High Density Galaxy Survey

aka Billion Object Apparatus (BOA)

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Outline

- Context
- Sample Selection
- Instrumentation
- Survey Design
- Programmatics and Challenges

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
- Systematic limitations of targeting/redshift completeness not yet clear

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 $z<1.5$
  - Explore to linear scales at $1.5<z<3.25$

- This workshop → cosmology at small scales, support of LSST/CMB, but lacking comprehensive science case

- Consider comprehensive science case for spectroscopic clustering program dedicated to saturating information content past $z=3$

Mode Counting

- Assume 14k sqdeg program
- Sample modes to nP=1
- Linear regime: kmax evolves as 1/g (0.15 at z=0)
- 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	500	2000
0.75<z<1.25	0.25	7.37	1500	6000
1.25<z<1.75	0.30	17.47	3000	12000
1.75<z<2.25	0.36	31.97	4000	
2.25<z<2.75	0.41	50.67	6000	
2.75<z<3.25	0.47	73.33	7000	
3.25<z<3.75	0.53	99.75	9000	

Mode Counting

- 20k/sqdeg galaxies to z<1.5
  - 200M modes with new sample
  - Access non-linear regime
  - kmax=0.38 (z=0.5); kmax=0.6 (z=1.5)
- 20k/sqdeg galaxies at 1.5<z<3.5
  - 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

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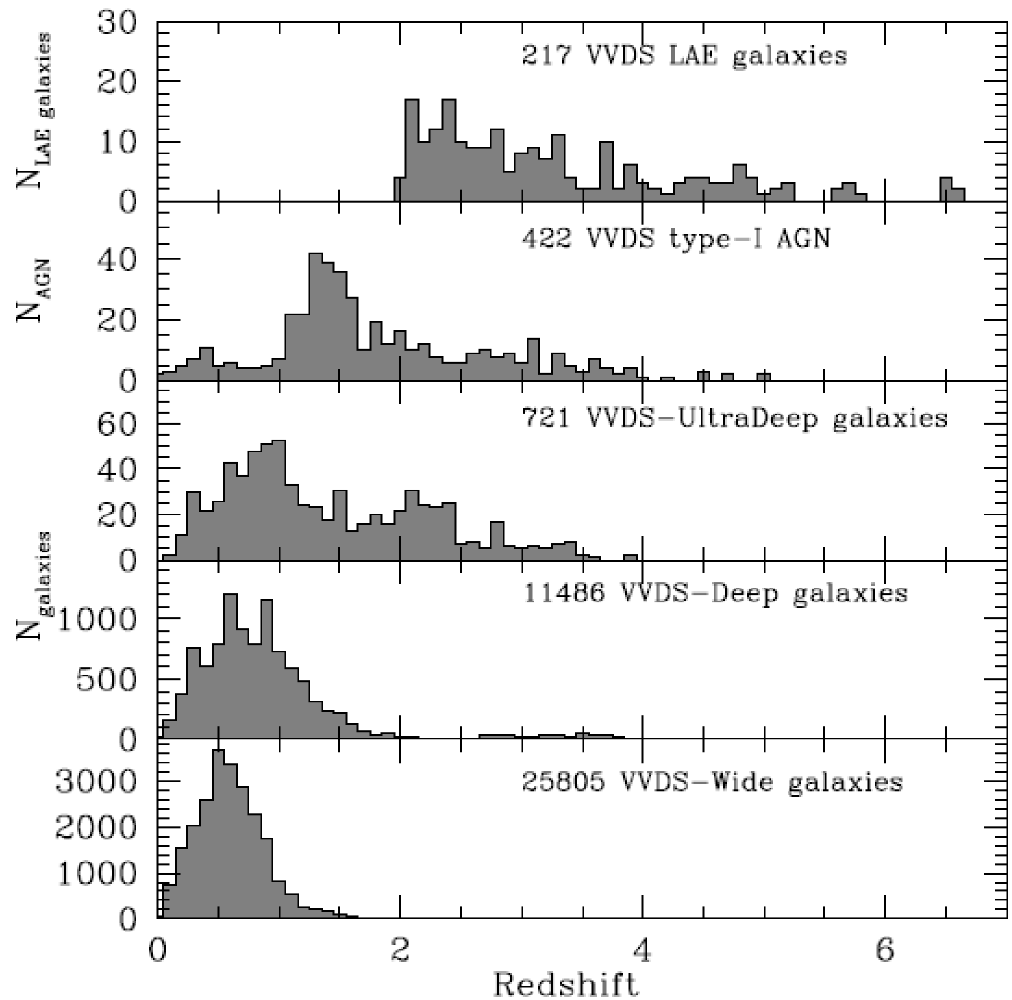
Sample selection (z<1.5)

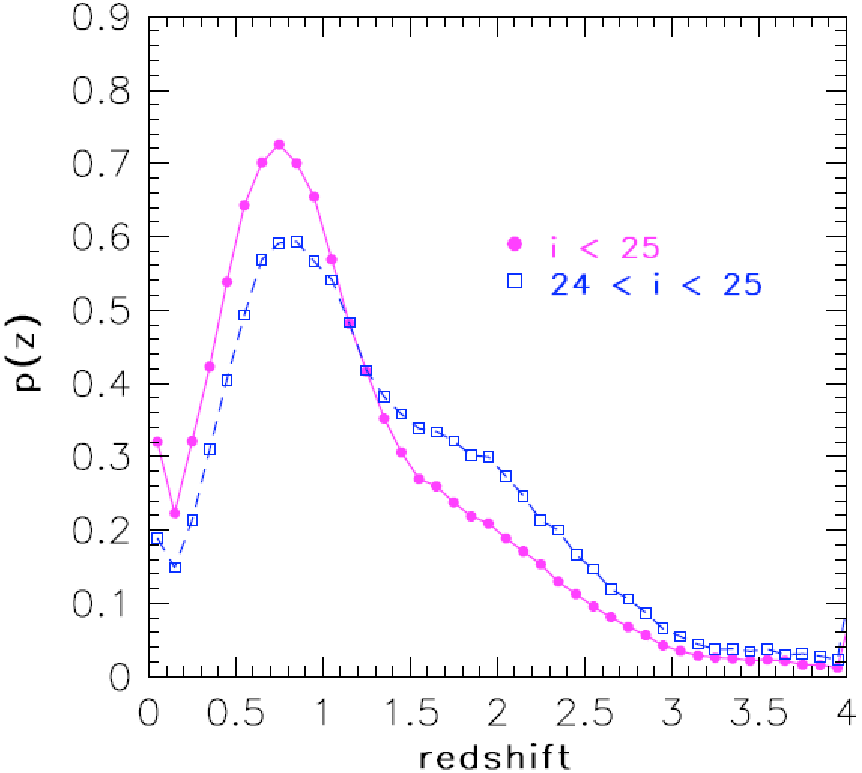
- Galaxy science programs → mass limited samples with 8-m telescopes
- VIMOS VLT Deep Survey (VVDS)
    - 20k per sqdeg at i<22.5
    - R=230
    - 5500<lambda<9350 \AA
- Results
    - Median(z)=0.55
    - 94% success rate (4.5hr exp)
    - 75% success rate (45min exp)
    - ~5% catastrophic failure rate
- i<22.5
    - Reduces imaging selection effects with simple selection

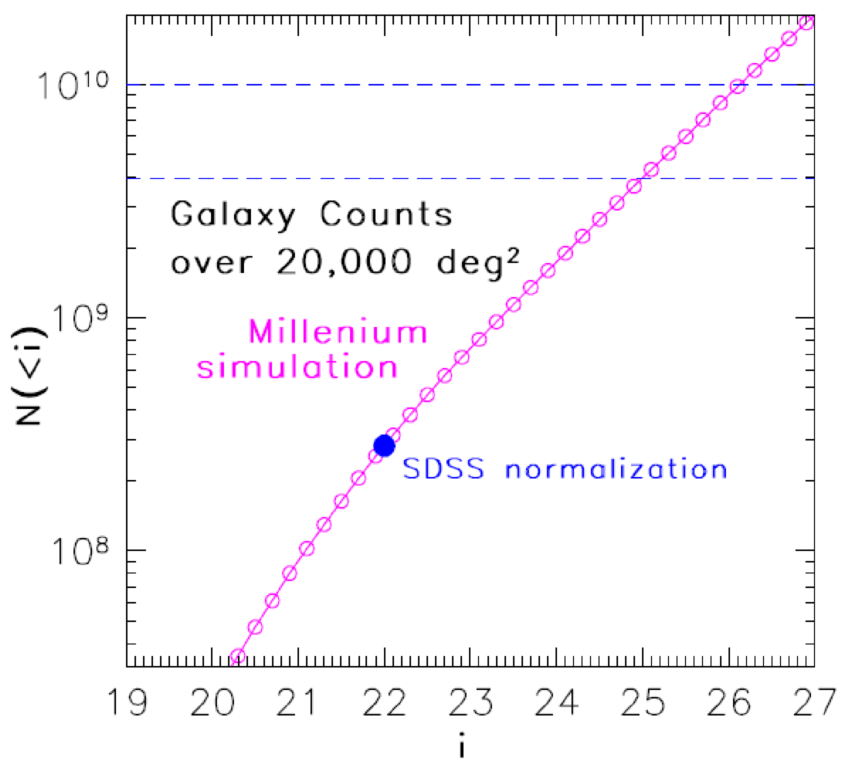
Le Fèvre, O. et al.: VVDS final data release: 35016 galaxies and AGN out to $z \sim 6.7$



Magnitude Limited Sample

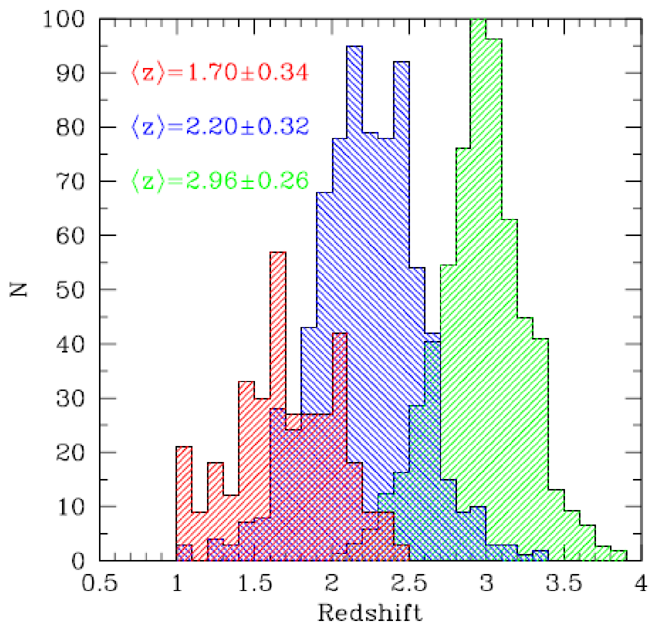
- VVDS results consistent with LSST science book assumptions
- Magnitude-limited sample favors z<1.5
- Tune magnitude limit to desired number density
  - 20k/sqdeg at i<22.5
  - 35k/sqdeg at i<23
- Need color selection to sample z>1.5

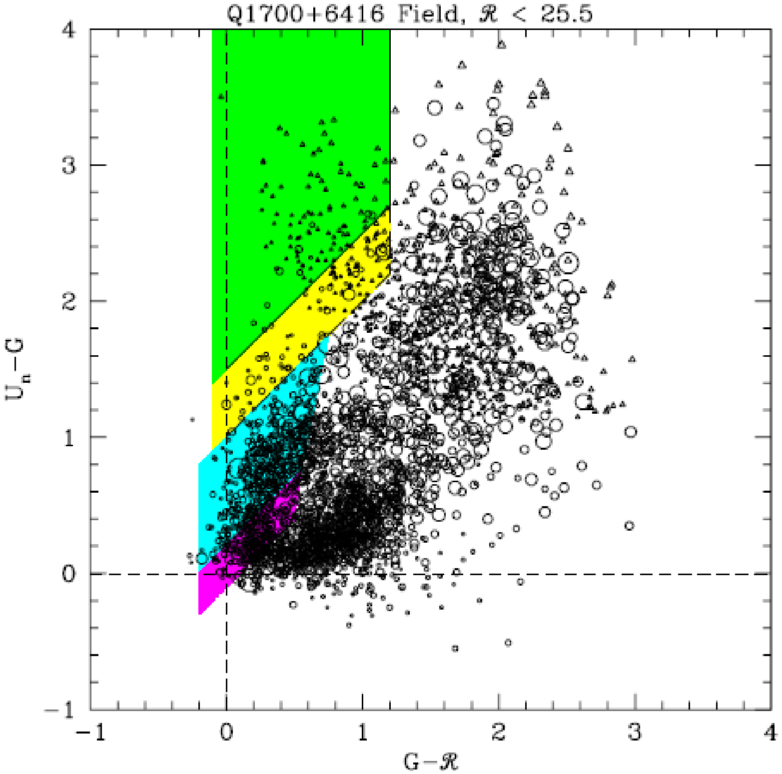




Sample selection (1.5<z<3.25)

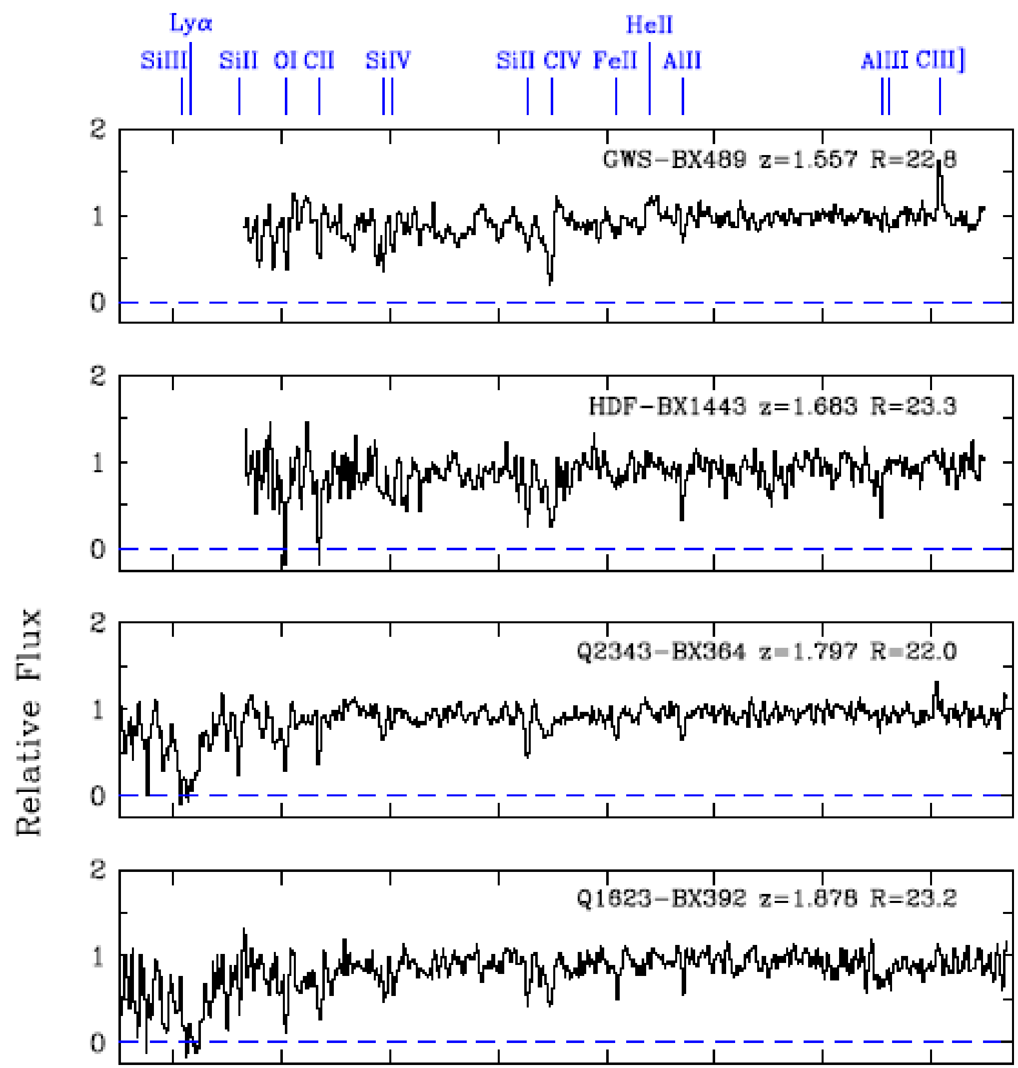
- Galaxy science programs → target star forming galaxies with 10-m telescope
- Steidel et al, LRIS on Keck I
  - 30k targets per sqdeg at r<25.5
  - R=1000
  - Redshifts from UV interstellar lines
  - 1.5 hour exposures
- Results
  - 90% success rate (good conditions, r<24.5)
  - 65-70% success rate (average)





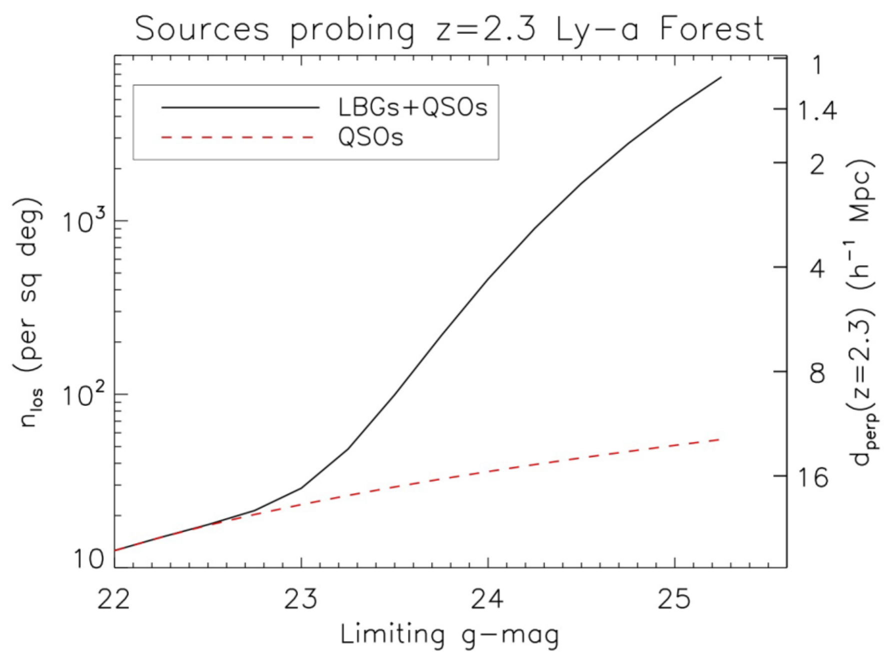
Sample selection (1.5<z<3.25)

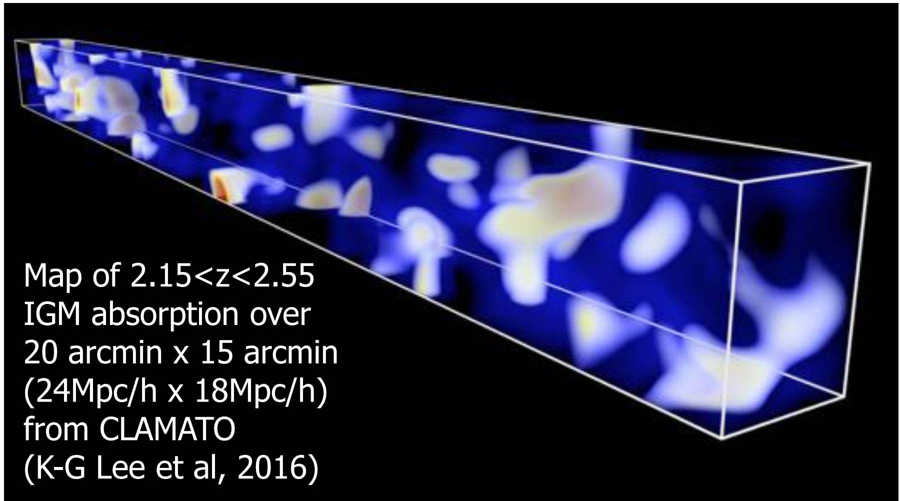
- UGR selection to r<25.5
  - Sensitive to u-band calibration
  - May have large fluctuations
  - 25% of all r<25.5 objects
- Observations at r<23.5
  - Very high success rates
  - Well-defined O, Si, C lines
- Reduce to r<24.5?
  - S/N increases by 2.5
  - Better for UV absorption
  - Ntargets~15k/sqdeg



Lyman-alpha Absorption Tomography at z>2

- 2500 sightlines per sq deg at r < 24.5 vs 15 per sq deg in BOSS (r < 21)
- Sightline separations of 2-3 Mpc/h → full 3D mapping down to non-linear scales
- K-G Lee et al 2014 showed that S/N = 2-3 per angstrom sufficient for tomographic reconstruction
- Ongoing CLAMATO survey over 1 sq deg on Keck-I/LRIS
  - (http://clamato.lbl.gov)
- BOA: 5000 per sq deg of UGR-selected targets (inc. TS overhead) with 3hrs integrations will cover all linear modes at 2.0 < z < 3.5





Map of 2.15<z<2.55 IGM absorption over 20 arcmin x 15 arcmin (24Mpc/h x 18Mpc/h) from CLAMATO (K-G Lee et al, 2016)

Survey Design

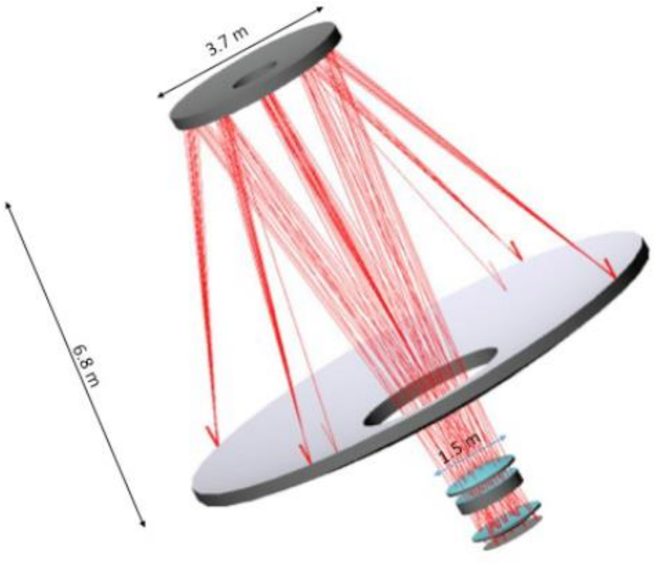
- 35k targets per sqdeg, 14k sqdeg
  - Magnitude limited sample to z<1.5
  - UGR selection for 1.5<z<3.25
  - 500M spectra
  - 15X DESI
- 350M Fourier modes
  - 30X DESI
- 10m telescope
  - 6X DESI collecting area
- 1 hr exposures for ?90%? redshift success
  - 2.4X DESI exposure times
- Overall ~4X better [OII] sensitivity than DESI for low z sample
- 3600-13,000 \AA
  - Includes IR channel for [OII] detection to z=2.5
  - R~4000 for sky subtraction and [OII] identification

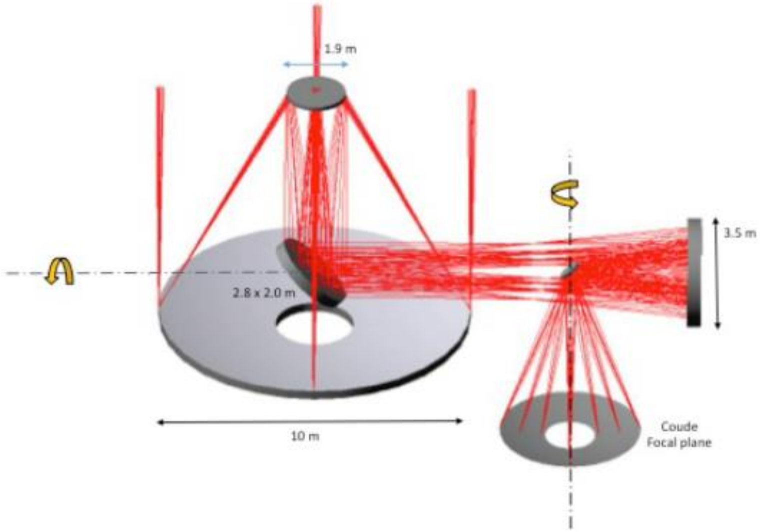
Survey Characteristics

- Conservative Assumptions
  - 1000 hours open shutter per year
  - 1 hr/exposure
  - 10 yr program
- 10,000 unique pointings
  - 2.5 degree FOV (4.9 sqdeg per field)
  - Three passes per coordinate (3hrs with repeat visits to lyman-alpha forest tomography targets)
- Assume 80% fiber efficiency
  - 13k fibers per sqdeg
  - 65k fibers for instrument
- Increase fiber density 2X to reach 1B spectra

Possible Telescope Design

- Two designs for massively multiplexed spectrographs on 10-m class telescope
  - Pasquini et al., 2016
- Fiber design
  - 2.5 degree diameter (4.9 sqdeg)
  - 1.3 meter focal plane diameter (Cass focus)
- Ring design
  - 1.5 degree diameter (1.0 sqdeg)
  - 4.6 meter focal plane diameter (Coude focus)
- Bigger spectrograph on bigger telescope:
  - Cass versus Coude
  - FOV considerations

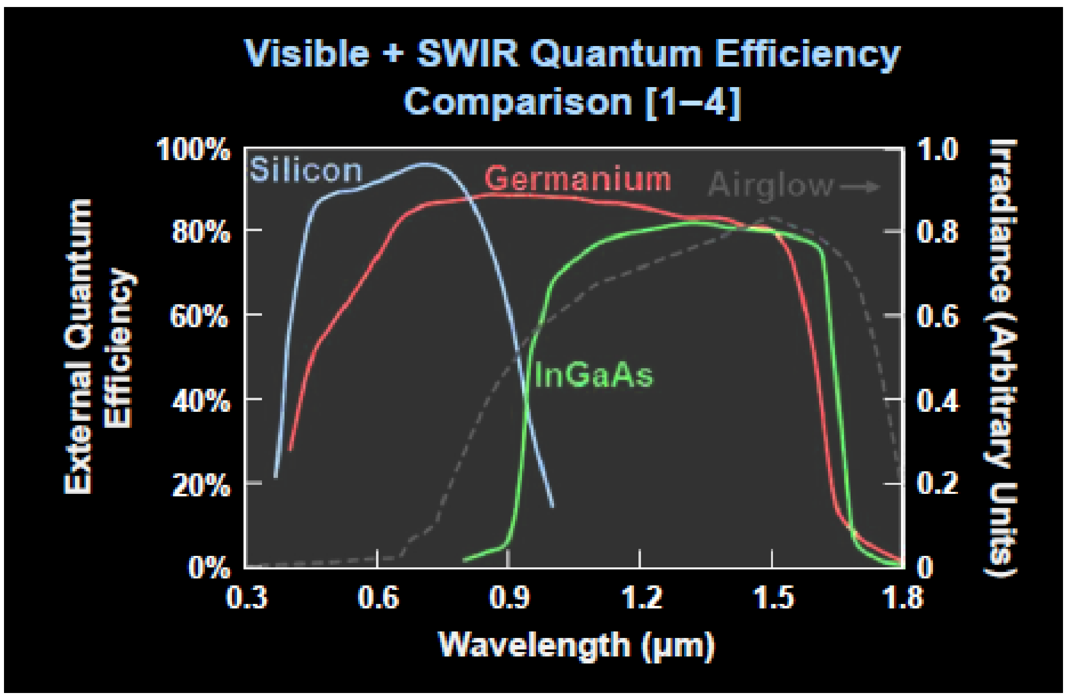


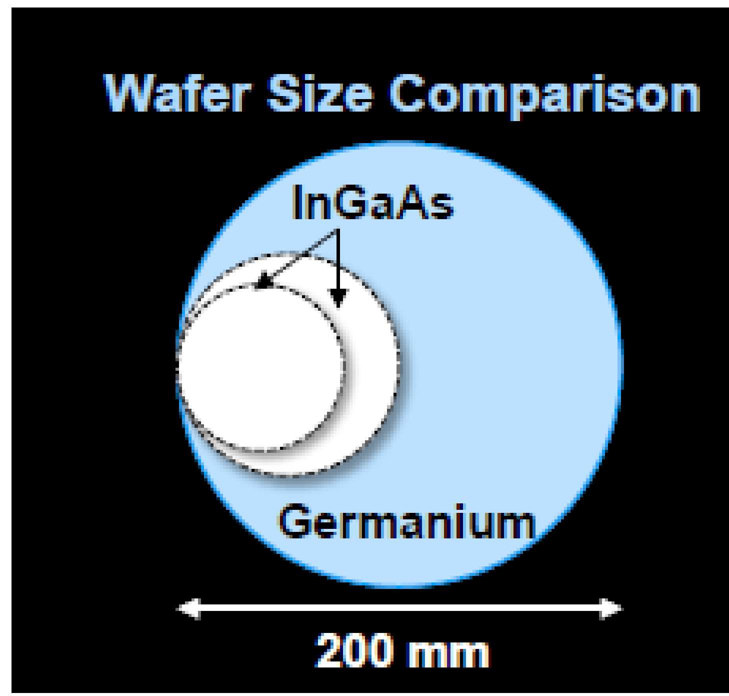


Spectrographs

- DESI design with 4th channel
- Silicon + Germanium CCDs
- Si for two channels, 3500<lambda<8000 \AA
  - Well-known technology
- Ge for two channels, 8000<lambda<13,000 \AA
  - New CCD's being developed at Lincoln Labs/LBNL

From Christopher Leitz (MIT LL)





Technical Challenges

- Details of target selection and exposure depth
  - What is optimal number density for $z<1.5$ and $z>1.5$?
  - What is the expected redshift success rate versus exposure time?
  - What are requirements for spectroscopic completeness?
  - What are maximal allowable uncertainties in the selection function?
- Fiber placement
  - How to fill focal plane with ~100,000 fibers?
- Spectrographs
  - DESI design with 4th channel possible
  - How to scale production to accommodate ~100,000 fibers?

Programmatics

- Complementarity to radio, IR, and CMB surveys
  - How do we weight independent clustering science versus programs to enhance LSST/cross-correlation science?
- Staged experiment?
  - Share telescope/instrument design with DESI-II/SSSI?
  - Instrument 10-meter telescope with ~5000-fiber spectrograph following DESI
  - Upgrade to ~100,000 fiber spectrograph after N years?

Summary

- 350M modes to explore after DESI
  - Nonlinear scales for $z<1.5$
  - Linear scales for $1.5<z<3.25$
- Target selections tested
  - Low z: magnitude-limited to appropriate density
  - High z: UGR selection at $r<24.5$ but sensitive to U-band
- Instrument
  - Requires ~100,000 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?