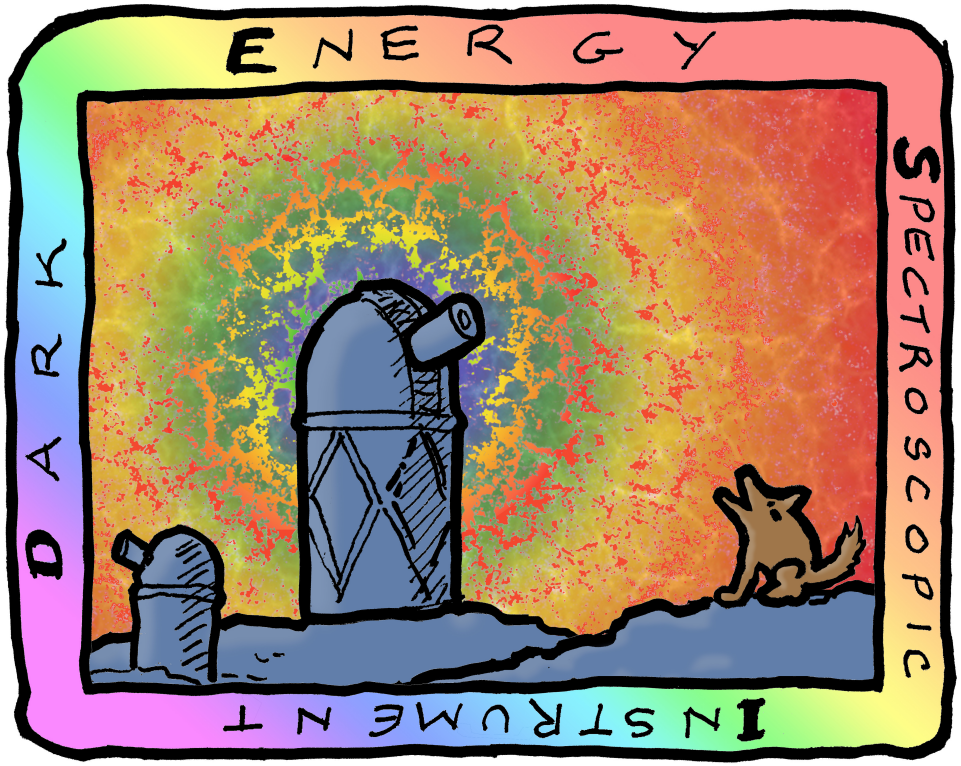


The Dark Energy Spectroscopic Instrument (DESI)

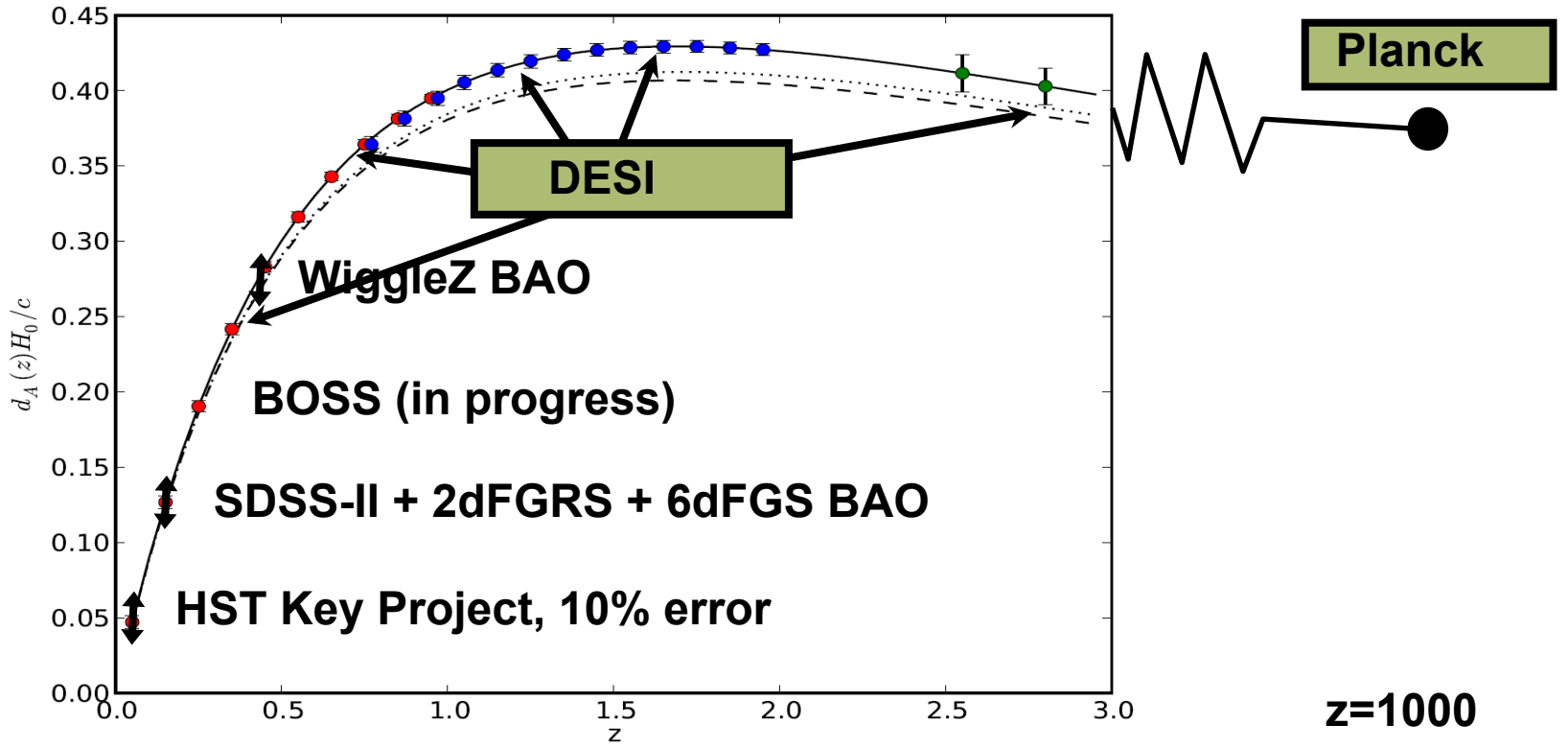
Peder Norberg
ICC, Durham University
on behalf of
David Schlegel (LBNL) for DESI

DESI collaboration meeting

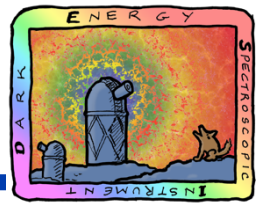
Berkeley (July 15th-18th 2013)

DESI Design Goals

- *BAO geometric probe with 0.3-1% precision from z=0.5 -> 3*
- *35 measurements with 1% precision*



DESI Status



September 2012 - Department of Energy (DOE)
Critical Design 0

4.2 Schedule Forecast

The current estimated dates for the major milestones are:

Critical Decisions (CD)	*Fiscal Year*
CD-0, Approve Mission Need	*FY 2012* ✔
CD-1, Approve Alternative Selection and Cost Range	*FY 2013* Jan. 2014
CD-2, Approve Performance Baseline	*FY 2014*
CD-3, Approve Start of Construction	*FY 2015*
CD-4, Approve Project Completion	*FY 2018*

DOE charge to
- satisfy Stage 4 dark energy experiment, rich scientific program
- technically advanced for 2018 start

DESI Status

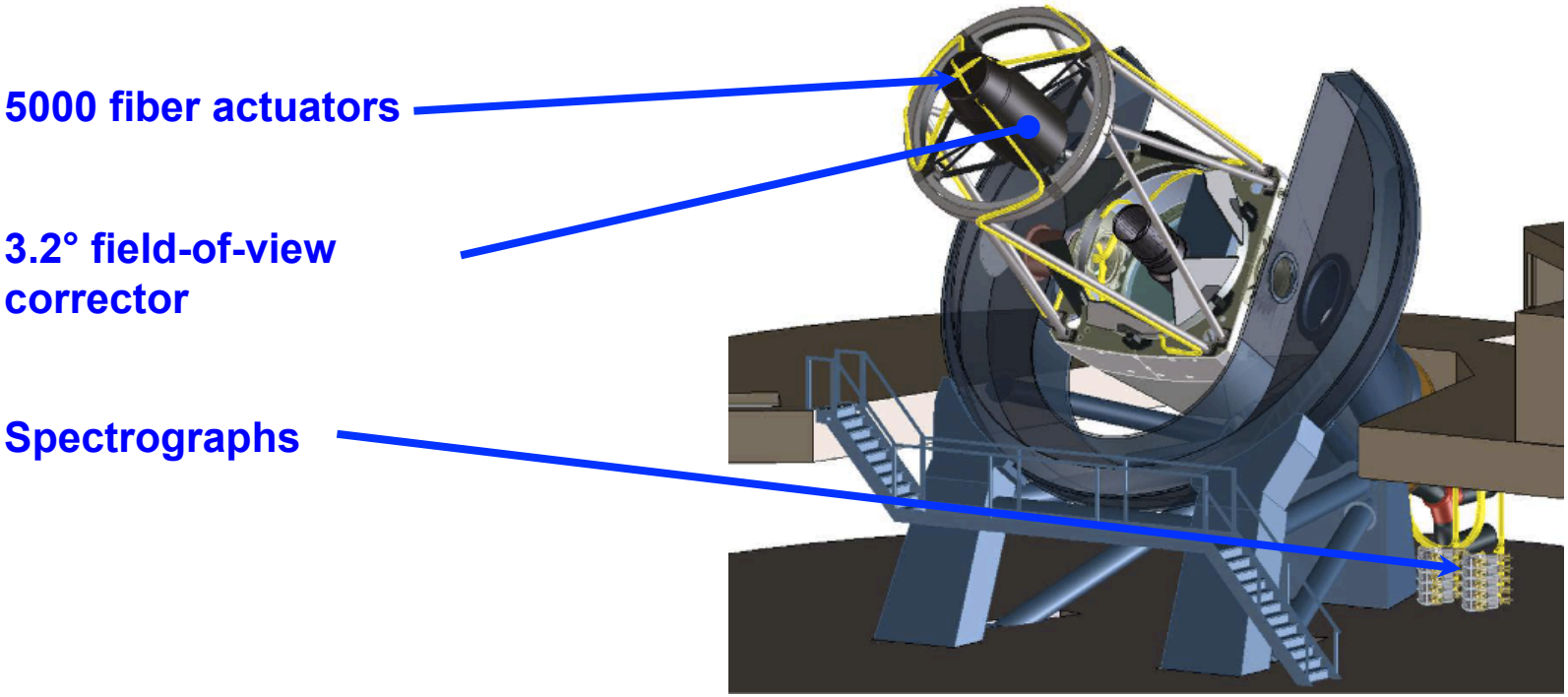
December 2012 - Department of Energy (DOE)
Project assignment to Berkeley Lab
No "downselect" between BigBOSS & DESpec

April 2013 - Site "alternatives analysis" completed
DOE has requested Kitt Peak 4-m as preferred site

MS-DESI Study to Support the Alternatives Analysis and Selection

April 5, 2013

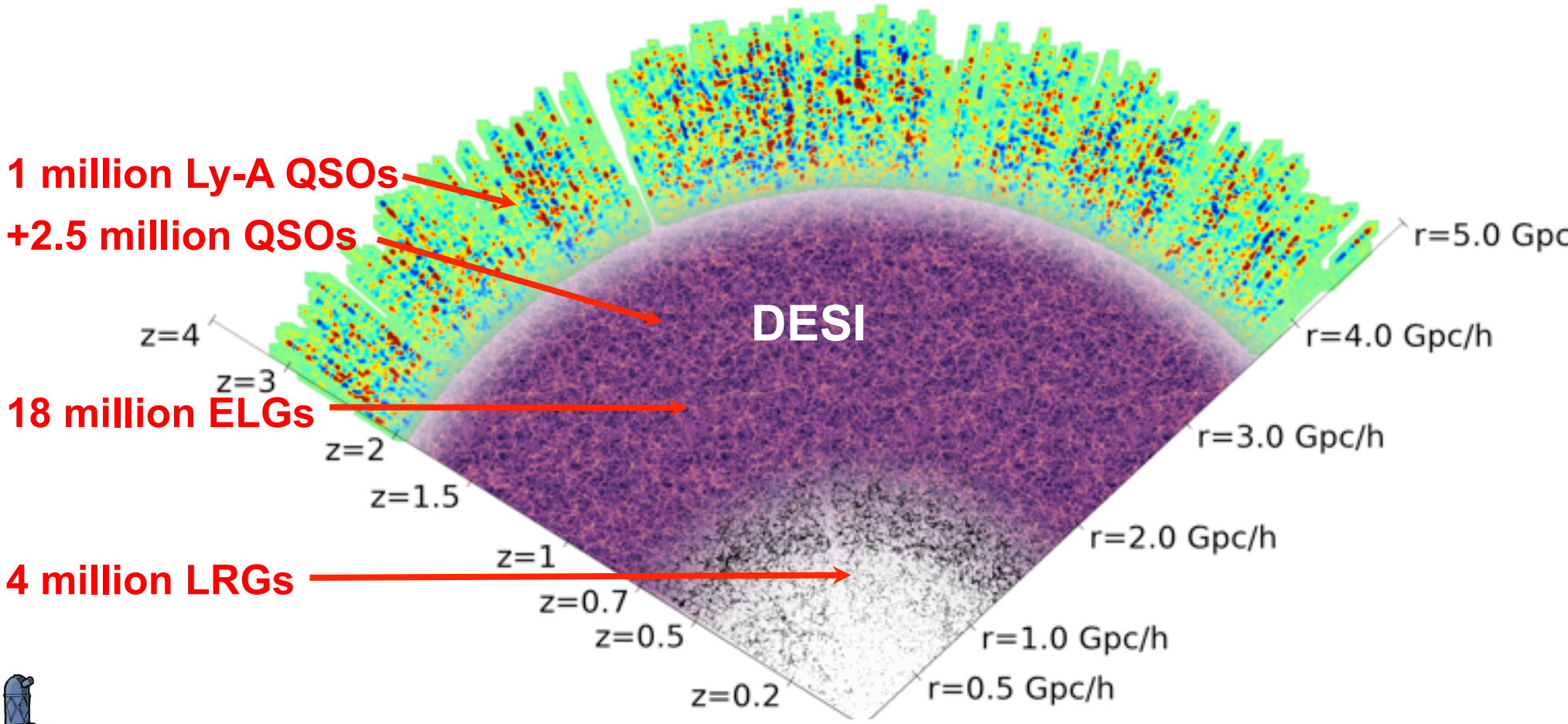
DESI at the Mayall Telescope



DESI requests 100% of the “dark-time” plus appropriate engineering time during the first several years

DESI Targets

Mayall telescope available up to 100% of dark time
>20 million targets
14,000 to 18,000 deg^2



1. Luminous Red Galaxies (LRGs)

LRGs have been the workhorse of BAO surveys (SDSS, BOSS)
All LRG spectra look nearly identical to z~1

Entire spectrum used for redshift,
dominant features are "4000 Angstrom break" and "Ca H+K lines" to z=1.2

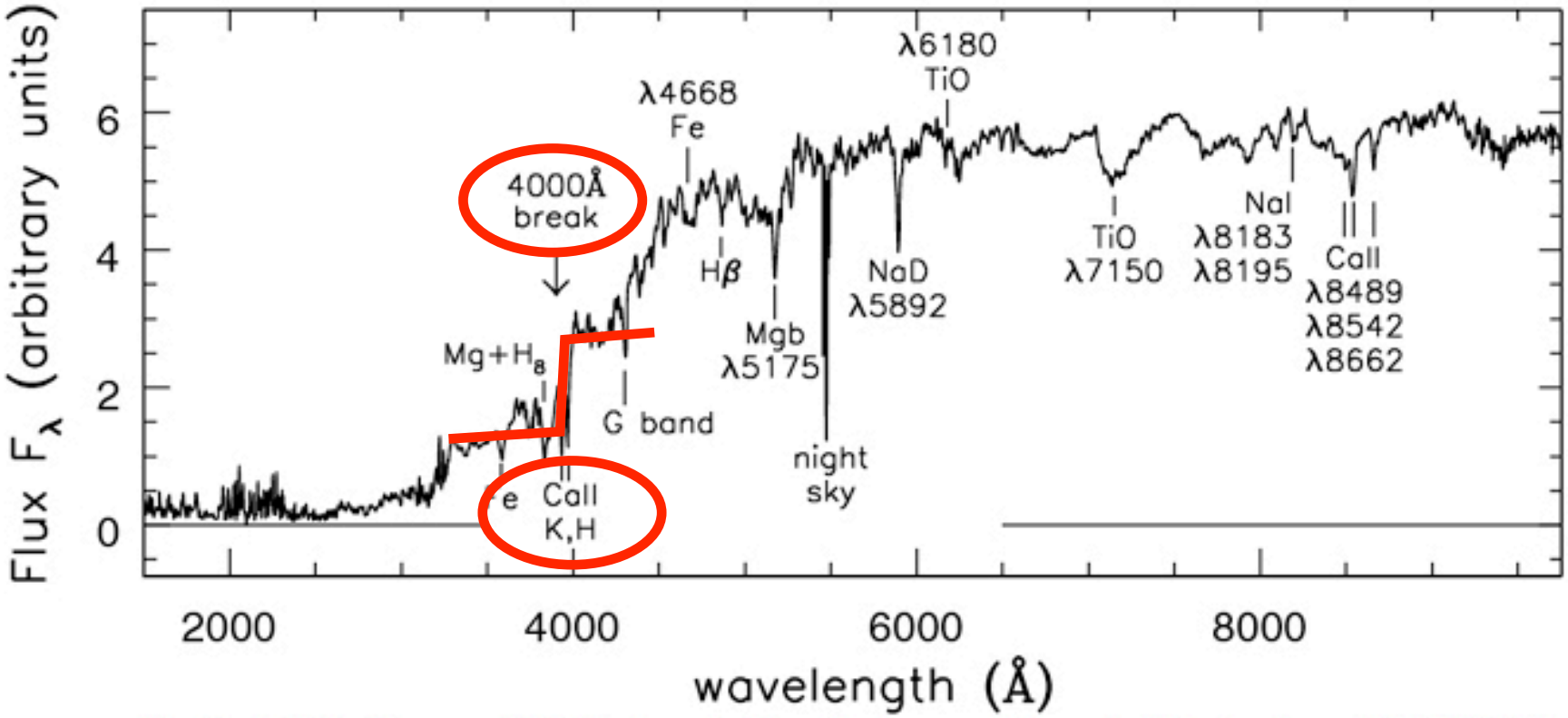
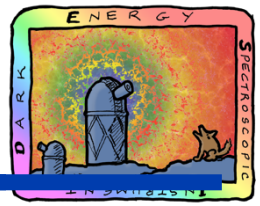


Fig 6.17 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

1. Luminous Red Galaxies (LRGs)



LRG tracers at 0.5 < z < 1

The most massive galaxies in the Universe
Excellent tracers of dark matter halos
Well-studied in N-body simulations

Test data:

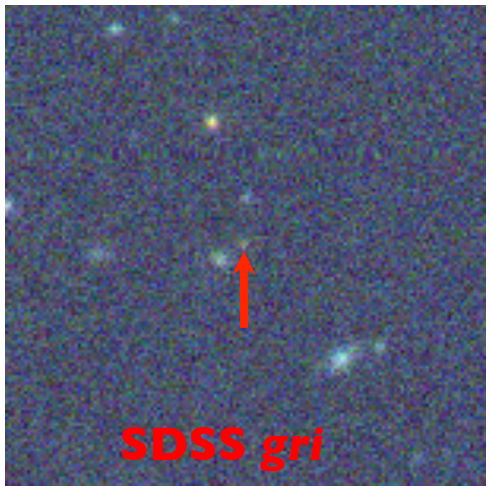
1.5 million LRGs from SDSS + SDSS-II + BOSS to z=0.7

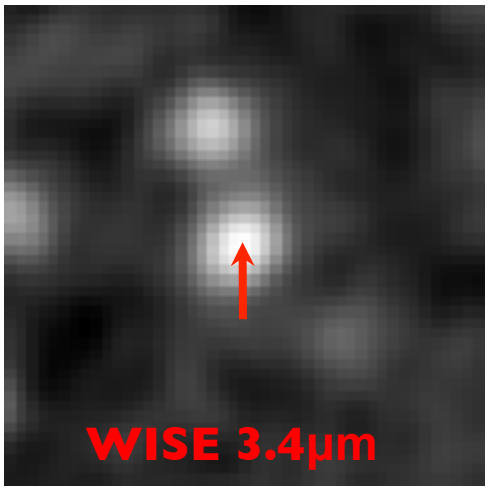
+20,000 WISE-selected LRGs from BOSS ancillary programs (2012-2013)

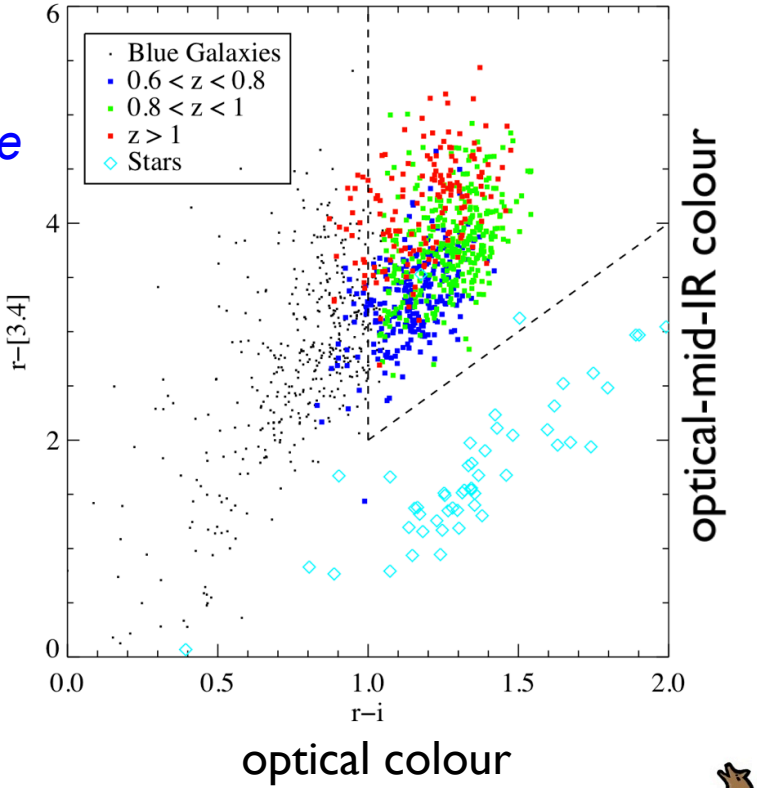
DESI targets:

4+ million LRGs to z=1

Selected at 3.4 micron from WISE satellite
+ SDSS/ZTF imaging (2-band only)





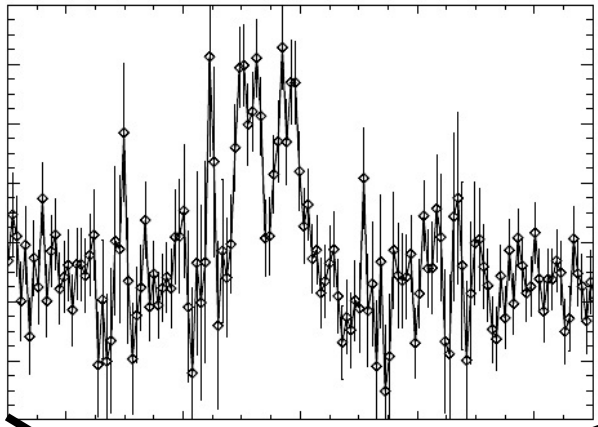


2. Emission Line Galaxies (ELGs)

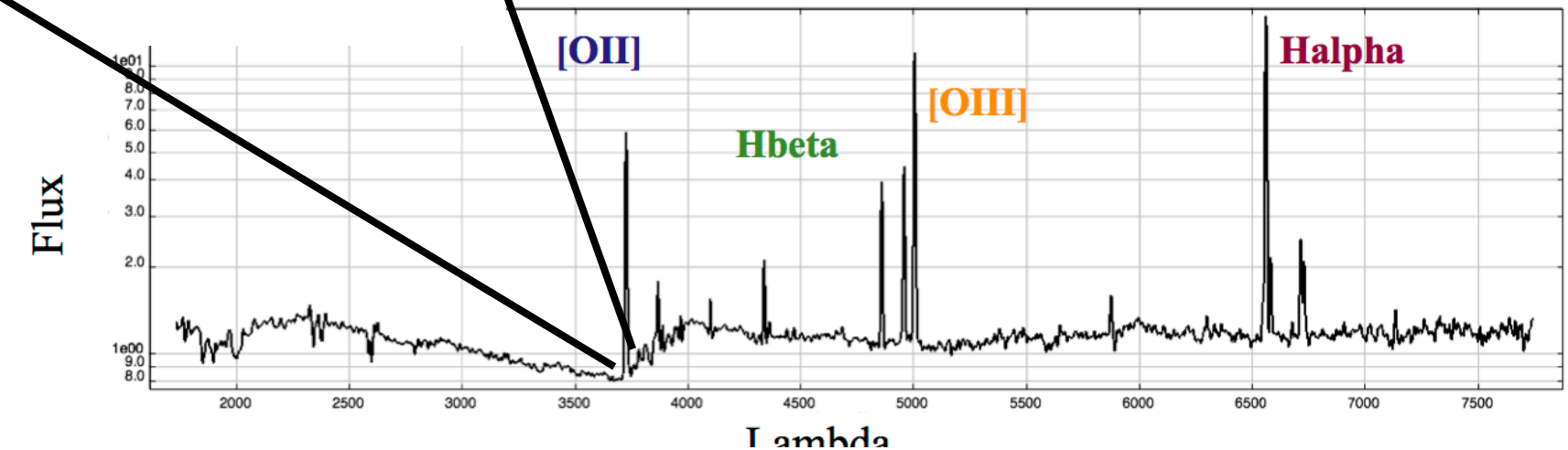
ELGs unique signature of [O II] doublet, detectable from z=0 to z=1.6

Well-studied as the ~5% brightest galaxies in the DEEP2 survey

ELGs drive DESI wavelength coverage, throughput, & resolution



[O II] doublet at 3726.032 + 3728.815 Ang
DESI detects to z=1.6 at 9700 Ang



2. Emission Line Galaxies (ELGs)

ELGs tracers at 0.5 < z < 1.6

Epoch of star formation peaks in these galaxies at z~1

Easy to select from optical colors

Test data:

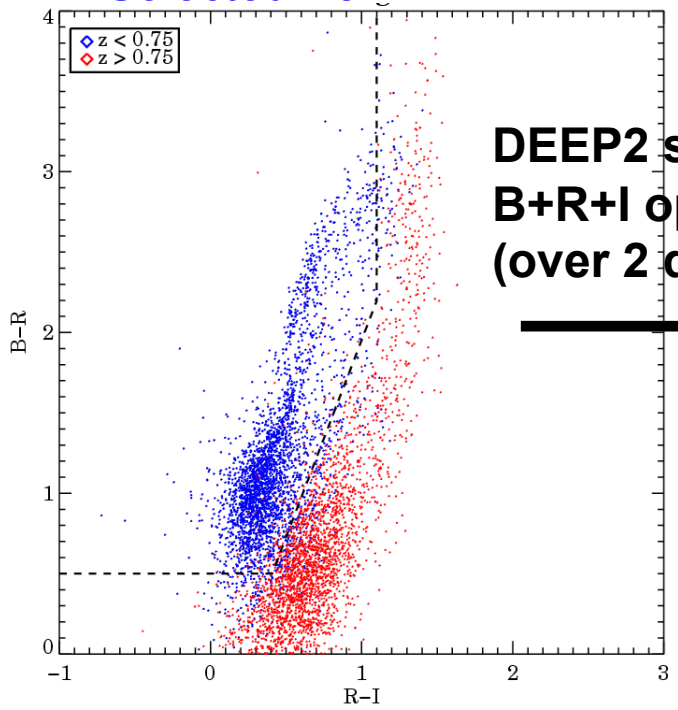
40,000 ELGs from DEEP2, VVDS over 4 deg^2 total

+40,000 ELGs from BOSS ancillary programs in 2012-2013 to z=1.6

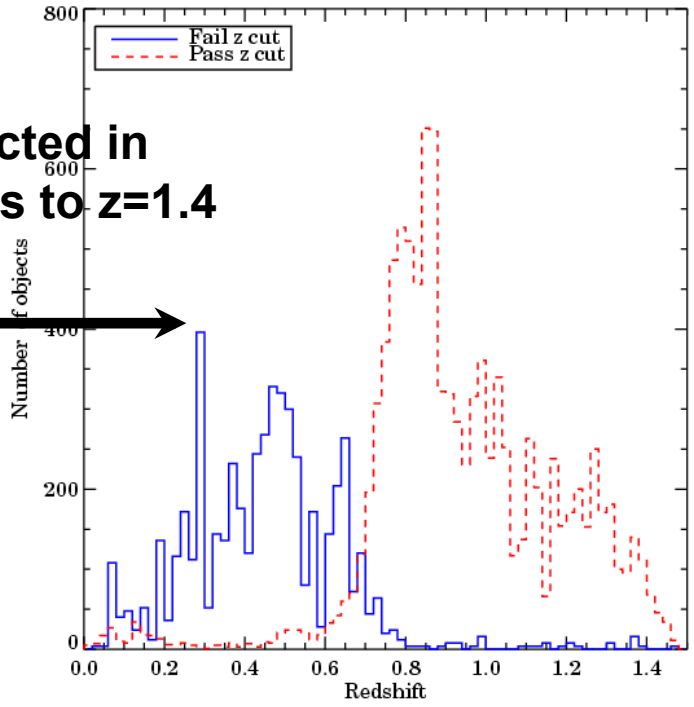
DESI targets:

18 million ELGs in DESI survey

Selected from ZTF

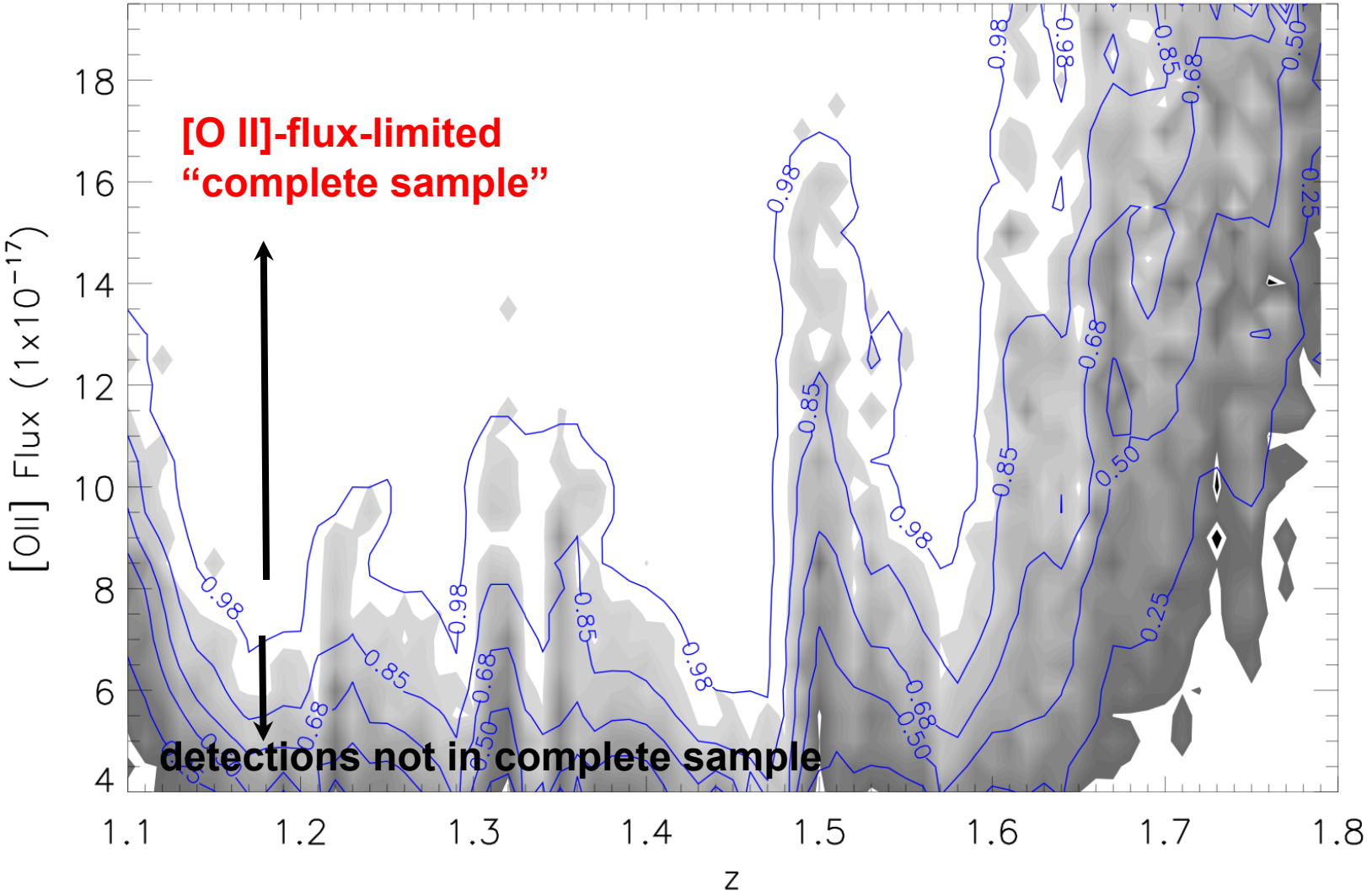


DEEP2 survey selected in B+R+I optical colors to z=1.4 (over 2 deg^2)



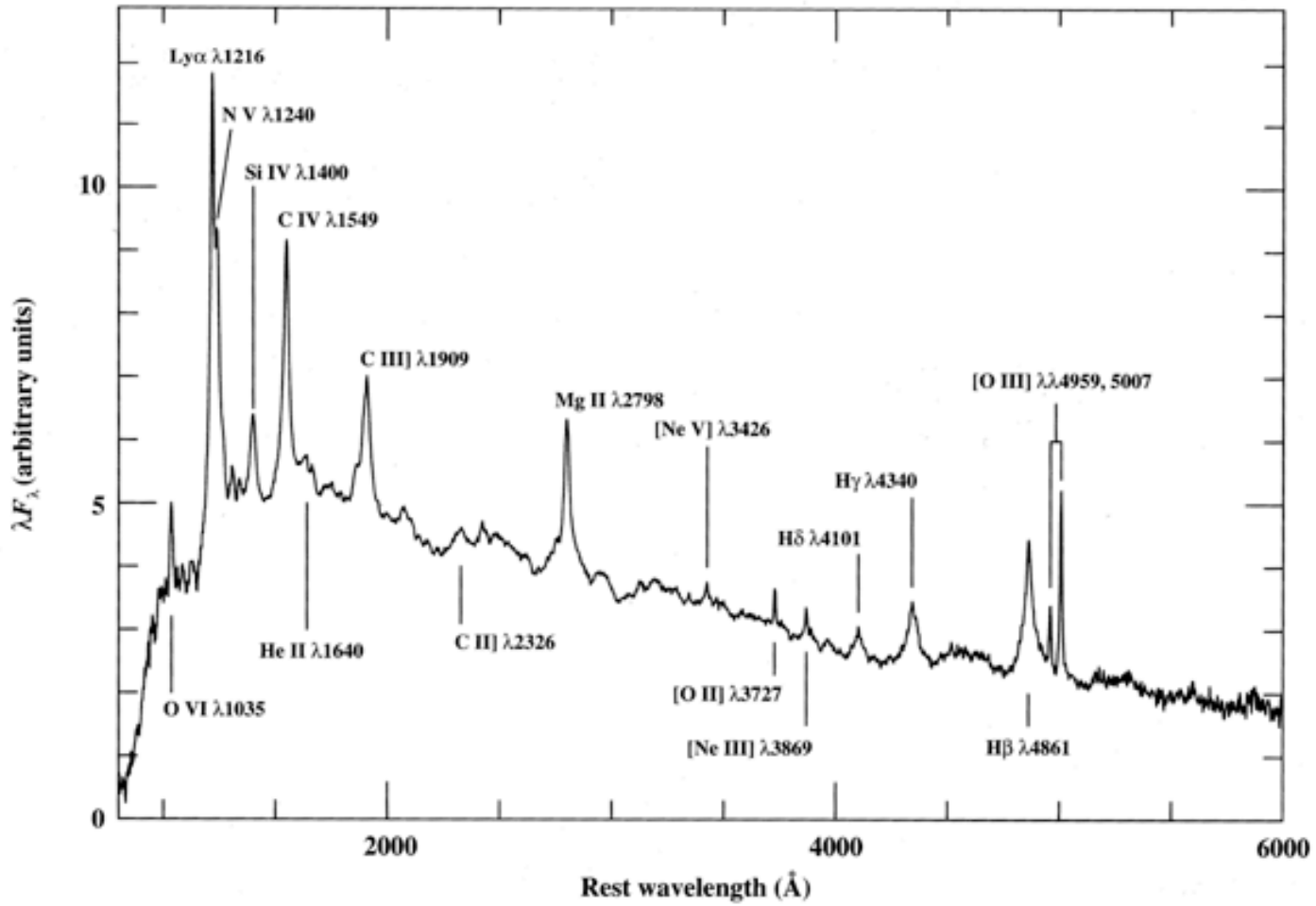
2. Emission Line Galaxies (ELGs)

ELG complete sample requires R > 4000 for high-confidence redshifts

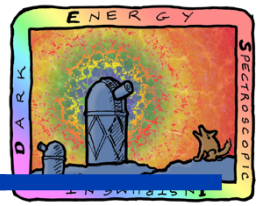


3. QSOs as tracers

QSO spectra are obvious even at very faint S/N
BOSS survey easily identifies to g=22, DESI extends to r=23



3. QSOs as tracers



QSO tracers at 0.5 < z < 3.5

The brightest objects at z > 2

+ QSO Lyman-alpha forest at 2.2 < z < 3.5

Test data:

BOSS spectra for 160,000 to g=22

+15,000 QSOs from BOSS +MMT ancillary programs to g=23.5

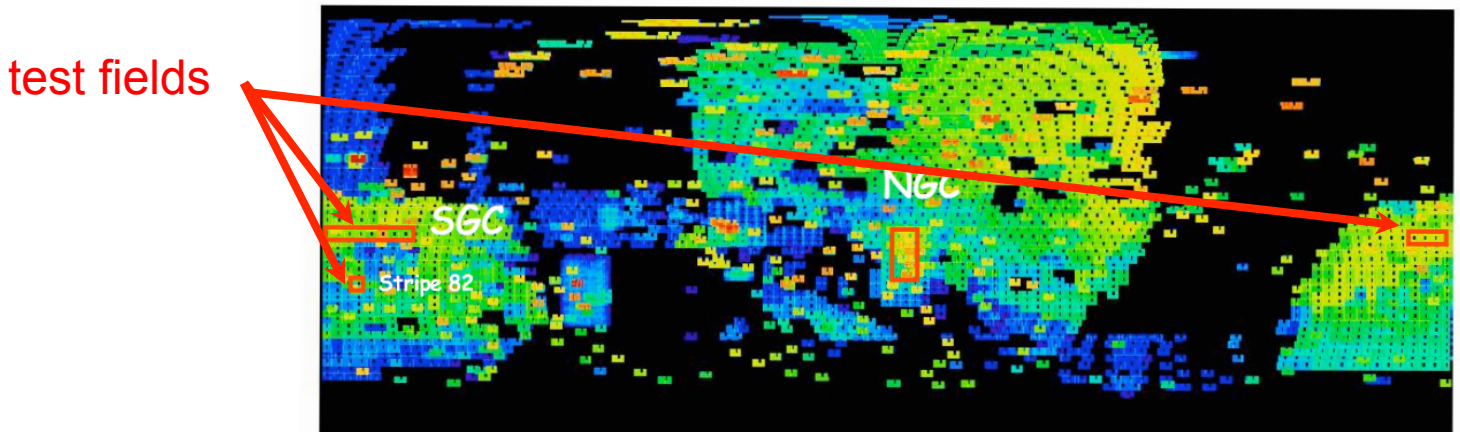
DESI targets:

2.5 million QSOs from ZTF

"Every QSO in the Universe"

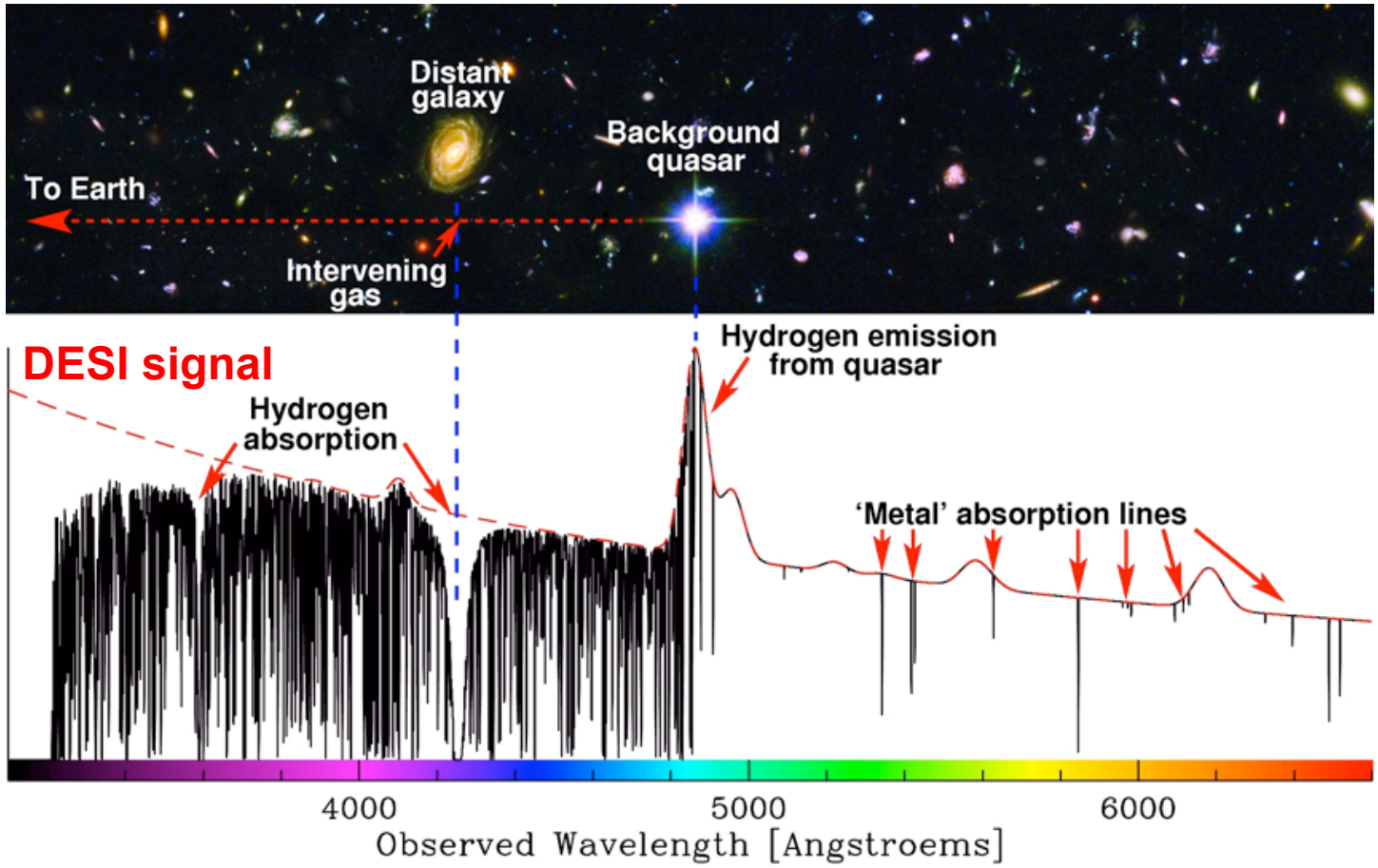
New: u-band selection from SCUSS

New: infrared selection from WISE

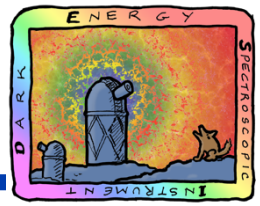


4. Lyman-alpha forest from QSOs

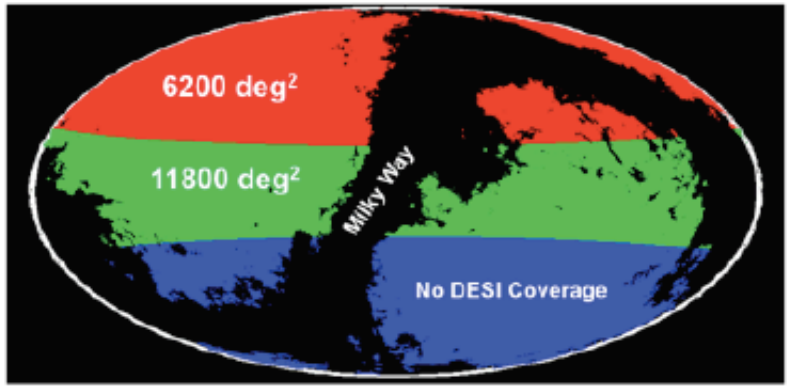
QSOs at z < 2.2 will be observed once → "tracer QSOs"
QSOs at z > 2.2 will be observed 5X for high S/N for "Lyman-alpha forest"



Imaging options for DESI



- **SDSS imaging is not deep enough for DESI targets and does not cover 14,000 deg^2.**
- Require deeper imaging over the 14,000 deg^2 DESI survey area:
  - LRG: WISE + ***rz:*** *r~23, z~21.5* (5sigma)
  - ELG: ***grz*** to *g~24, r~23.5, z~23* (5sigma), or ***ugr*** to *ug~24, r~23.5*
  - Quasars: WISE + ***u****/g/r/z~23.5* + **variability data**
- *More photometric bands will minimize contaminants, making the target selection more efficient, but is not a requirement.*

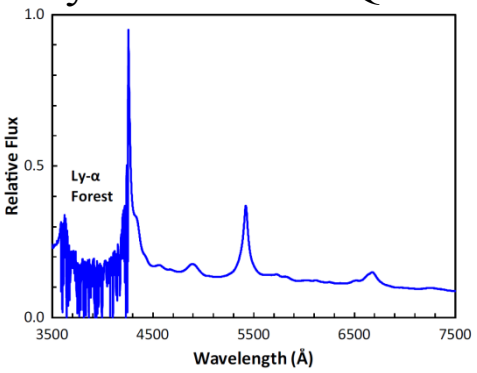


- ***Imaging Plan:*** *(options)*
  - ***WISE (completed)***
  - ***DEcam (grz over equatorial region)***
  - ***ZTF (variability data in g & r)***
  - ***CFHT/Megacam (ugrz over Norhtern sky)***
  - ***Bok 2.3m (u over Northern sky)***
  - *Pan-STARRS (grizy with variability)*

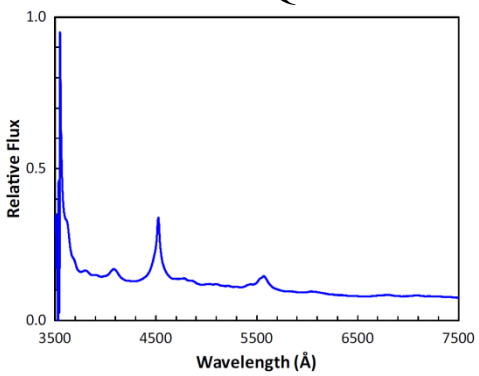
Summary of Science Requirements

- DESI Science Requirements
  - Detect Lyman-α forest in QSOs from $2.2 < Z < 3.5$
  - Tracer QSOs from $0.5 < Z < 2.2$
  - Detect 400 nm break in LRG from $0.5 < Z < 1$
  - Detect ELG OII from $0.5 < Z < 1.6$
  - → Band pass from 360 to 980 nm
- Throughput requirements come from required signal to noise
- Spectral resolution requirements are driven by ELG OII doublet resolution (→ R~4000)
- Spatial imaging requirements come from cross contamination of fibers
- Number of fibers comes from the required number of galaxies and cost considerations (→ ~5000)

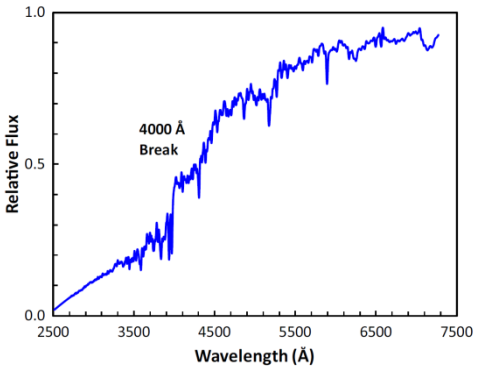
Lyman-α forest QSO



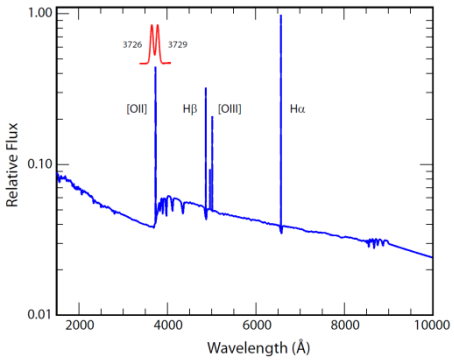
Tracer QSO

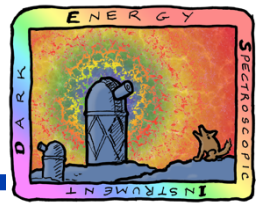


LRG



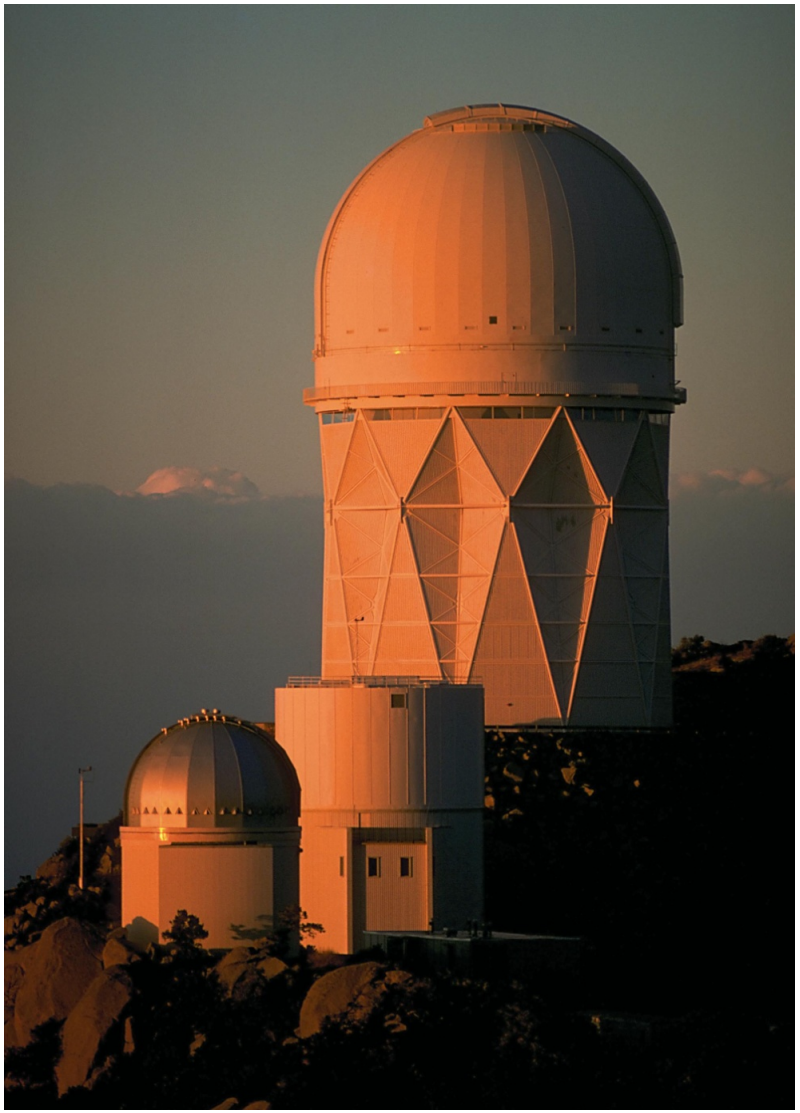
ELG



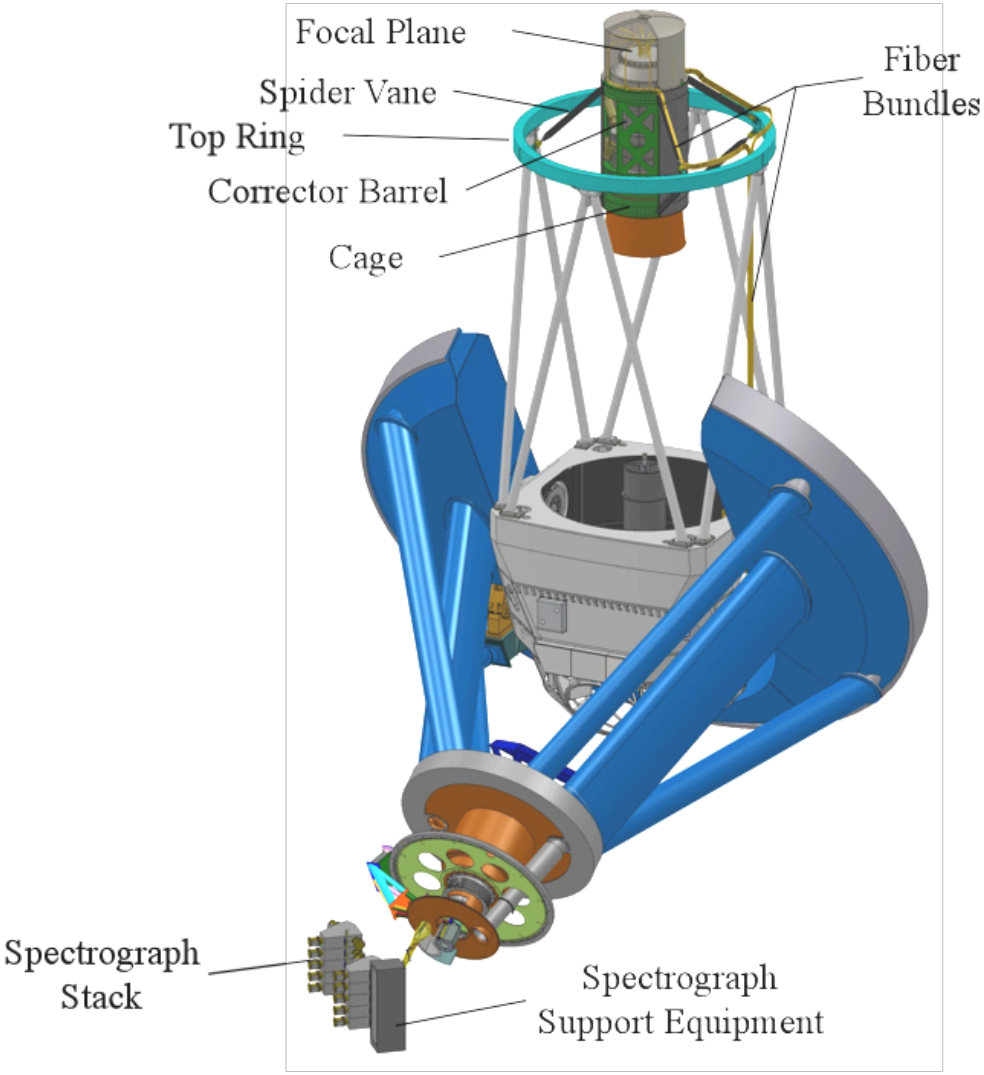


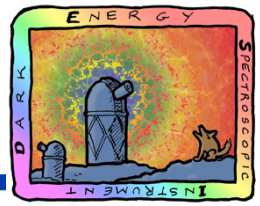
Instrument Design

DESI instrumentation



Mayall Telescope

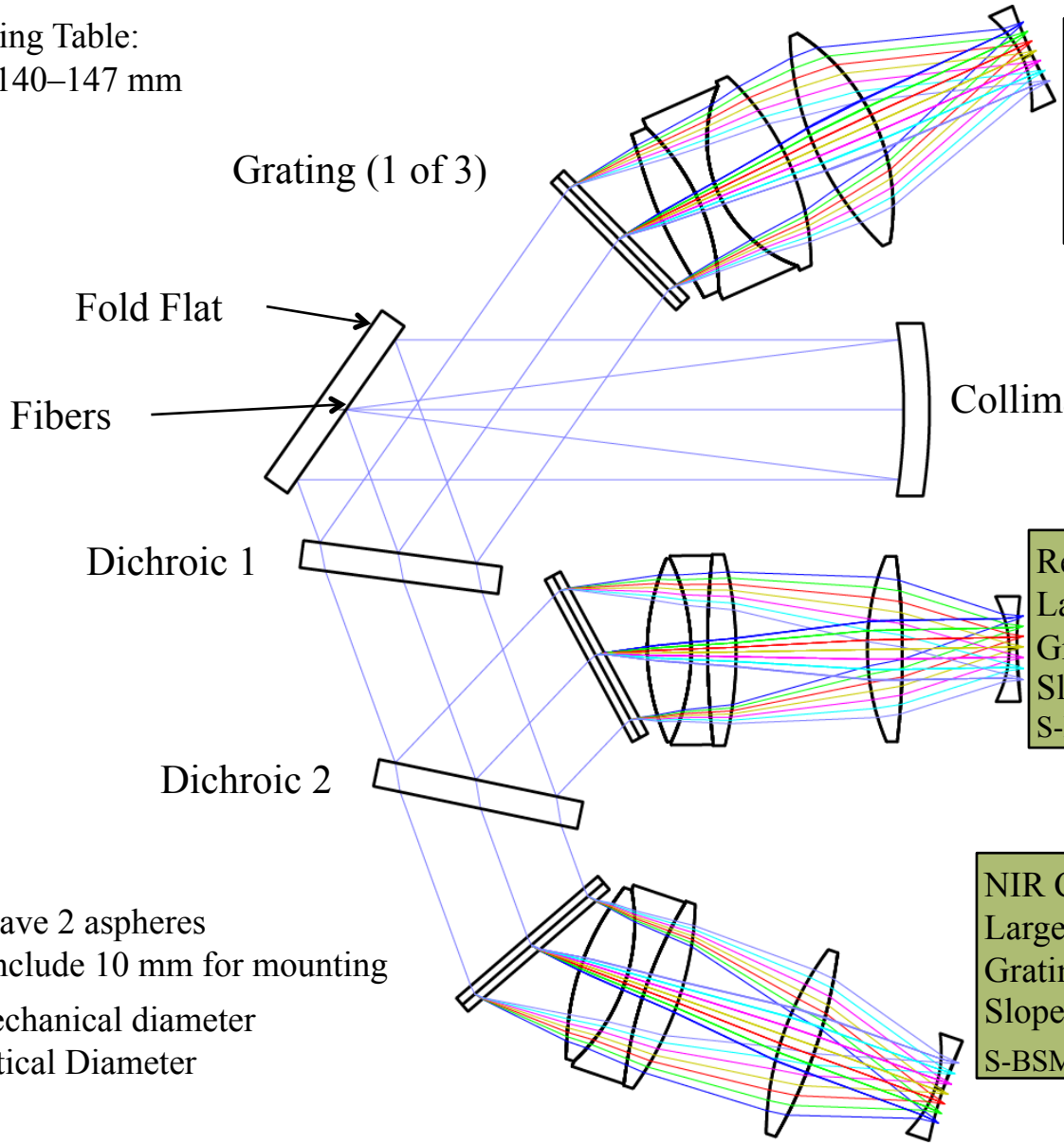




Spectrographs

3-Arm Spectrograph

Small Grating Table:
Size up to 140–147 mm



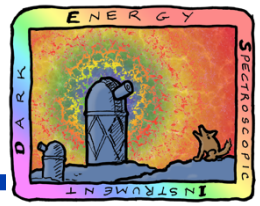
Blue Camera
Largest Lens = 192 mm (M)
Grating = 135 mm (O)
Slope deviation = 80 µm/mm
CaF_2/N-BAK2/CaF_2/CaF_2/Silica

Red Camera
Largest Lens = 161 mm (M)
Grating = 139 mm (O)
Slope deviation = 75µm/mm
S-BSM4/S-TIM22/S-LAL12/S-LAL12/Silica

NIR Camera
Largest Lens = 166 mm (M)
Grating = 142 mm (O)
Slope deviation = 72µm/mm
S-BSM4/S-TIM22/S-LAL12/S-LAL12/Silica

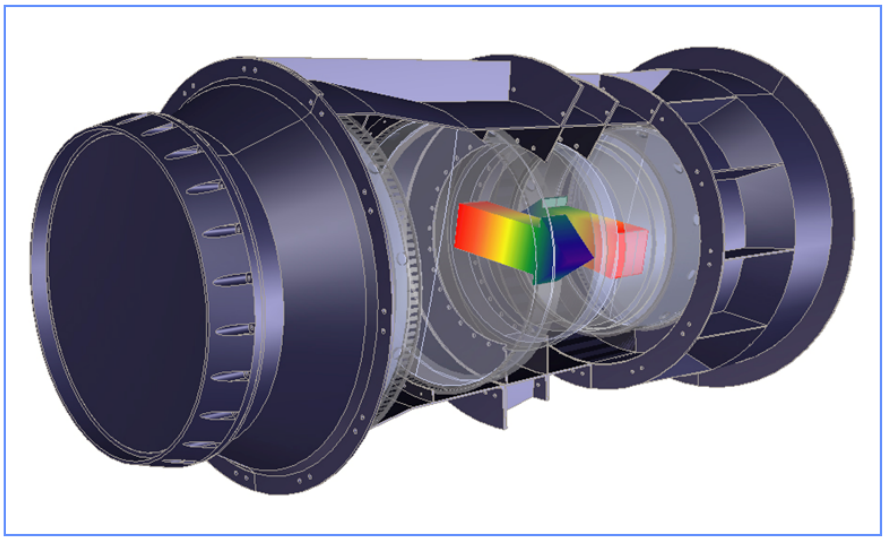
Cameras have 2 aspheres
All sizes include 10 mm for mounting

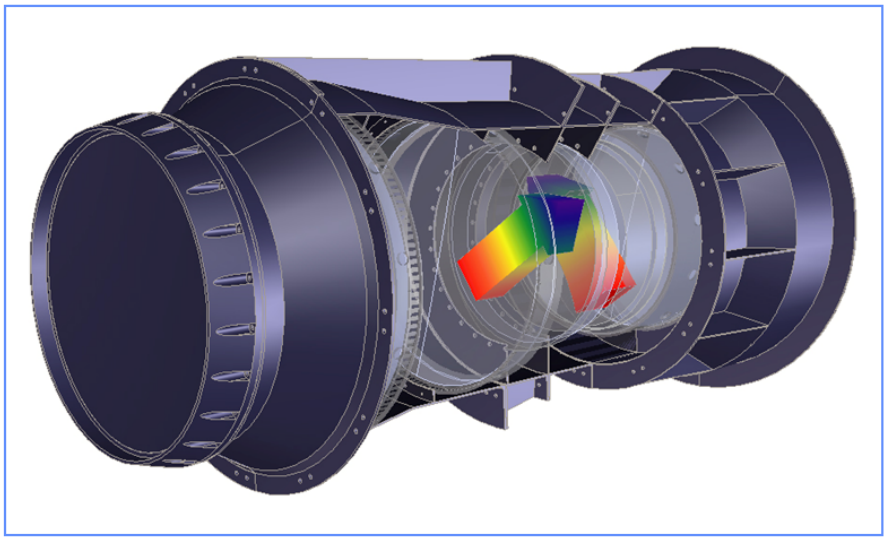
(M) = Mechanical diameter
(O) = Optical Diameter

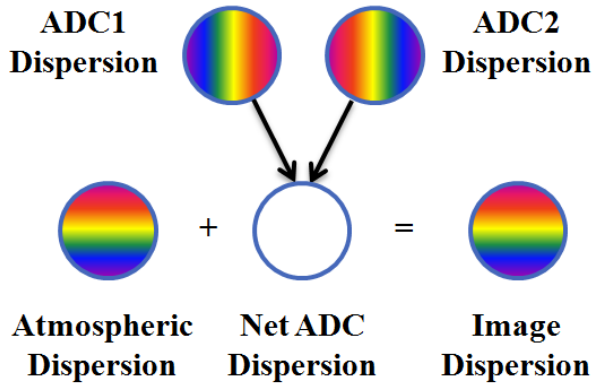


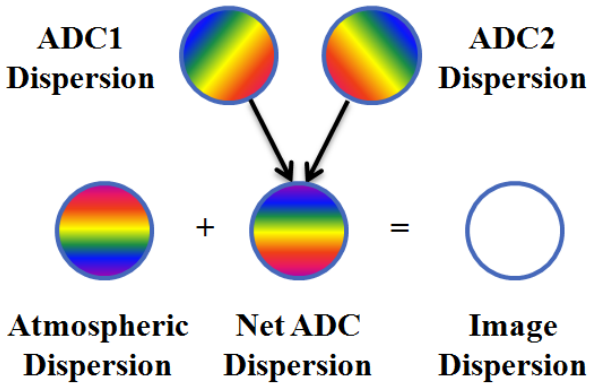
Corrector optics

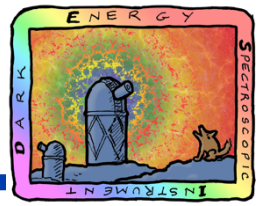
Examples of ADCs











Focal Plate System

Focal Plate Evolution

Monolithic (IAA/LBNL)

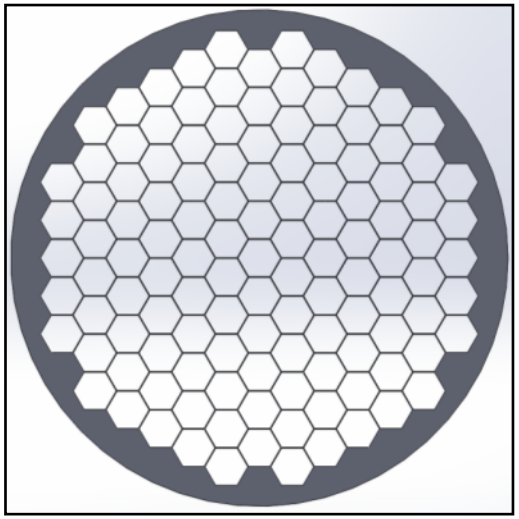
5000 holes in big plate

1 positioner per hole

Rafts (USTC)

~100 holes in big plate

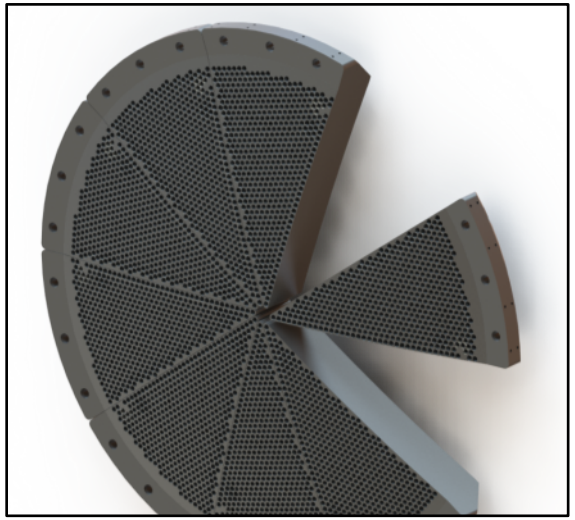
~50 positioners per raft



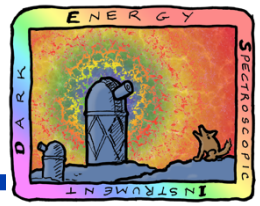
Wedges (IAA/LBNL)

10 pie-shaped wedges

500 positioners per wedge



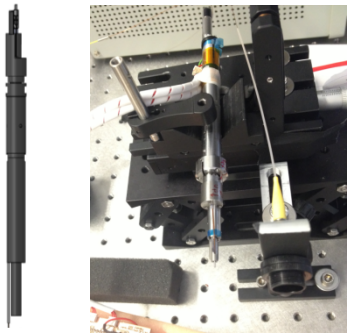
	Monolithic	Rafts	Wedges
Area density	Ideal	Low	Near-ideal
Machining risk	High	Moderate	Moderate
Integration	Complex	Simple	Simple
Alignment	Simple	Complex	Moderate
Stiffness	Ideal	Low	Moderate



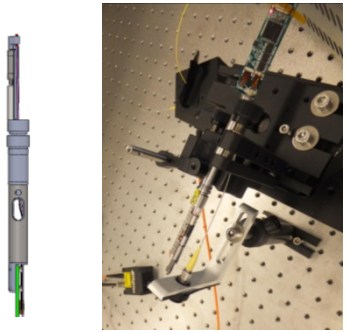
Actuators
(fibre positioners)

Actuator Development

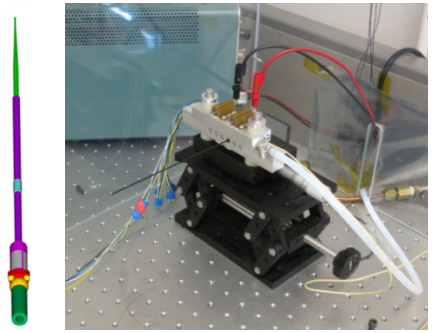
- Actuator Testing at LBNL
  - LBNL R-Theta
  - LBNL Theta-Phi
  - IAA Theta-Phi (side)
  - USTC Theta-Phi (LAMOST)
  - AAO Spine (Echidna)
- Initial results suggest all actuators should be able to meet XY targeting goals



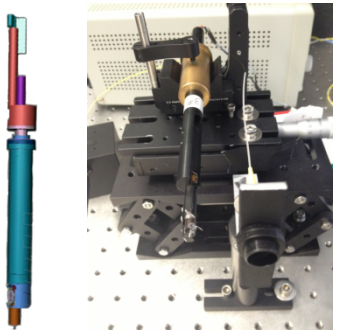
IAA T-P 12mm



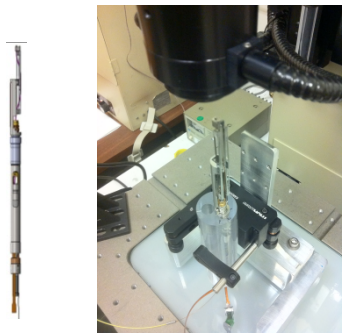
LBNL T-P 12mm



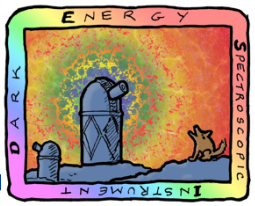
AAO 8mm



USTC T-P 12mm



LBNL R-T 12mm

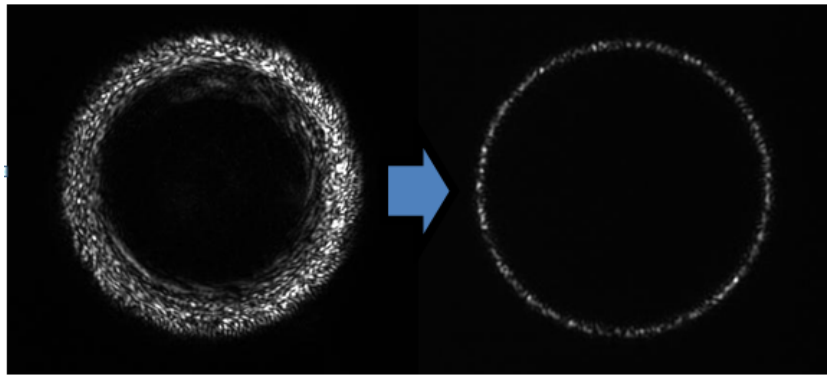


Fiber System Design

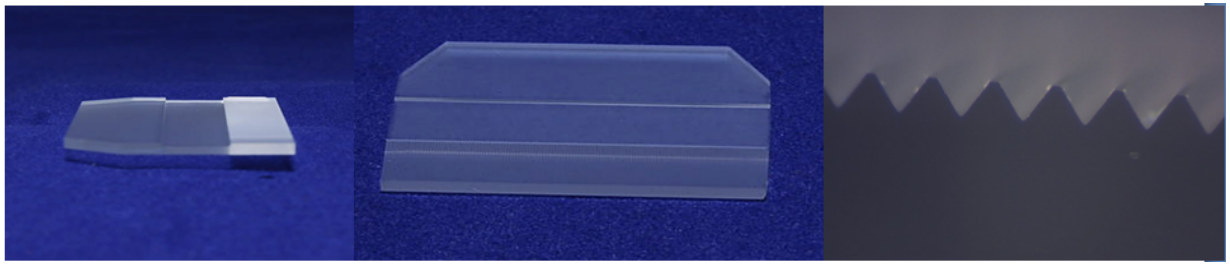
Durham Fiber System Development

- Fibre cable mechanical test built for on-telescope tests by LBNL & NOAO

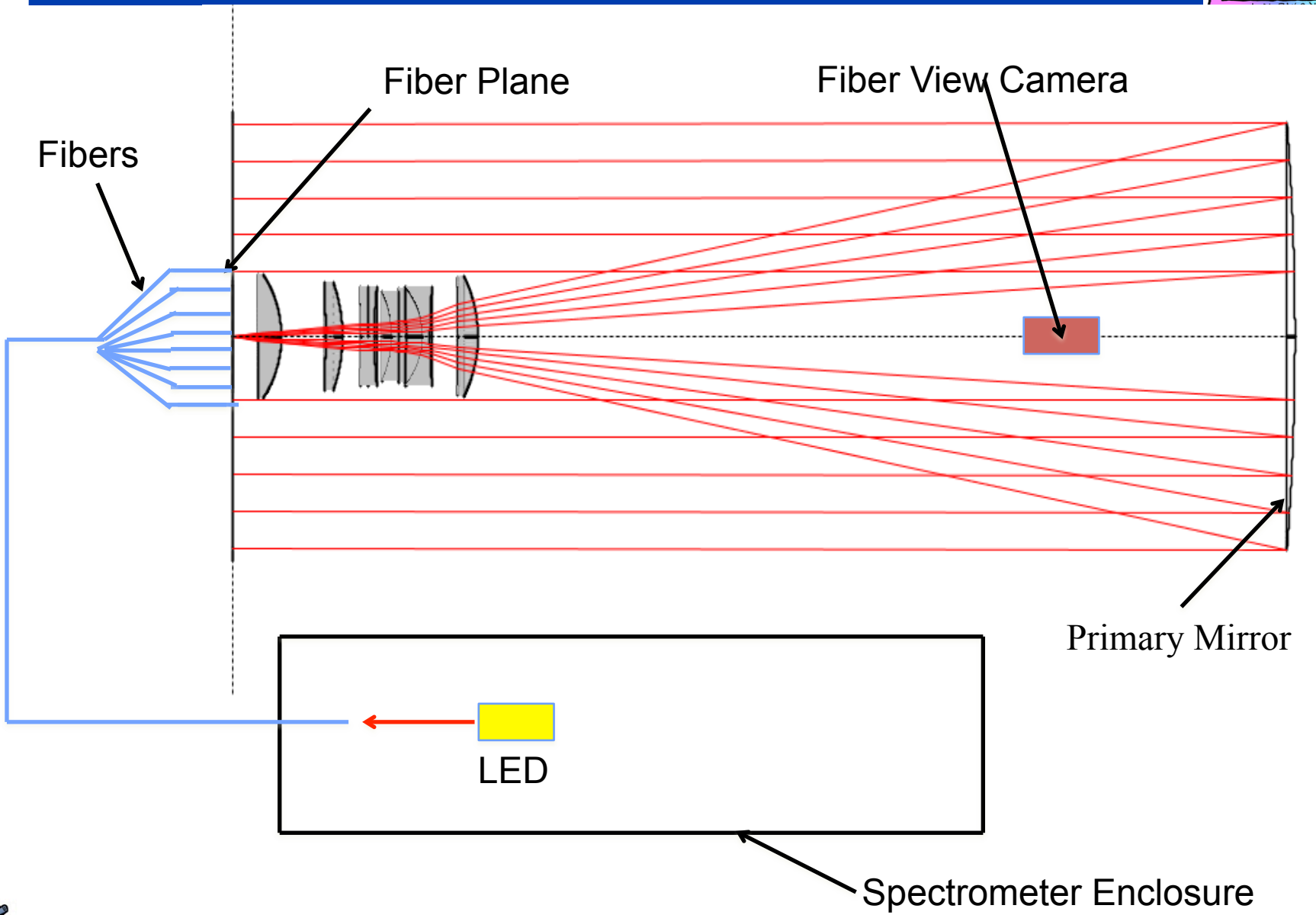
- Process optimisation for fibre-termination
  - Ultra-low FRD
  - Fibre axial alignment [with LBNL]
  - Full-length fibres with ultra-low FRD
  - [Long-term testing with actuators: LBNL]

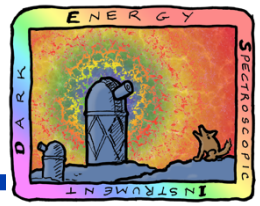


- Prototype slit unit
  - metrology verification
  - optical testing



DESI Fiber View Camera

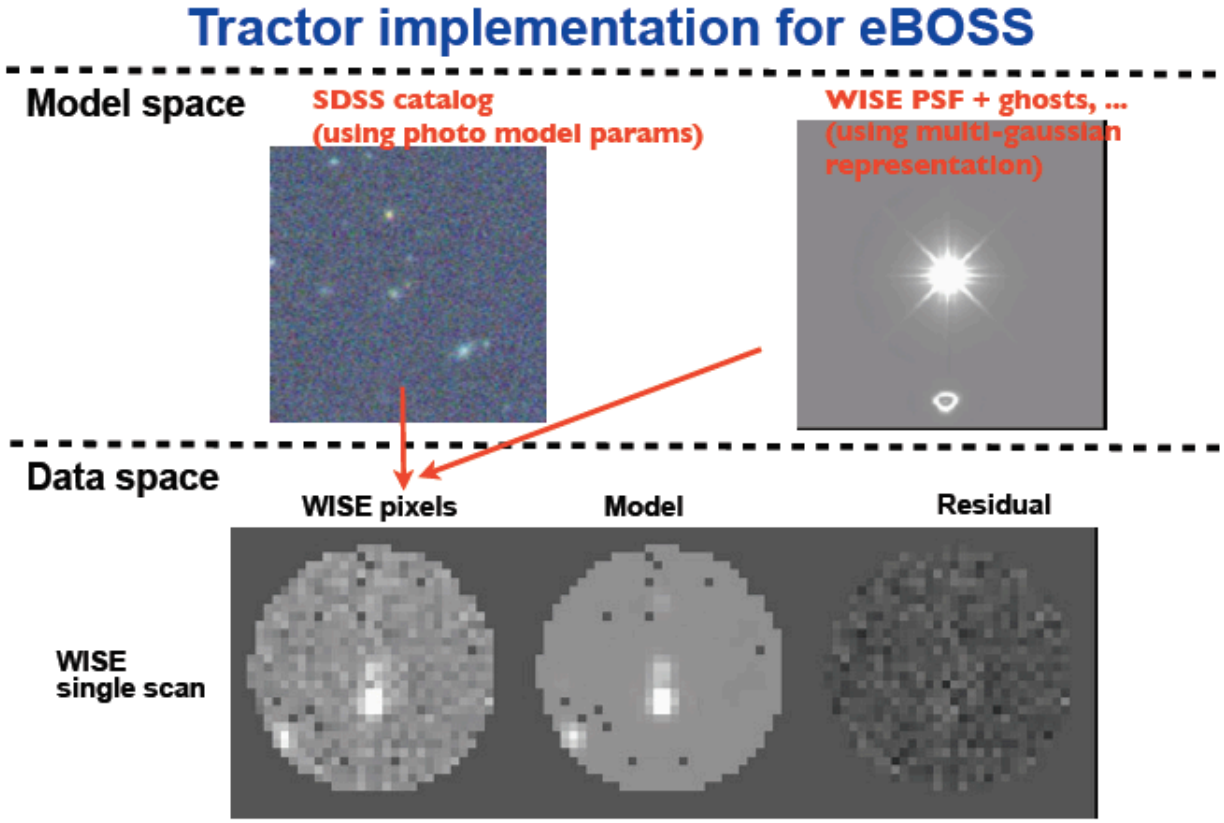




Pipelines/Data Management/Simulations

Tractor

- Motivation: multi-band imaging with consistent colours from different telescopes
- General method for measuring astronomical objects (image space)
- Given catalogue & calibration, predict noise free image
- Goal: find catalogue that minimises model image - real image

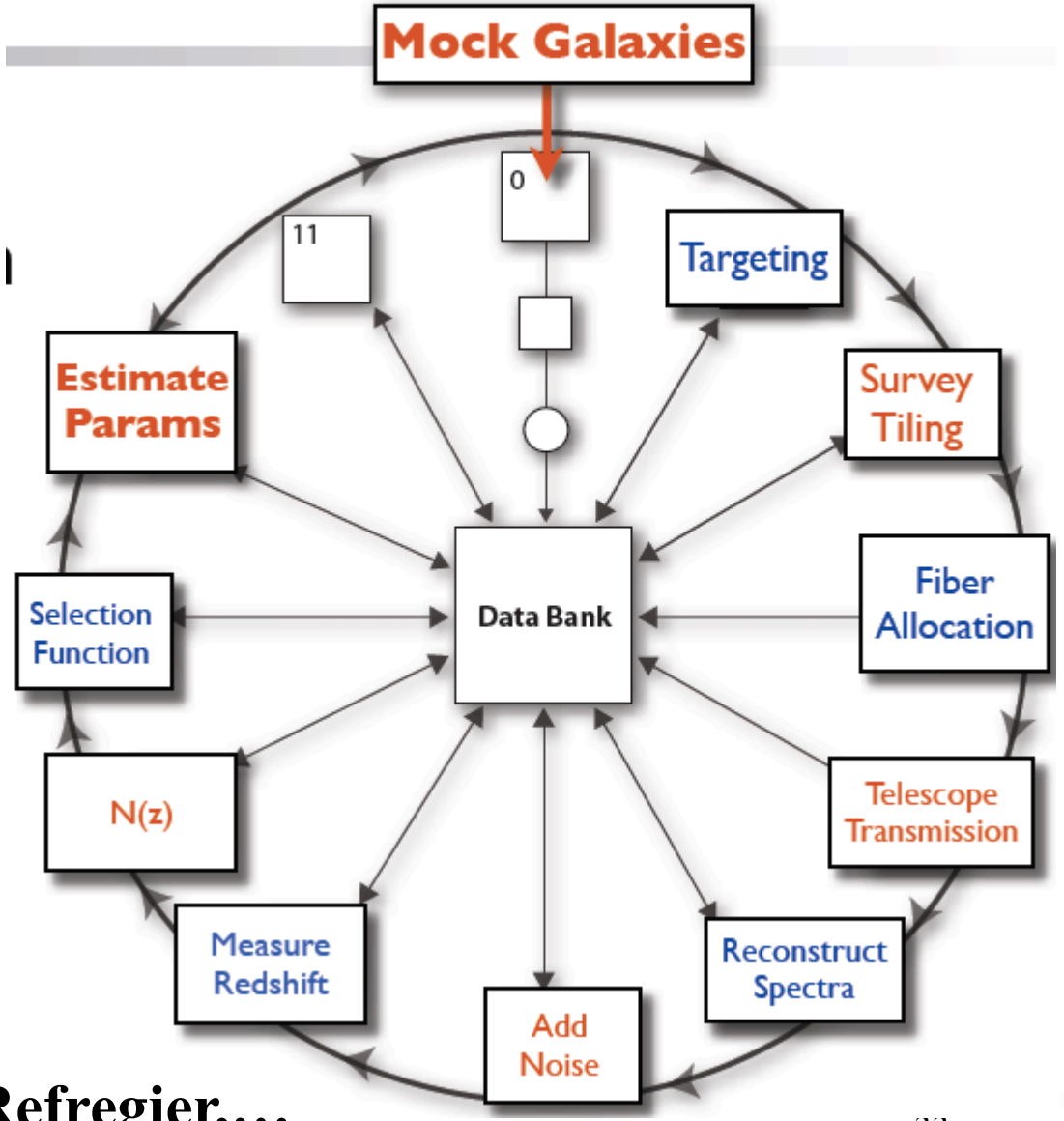


Lang & Schlegel

SPOKES/End-to-End simulations

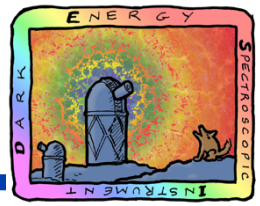
- Experimental design & development:
  - Optimize
  - Verify
  - Prepare

- Key ingredients:
  - Fast
  - Reproducible
  - Integrated
  - Flexible
  - End-to-End



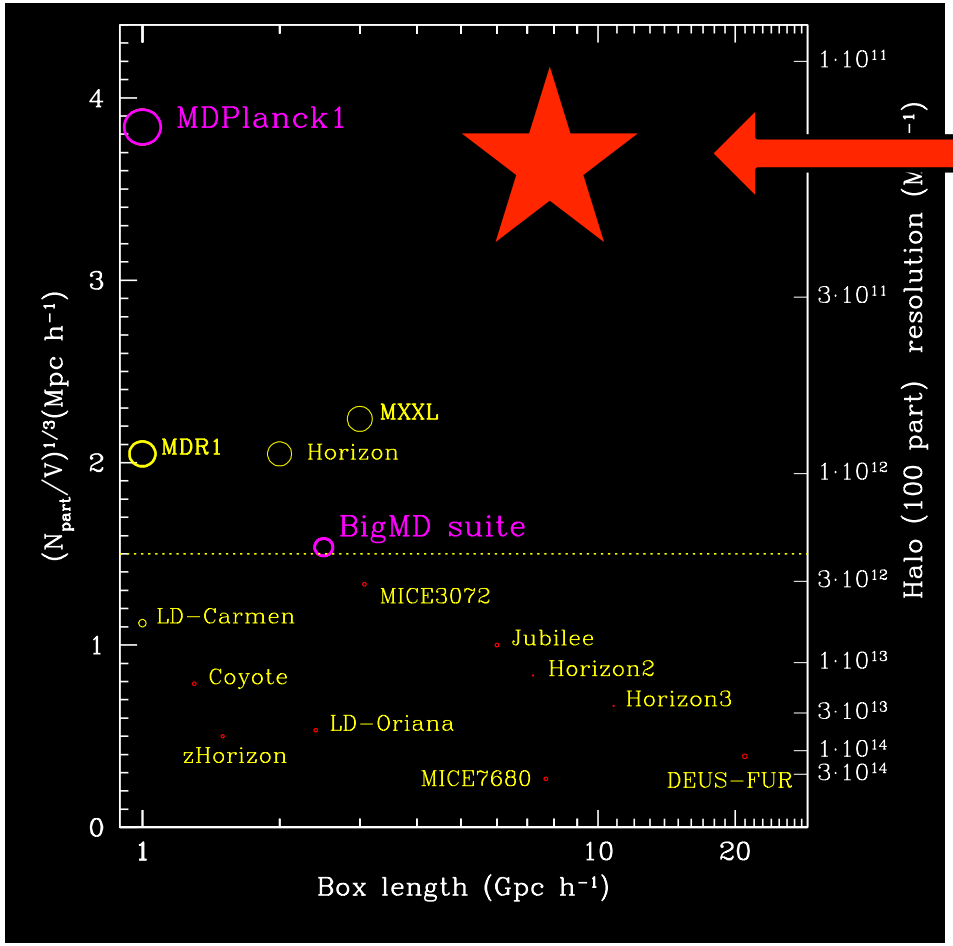
Nord, Amara, Refregier,…

N-body simulations



- **Simulations are the basic tool for theory/modeling:**
- Precision cosmology = statistical inverse problem
- Simulations provide predictions as well as means for estimating errors
- Synthetic catalogs play important roles in testing and optimizing DM/DA pipelines and in mission optimization
- **Prospective Roles in DESI:**
- Theory: 1) BAO/RSD/P(k)/etc. predictions, 2) Error propagation through nonlinear processes (reconstruction, FoG compression), 3) Covariance matrices (many realizations, cosmological dependence?)
- Pipeline Validation
- Survey Design
- **Simulation Type:**
- N-body simulations and derived products (catalogs, emulators)
- Hydro simulations and derived products (Ly-alpha P(k))

N-body simulations

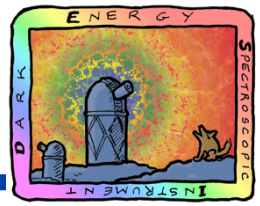


DESI needs

DESI simulation WG expertise in:

- N-body
- HOD/SHAM
- GALFORM
- Ly-α
- ….

DESI status



DOE project: mission needs approved (CD-0); next step CD-1 (Jan-2014)

$2.1M grant from Gordon and Betty Moore Foundation

Funding spectrograph #1 (of 10)
Funding blanks for telescope corrector
Funds in hand

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A big boost to BigBOSS

$2.1 Million Grant to Berkeley Center for Cosmological Physics advances dark energy research at UC Berkeley and Berkeley Lab

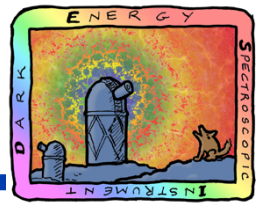
Dec. 4, 2012

Berkeley, Calif. — A $2.1 million grant from the Gordon and Betty Moore Foundation to the University of California at Berkeley, through the Berkeley Center for Cosmological Physics (BCCP), will fund the development of revolutionary technologies for BigBOSS, a project now in the proposal stage designed to study dark energy with unprecedented precision. BigBOSS is based at the U.S. Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab).

"BigBOSS is the next big thing in cosmology," says Uroš Seljak, Director of the BCCP, who is a professor of physics and astronomy at UC Berkeley and a member of Berkeley Lab's Physics Division. "It would map millions and millions of galaxies, allowing us to measure dark energy to high precision - and would yield other important scientific results as well, including determining neutrino mass and the number of neutrino families."

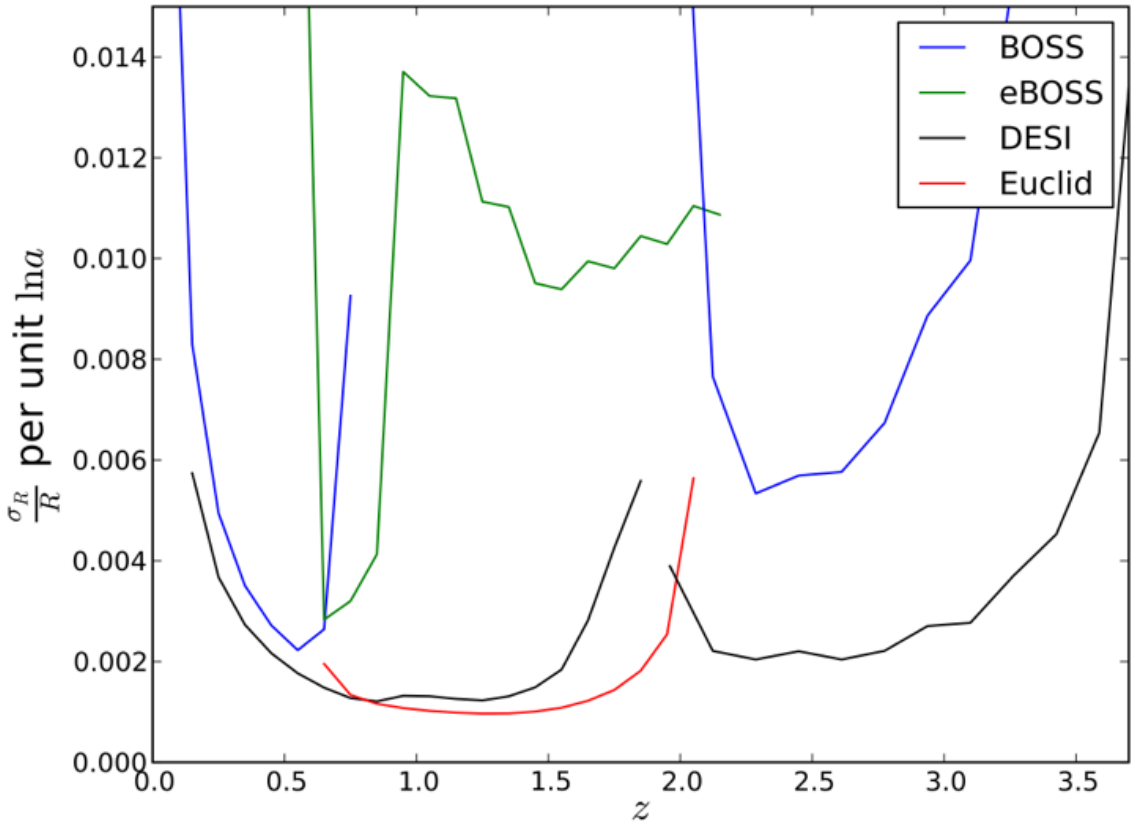
Dark energy is the unknown something that appears to account for almost three-quarters of the mass-energy of the universe and is the cause of its accelerating expansion. The discovery of the accelerating universe, announced in 1998 by two teams, resulted in the 2011 Nobel Prize in Physics, divided between Berkeley Lab and UC Berkeley astrophysicist Saul Perlmutter, leader of the Supernova Cosmology Project, and Brian Schmidt and Adam Riess of the competing High-z Supernova Search team.

DESI in a nutshell



- Dedicated BAO+RSD experiment:
near cosmic-variance z < 1.5, unique capabilities z > 2

- Site selection: Kitt Peak 4-m (Mayall) on track for 2018 start



Pat McDonald