Spectroscopic Surveys: High Density Clustering After DESI

aka Billion Object Apparatus (BOA)

Kyle Dawson

University of Utah

Anze Slosar

Brookhaven National Laboratory

November 10, 2015

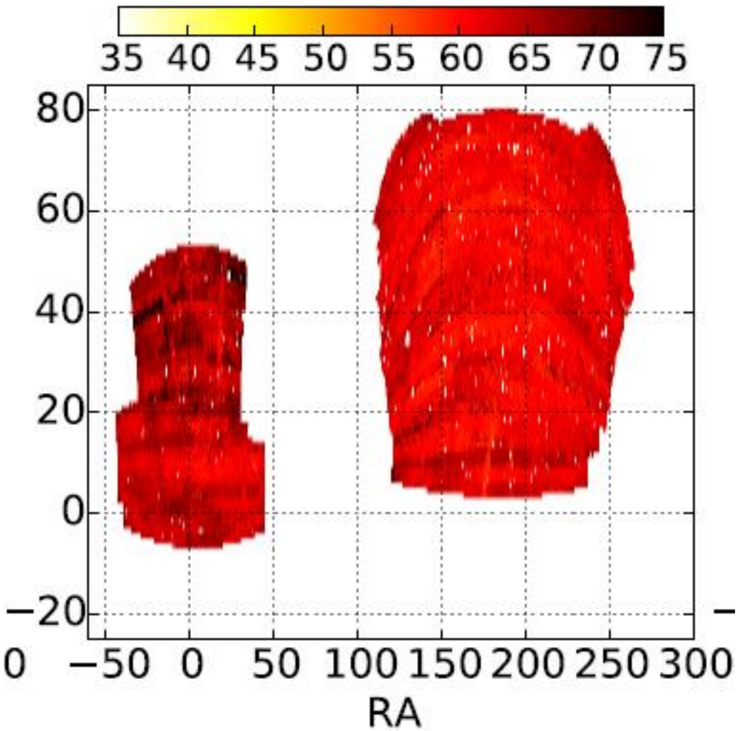
Current Status

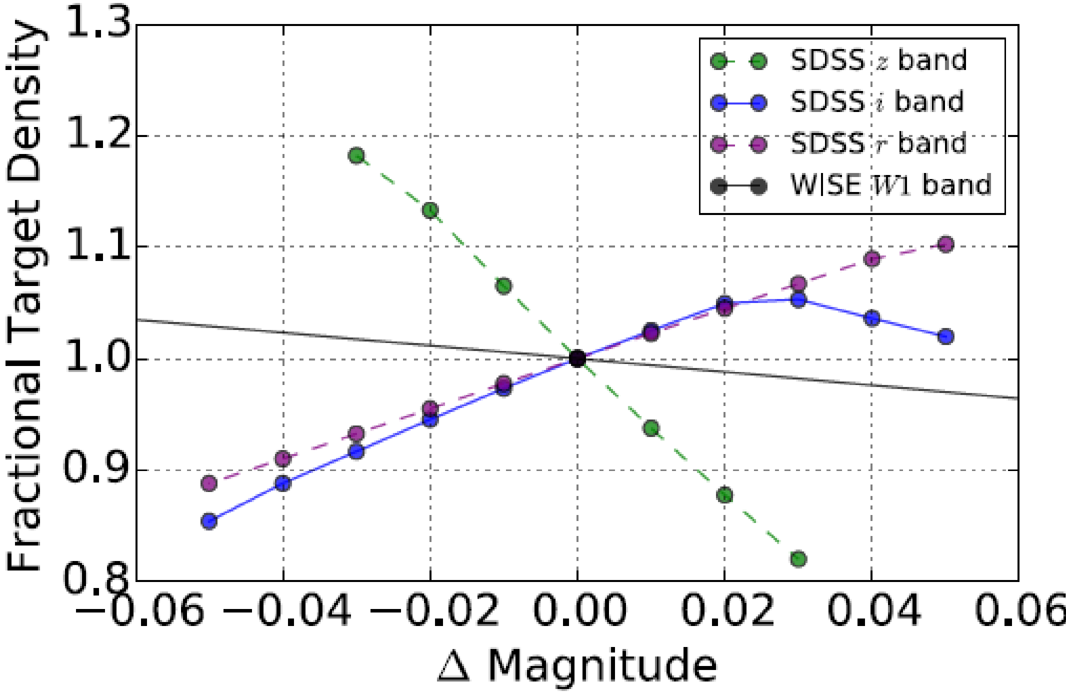
BOSS/eBOSS/DESI

- Excellent programs
  - Measure BAO near cosmic variance limit to $z<1.5$
  - Percent level BAO at $z>1.5$
  - RSD measurements possible to kmax=0.2
  - Nearly 40M spectra
- Fiber fed positioner depends on imaging for target selection
  - Convolves selection function across multiple imaging surveys
  - Sensitive to zeropoint calibration
- Galaxies at higher redshifts are faint and hard to classify
  - LRG ID-ed by absorption, need high S/N
  - ELG ID-ed by narrow emission, separate from sky residuals

Target Selection Systematics

- Variations in imaging conditions introduce structure into target selection
  - SGC and NGC feature different systematics
  - Steepest relationship: zband imaging conditions for LRG
  - Steepest relationship: image depth for QSO selection
- Calibration of imaging data essential
  - 0.01 magnitude rms errors in zband zeropoint cause 6.2% LRG density change

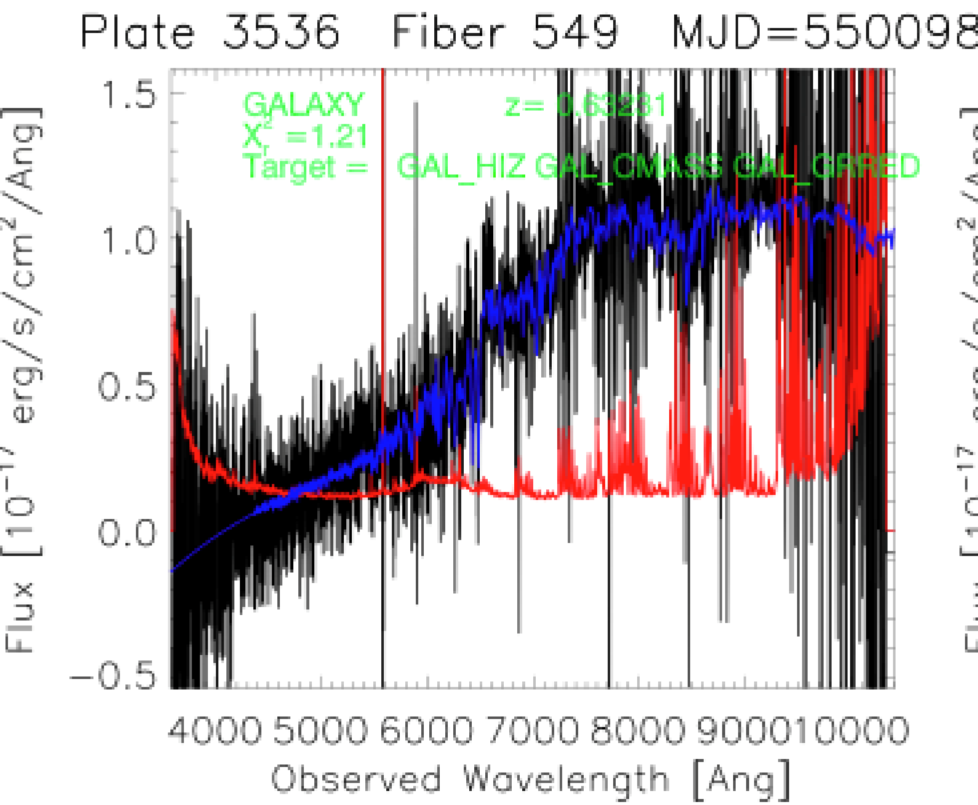




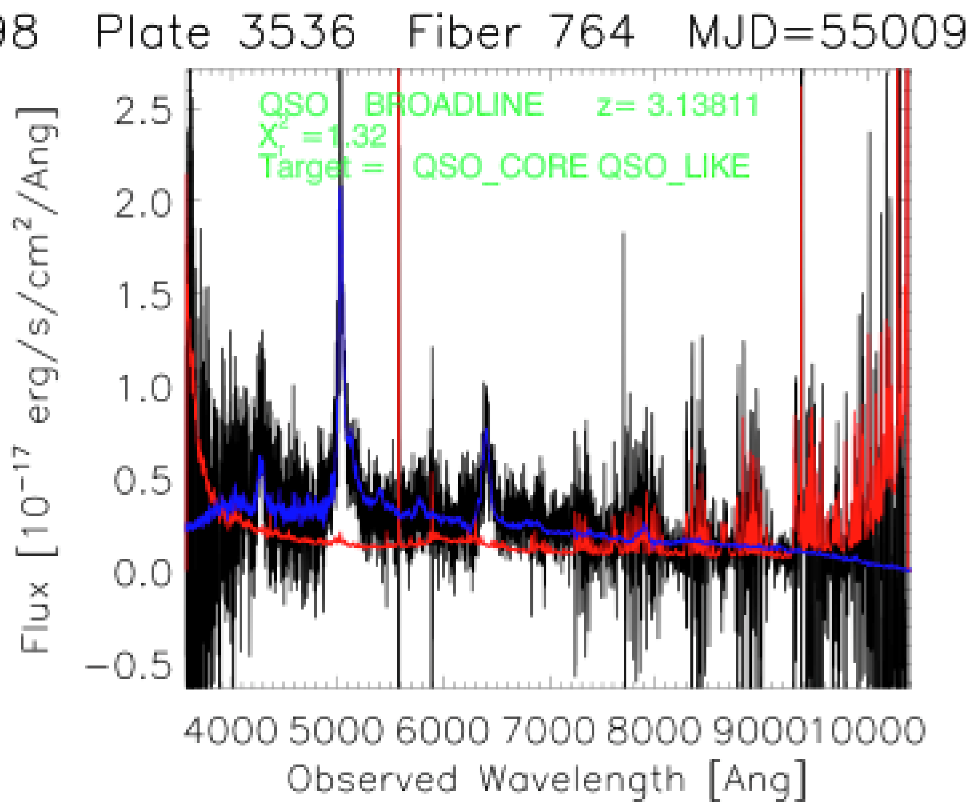
Characteristic Spectra from BOSS

- Galaxies classified automatically at 98.5% completeness
- Quasars classified via visual inspection, >400,000 spectra inspected

Galaxy *i-band*=20, z=0.6

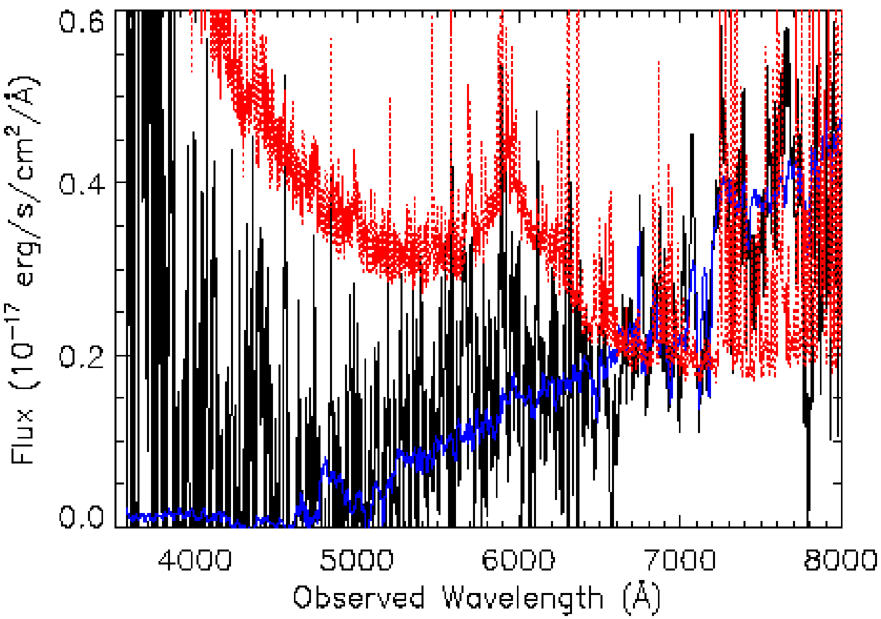


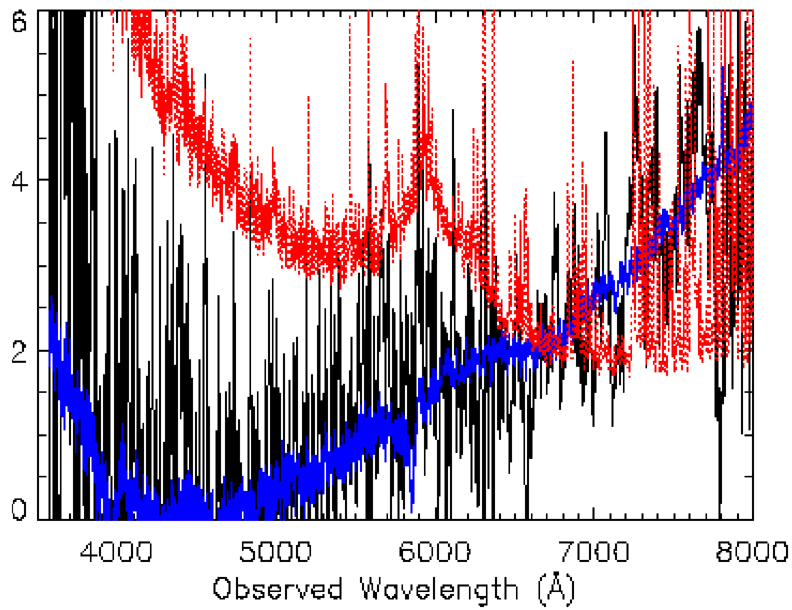
QSO *g-band*=22, z=3.1



Characteristic Spectra from eBOSS

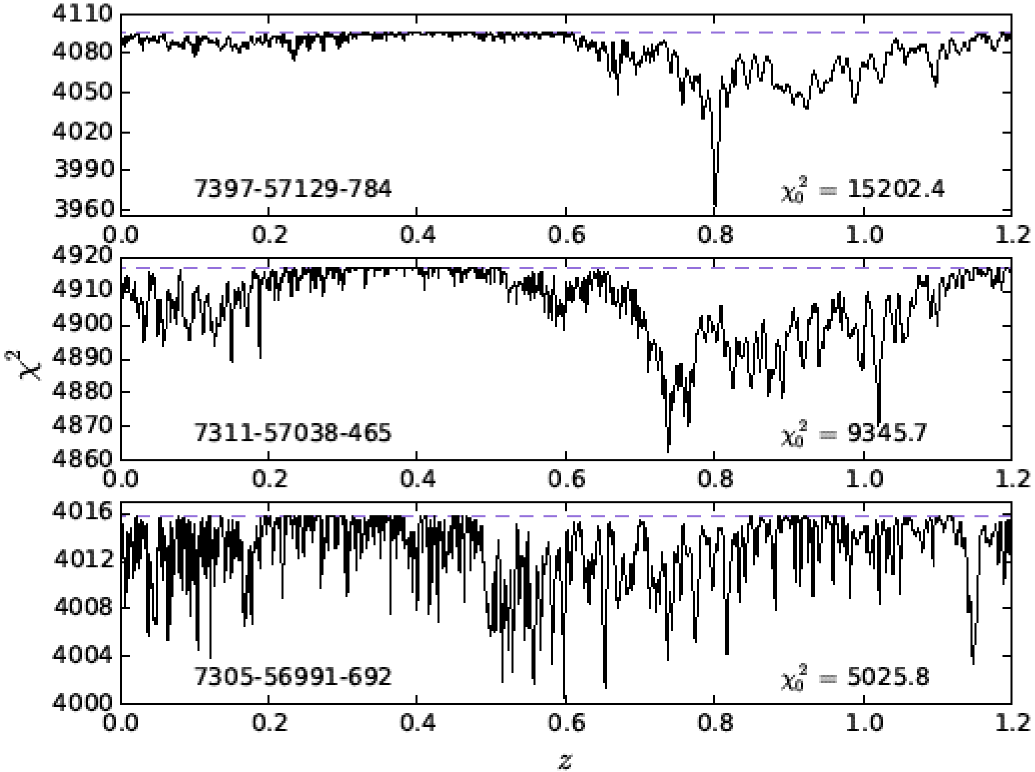
- QSO → understand astrophysics to reduce systematics in redshift estimates
- LRG spectra are faint
  - Reduces classification efficiency relative to BOSS (30% failure if routines unchanged)
- Flux calibration is essential
  - Loss of information due to non-physical broad-band spectral features
  - Should improve with bench mount system in DESI

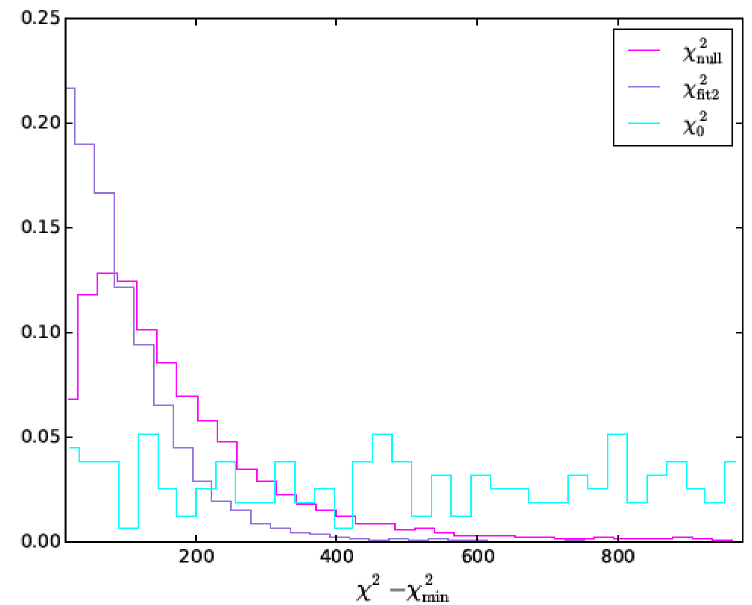




Spectroscopic Completeness in eBOSS

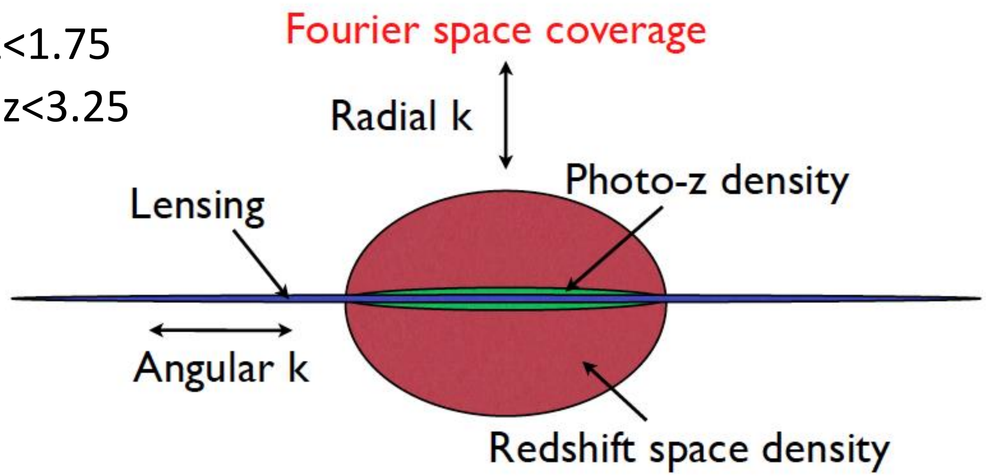
- LRG spectra are faint
  - Difficult to discriminate non-physical continuum from astrophysical signal
  - Small delta chisq from astrophysical templates
  - Many local minima





Statistical Limitations of BOSS/eBOSS/DESI

- BOSS/eBOSS >3 orders magnitude smaller sample than LSST
  - Galaxy population demographics not well-sampled
- DESI - science reach still not statistically limited
  - Lack mixed bias tracers and high density sampling of large modes
  - Room to improve RSD at small scales (k>0.2)
- Statistics for future optical spectroscopic survey
  - More modes to explore
  - Can increase mix of tracer bias
  - Explore to non-linear scales at z<1.75
  - Explore to linear scales at 1.75<z<3.25



Red: Fourier space coverage of spectroscopic surveys
Blue: Lensing (Primarily CMB)
Green: Photo-z density field

More galaxies, Wider redshift range

Mode Counting

- Assume 14k sqdeg program
- Sample modes to nP=1
- Linear regime: kmax evolves as 1/g (0.15 at z=0)
- Bias evolves as 0.84/g
- Nonlinear regime → increase kmax by factor of 2, 8X increase in N modes

Redshift	kmax	Modes (Millions)	N (per sqdeg)	N (nonlinear)
0.25<z<0.75	0.19	1.75	424	1600
0.75<z<1.25	0.25	7.37	1410	5600
1.25<z<1.75	0.30	17.47	2713	10800
1.75<z<2.25	0.36	31.97	4178	
2.25<z<2.75	0.41	50.67	5744	
2.75<z<3.25	0.47	73.33	7383	
3.25<z<3.75	0.53	99.75	9076	

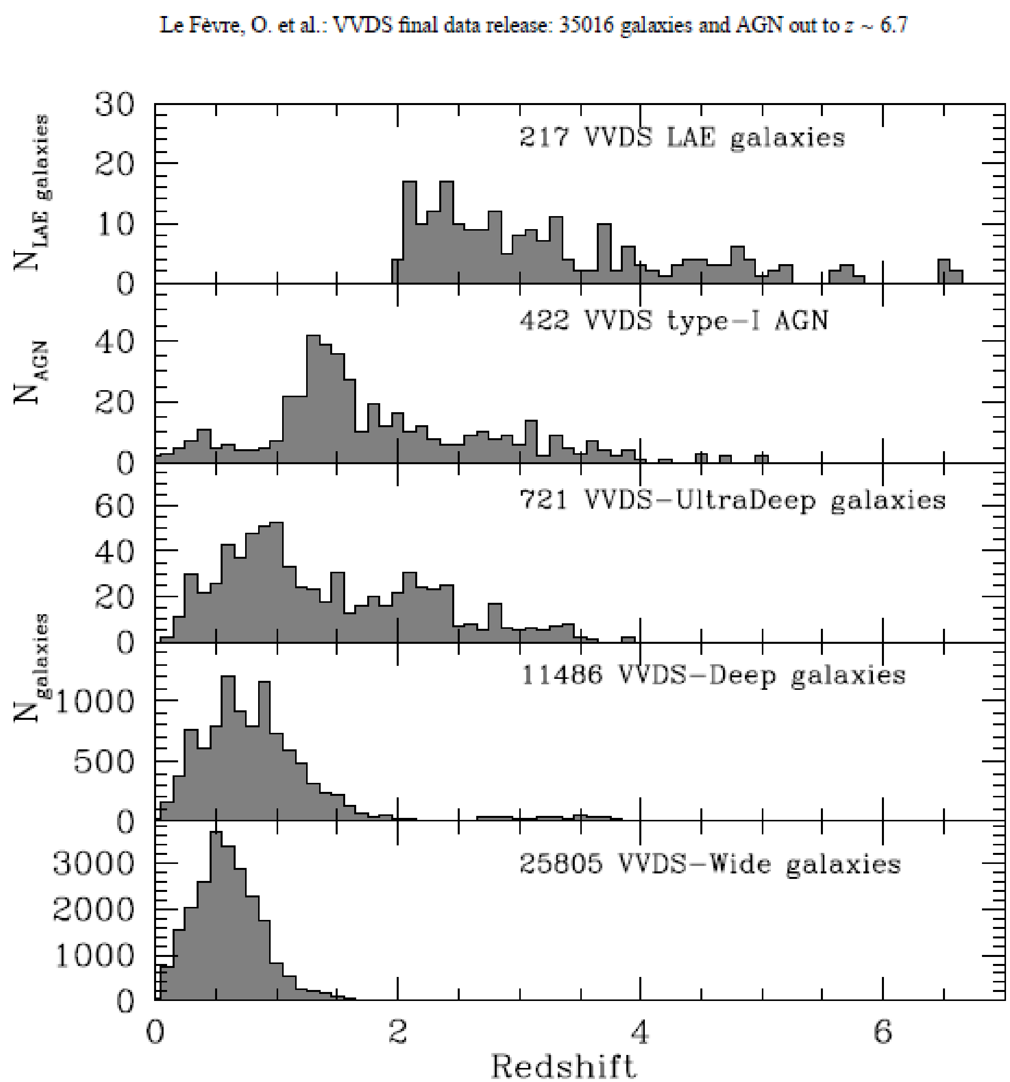
Mode Counting

- DESI → 0<z<1.5 to kmax=0.2, 10-15M modes
- Proposal: 20k/sqdeg galaxies to z<1.75
  - 200M modes with new sample
  - kmax=0.38 (z=0.5); kmax=0.6 (z=1.5)
- Proposal: 20k/sqdeg galaxies at 1.75<z<3.25
  - 150M modes with new sample
  - New BAO, kmax=0.36 (z=2), kmax=0.47 a(z=3)
- 40k galaxies/sqdeg → full power spectrum to kmax=0.35 and z<3.25

Redshift	kmax	Modes (Millions)	N (per sqdeg)	N (nonlinear)
0.25<z<0.75	0.19	1.75	424	1600
0.75<z<1.25	0.25	7.37	1410	5600
1.25<z<1.75	0.30	17.47	2713	10800
1.75<z<2.25	0.36	31.97	4178	
2.25<z<2.75	0.41	50.67	5744	
2.75<z<3.25	0.47	73.33	7383	
3.25<z<3.75	0.53	99.75	9076	

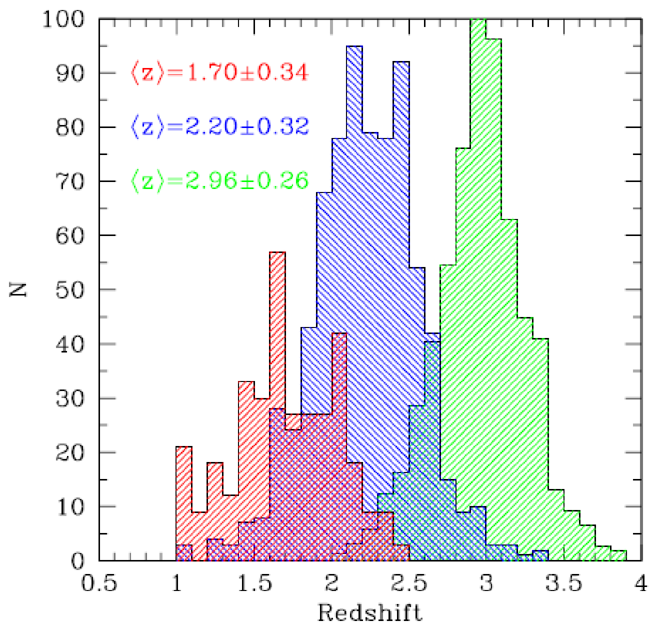
Sample selection (z<1.75)

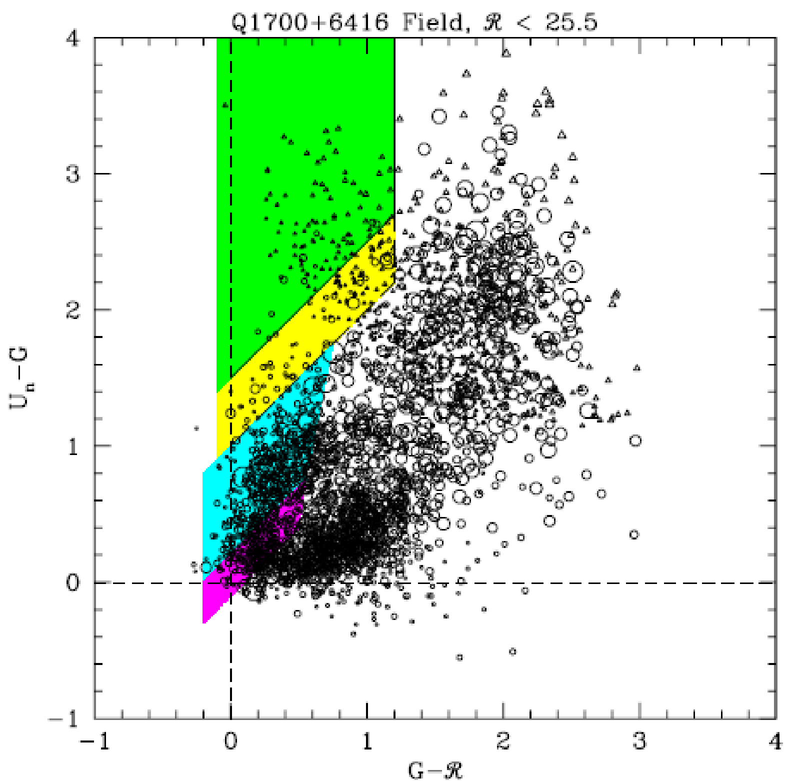
- Galaxy science programs → mass limited samples with 8-m telescopes
- VIMOS VLT Deep Survey (VVDS)
  - 20k per sqdeg at i<22.5
  - R=230
  - 5500<lambda<9350 \AA
- Results
  - Median(z)=0.55
  - 94% success rate (4.5hr exp)
  - 75% success rate (45min exp)
- i<22.5
  - Reduces imaging selection effects with simple selection
- Choose g-band limited survey?
  - N(z) not known
  - Should increase <z>



Sample selection (1.75<z<3.25)

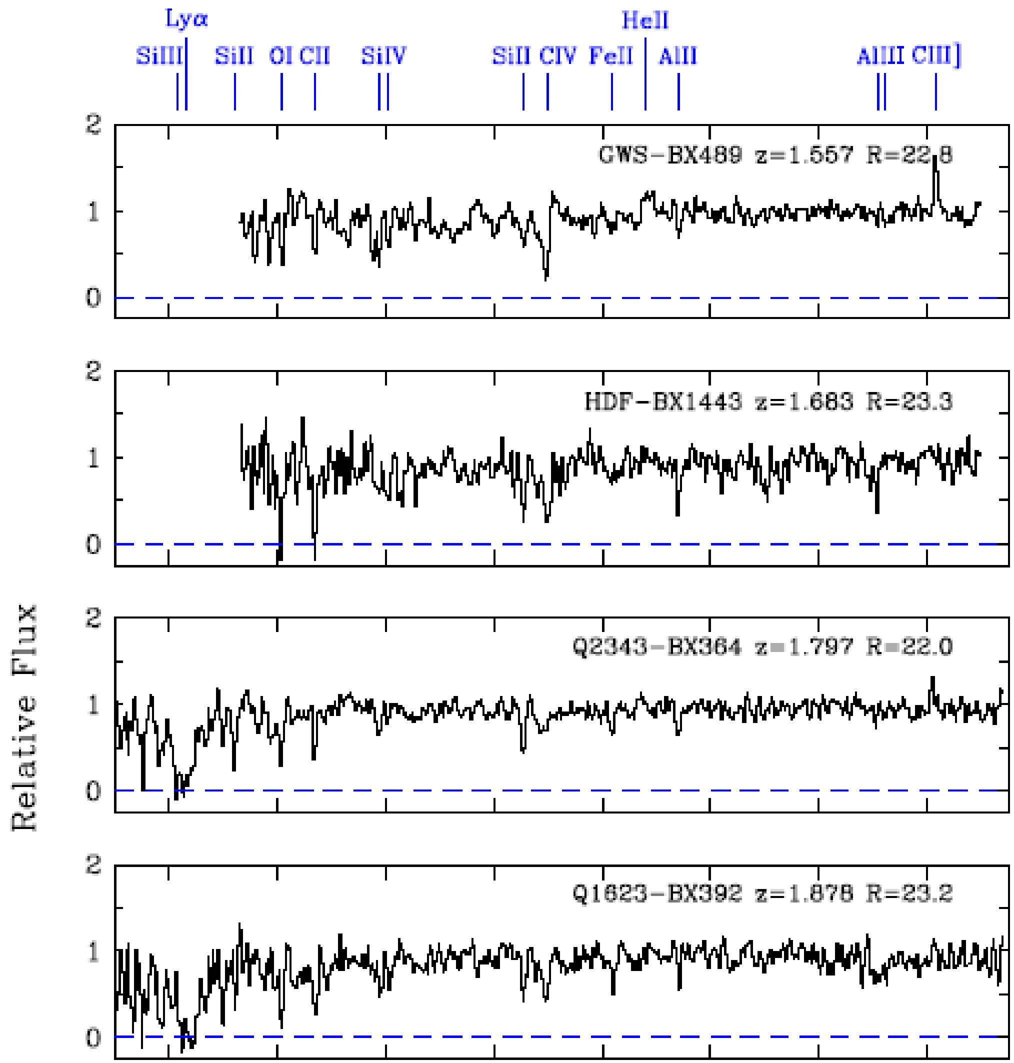
- Galaxy science programs → target star forming galaxies with 10-m telescope
- Steidel et al, LRIS on Keck I
  - 40k per sqdeg at r<25.5
  - R=1000
  - Redshifts from UV interstellar lines
  - 1.5 hour exposures
- Results
  - 90% success rate (good conditions)
  - 65-70% success rate (average)





Sample selection (1.75<z<3.25)

- Well=studied luminosity function, e.g. Reddy et al 2008, 2009
- UGR selection to r<25.5
  - Sensitive to u-band calibration
  - May have large fluctuations
  - 25% of all r<25.5 objects
- Observations at r<23.5
  - Very high success rates
  - Well-defined O, Si, C lines
- Reduce to r<24.5?
  - S/N increases by 2.5
  - N=20k/sqdeg



Survey Design

Overview

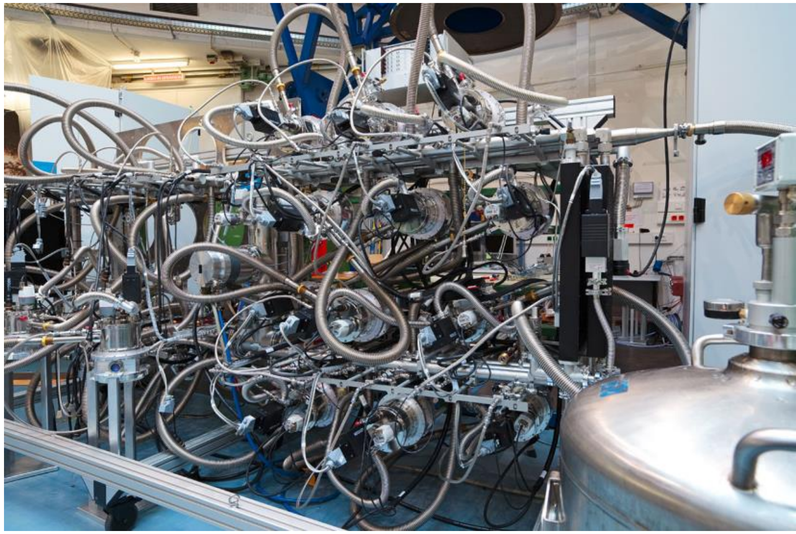
- 40k per sqdeg, 14k sqdeg
  - Could be g-band or r-band limited, but need to test n(z)
  - 560M spectra
  - 15X DESI
- 350M Fourier modes
  - 30X DESI
- 10m telescope
  - 6X DESI collecting area
- 1-2 hr exposures for 90% redshift success
  - 2-4X DESI exposure times
- Overall ~4X better [OII] sensitivity than DESI for low z sample
- 3600-14,000 \AA
  - Includes IR channel for [OII] detection to z=2.6
  - R~1000's for UV absorption and [OII] identification

Overview

- Overlap with LSST footprint
  - Deep ugriz imaging
  - Better control over targeting systematics
- Deep exposures
  - Better control over spectroscopic systematics
- Major improvement over VVDS with better resolution/wavelength coverage
- Improvement over Keck program with better control of exposure times

Survey Characteristics

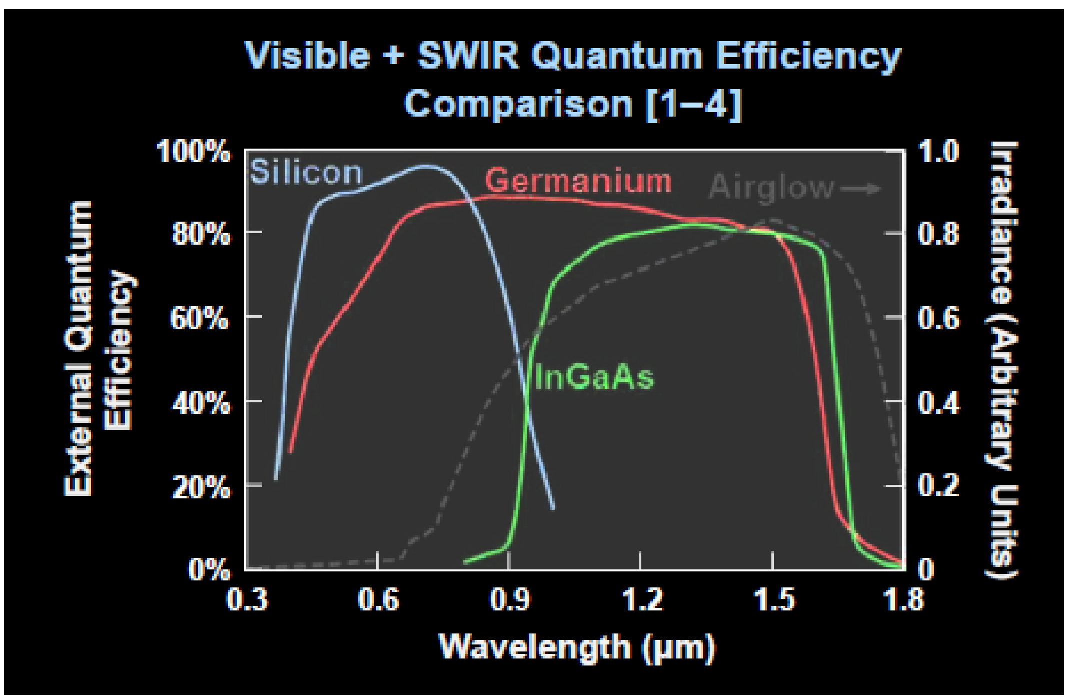
- Assume 1000 hours open shutter per year
- Assume 10 year program
- 5000-10,000 unique pointings
  - Requires 1.4 - 2 degree FOV
  - 1.5 - 3 sqdeg per field
- Assume 80% fiber efficiency
  - 50k fibers per sqdeg
  - 75k - 150k fibers for instrument
- Bigger spectrograph on bigger telescope: large!
  - E.g. MUSE on VLT, 50 m^3 for 100,000 traces
  - MUSE at Nasmyth focus, image slicer
- Difficult to scale to orders of magnitude bigger than DESI
  - How to scale to 100's of thousands of fibers?

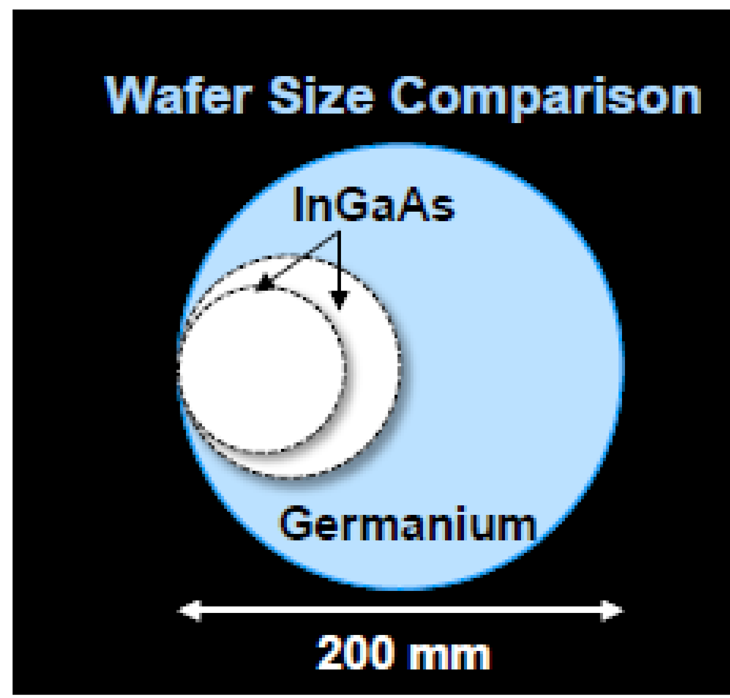


Detectors

- Silicon + Germanium CCDs
- Si for two channels, 3500<lambda<8000 \AA
  - Well-known technology
- Ge for two channels, 8000<lambda<14,000 \AA
  - New CCD's being developed at Lincoln Labs
  - 2k x 2k target by 2019, low dark current, low read noise

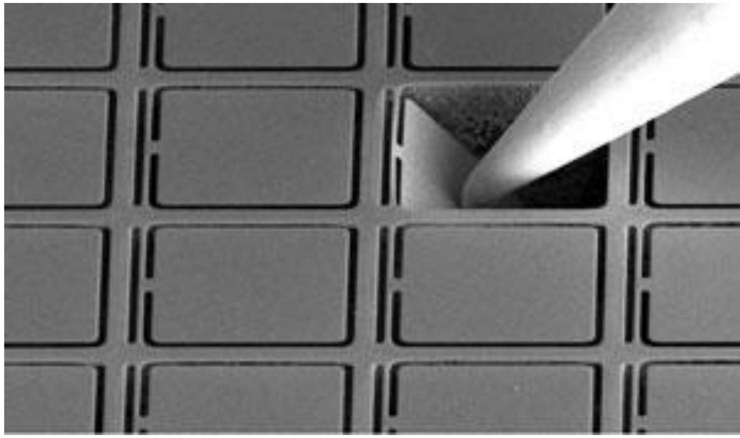
From Christopher Leitz (MIT LL)

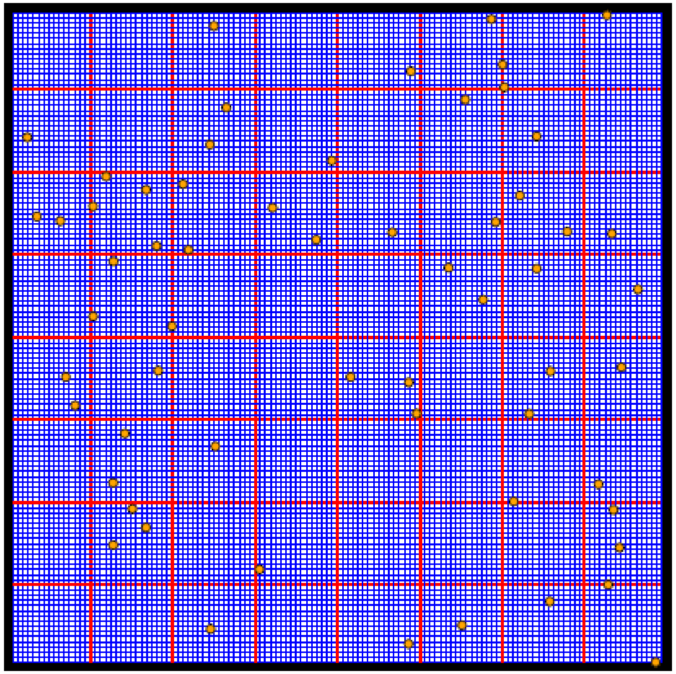




Possible Fiber Design

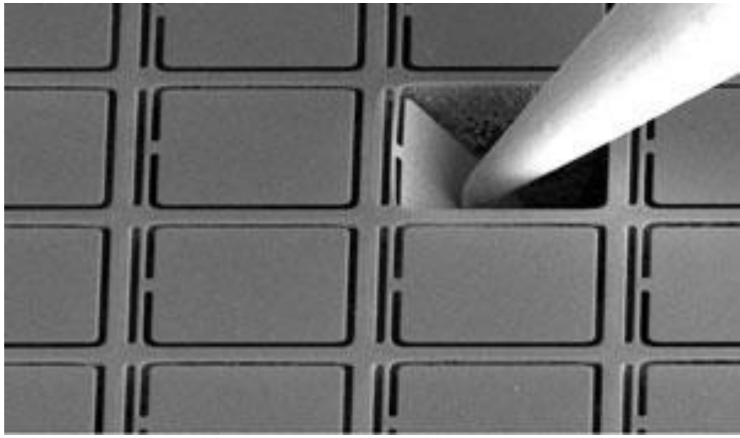
- Field very crowded for fiber positioners
- Fill focal plane with lenslet arrays
- Couple ~hundreds of lenslets to single fiber
- Flip to appropriate lenslet through microshutter
- Flip between cells between exposures to resolve “fiber collisions”
- Battle Liouville’s theorem in focal plane



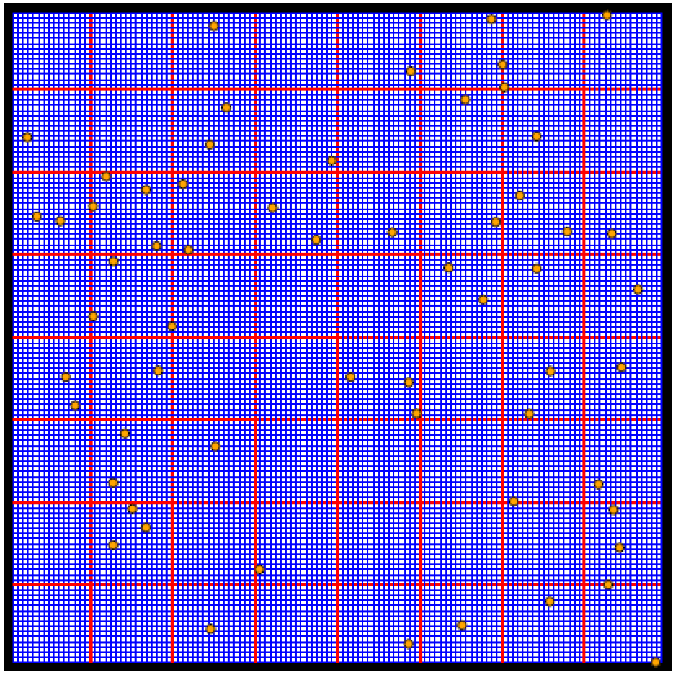


Other Possible Designs

- Fill focal plane with massive fiber bundle
- Run fibers to spectrographs
- Feed ~100 fibers to each trace
  - Perpendicular to slithead
  - ~100 wavelength solutions
- Flip between output using microshutter array
- No battle with Liouville
  - only 1/3 fill factor
  - Major fiber run



- Use massive image slicer at Nasmyth
- No target selection, selection function completely contained in spectra
- Need massive instrument and number of pixels
  - 1” x 1” sampling would be 13M traces for 1 sqdeg
  - Requires 3000 4k x 4k CCDs for each channel
- Use microshutter array to parallelize???



Summary

- 350M modes to explore after DESI
  - Nonlinear scales for z<1.75
  - Linear scales for 1.75<z<3.25
- Target selections tested
  - Low z: i<22.5, but too many z<1 galaxies
  - High z: UGR selection at r<24.5 is correct density, but sensitive to U-band
- Instrument
  - Requires 100’s of thousands targets simultaneously,
  - Dedicated 10m telescope in southern hemisphere
  - Examine balance of telescope size, fiber number, etc.
  - Optical to IR coverage
- Scientific argument
  - Data argument is clear: fully sample density field to z<3.25
  - Map improved sampling onto which cosmological parameters?
  - What are acceptable levels of completeness, catastrophic failures?