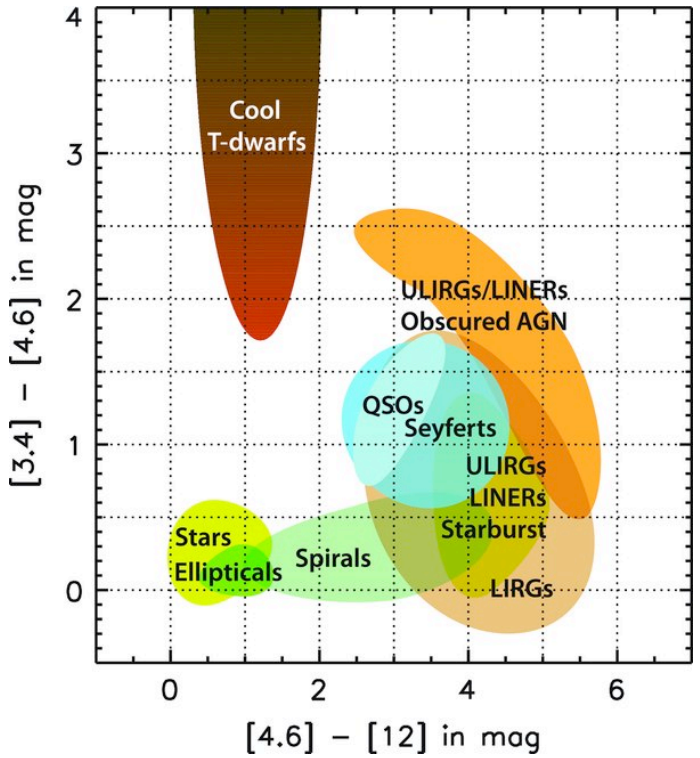
- BOSS "Contingency"
  - High S/N z>2.2 Quasars
- Continue to build Stripe 82 legacy

QSO BAL Spectro-variability



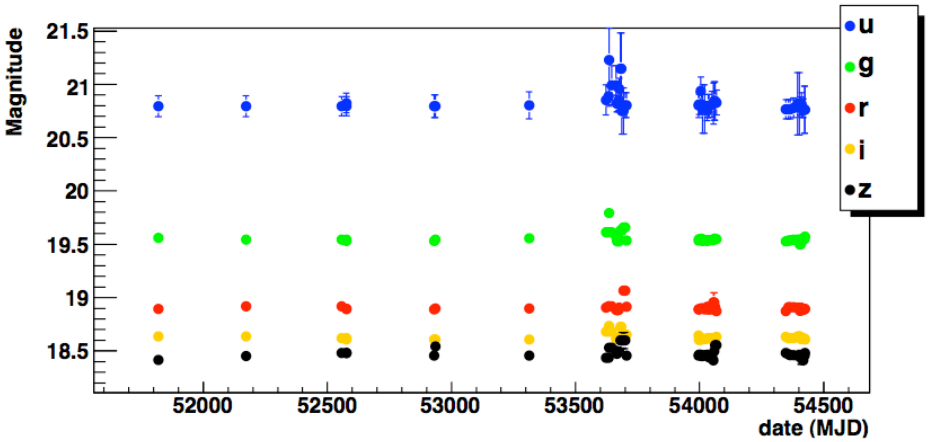
Courtesy: Niel Brandt & Nur Filiz Ak

WISE

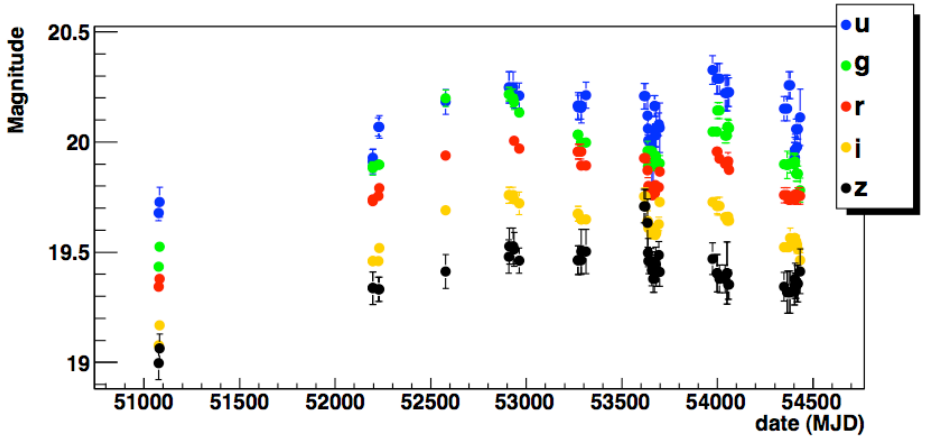


Wright et al. (2010)

+



(MIR) Variability



= ~70 AGN deg^2

Science Goals

- BOSS "Contingency"
  - High S/N z>2.2 Quasars

- Continue to build Stripe 82 legacy

- Obscured (via WISE) and unobscured QSOs down to g=23

- QSO BAL Monitoring

- Spectro-variability for point sources (**TDSS; S. Anderson P.I.**)

Strengths of BOSS+

- All targeting/variability data in hand!!
- Same hardware
- Same software
- Same “peopleware” (more or less)

Conclusions

1. Statistical QSO surveys came of age in 2000-08

2. Today:
   i. Have unprecedented z>2 quasar dataset being gathered via BOSS Quasar Survey
   ii. (Early) Quasar Luminosity Function key result in-hand

3. Potential to use all-sky MIR surveys as next-generation quasar finders for spectroscopic followup e.g., BOSS-Plus...

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