Future large AGN samples for clustering measurements: eBOSS and its AGN sample

Adam Myers, University of Wyoming

For the SDSS-III/BOSS and SDSS-IV/eBOSS collaborations

Outline

1. Broad Overview of the SDSS-IV/eBOSS sample
   LRGs, ELGs, main sample "CORE" quasars, TDSS, SPIDERS
2. SEQUELS
   The Sloan Extended QUasar ELG and LRG Survey
3. Considerations in Observational Systematics
   Projections are fun but it's never that easy
4. Quick look: how well will we constrain clustering
   Quasar bias, b(z), b(L)
5. Conclusions
   Half-a-million quasars, half-a-million quasars, half-a-mill...

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Broad Overview of SDSS-IV/eBOSS

- SDSS-IV/eBOSS will make ~2% measurements of the BAO scale at new redshifts using SDSS-III/BOSS infrastructure that has already made such BAO measurements at z~0.6 and z~2.3
- eBOSS will run for a projected 6 years from summer 2014 to 2020...SDSS-III officially switched over to SDSS-IV on July 1st
  - eBOSS will obtain spectroscopy over ~7500 deg^2 of unique area ~4500 deg^2 in the SDSS NGC, and ~3000 deg^2 in the SDSS SGC (~1500 deg^2 of which will be repeated)
- Although eBOSS is designed as a BAO survey, the main BAO constraint will be made through clustering statistics, so careful work is being conducted to ensure that the eBOSS quasar sample is "uniformly" or "statistically" selected and controlled

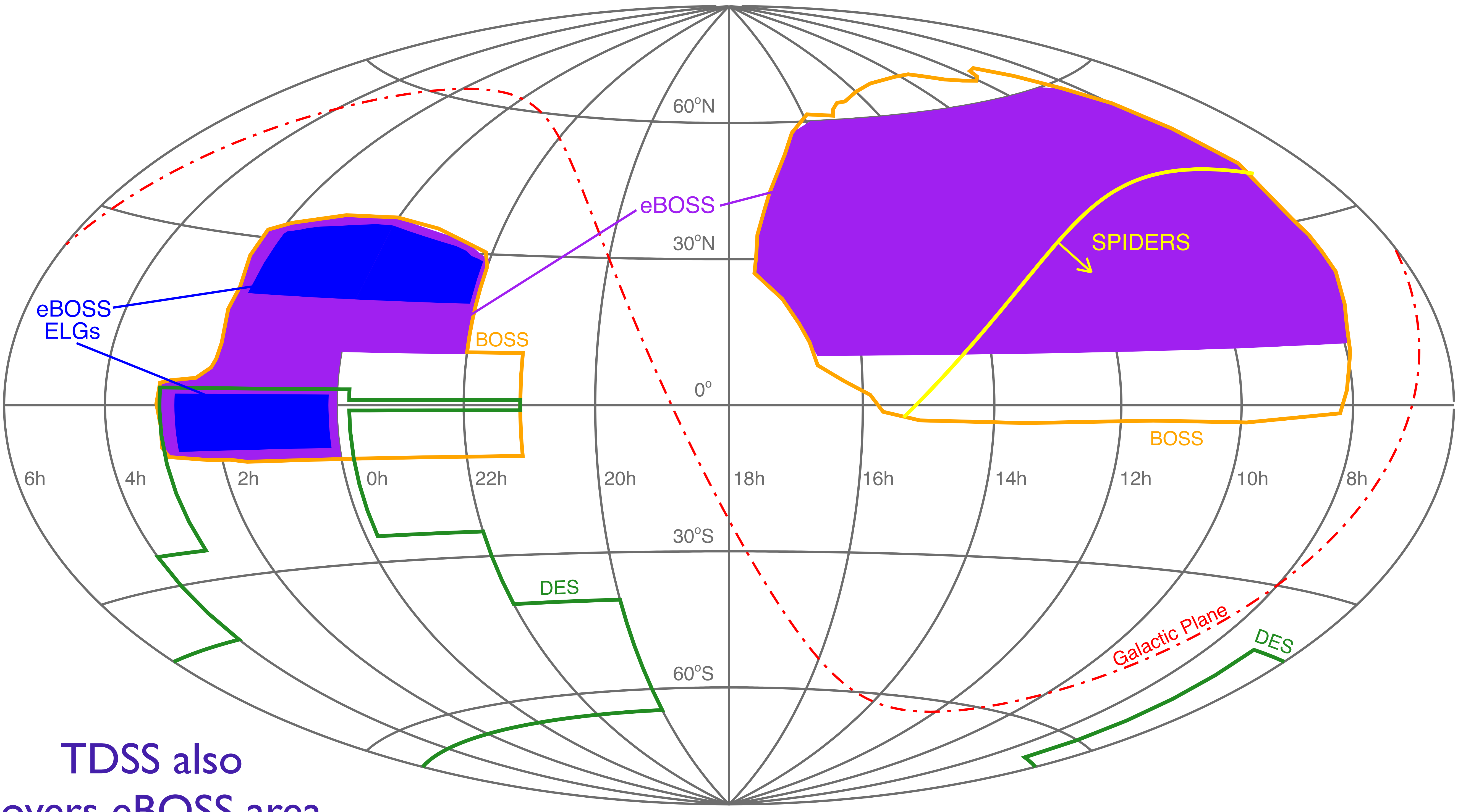
Broad Overview of SDSS-IV/eBOSS

- In pursuit of the key BAO project of eBOSS we will obtain spectroscopy of 4 main samples
  - A statistical sample of ~300,000 $0.6 < z < 1.0$ LRGs (over ~7500 deg^2)
  - A uniform "CORE" sample of ~500,000 $0.9 < z < 2.2$ quasars (over ~7500 deg^2)
  - Adding ~60,000 $z > 2.2$ quasars to the BOSS sample to study clustering in the Lyα Forest (over ~7500 deg^2)
  - ~200,000 $0.7 < z < 0.9$ ELGs (over ~1500 deg^2 but repeated twice at a higher target density)

SDSS-IV/TDSS & SDSS-IV/ SPIDERS

- **TDSS:** A *further* ~1–2 r < 20.5 quasars deg^{-2} over 7500 deg^2 via variability selection in Pan-STARRS imaging
  - typically slightly obscured or host-galaxy dominated in SDSS imaging
  - also conducts repeat spectroscopy of known AGN (reverberation mapping, monitoring of lines etc.)
- **SPIDERS:** A *further* ~5–10 r < 22 quasars deg^{-2} over 2000–3000 deg^2 via follow-up of ROSAT & eROSITA
  - often slightly obscured and/or host-galaxy dominated
  - also a cluster sample...Andrea covered this yesterday

eBOSS

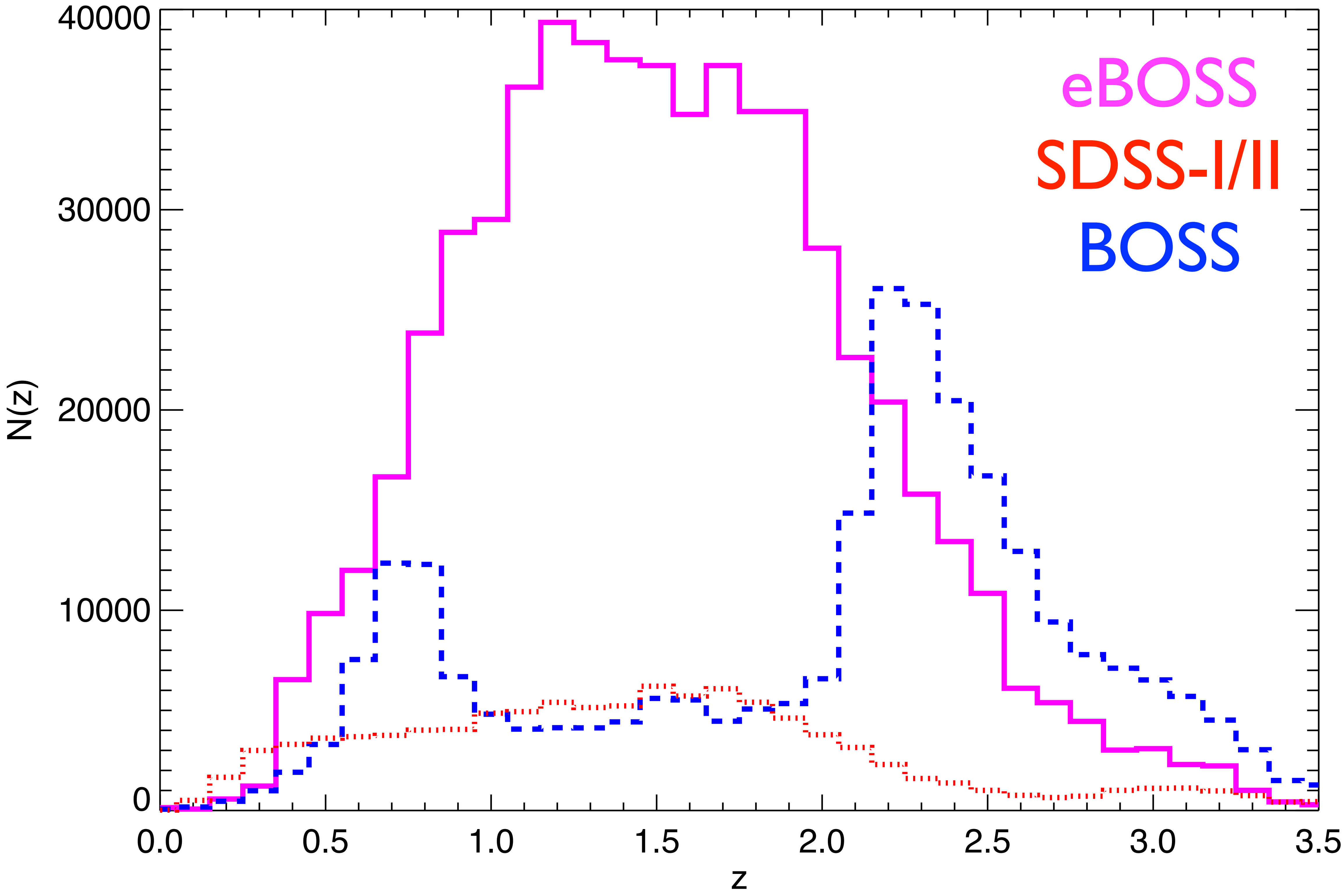


TDSS also
covers eBOSS area

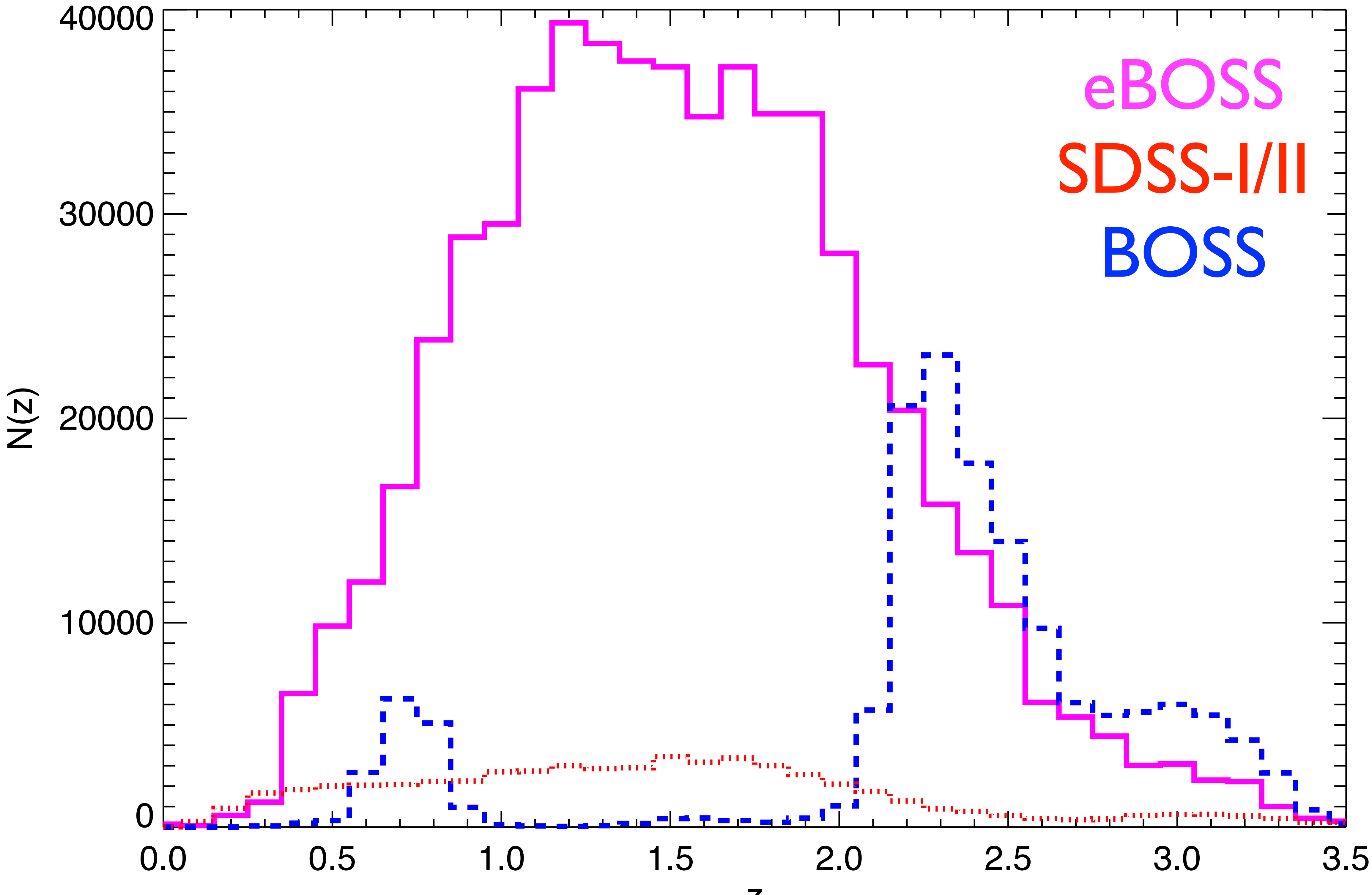
The SDSS-IV/eBOSS main Quasar Samples compared to SDSS I-III

- ~500,000 statistically selected "CORE" $0.9 < z < 2.2$ quasars
- Add ~60,000 $z > 2.2$ quasars to BOSS via a combination of variability selection and from the CORE selection
    - *(the N(z) of the CORE sample tails to high redshift*; there will be ~45,000 *new* CORE quasars at $z > 2.2$, and ~80,000 uniformly selected at $z > 2.2$, including *known* quasars)
- Compare to SDSS-I, II, which obtained ~70,000 $0.9 < z < 2.2$ quasars, ~45,000 of which were statistically selected
- Compare to SDSS-III, which will obtain a total of ~45,000 $z < 2.2$ quasars (~10,000 of which will be statistically selected)

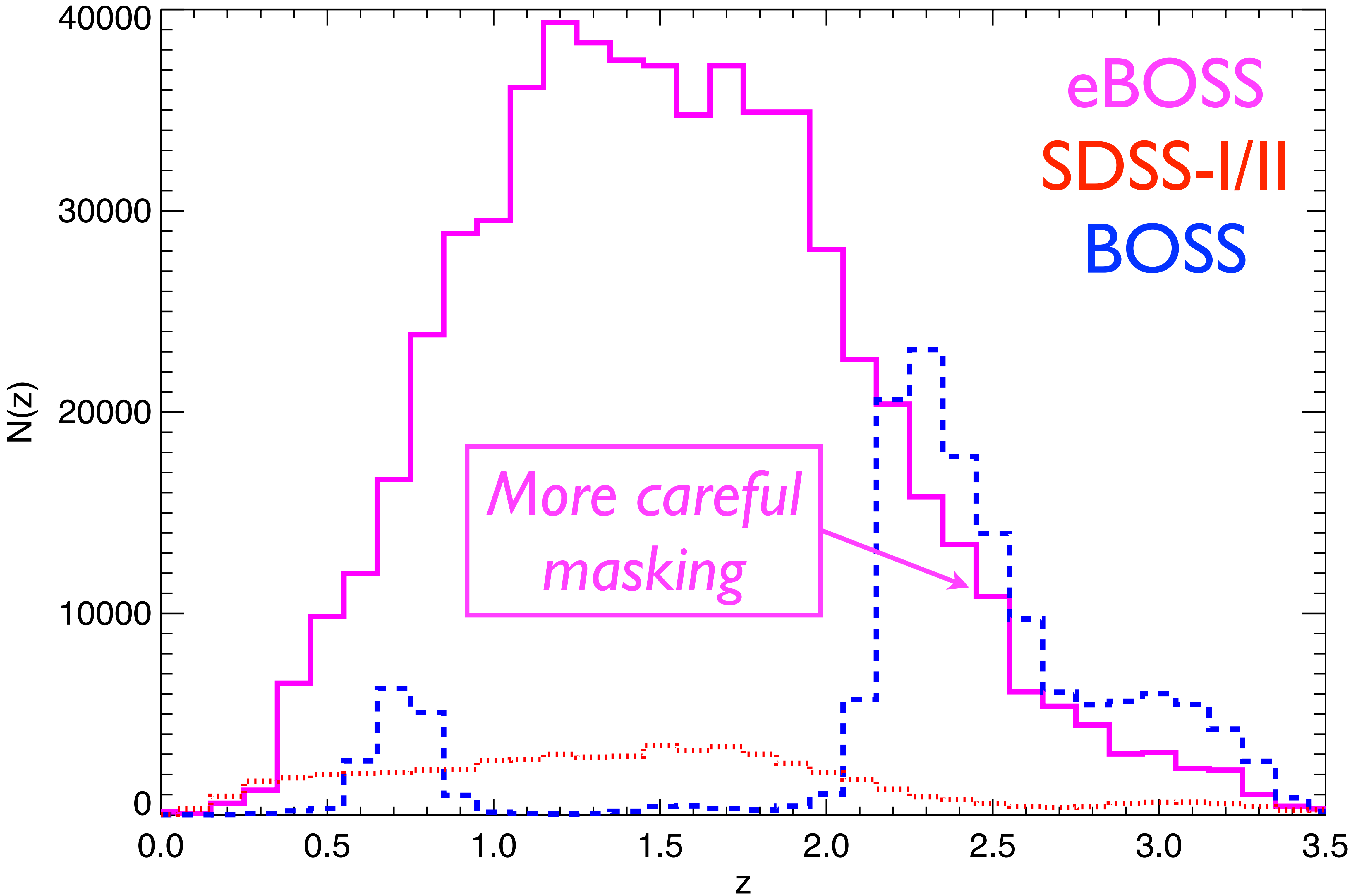
Projected eBOSS quasars



Projected eBOSS quasars



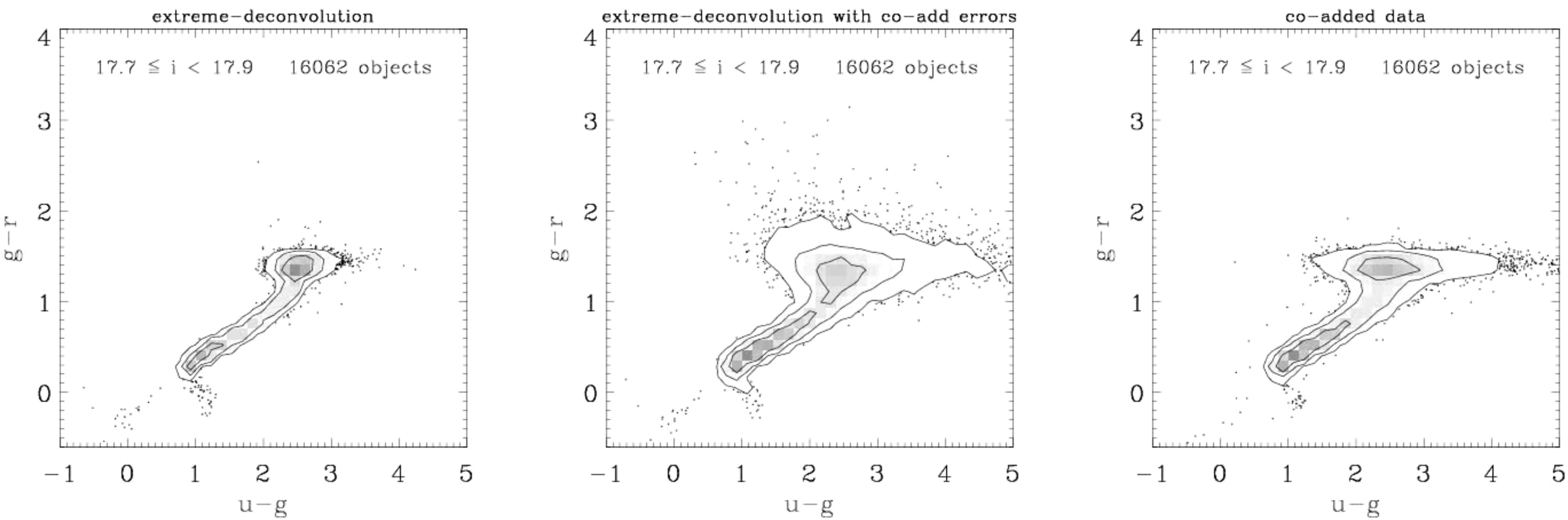
Projected eBOSS quasars



Cross-Correlations!

- There is huge potential for cross-correlation AGN and quasar studies in SDSS-IV:
  - A statistical sample of ~300,000 0.6 < z < 1.0 LRGs
  - ~500,000 0.9 < z < 2.2 quasars *(the N(z) tails to low z;* there will be ~50,000 *new* quasars at z < 1.0, and ~75,000 uniformly selected at z < 1.0, including *known* quasars)
  - A further of order 10,000 new variability-selected z < 1.0 AGN from TDSS
  - A further of order 20,000 new X-ray selected z < 1.0 AGN from SPIDERS
- Also, SDSS-IV is overlain on SDSS-I–III, so there will be fewer fiber collision effects between quasar pairs, augmenting small-scale clustering studies and the HOD

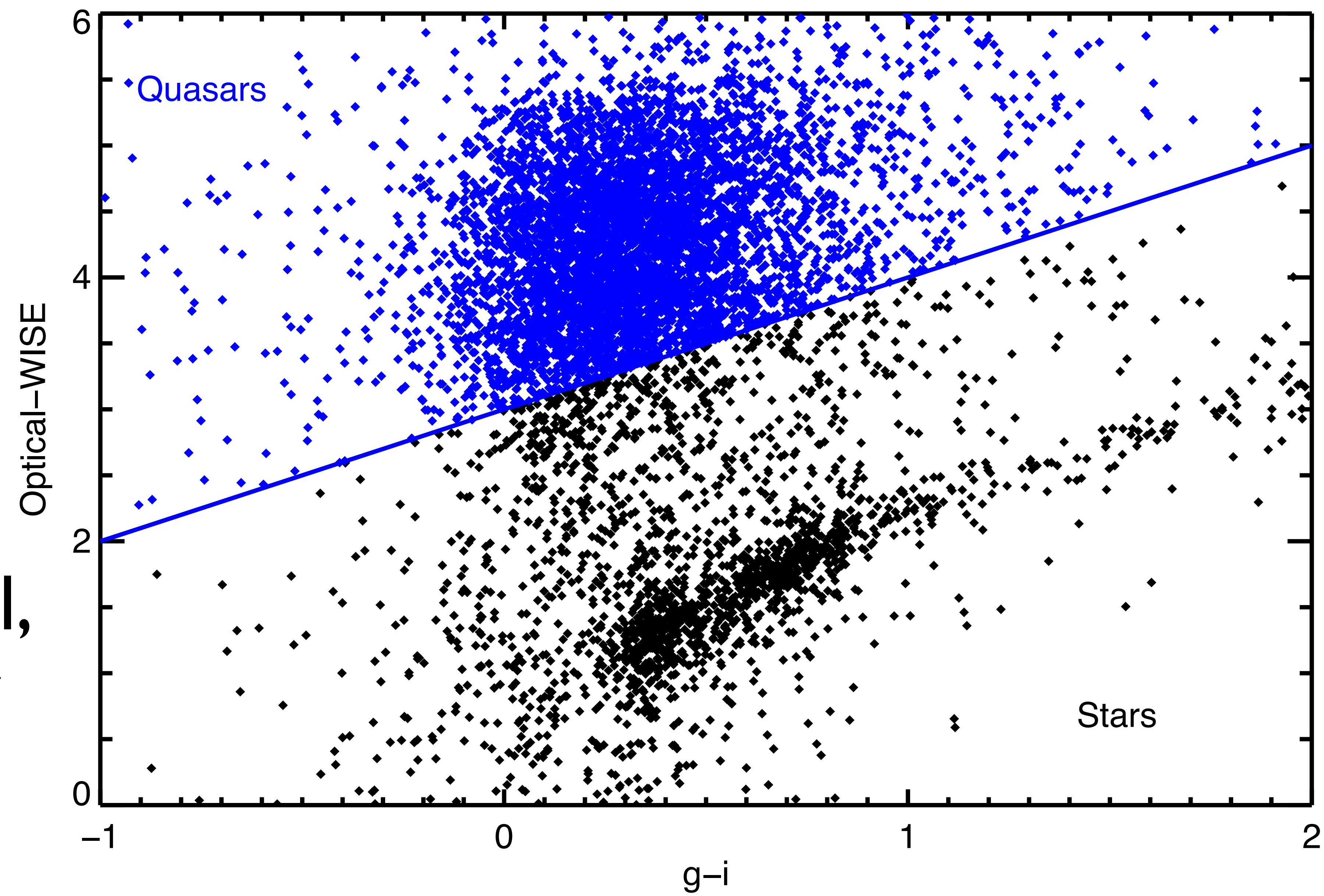
Extreme Deconvolution



Bovy et al. (2011, 2012)

WISE stellar rejection

- Optical flux is a weighted stack of SDSS g,r, i
- WISE flux is a weighted stack of W1, W2
- WISE and optical, here, are in their "native" units (Vega, AB)



- We use the most recent, deepest WISE data force-photometered at SDSS positions (by Dustin Lang)

"CORE" quasar selection for eBOSS

- Take all SDSS PRIMARY point sources with (extincted) $r < 22$ or $g < 22$
- Force photometer WISE at the positions of these sources
- Take all sources with an XDQSOz probability PQSO > 0.2
- Retain all sources that pass WISE-optical color cuts
- Do not retarget any sources with a previous good spectrum from SDSS-I, SDSS-II or SDSS-III ("good" here essentially means that a fiber was placed on the object)
- Obtain ~1-hour spectroscopic exposures of all CORE targets with the SDSS-III/BOSS spectroscopic set up

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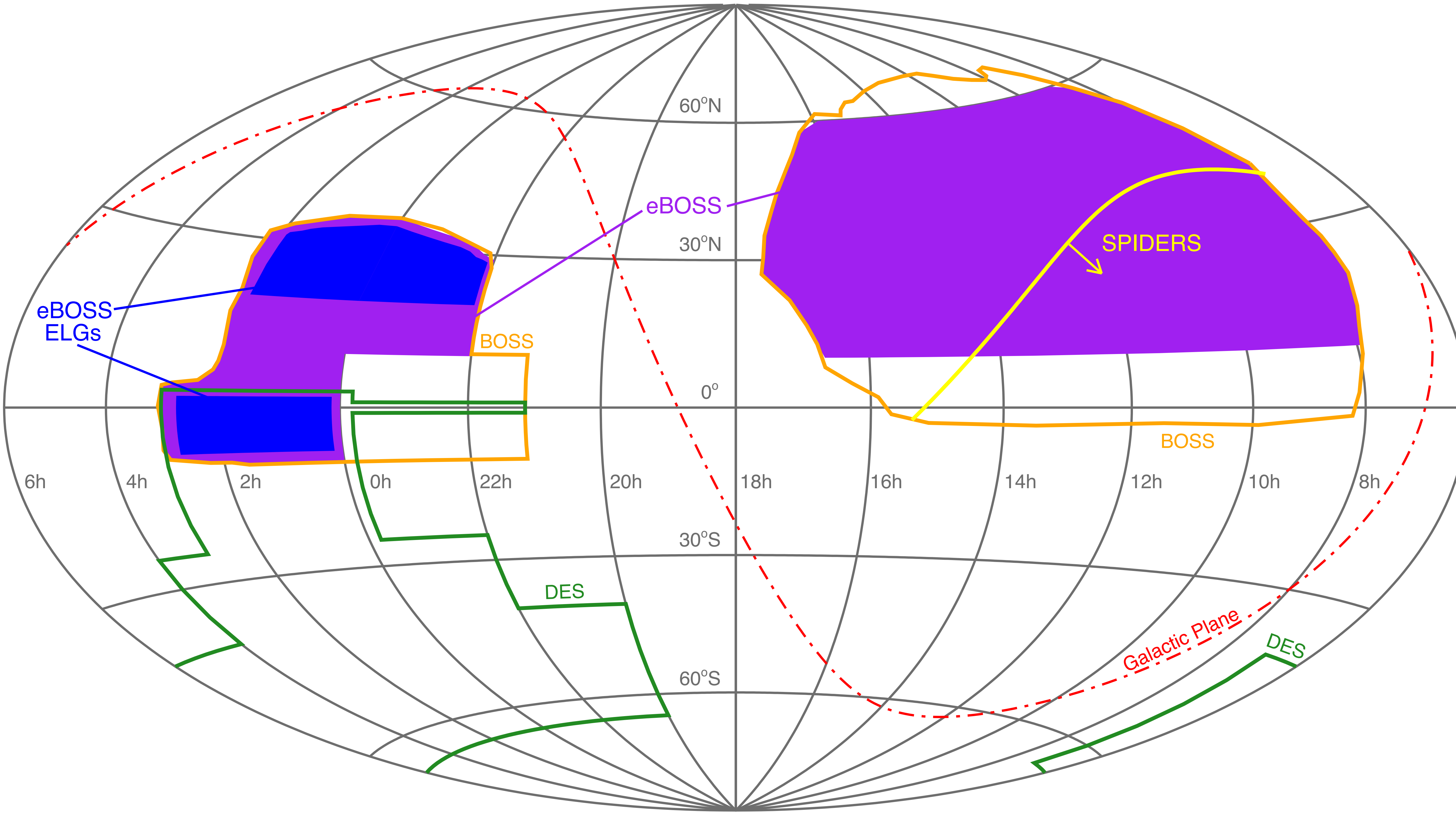
SEQUELS - The Sloan Extended QUasar, ELG and LRG Survey

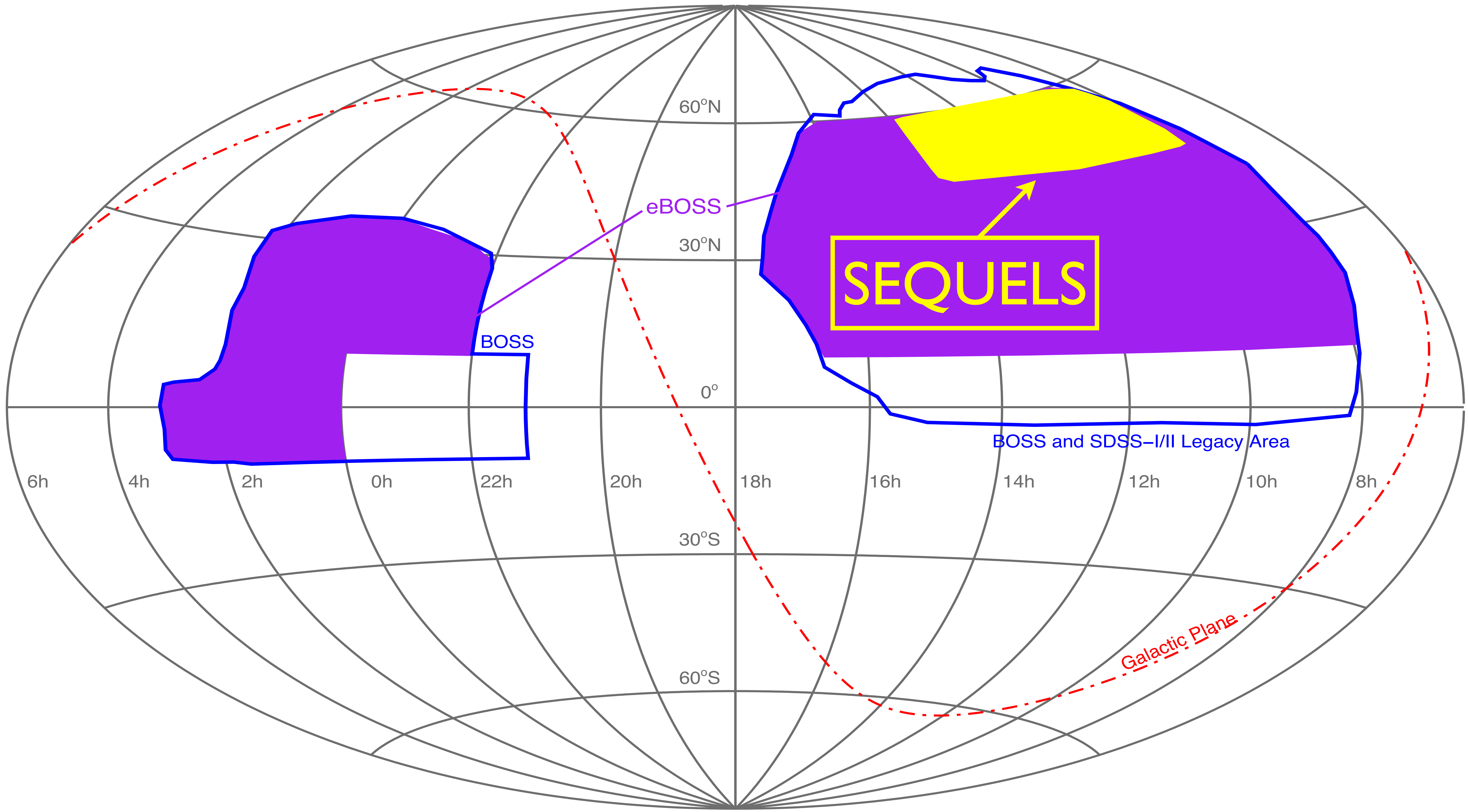
- An ~800 deg^2 SDSS-III survey near the center of the North Galactic Cap to test target selection for eBOSS
- An impressive survey in its own right...if complete it should produce ~55000 statistically selected $0.9 < z < 2.2$ quasars
- The first SEQUELS data will be released as part of SDSS DR12 at the end of this year
- Plates containing SEQUELS quasars have been observed as part of SDSS-III since January, 2014
    - also tests the eBOSS LRG/ELG target selection, but we will stick to discussing the CORE quasar sample

eBOSS



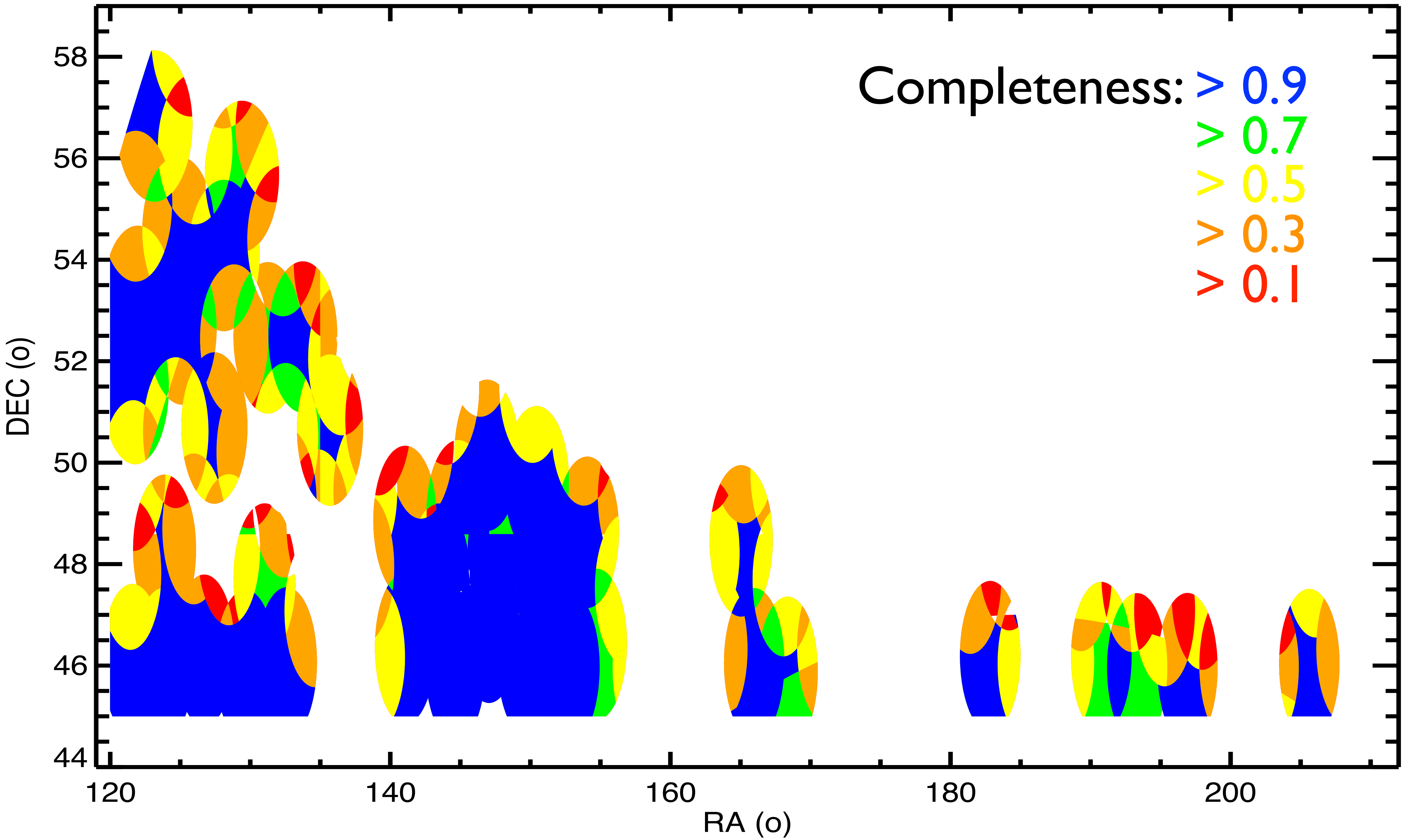
60°N
30°N
0°
30°S
60°S
6h
4h
2h
0h
22h
20h
18h
16h
14h
12h
10h
8h
eBOSS
eBOSS
ELGs
BOSS
BOSS
SPIDERS
DES
DES
Galactic Plane

SEQUELS



60°N
30°N
0°
30°S
60°S
eBOSS
BOSS
SEQUELS
BOSS and SDSS–I/II Legacy Area
Galactic Plane
6h
4h
2h
0h
22h
20h
18h
16h
14h
12h
10h
8h

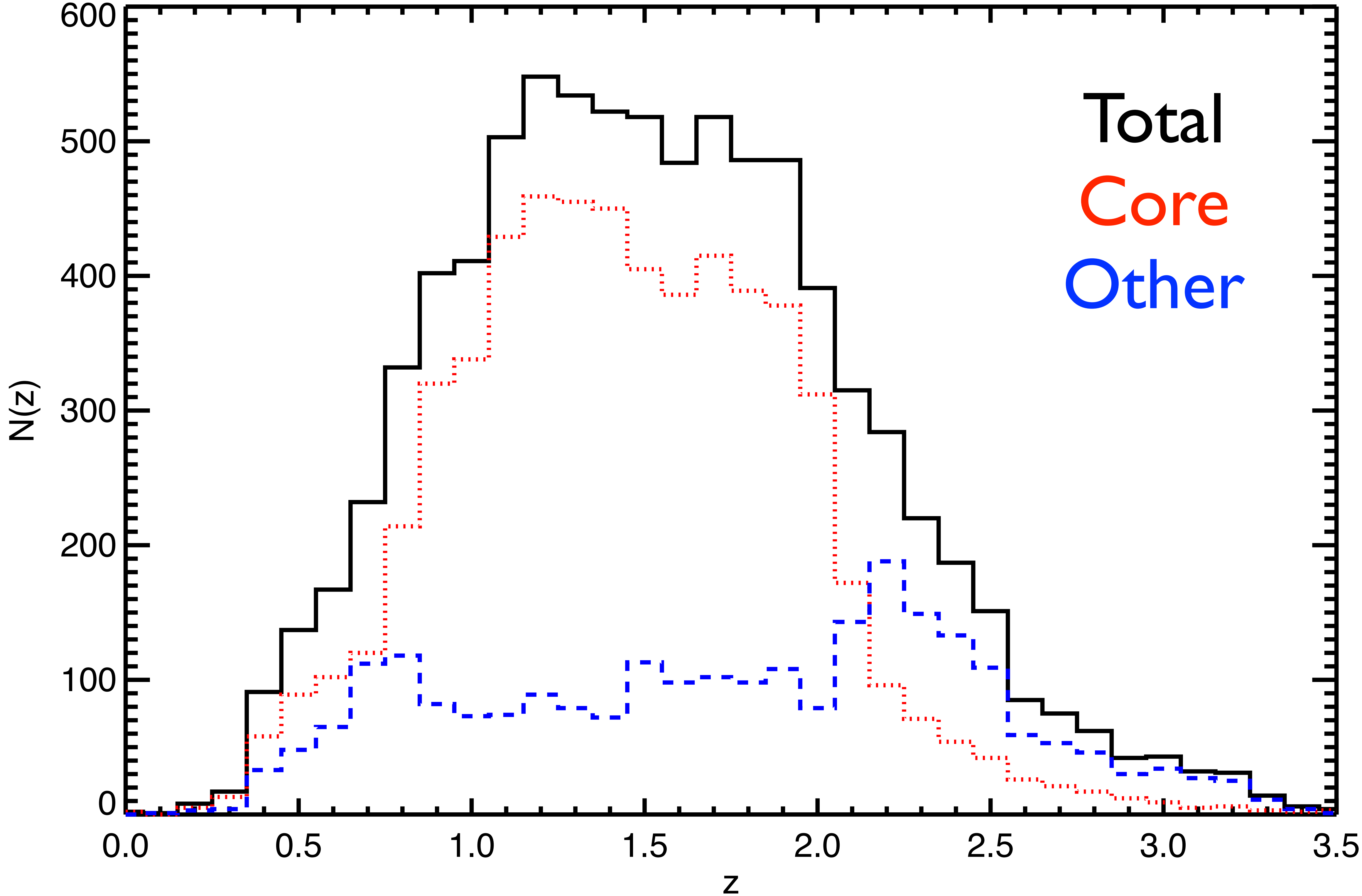
SEQUELS as of May



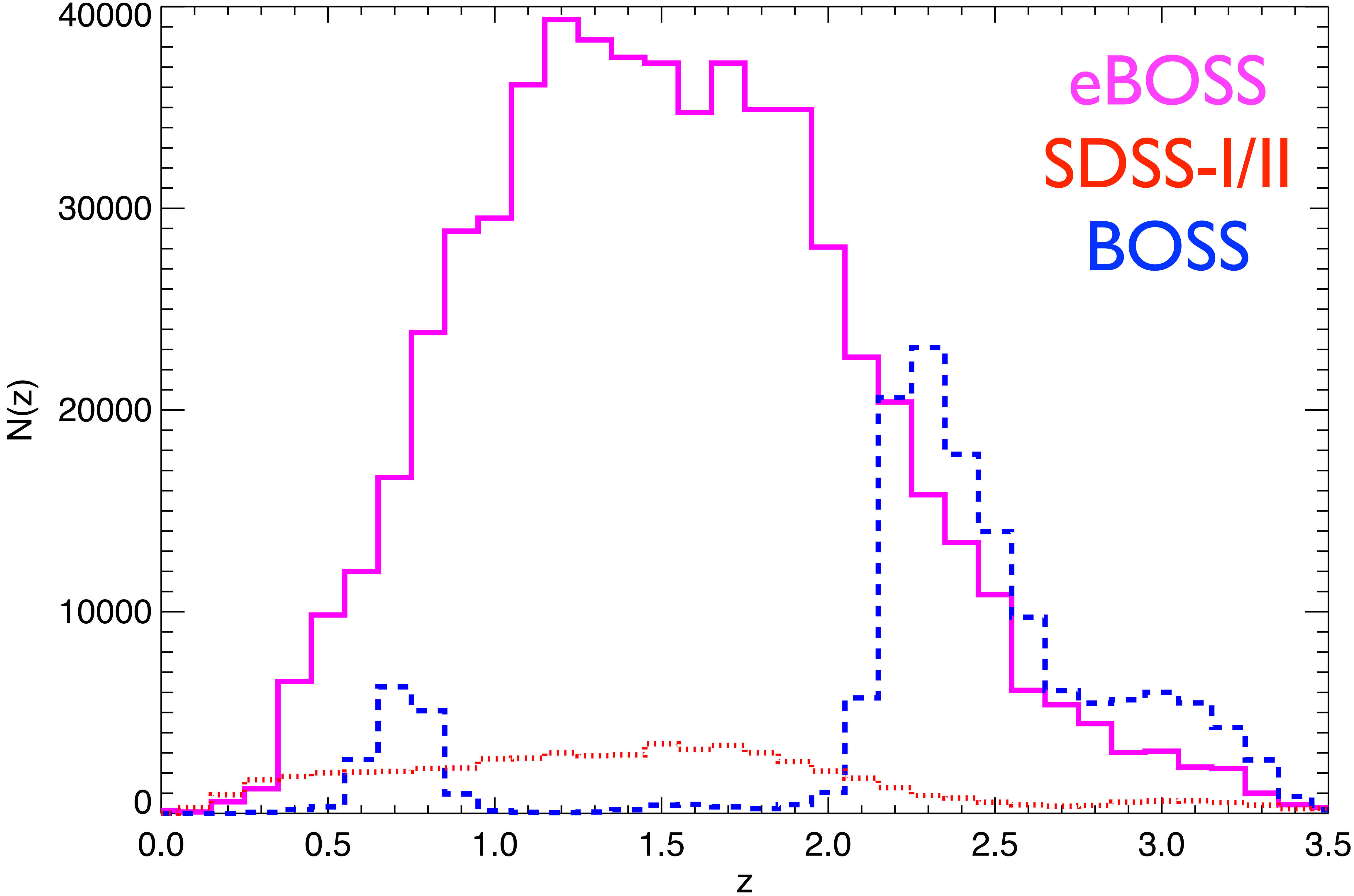
SEQUELS as of May

- Through the first 40 SEQUELS plates, the effective area is 146.1 deg^2 (the total area covered is 202 deg^2)
- There are ~13,000 new quasars in SEQUELS and also a total of ~13,000 statistically selected quasars in the CORE sample
- In areas of > 90% completeness, for CORE quasars:
  - there are 59 deg^{-2} new $0.9 < z < 2.2$ quasars
  - there are 10 deg^{-2} previously known $0.9 < z < 2.2$ quasars
  - a total of 69 deg^{-2} statistically selected $0.9 < z < 2.2$ quasars
  - 7500 deg^2 x 69 deg^{-2} ~ 515,000 CORE quasars

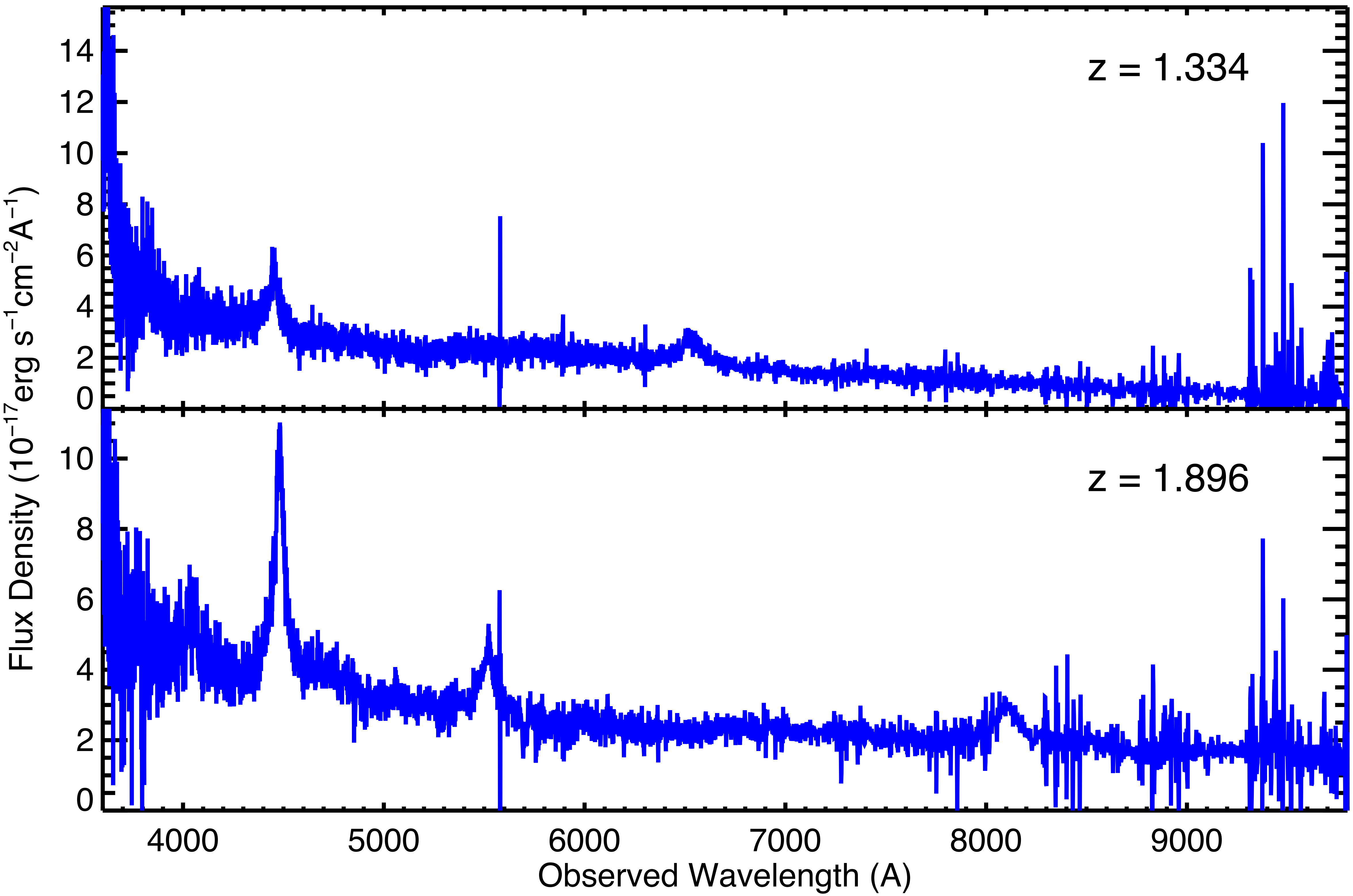
SEQUELS quasar N(z)



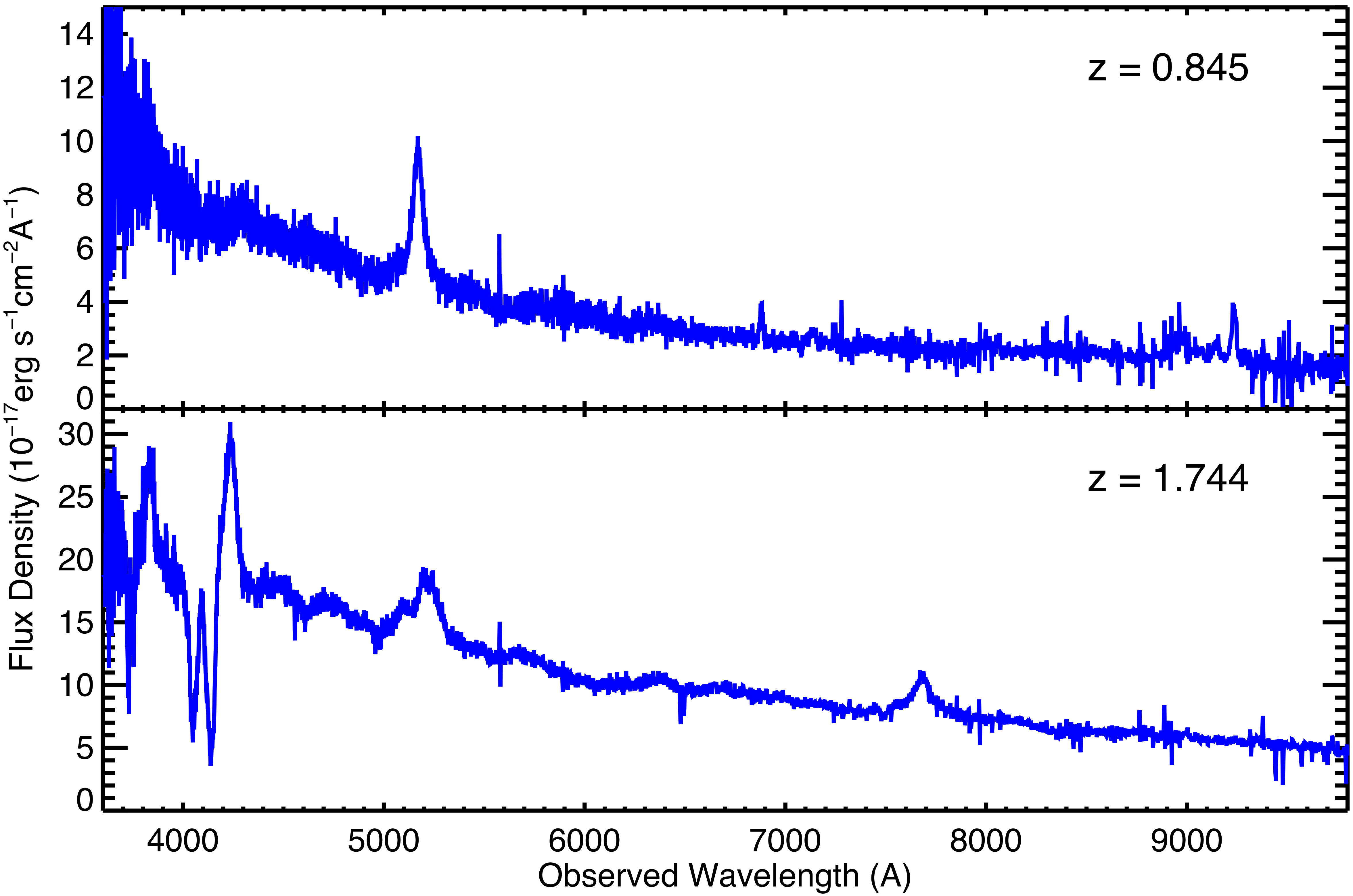
Projected eBOSS quasars



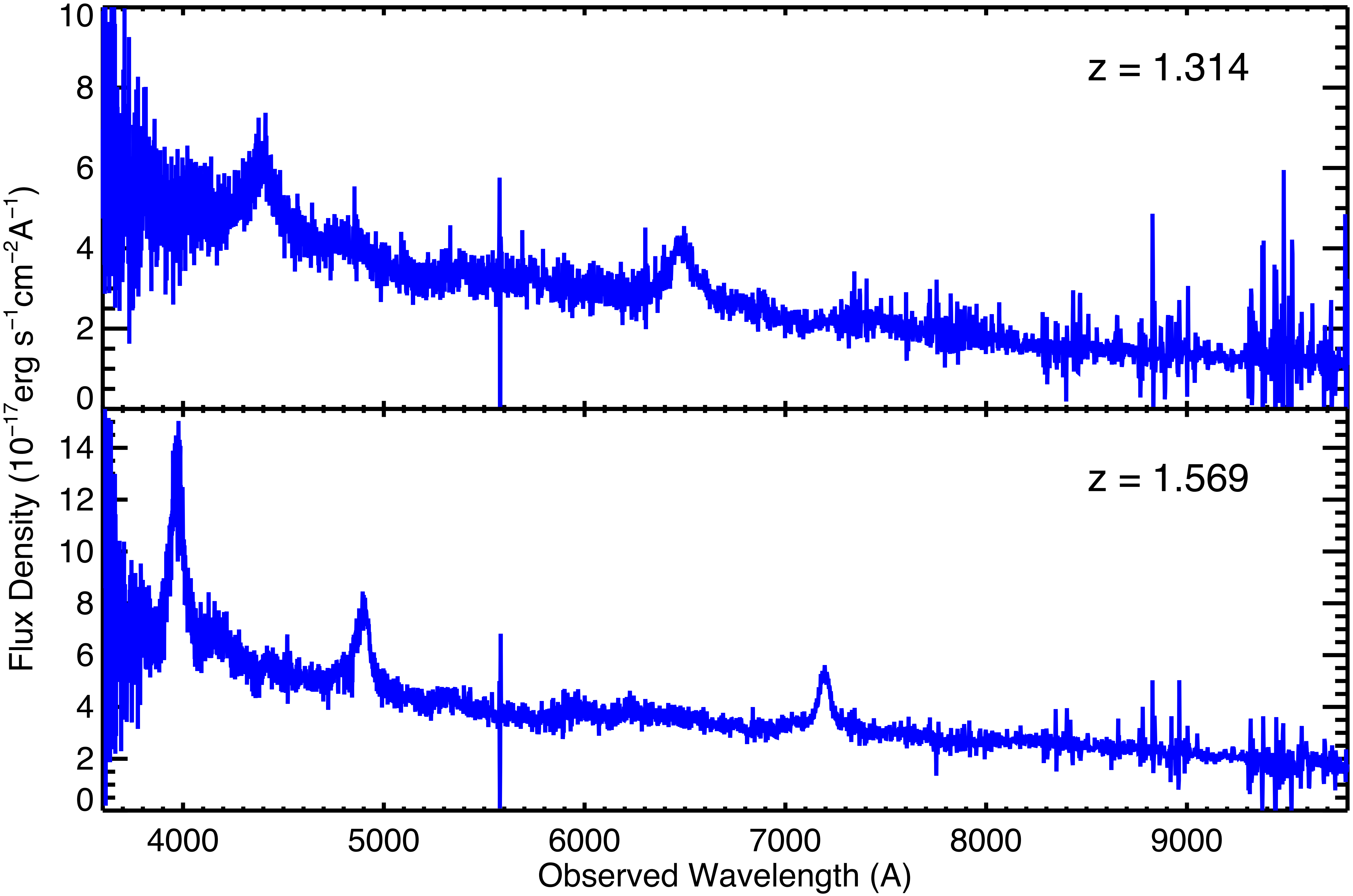
Typical SEQUELS spectra



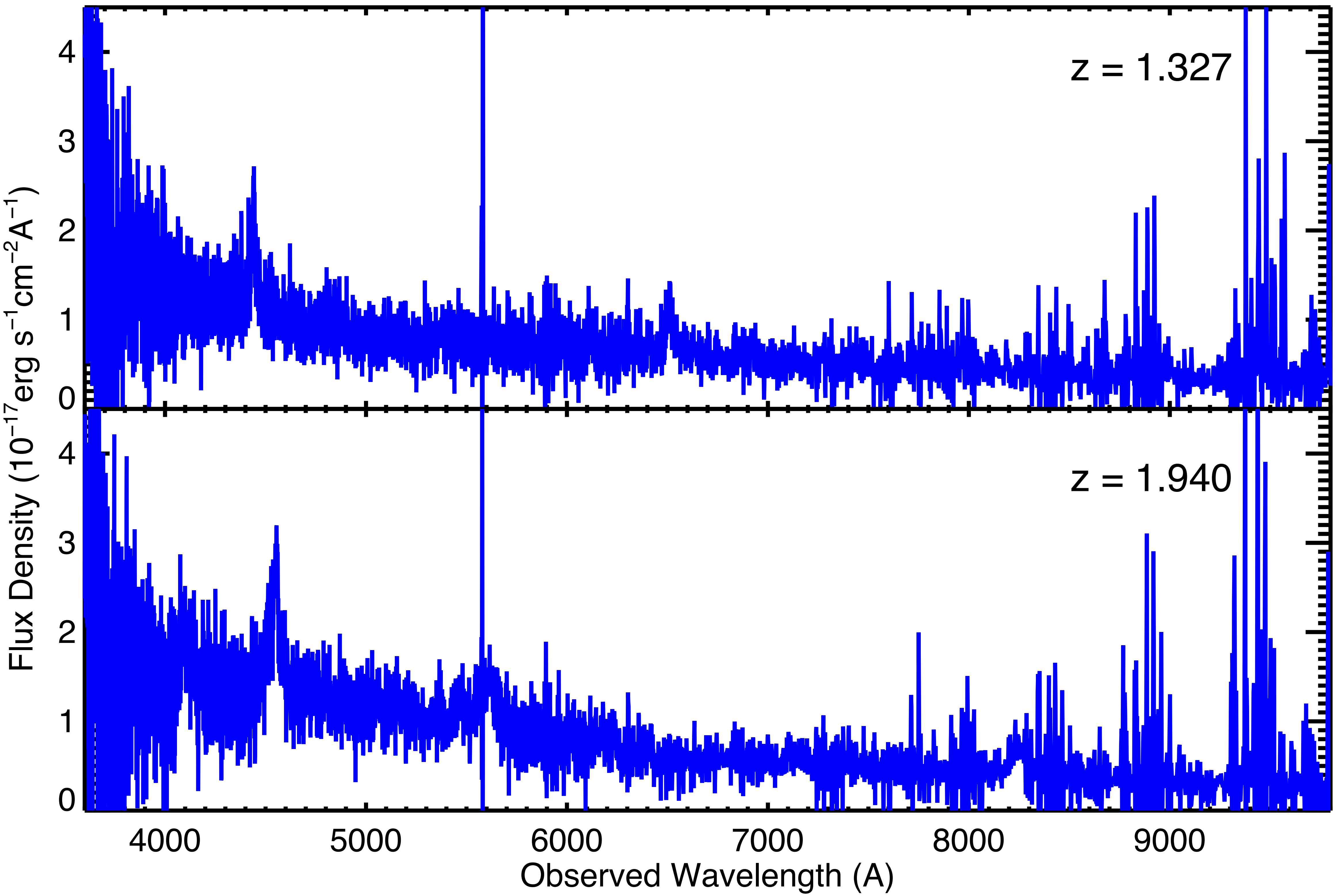
SEQUELS spectra g~20



SEQUELS spectra g~21



SEQUELS spectra g~22



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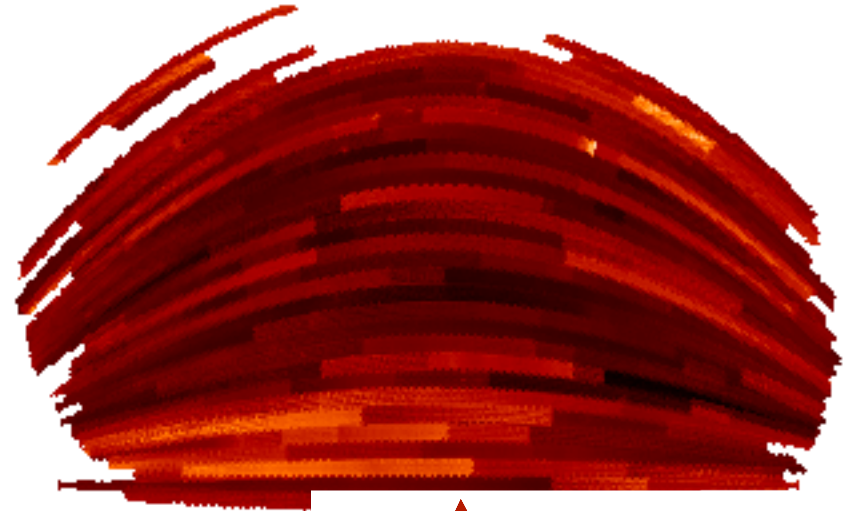
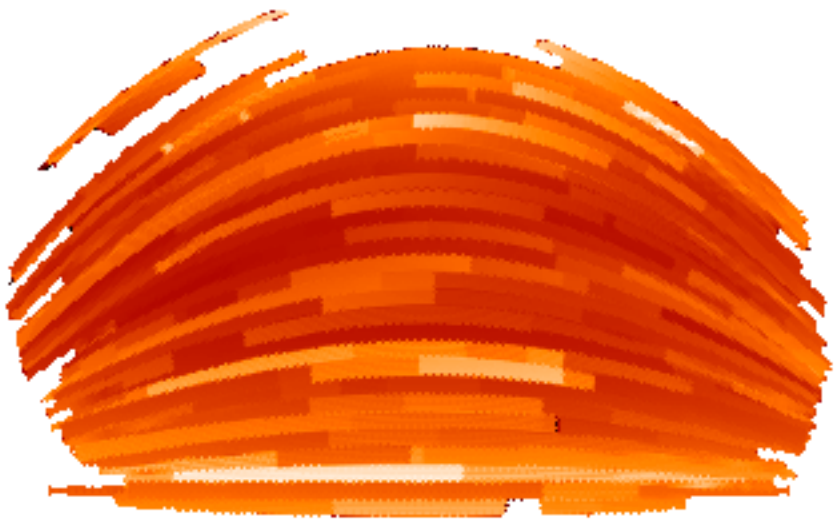
Example: Richards et al. (2009) Systematics Masks

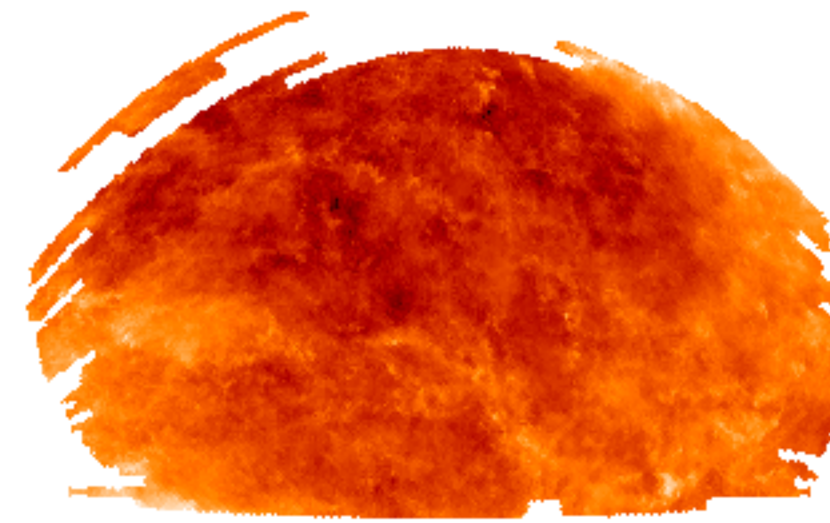


Sky Brightness

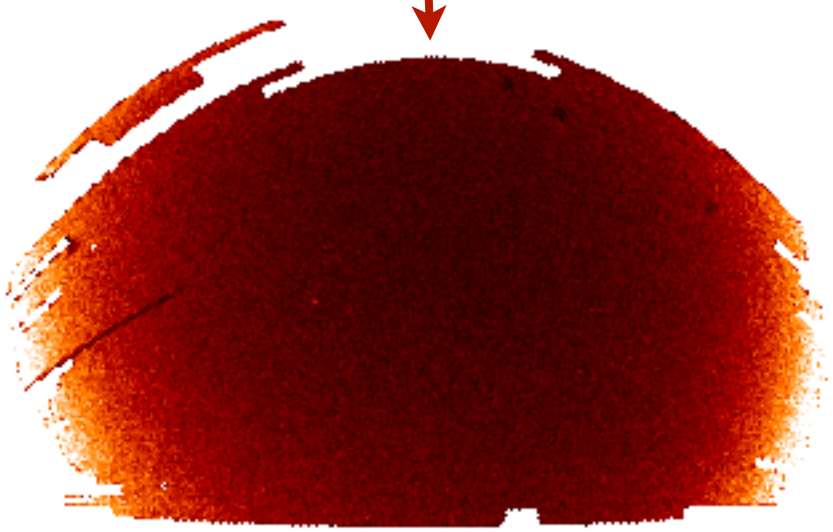
Airmass



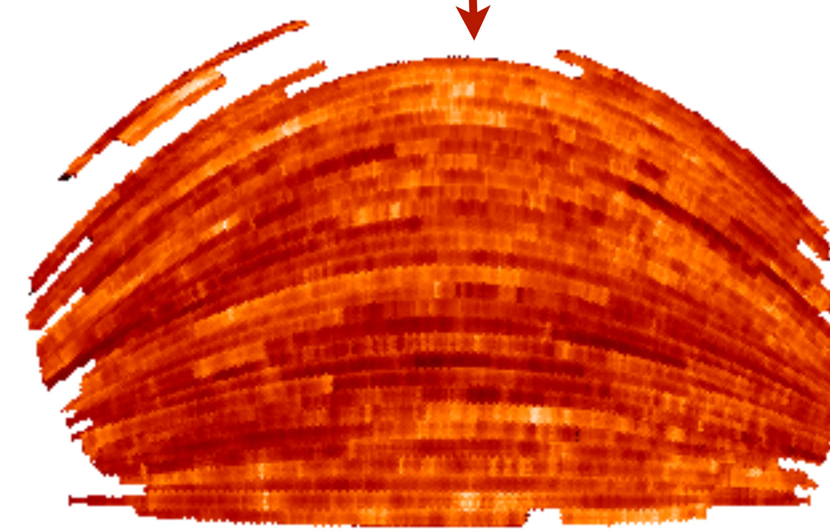
Extinction



Stellar Density



Seeing



Leistedt et al. (2013)

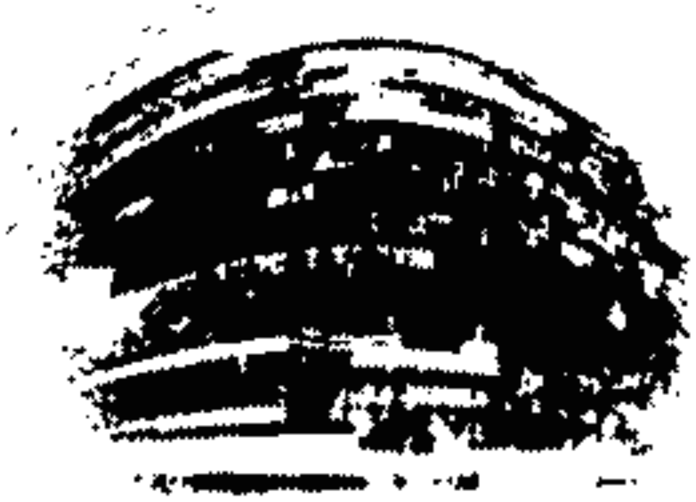
Example: Richards et al. Systematics

8400 deg^2

6105 deg^2

4990 deg^2

4165 deg^2



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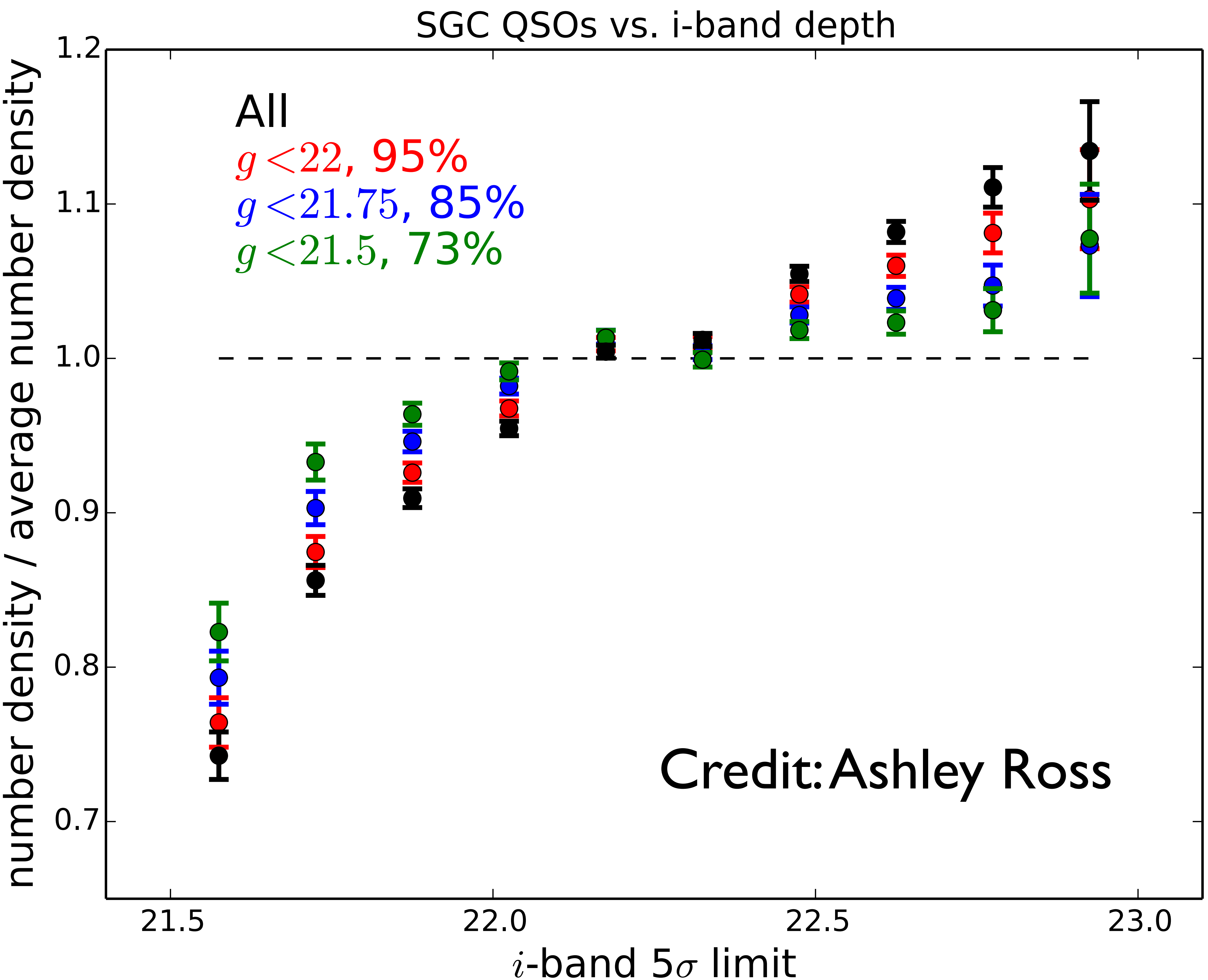
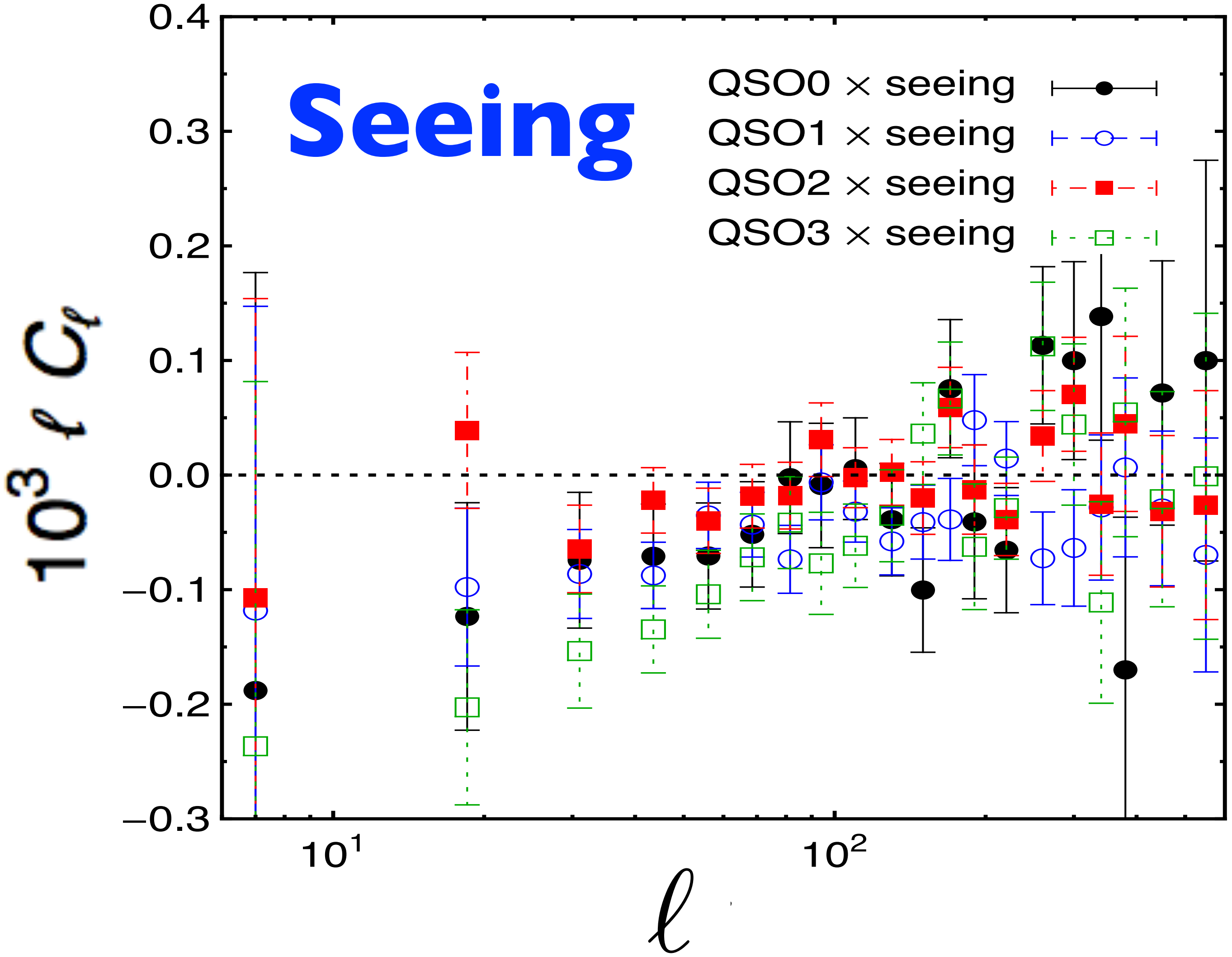
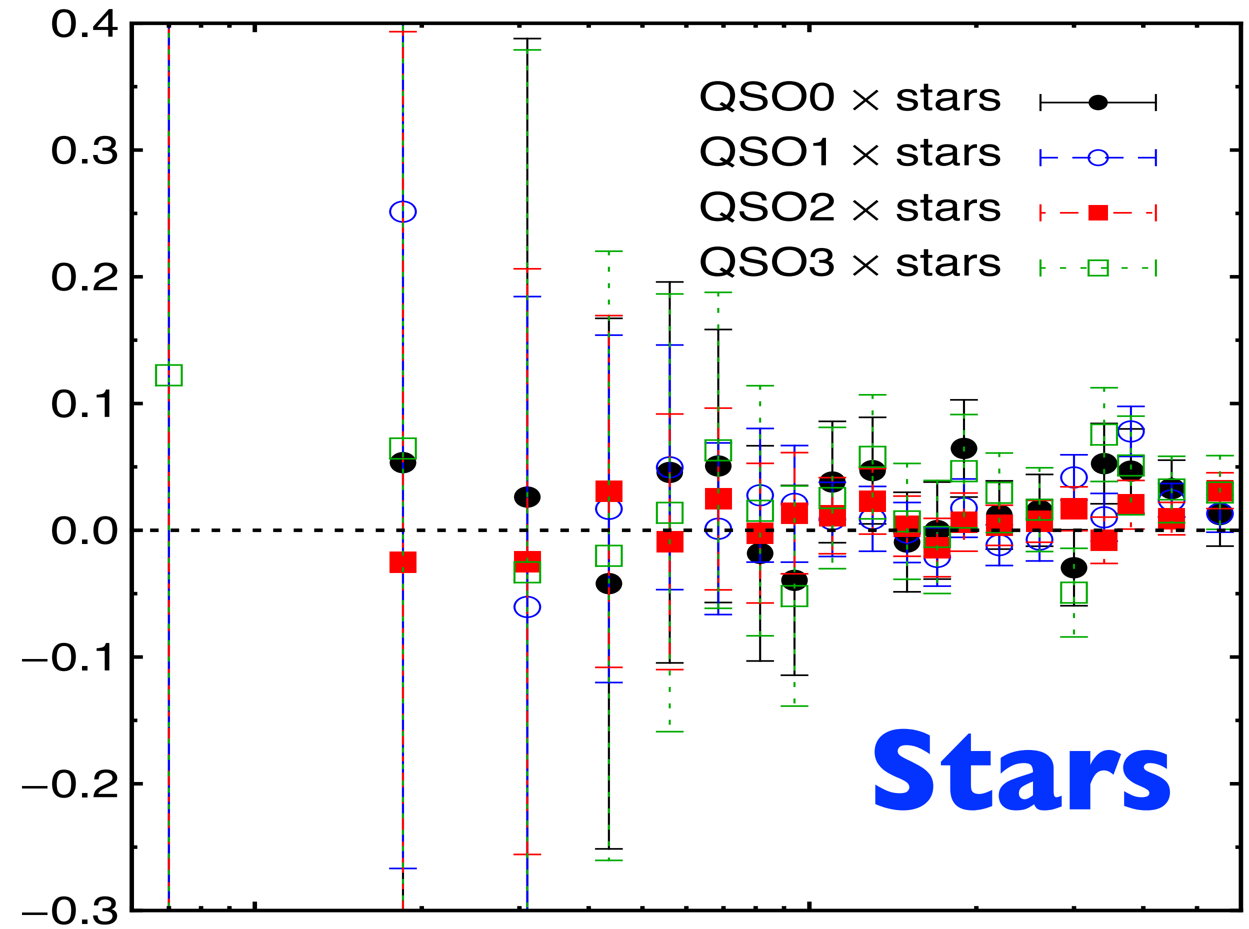
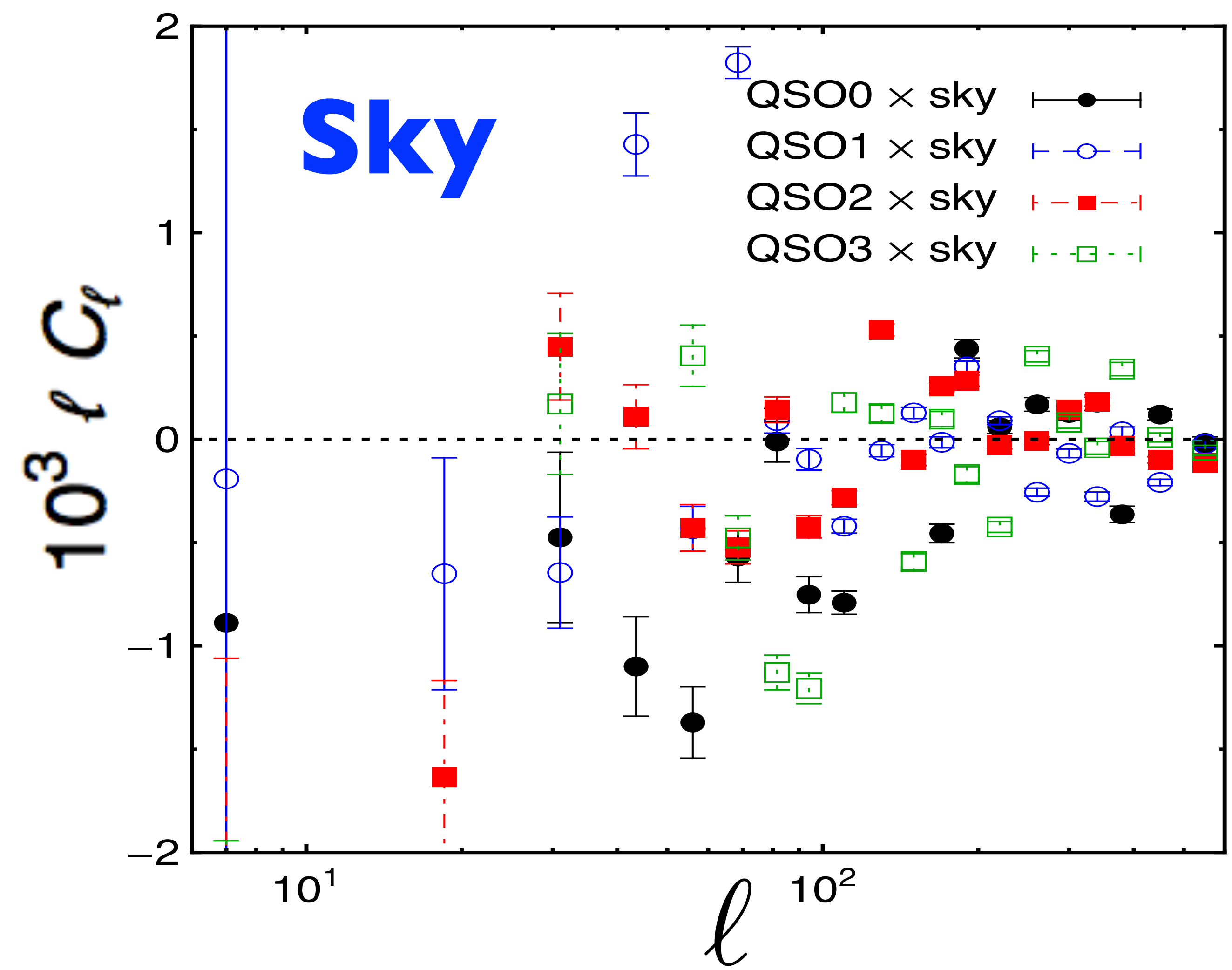

SGC QSOs vs. i-band depth
All
$g<22$, 95%
$g<21.75$, 85%
$g<21.5$, 73%
Credit: Ashley Ross
number density / average number density
1.2
1.1
1.0
0.9
0.8
0.7
21.5
22.0
22.5
23.0
i-band 5σ limit

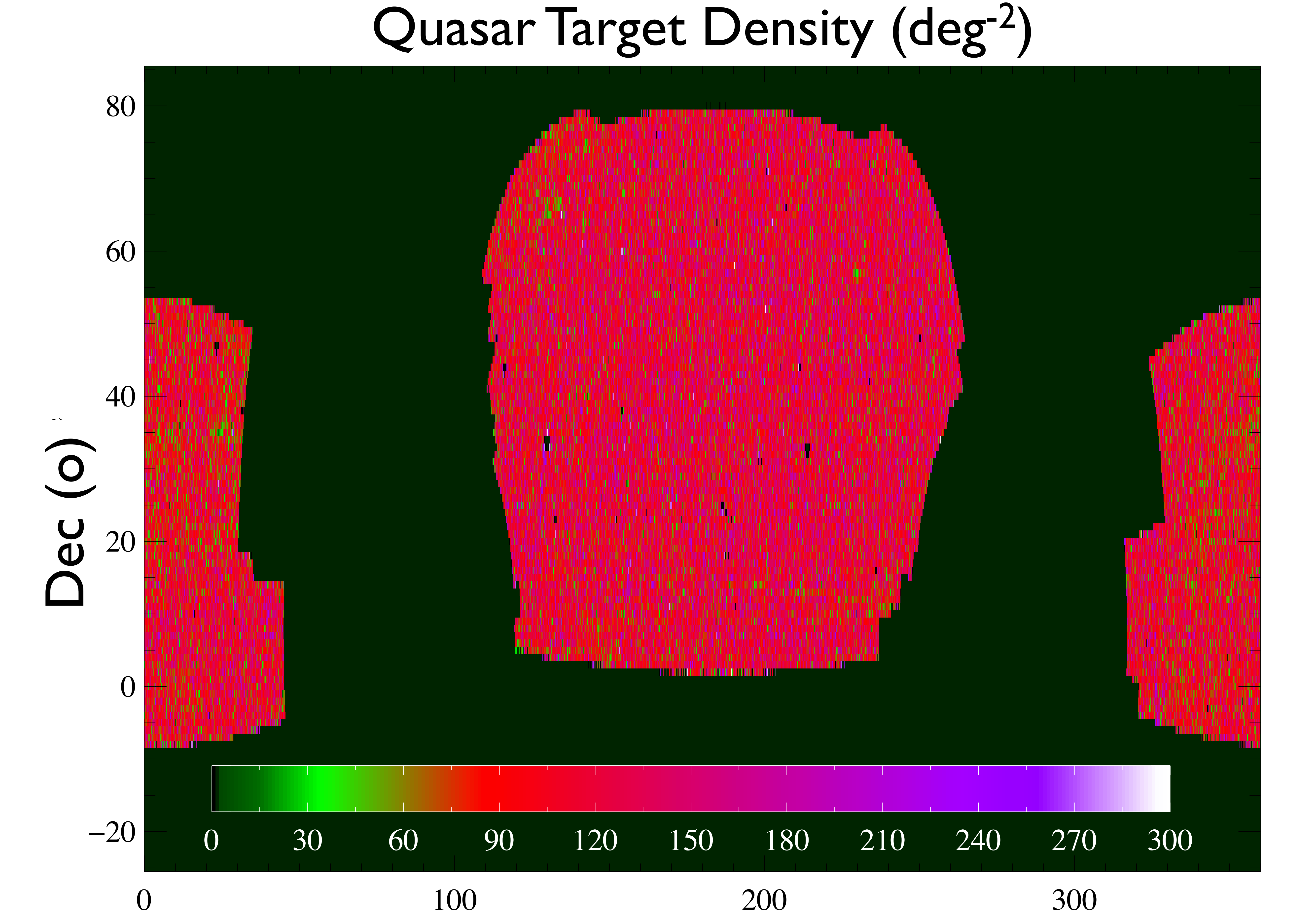




Some of the cross-correlation systematics

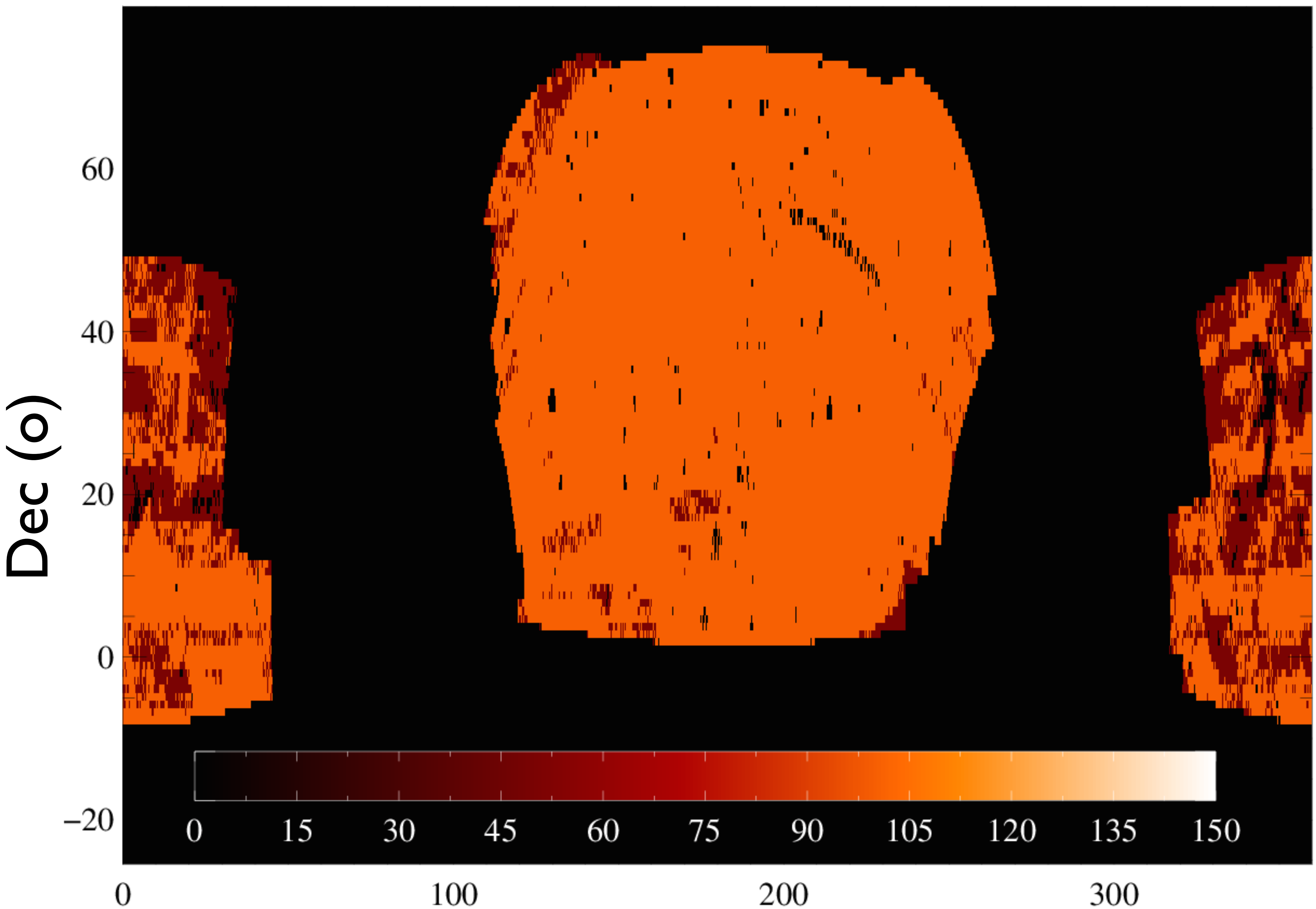


Ho et al., *arXiv:1311.2597*



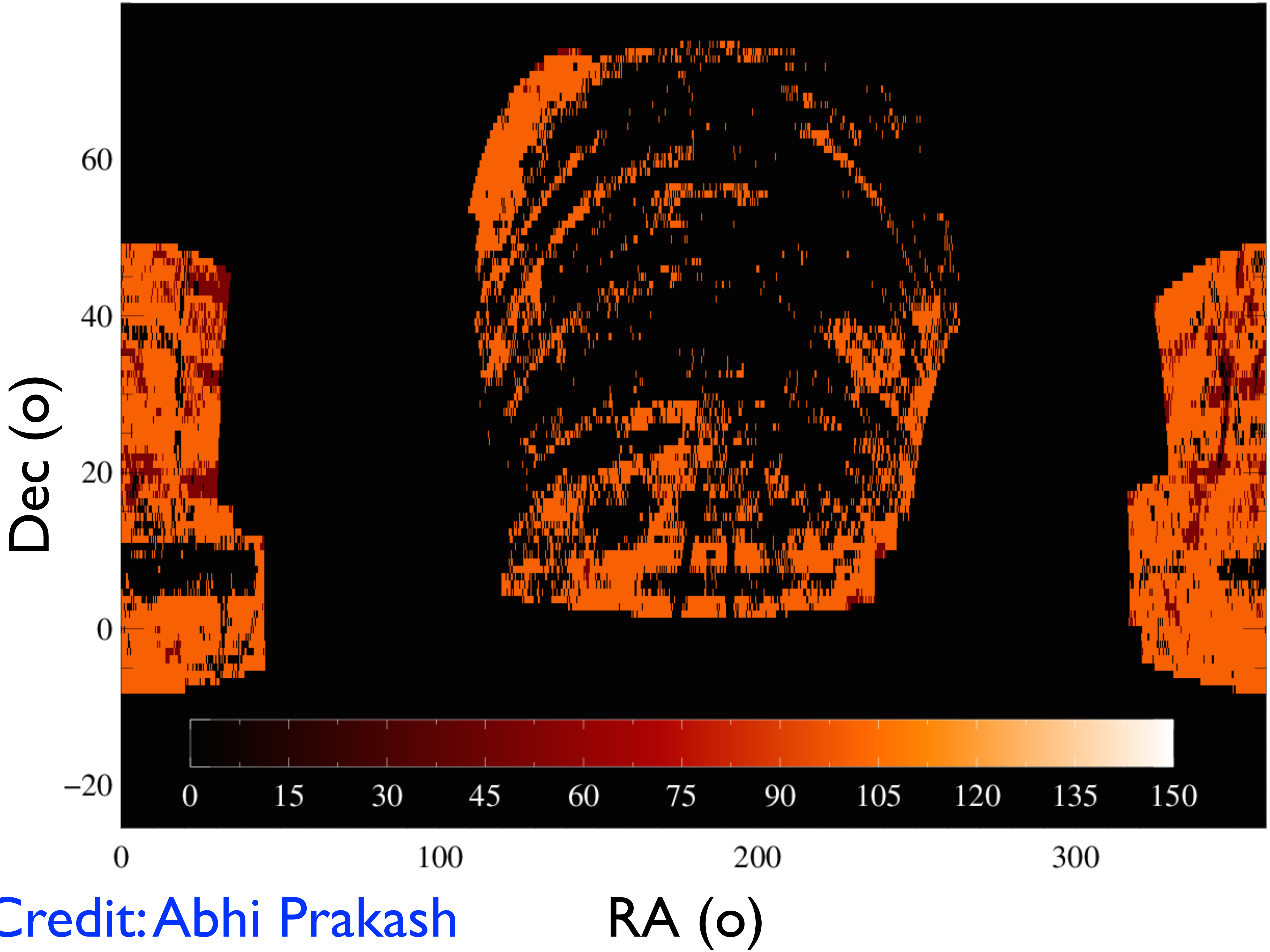
Credit: Abhi Prakash

Quasar Target Density using NGC model (deg^{-2})



Credit: Abhi Prakash

Quasar Target Density using SGC model (deg^{-2})



Credit: Abhi Prakash

Model Number	Model Coeff w1_covmedian,moon_good,w1_median (common)	CHI SQUARE	RED. CHI SQ	FRAC of Pixels < 15% variation
		SCG	SGC	SGC
		NGC	NGC	NGC
7.	lat_good,ext_r,psf_fwhm_z,skyflux_z	11239.929	1.3446500	0.801458
		26172.206	1.2989977	0.974845
8.	lat_good,ext_r,psf_fwhm_i,skyflux_i	11156.958	1.3347240	0.779823
		26126.749	1.2967416	0.971521
9.	lat_good,ext_r,psf_fwhm_r,skyflux_r	11077.111	1.3251718	0.762611
		26025.894	**1.2917359**	**0.959911**
10.	Cosec(lat_good),ext_r, psf_fwhm_z, skyflux_z	11151.552	1.3340773	0.791418
		26206.154	1.3006826	0.975639
11.	Cosec(lat_good),ext_r, psf_fwhm_i, skyflux_i	11078.558	1.3253449	0.769543
		26158.135	1.2982993	0.971273
12.	Cosec(lat_good),ext_r, psf_fwhm_r, skyflux_r	**11014.515**	**1.3176833**	**0.752570**
		26052.438	1.2930533	0.960705

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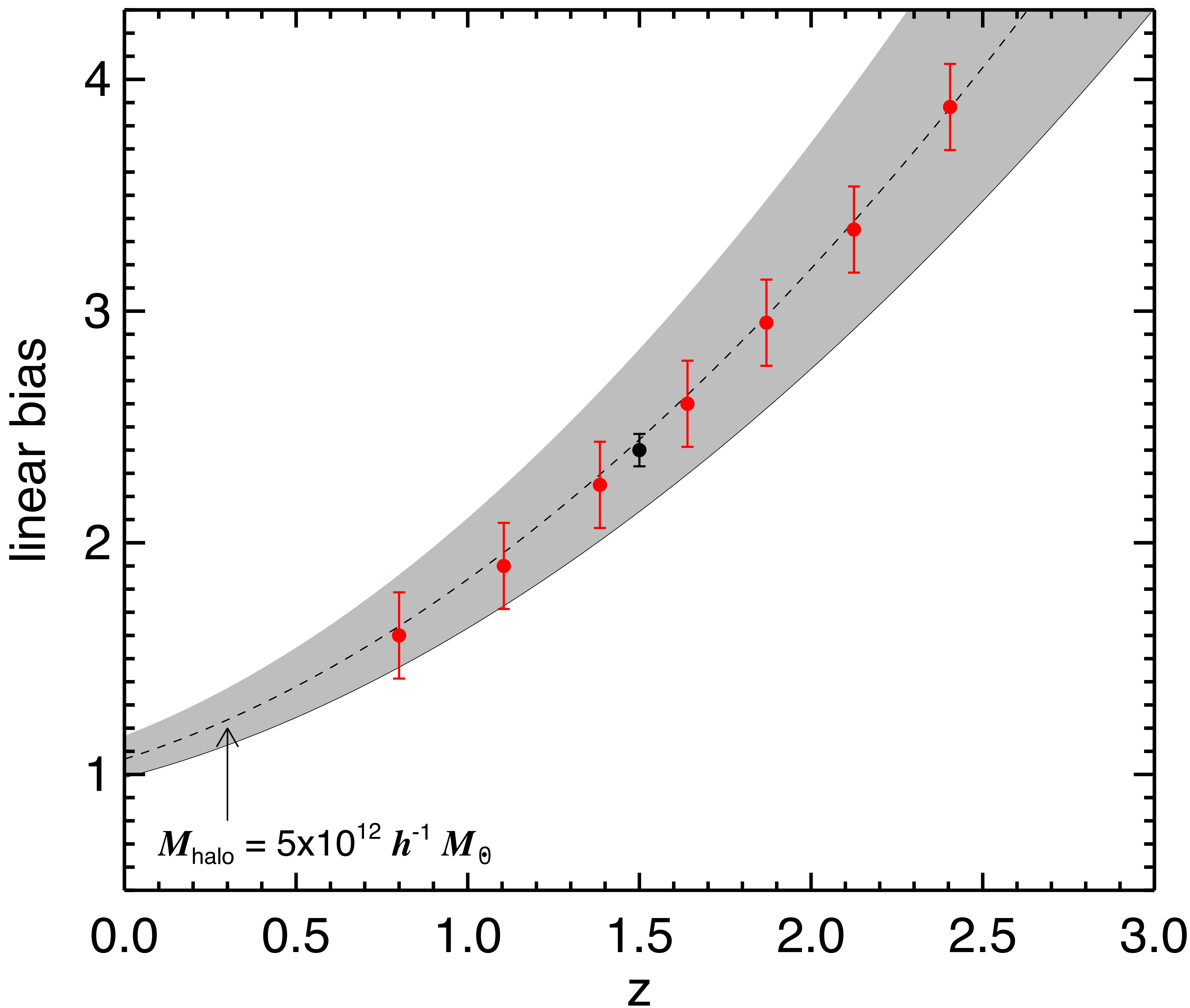
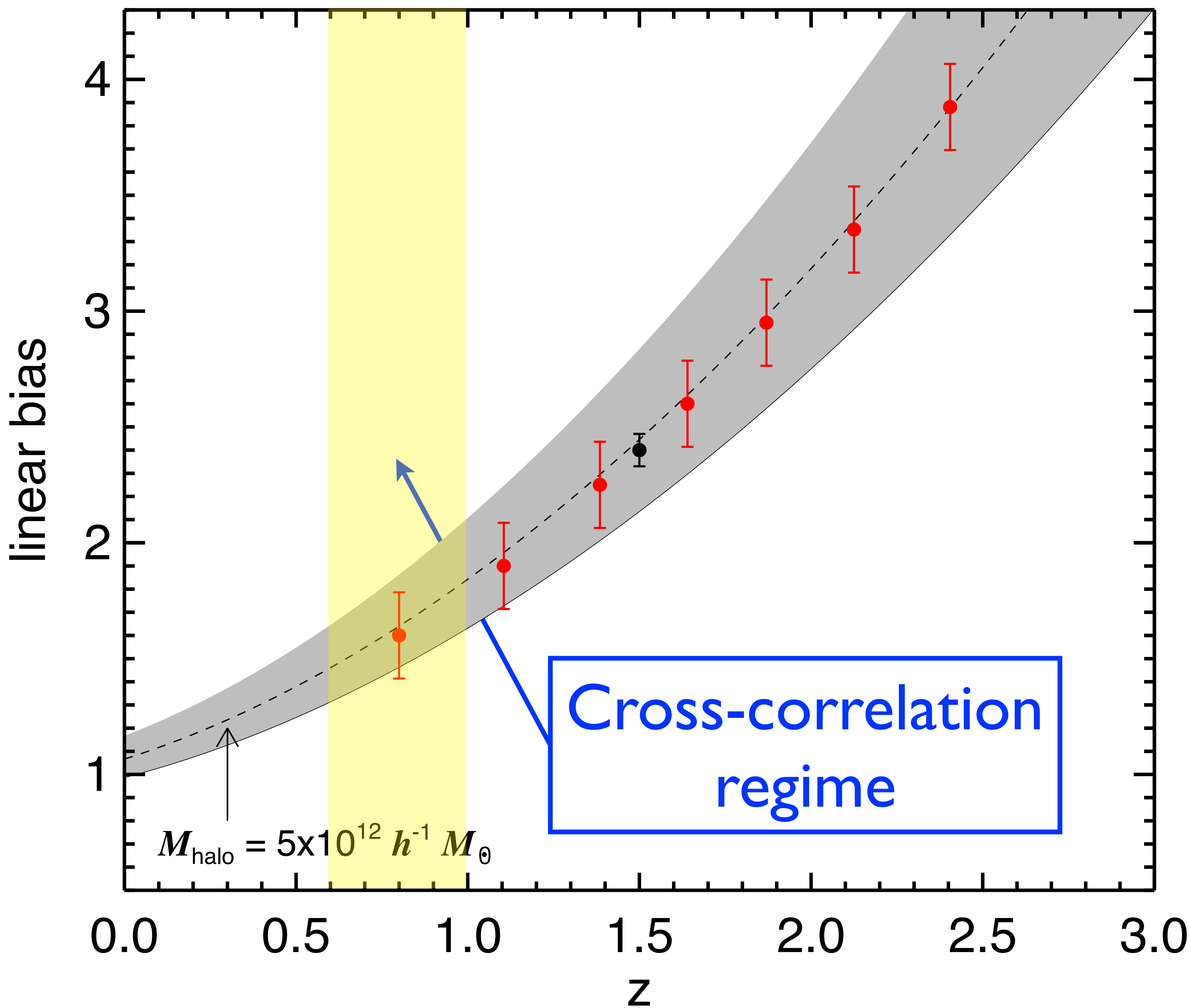
eBOSS Quasar Clustering



eBOSS Quasar Clustering



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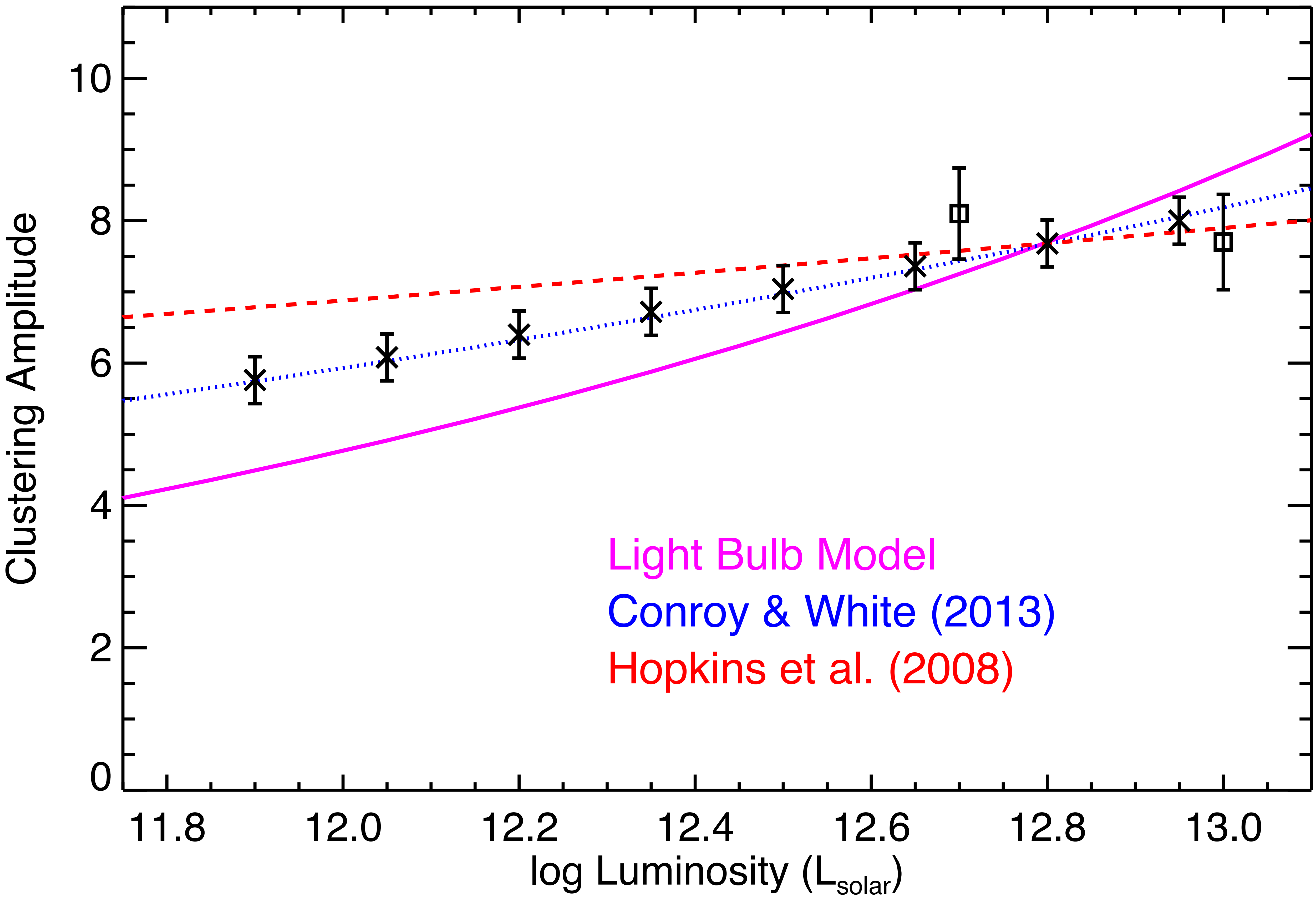

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Conclusions - Projecting from SEQUELS to eBOSS

- SDSS-IV/eBOSS is *the* next-generation quasar survey:
  - It will produce spectra of ~500,000 *statistically targeted* "CORE" $0.9 < z < 2.2$ quasars over 7500 deg^2 (an order of magnitude more than previous surveys)
  - About 440,000 of these quasars will be new identifications not in SDSS I-III or other surveys
- Including the CORE beyond $0.9 < z < 2.2$, eBOSS will comprise ~520,000 spectra of newly identified quasars
  - With Lyα quasars, TDSS and SPIDERS, this will approach ~600,000 spectra of newly identified quasars

Conclusions - Projecting from SEQUELS to eBOSS

- SDSS-IV/eBOSS is *the* next-generation quasar survey:
- With TDSS, SPIDERS, and the CORE quasar sample's tail, we can cross-correlate 100,000 $0.6 < z < 1.0$ AGN with 300,000 spectroscopically confirmed LRGs...
- As SDSS-IV quasars overlie earlier SDSS quasars, there is improved scope for small-scale clustering studies
- Care must be taken to control for imaging masks as we're pushing the limits of the SDSS imaging
- But, the general scope for new constraints on AGN clustering is *vast*

Future large AGN samples for clustering measurements: eBOSS and its AGN sample

Adam Myers, University of Wyoming

For the SDSS-III/BOSS and SDSS-IV/eBOSS collaborations