BigBOSS

Instrument + Capabilities

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for the BigBOSS collaboration
13 September 2011

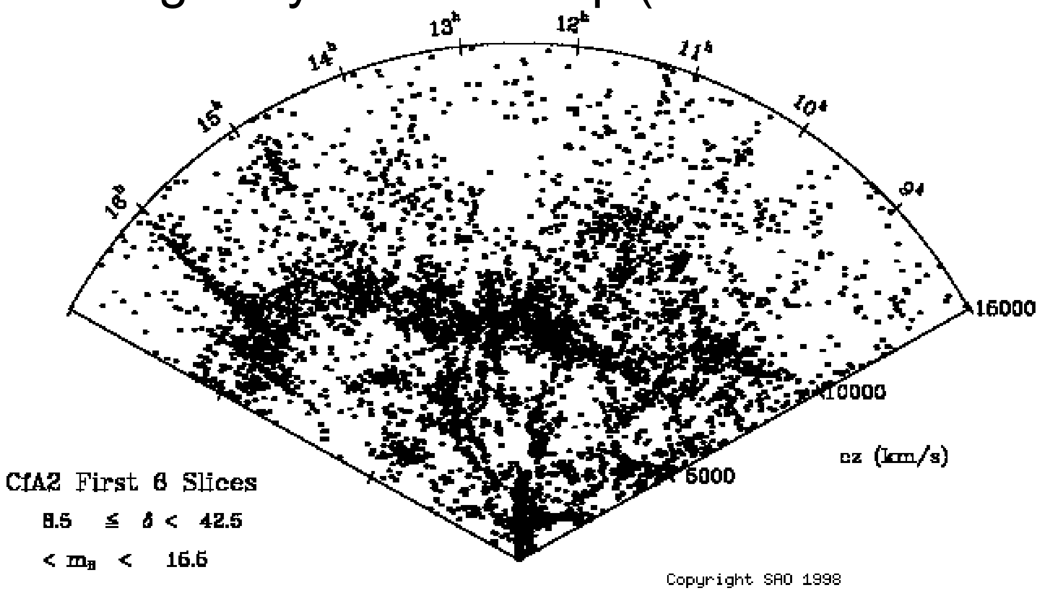

BigBOSS
It’s all about the numbers

Cosmology from maps

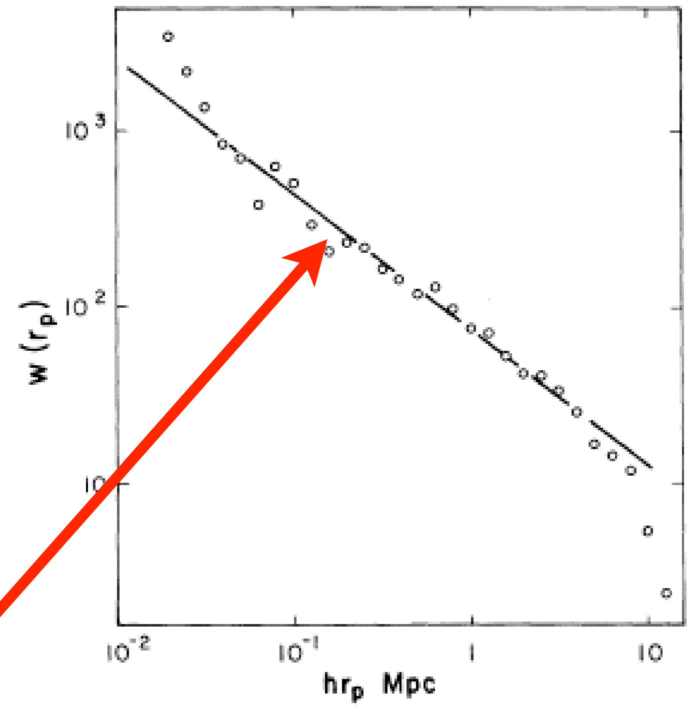
Mapping the Universe

Earliest maps of the Universe, ~10^3 galaxies

CfA2 galaxy redshift map (Geller & Huchra 1989)



Correlation function

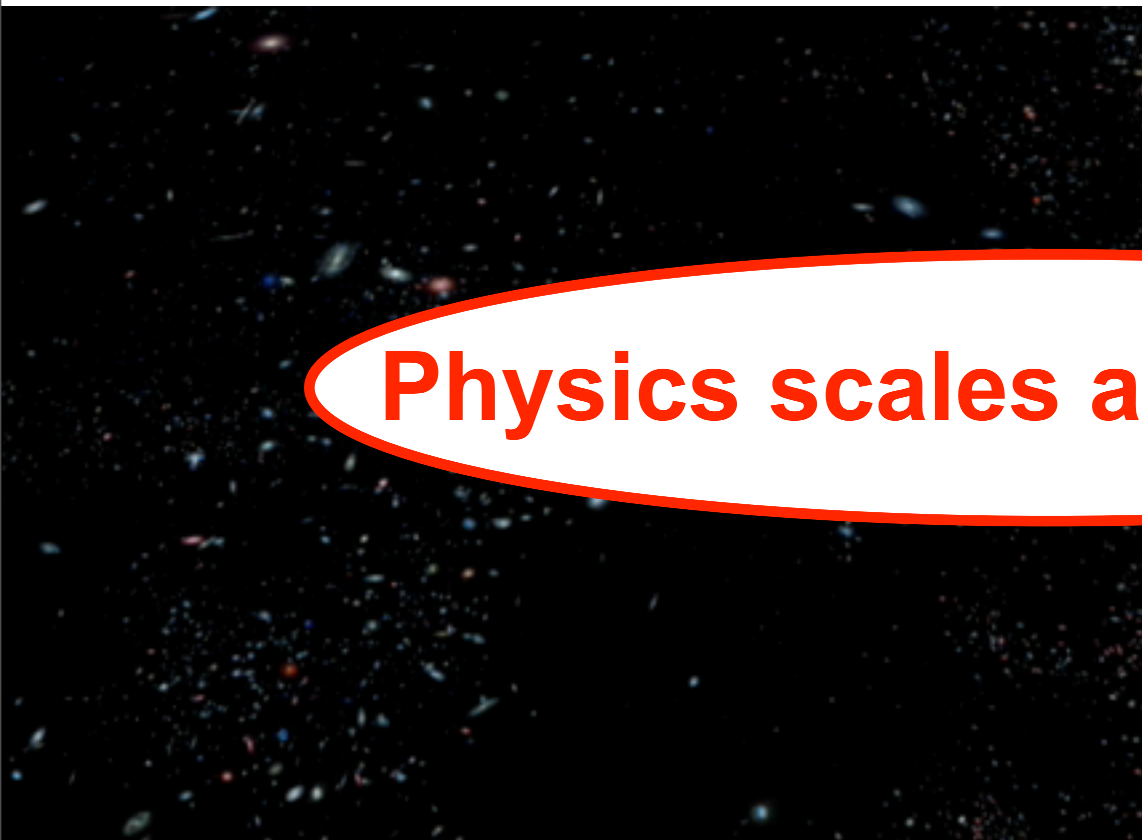


What did we learn?
Galaxy (~matter) fluctuations are ~Gaussian, scale-free
Grav. growth explains CMB fluctuations → galaxies

Mapping the Universe

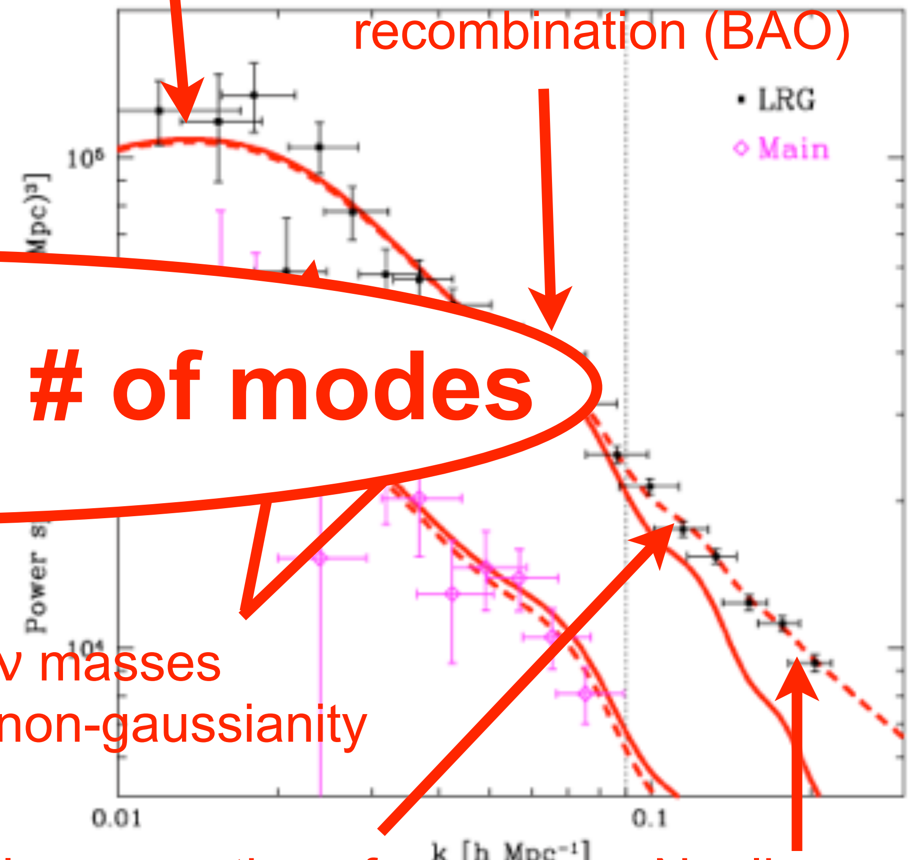
Today's maps of the Universe
~10^6 galaxies

SDSS-I



Horizon size at matter-radiation equality

Sound horizon scale at recombination (BAO)



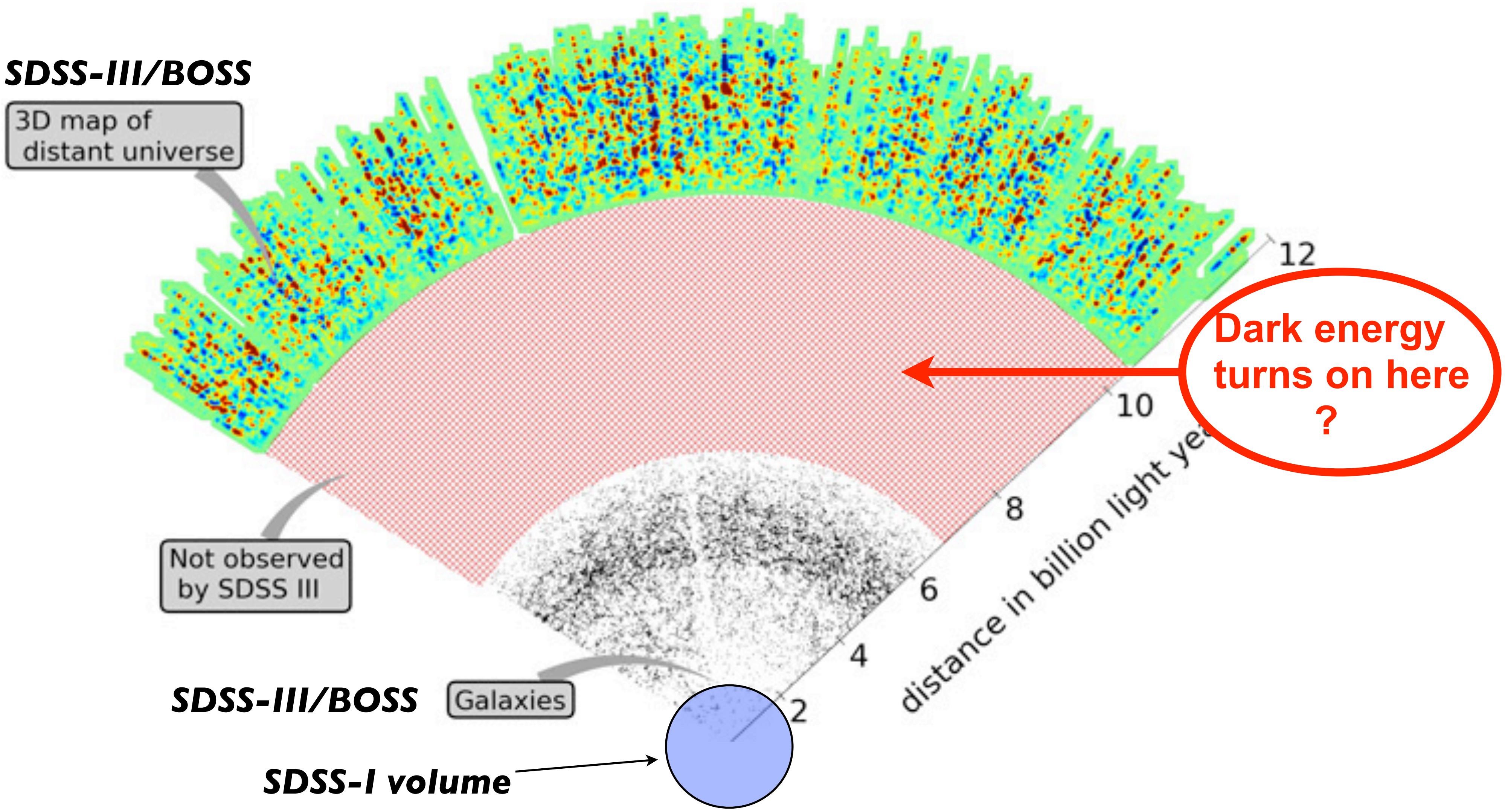
Physics scales as # of modes

ν masses
non-gaussianity

Galaxy halo occupation of dark matter halos (HOD)

Nonlinear growth

Mapping the Universe



Status July 9, 2011: 470,000 galaxy redshifts + 50,000 high-z QSOs

Mapping the Universe

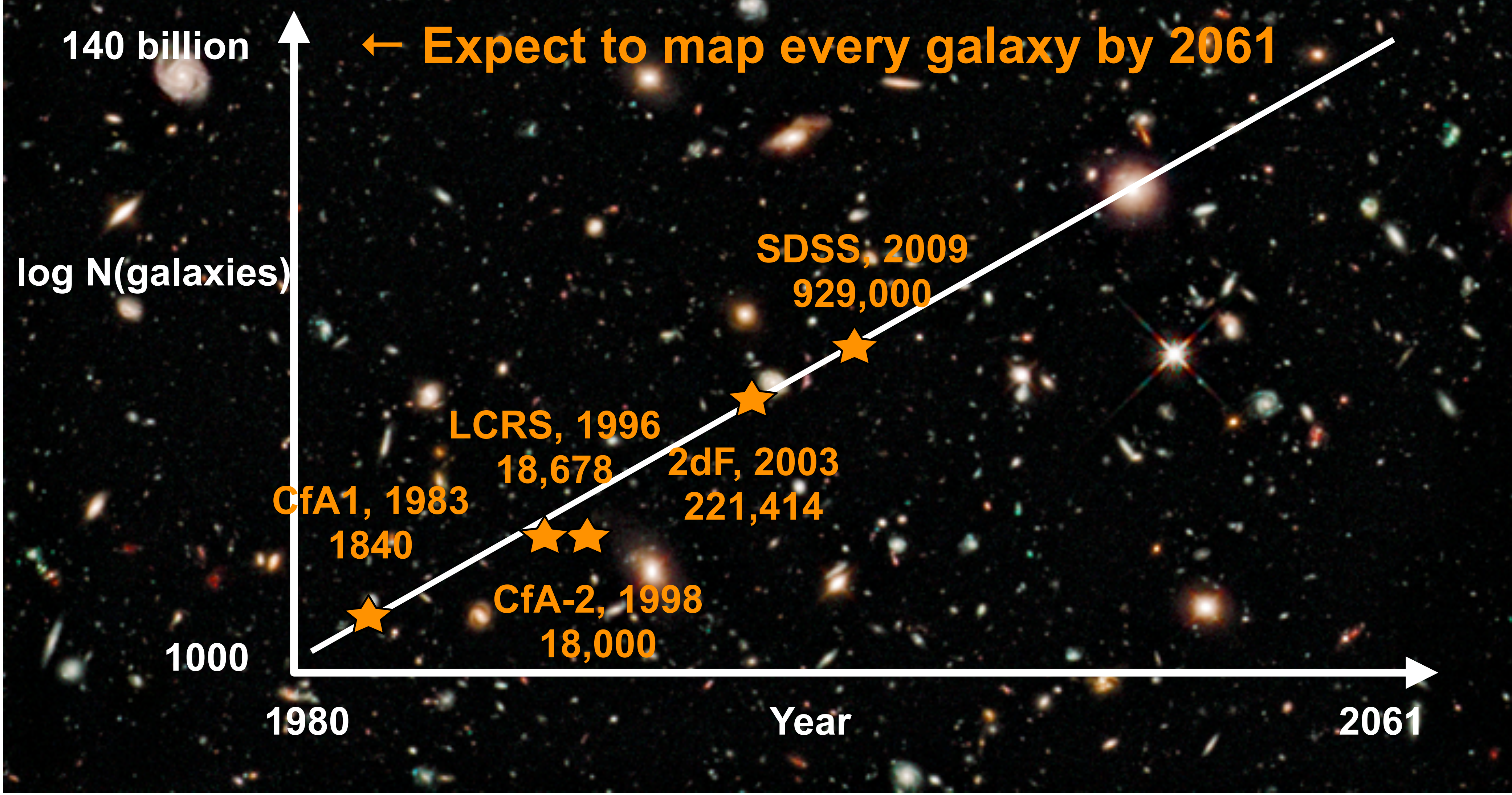
"It's all about the numbers"

SDSS I+II: 900,000 galaxies in 2009
Max. 640x9 per night to z~0.5

SDSS-III/BOSS: 2.5 million in 2014
Max. 1000x9 per night to z~0.9

SDSS plug plates don't scale to more...

Mapping the sky in 3-D: What's possible?



HST Ultra-Deep Field
10,000 galaxies / (11 arcmin^2)

What is BigBOSS?

What is BigBOSS?

Construct BigBOSS instrument:

3 deg diameter FOV prime focus corrector
5000 fiber positioner, 1 min. reconfiguration
10x3 spectrographs, 3600-10,400 Ang

Conduct BigBOSS Key Project

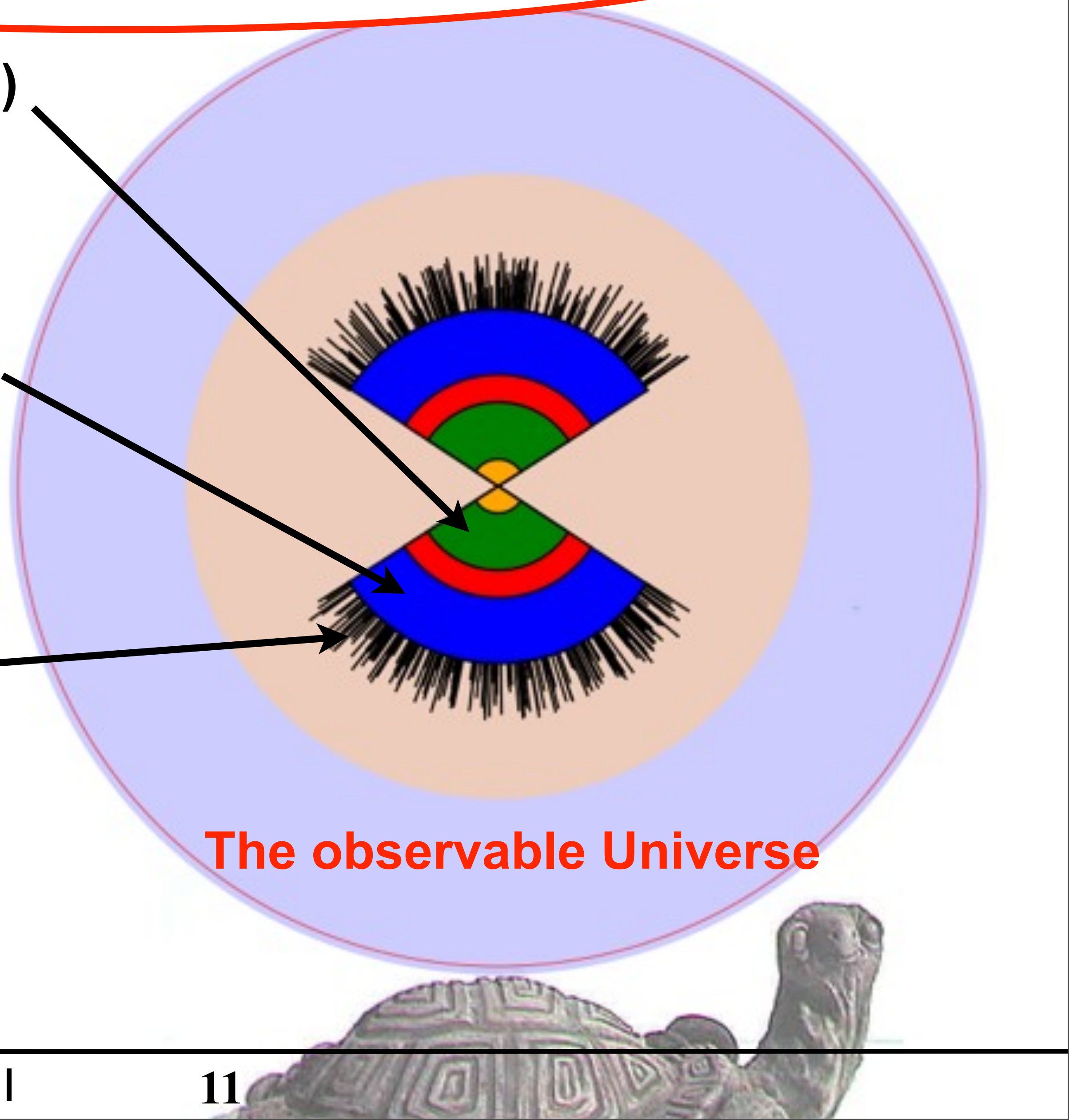
495 nights at Mayall 4-m
14,000 deg^2 survey
50,000,000 spectra

- 20,000,000+ galaxy redshifts
- 3,000,000+ QSOs

What is BigBOSS?

It's the "easy target" survey

- **Luminous Red Galaxies (LRGs)**
  - Selected to z<1
  - Efficient BAO tracers, large bias
- **Emission-line galaxies (ELGs)**
  - Selected 0.7<z<1.7 when the Universe was forming stars
  - Redshifts from [O II], [O III] emission lines, R~5000
- **QSOs**
  - Target ***all*** of them!
  - 3-D density map from Ly-alpha forest z>2.2



What is BigBOSS?

BigBOSS Design Philosophy

➩ **Optimize for redshifts**

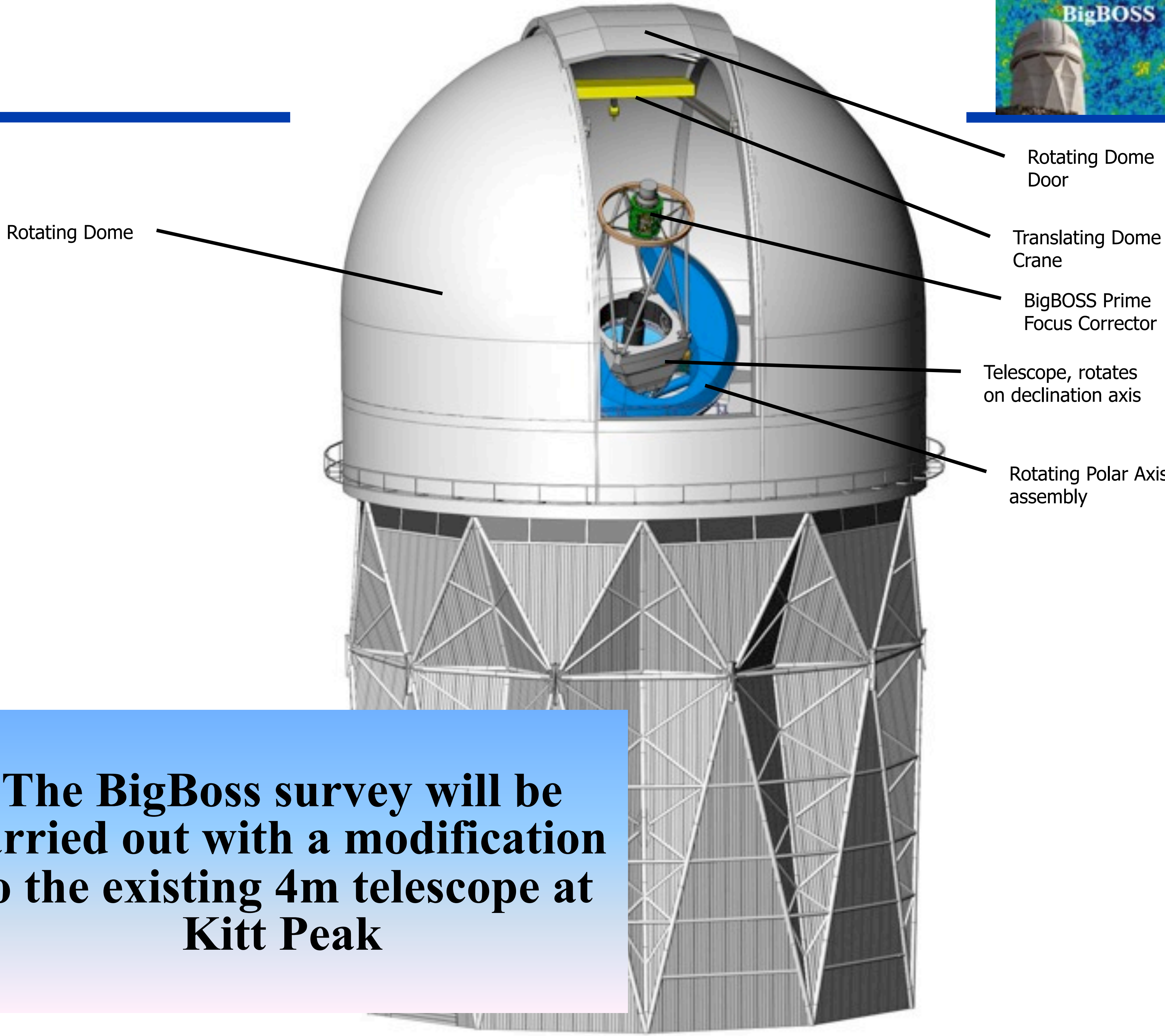
➩ **Simple design ⇔ high throughput**

BigBOSS Instrument = Telescope

+ Instrument

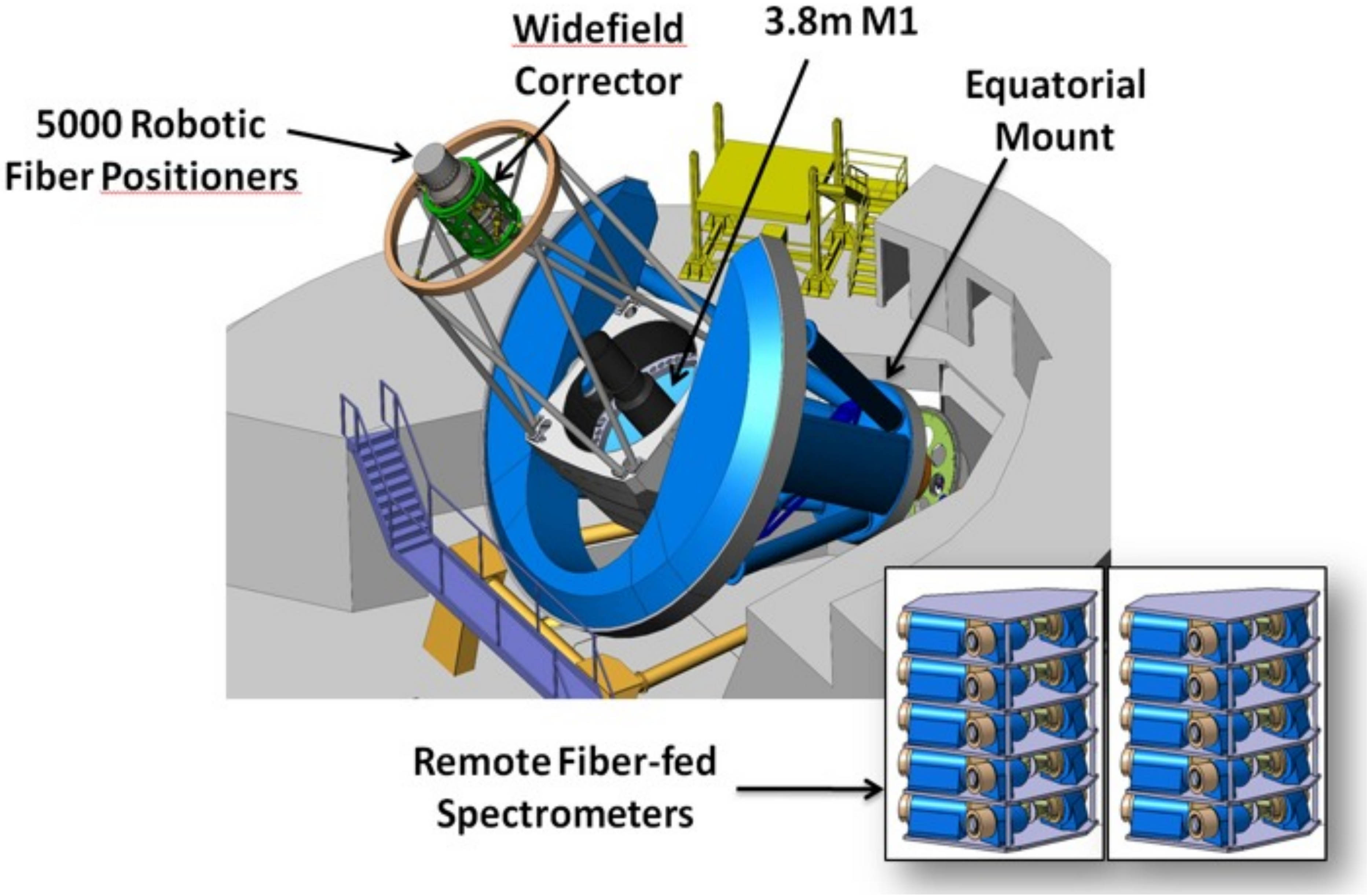
+ Data Reduction Method

The BigBOSS Instrument



The BigBoss survey will be carried out with a modification to the existing 4m telescope at Kitt Peak

Observatory Baseline Architecture



The U.S. wide-field "national treasures"

Which 4-m telescopes allow wide fields?

45% étendue of LSST

KPNO 4-m
CTIO 4-m
CFHT 3.6-m
Calar Alto 3.5-m
ARC 3.5-m (Apache Point)
WIYN 3.5-m (Kitt Peak)
Discovery Channel 4.2-m
WHT 4.2-m
ESO 3.6-m
SOAR 4.2-m
UKIRT 3.8-m
Galileo 3.58-m
ESO NNT 3.58-m
VISTA 4-m
AAT 3.9-m ← **2-deg FOV exists**

3-deg FOV possible

BigBOSS Collaboration

Partners are experienced
(Current commitments only to R&D)

USTC (China): Fiber positioners

LAMOST fiber positioners

IAA (Spain): Focal plane & positioner des.

GTC Nasmyth mount + positioner design

Fermilab (U.S.): Telescope top-end + lens cell
UCL (U.K.): Telescope optics

Dark Energy Survey top-end + optics

Durham + IEU (Korea): Fibers + testing
FMOS + Fibers for physics exp'ts

LAM + CPPM (France): Spectrographs

VIMOS spectrographs

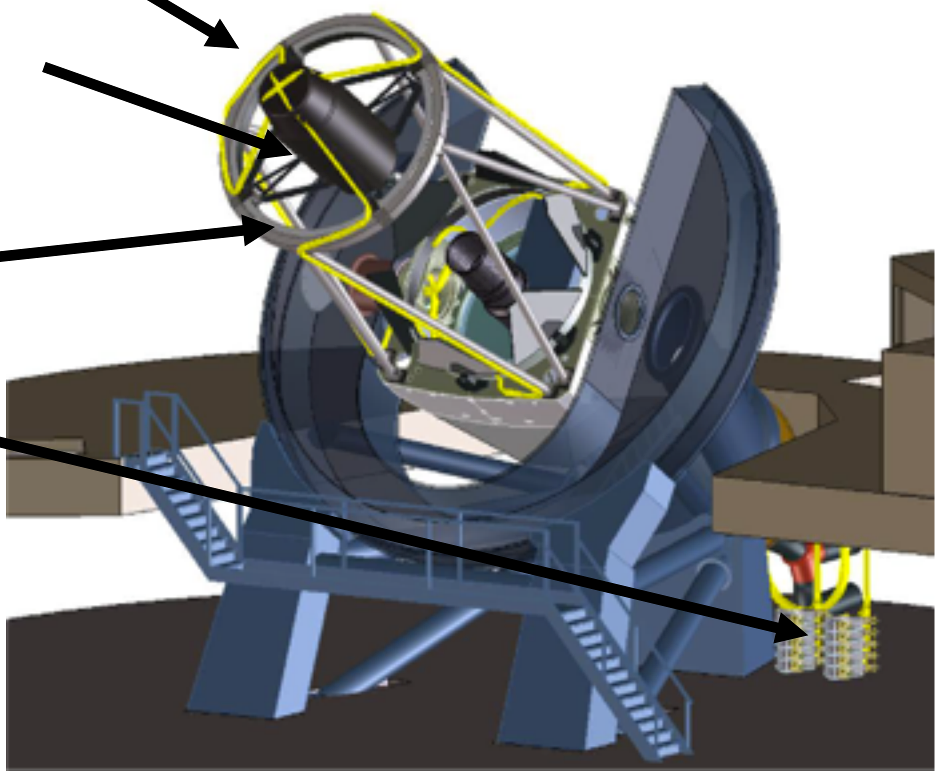
CEA (France): Cryo systems

Megacam cryo

Berkeley Lab (U.S.): CCDs + electronics, optical design, project management

JDEM optical design
DES, BOSS, JDEM detectors

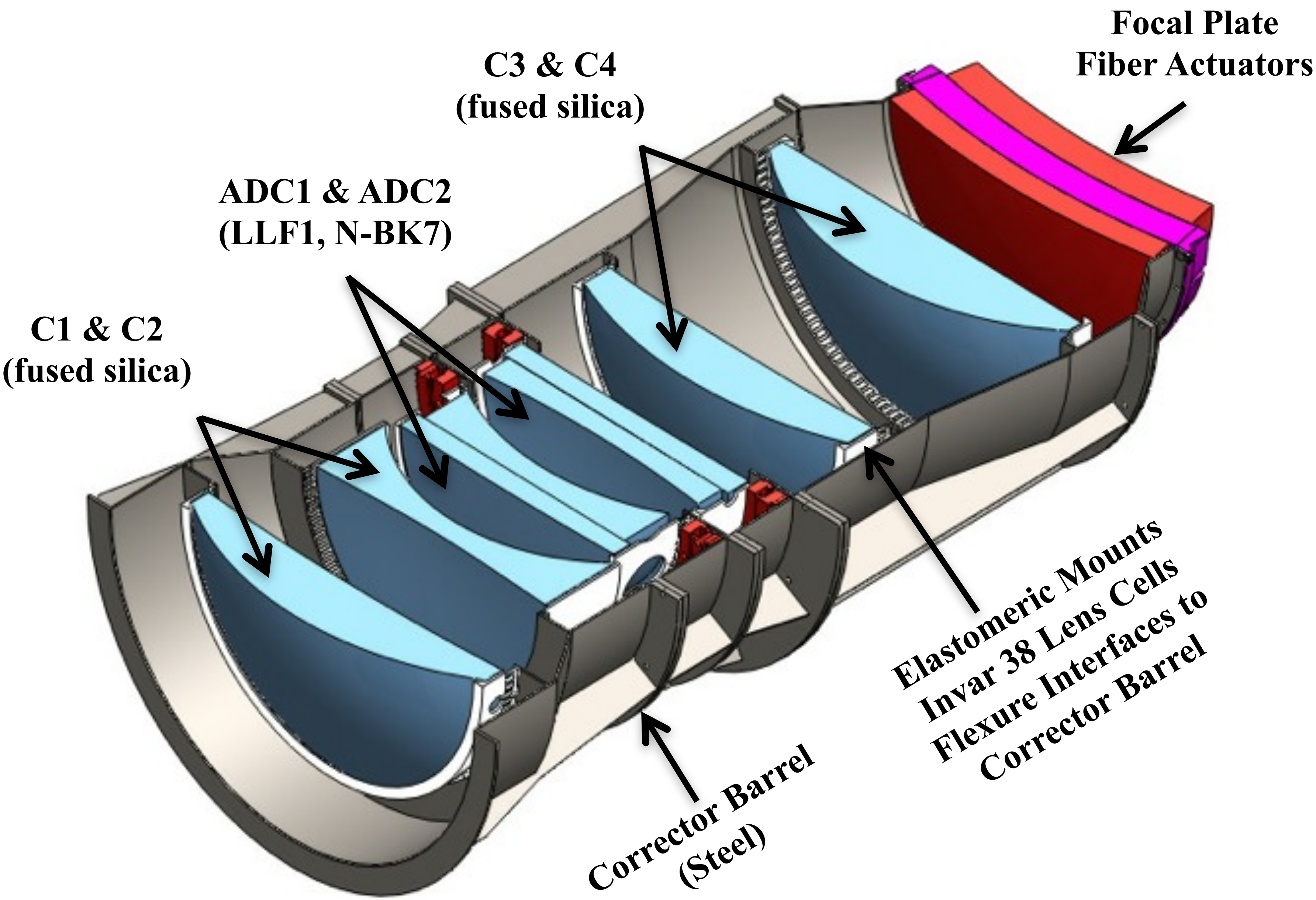
Yale: fiber view camera /*QUEST*
U Michigan: calibration hardware /*JDEM*
SLAC, Ohio State: data acquisition + guiding + *WF* /*BOSS, DES, LSST*
NOAO: telescope interface, operations



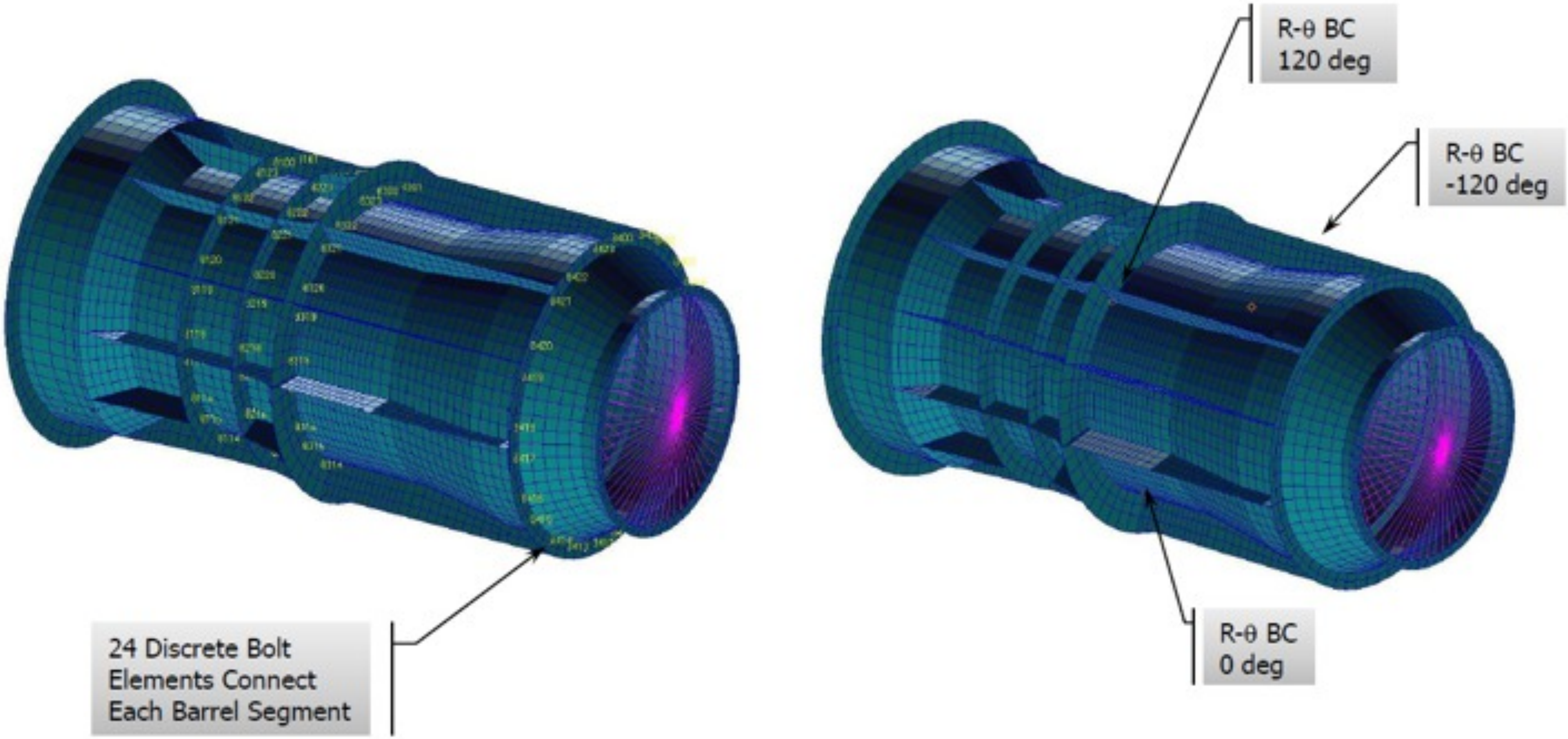
Corrector constraints

- FOV must be roughly 3° or larger, or use factor is diminished due to Poisson statistics of galaxies
- Chief ray normal design
  - f/4.5 → f/4 (spectrometer input)
  - $<0.5^{\circ}$ (mean) chief ray deviation
  - Remaining budget to FRD and two fiber connectors
- LLF6 (used on existing Mayall corrector)is no longer available. Use fused silica, N-BK7 and LLF1 for corrector.
  - Maximum size of LLF1: ~0.9m diameter
- Maximum corrector lens element size: 1.25m (including 15mm radius for mechanical mount).
- Focal plate may be curved, but ROC should be greater than 2.5m (as large as possible, to avoid constraints on actuators)

Corrector Cutaway



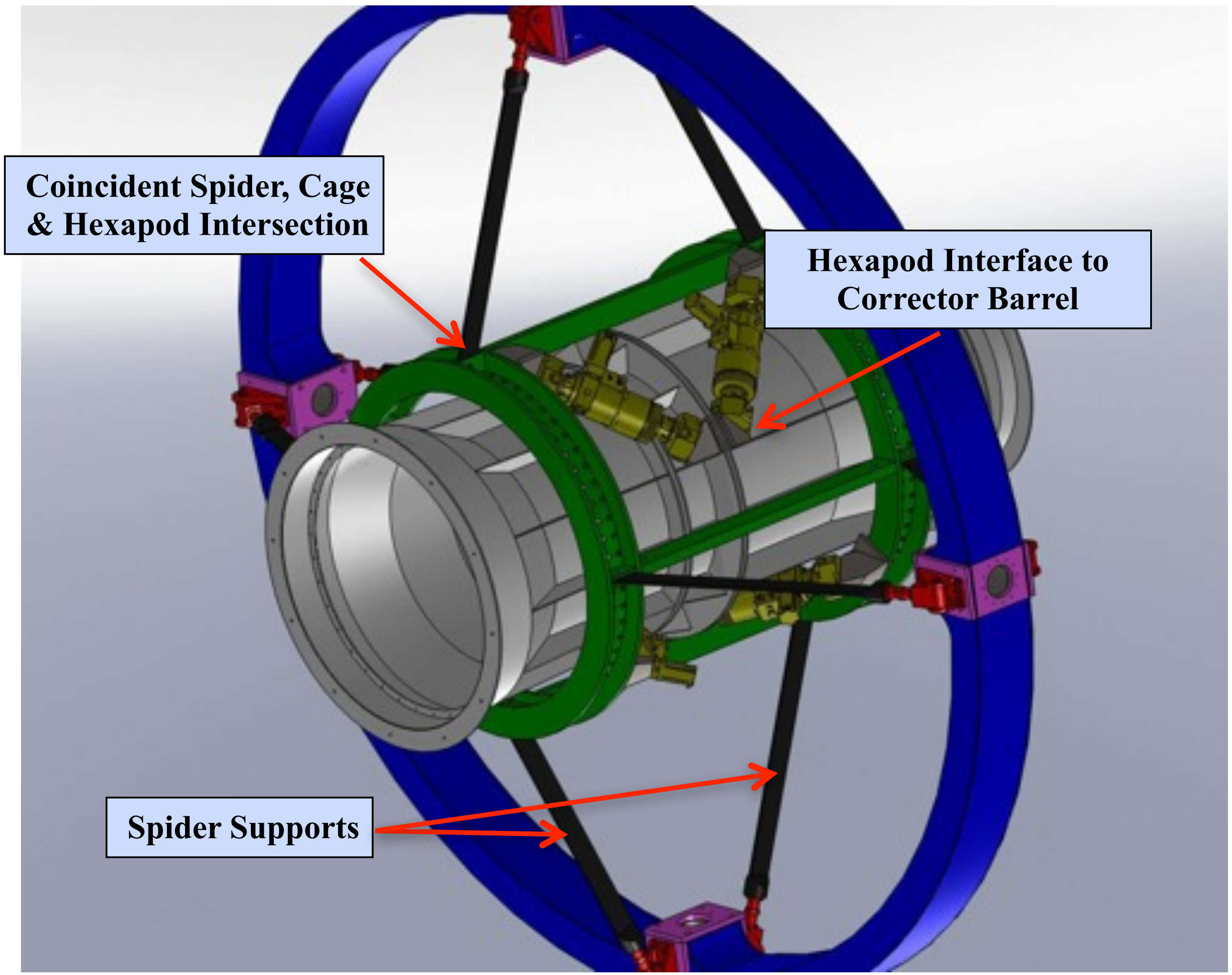
Finite Element Modeling



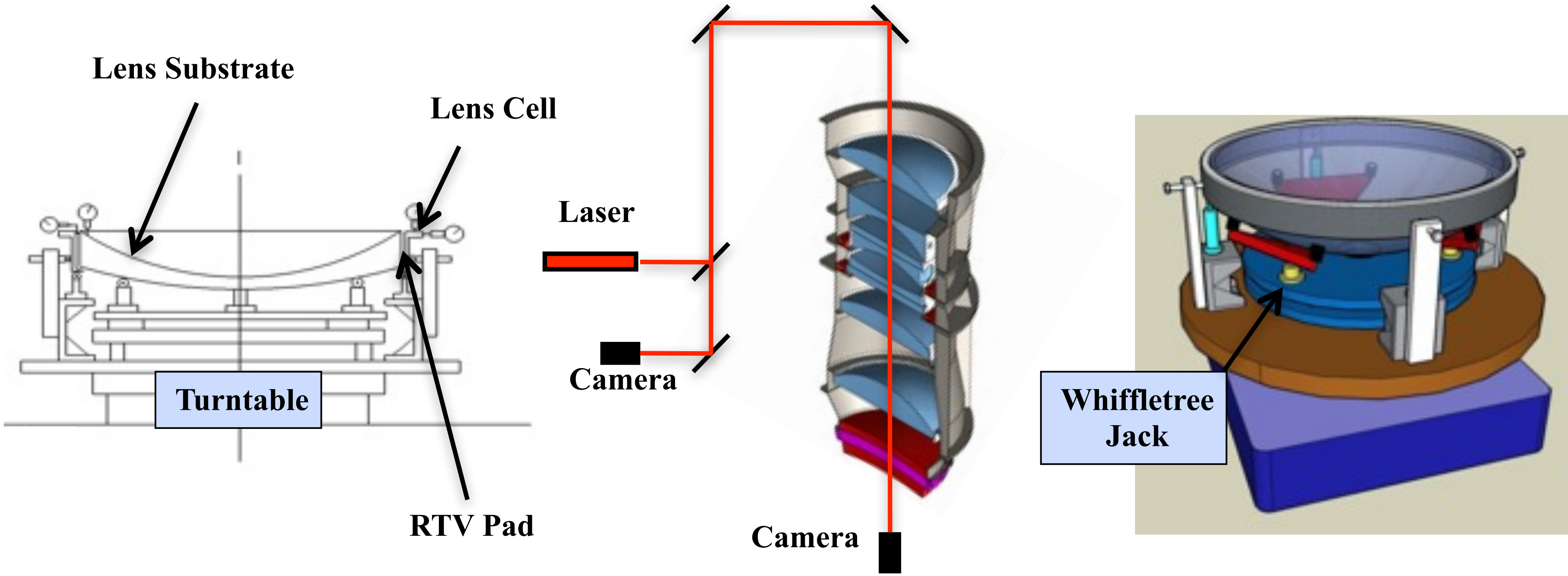
- Model has gussets removed on ADC1 and C4 Barrel Sections
- —Barrel sections connected by 24 bolt (CBAR) elements
- —Model fixed at 3 locations (0-120-240deg) in R-□

Hexapod (6-DOF)

- Hexapod mounts to spider intersection points and CG of corrector barrel
- Yaw Pitch and translation allow focus compensation
- Roll allows improved target selection

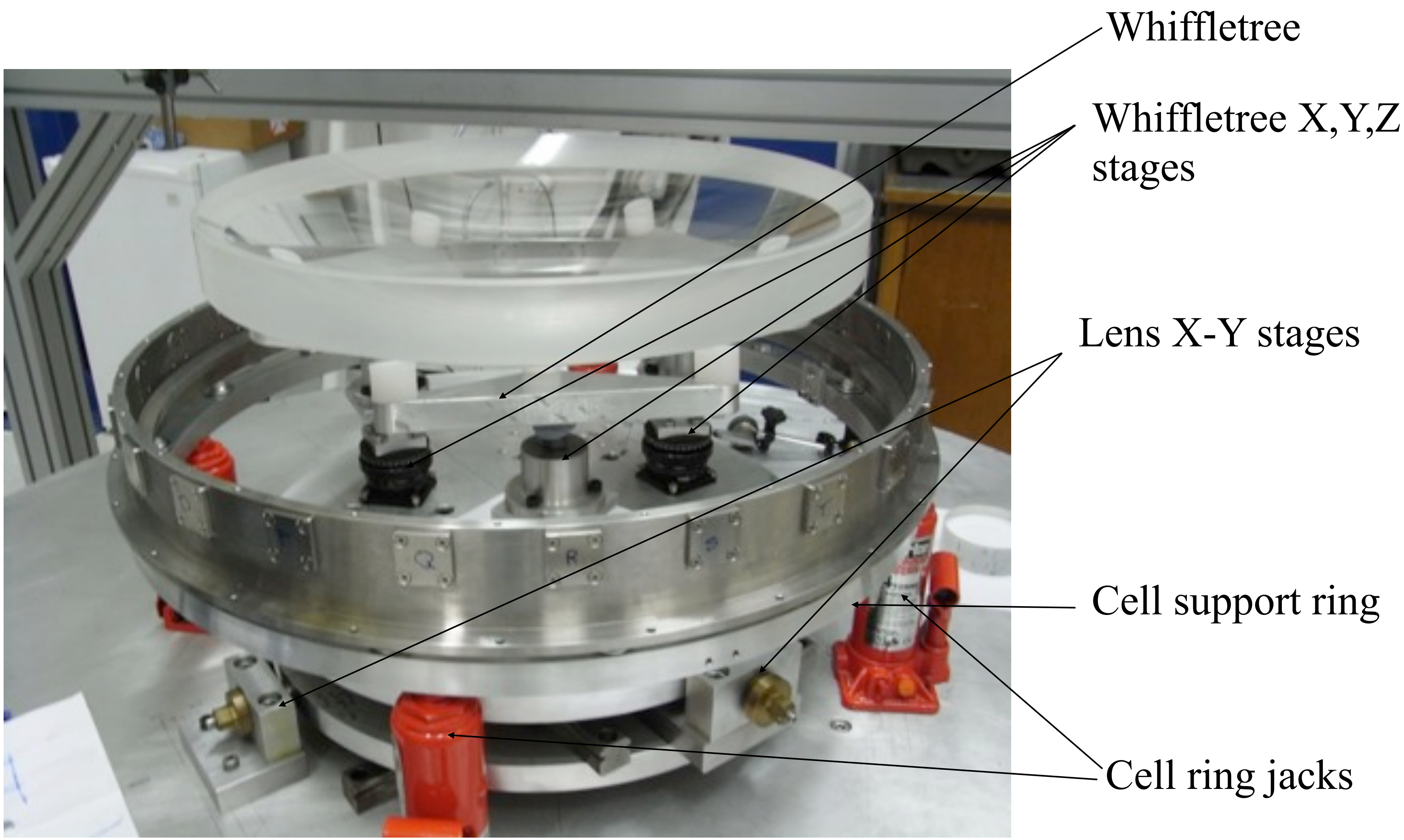


Corrector Alignment



- **Low CTE lens cell (Invar 38)**
- **RTV pads (Doel, Fata, Fabricant) installed after rotary table alignment of lens and cell**
- **Flexure link to A36 steel corrector barrel**
- **Shims to correct for element manufacturing and glass pour data**

Lens-Cell alignment Rig (Doel, DES)



Optical System Throughput

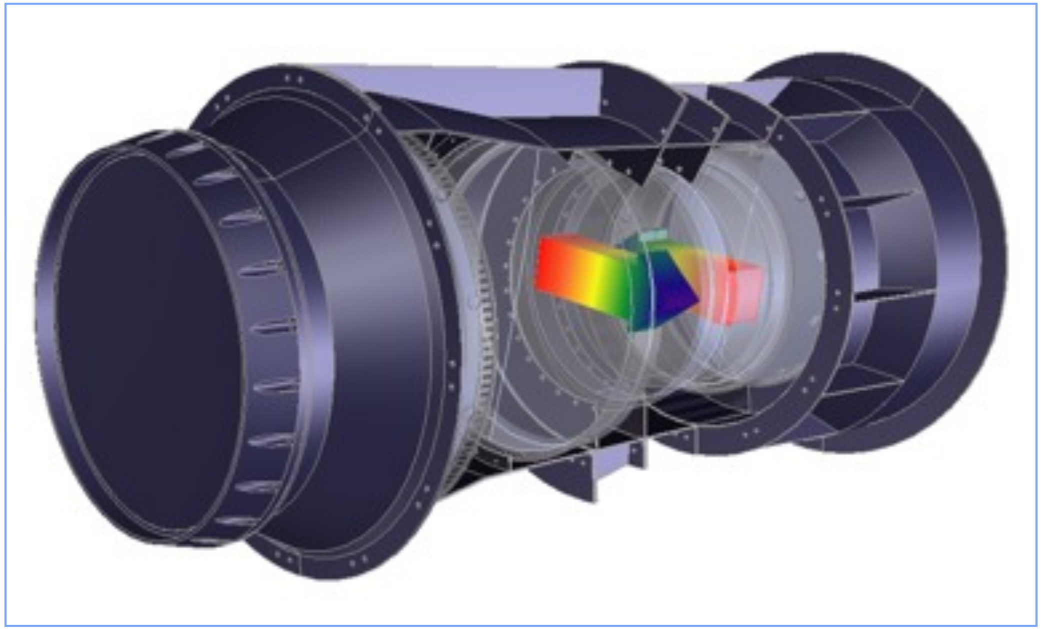
Throughput >~ SDSS-III/BOSS spectrographs

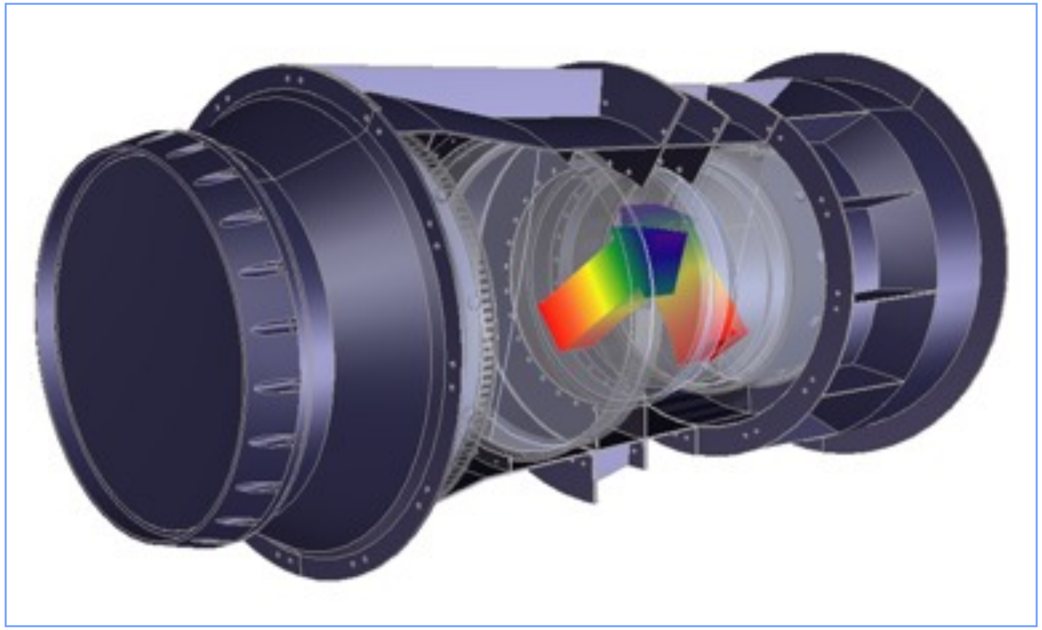
	Wavelength (nm)								
	375	400	500	600	700	800	900	1000	1100
Atmosphere at zenith	0.660	0.720	0.829	0.890	0.930	0.960	0.960	0.950	0.950
Pupil Obscuration (1.8m)	0.775	0.775	0.775	0.775	0.775	0.775	0.775	0.775	0.775
WFC Support Truss Obscuration	0.991	0.991	0.991	0.991	0.991	0.991	0.991	0.991	0.991
Primary Reflectance	0.909	0.909	0.906	0.897	0.877	0.852	0.876	0.924	0.930
WFC material transmission	0.777	0.869	0.893	0.898	0.909	0.909	0.909	0.909	0.899
Lens Surface coating throughput	0.834	0.865	0.908	0.834	0.804	0.844	0.876	0.785	0.652
Throughput to fiber	**0.299**	**0.378**	**0.468**	**0.460**	**0.458**	**0.446**	**.459**	**0.479**	**.476**

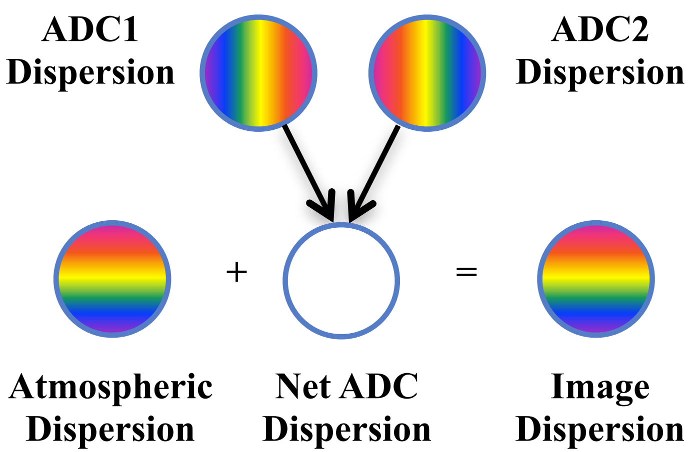
Fiber Injection Efficiency

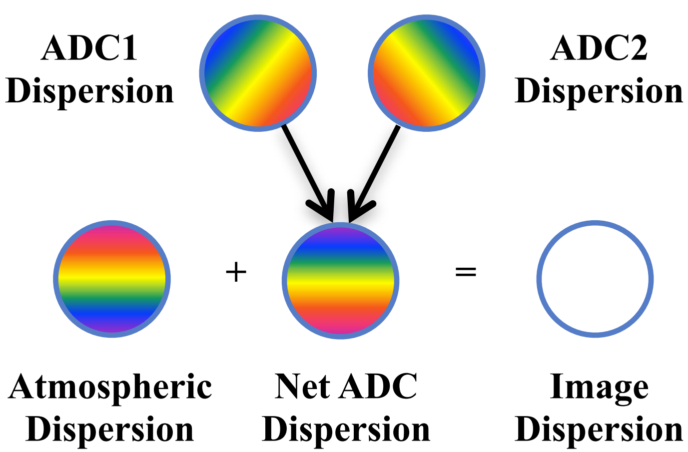
- **Fiber injection efficiency**
  - — Misalignment (angular) of chief ray with respect to fiber normal
  - — Galaxy image size at focal surface
    - Geometric blur (residual phase, as-built, thermal & dynamic)
    - Galaxy size (Sersic inverse exponential galaxy, 0.3 arcsec EE50 radius)
    - Atmospheric seeing (Moffat 1 arcsec FWHM, β=3.5)
  - — Lateral misalignment of galaxy image relative to fiber
    - Galaxy image convolved with circular fiber to estimate throughput
    - Sources of misalignment between fiber and galaxy image are key to throughput budget
      - — Astrometry errors
      - — Focal plane thermal shifts
      - — Dynamics (rotational mode of corrector on spider support vanes)
      - — Fiber positioning errors (mechanical and fiber view camera)
- **Throughputs may be estimated by RSSing uncorrelated misalignment components or multiplying resulting throughputs**

Atmospheric Dispersion Compensator

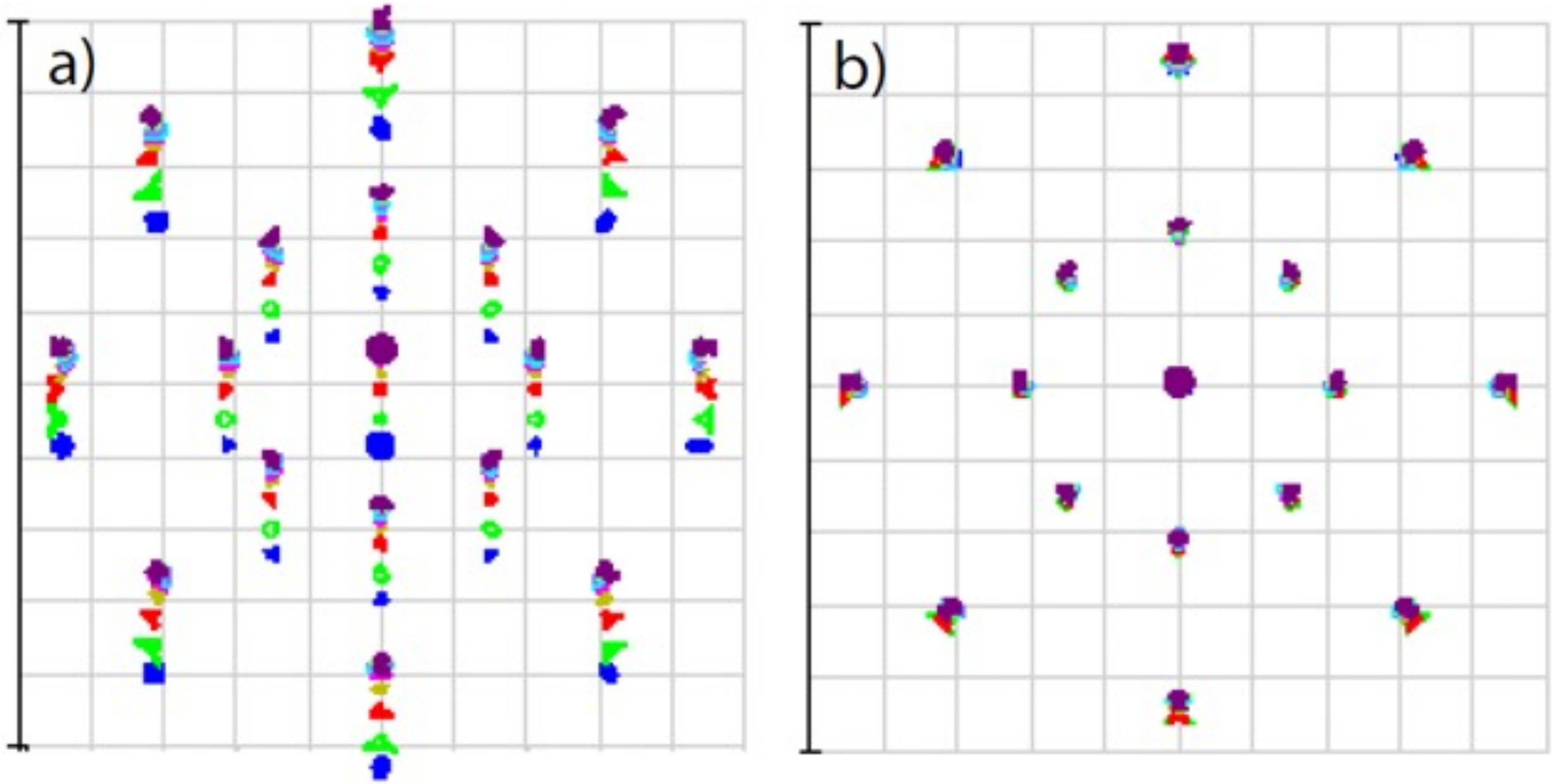








Atmospheric Dispersion Correction



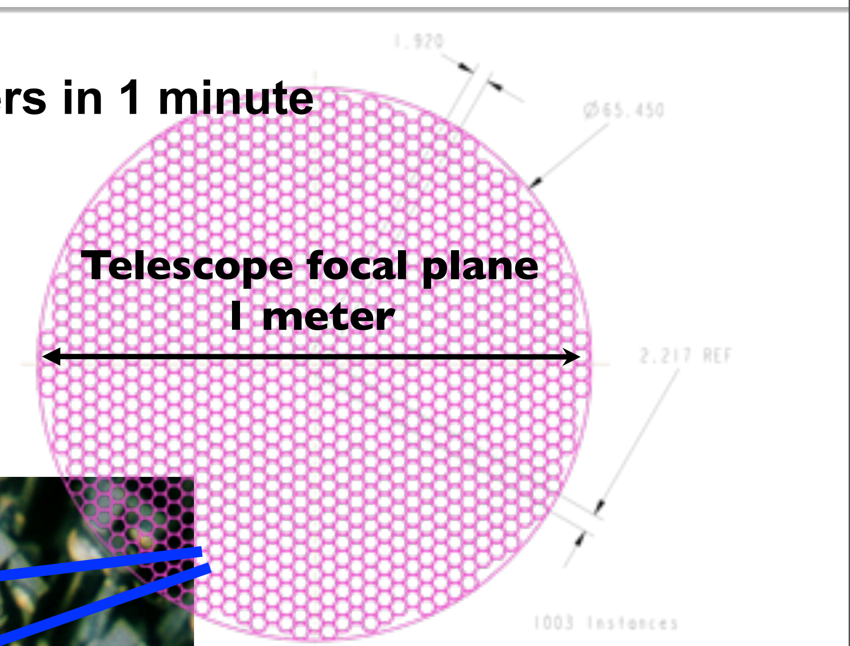
Geometric raytrace shows eects of atmospheric dispersion on telescope point spread function. a) A heavily chromatically aberrated view of the sky 60 from zenith. Overall scale is 1m square, PSF exaggerated by factor of 106. This chromatic aberration is removed by rotating the ADC prisms 85 as shown in b). The dispersion being compensated here is 3 arcsec.

BigBOSS fiber positioners are under development by USTC (LAMOST group)

Fiber plug-plates (for SDSS) no longer feasible

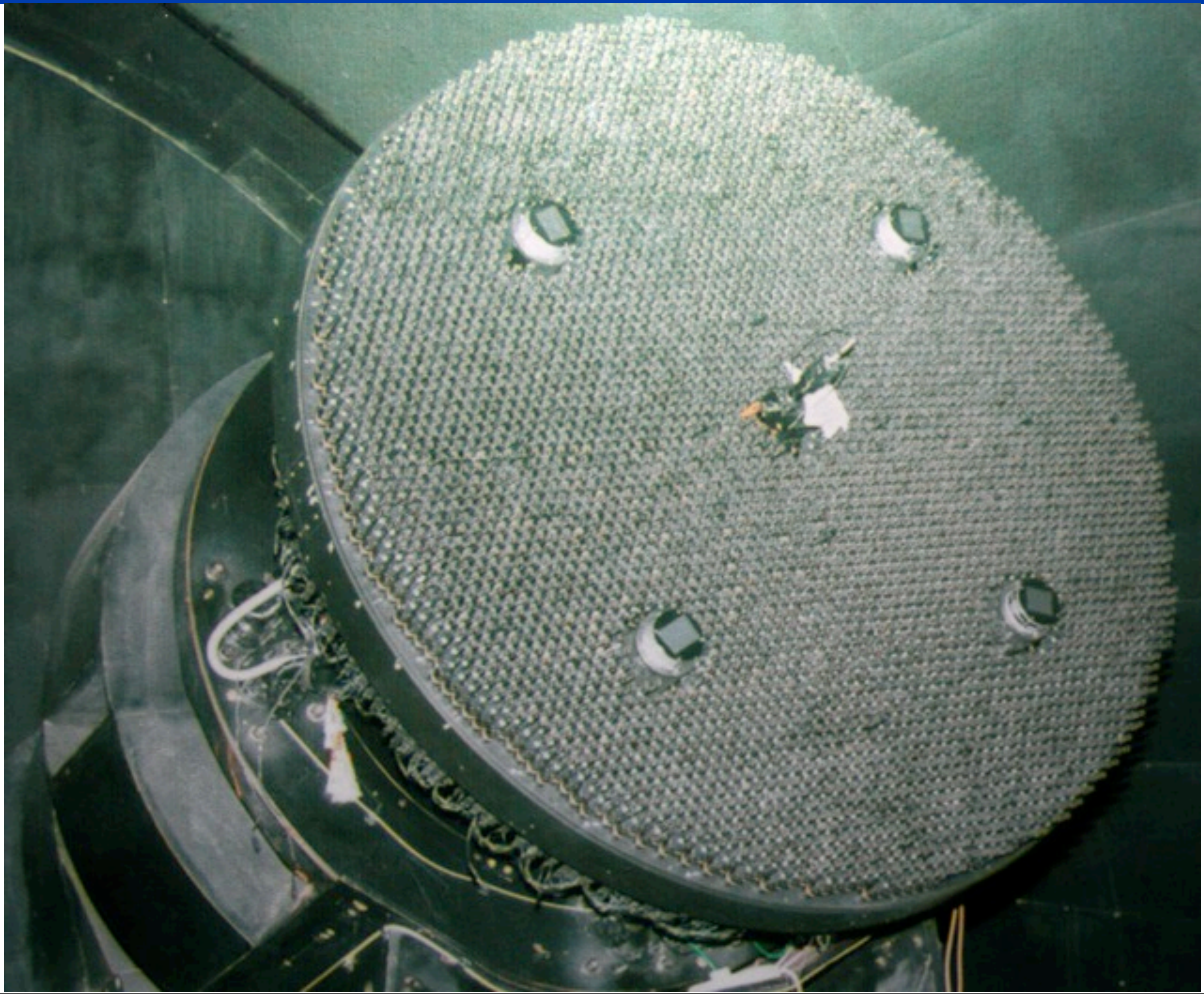
Robotic system necessary for reconfiguring 5000 fibers in 1 minute

Norm Blythe @ SDSS

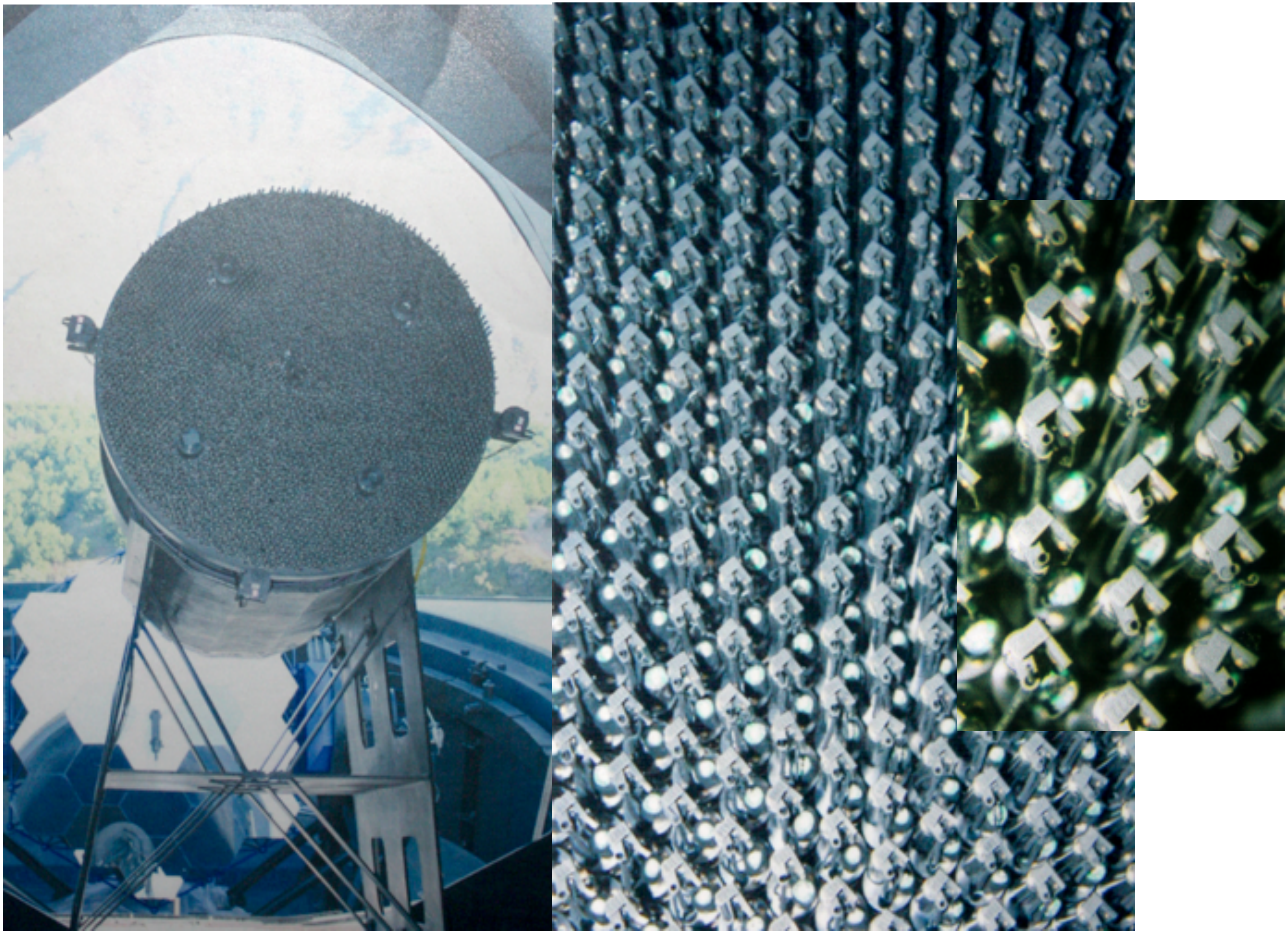


Every position on 3 deg field can be reached, typically by only 1 fiber

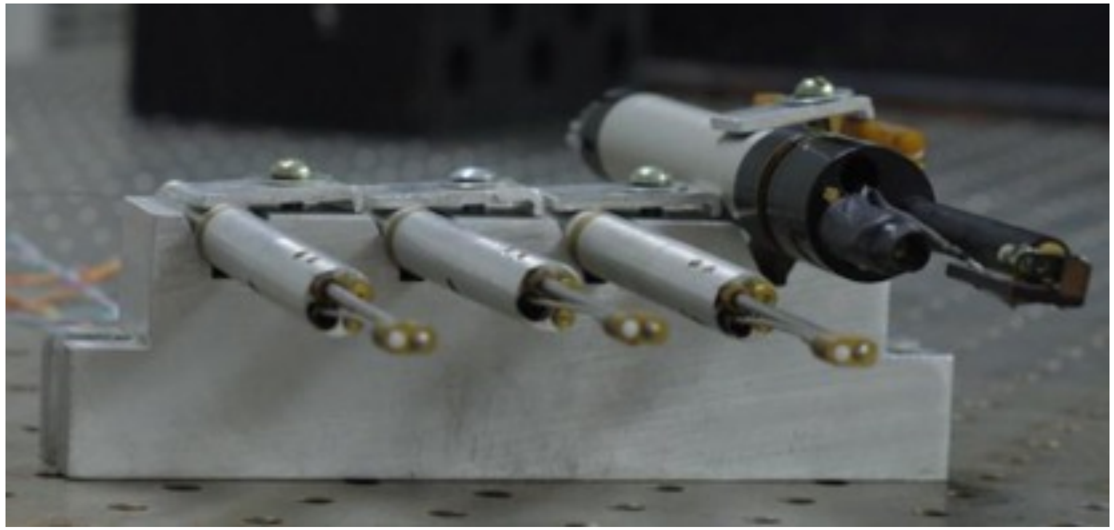
LAMOST Integrated Focal Plane



LAMOST 25.6mm Fiber Positioners



USTC BigBOSS Fiber Actuators



- **LAMOST actuator shown to right (25.6 mm pitch)**
- **BigBOSS actuator prototypes to left, and below (12 mm)**

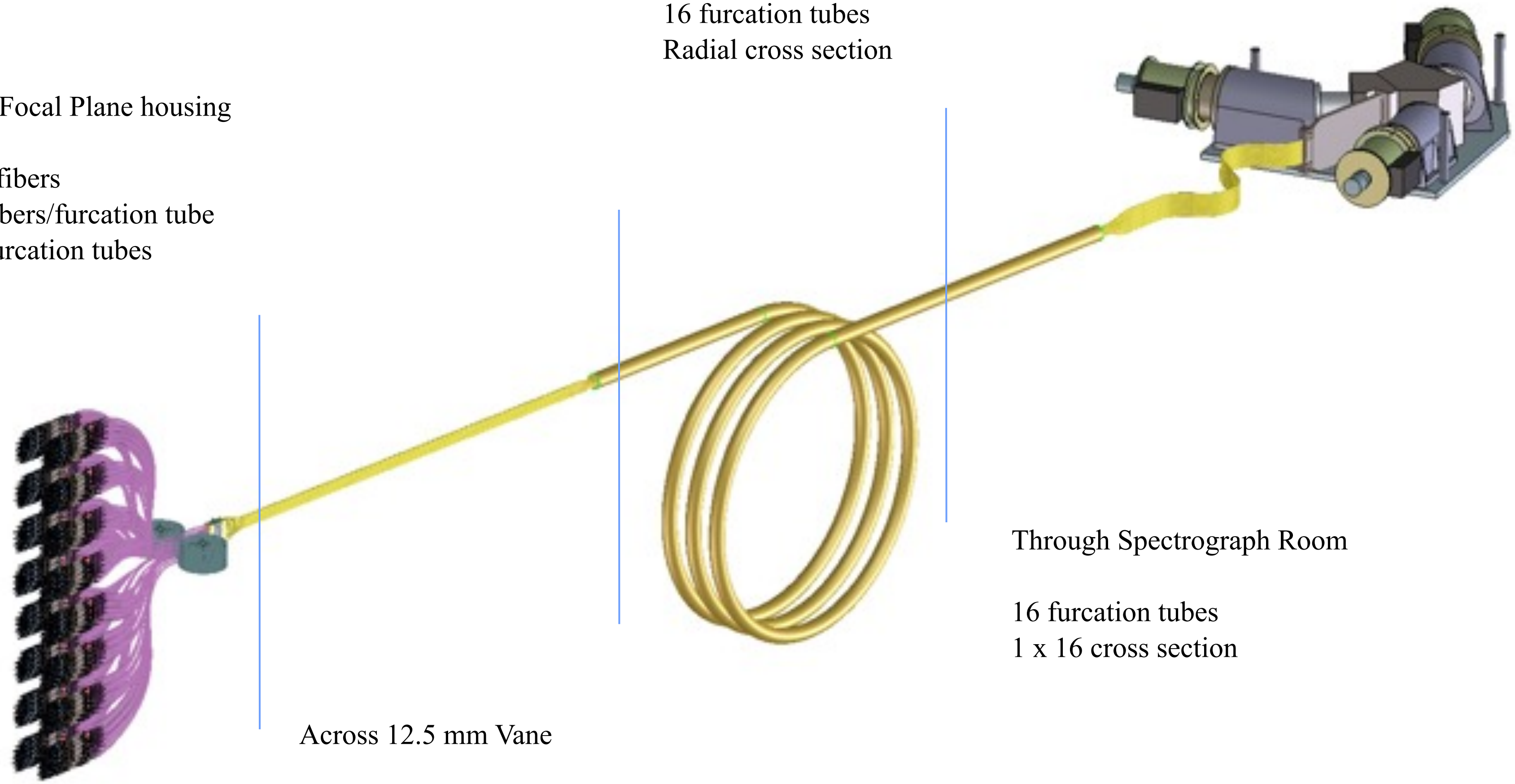
Typical Cable Assembly   End-to-end

Through Telescope

16 furcation tubes
Radial cross section

Into Focal Plane housing

512 fibers
32 fibers/furcation tube
16 furcation tubes



Through Spectrograph Room

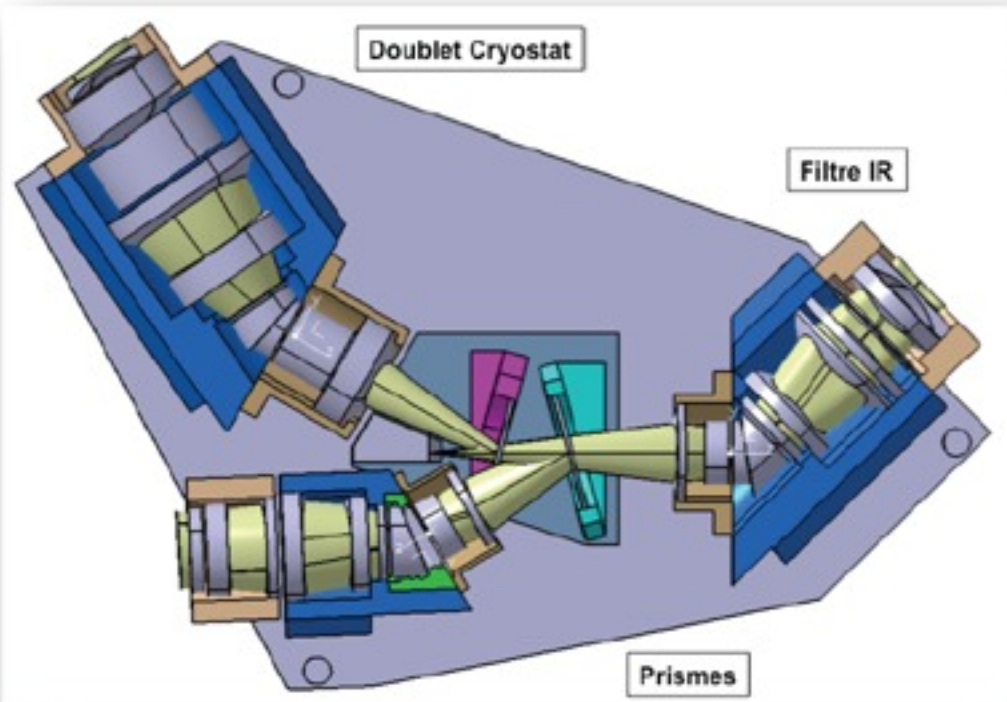
16 furcation tubes
1 x 16 cross section

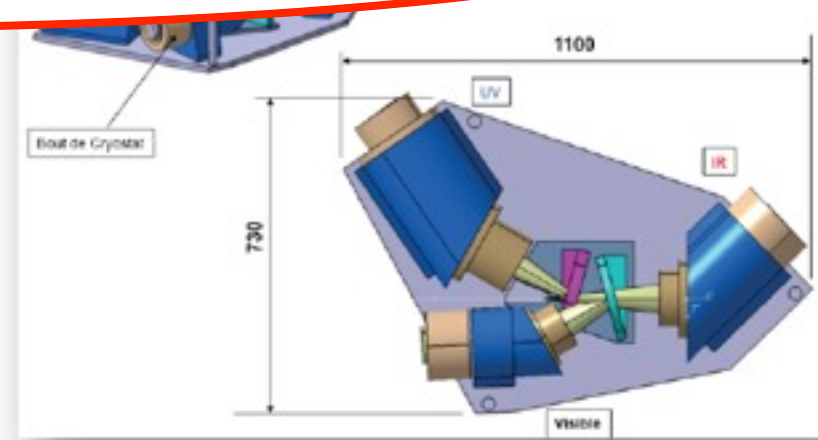
Across 12.5 mm Vane

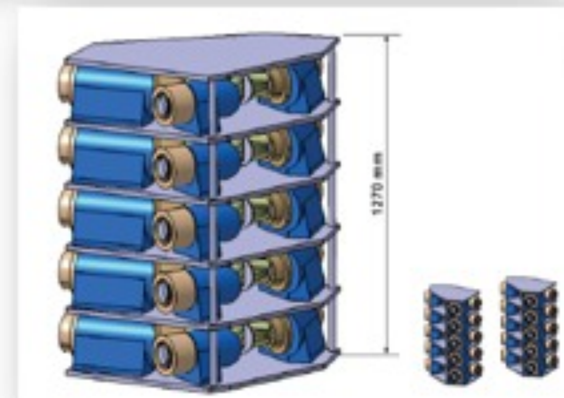
16 furcation tubes
2 x 8 cross section

Spectrograph Layout (Prieto)

Spectrographs are fixed: no grating changes, etc



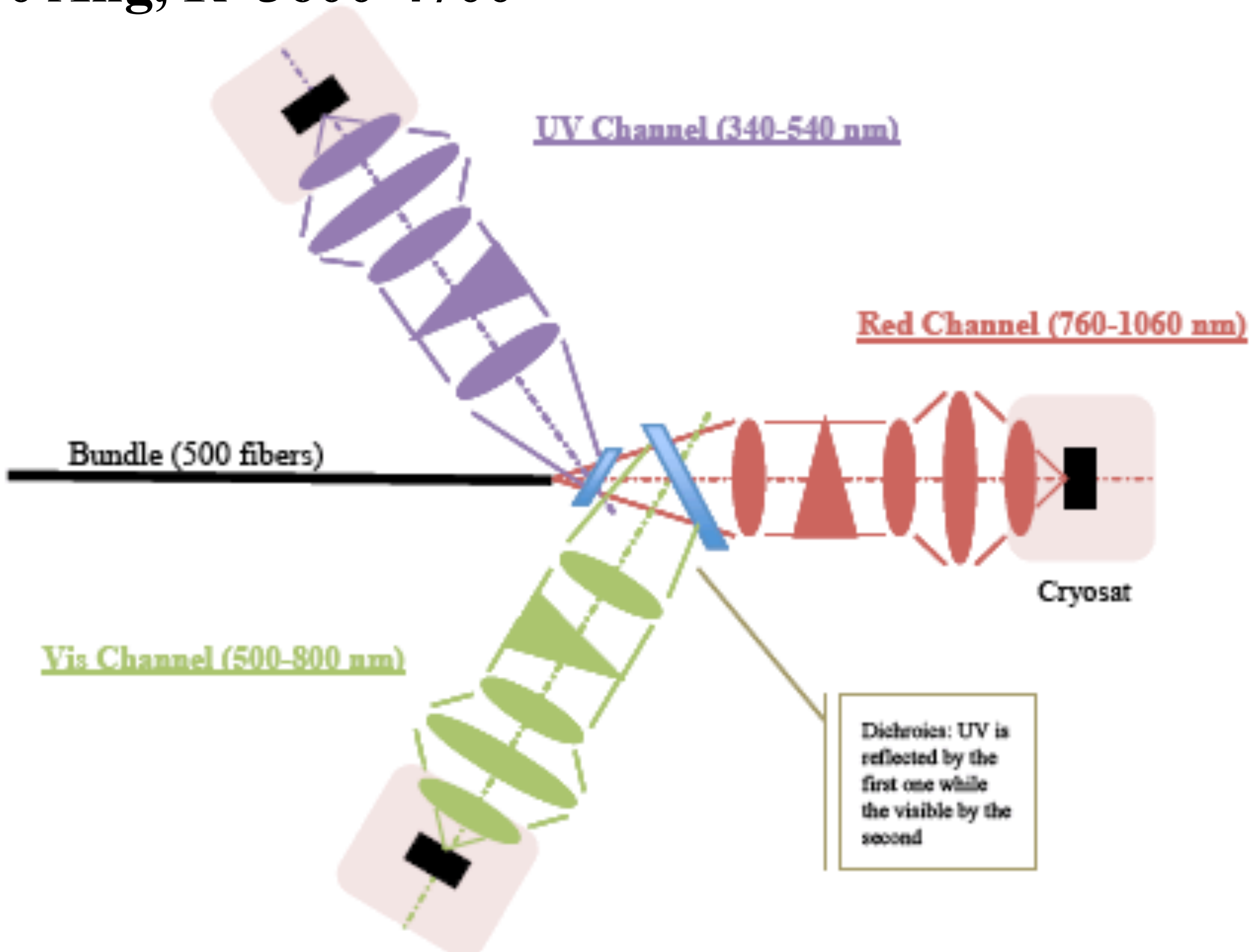




- **500 fibers per spectrometer**
- **Three channels and cryostats per spectrograph**
- **Full coverage 3600 - 10,400 Ang**

Spectrographs

- **3-arm spectrographs**
- **Blue: 3600-5400 Ang, R~2300-3500**
- **Visible: 5000-8000 Ang, R~2400-3600**
- **Red: 7600-10,400 Ang, R~3600-4700**



Spectrograph Detectors

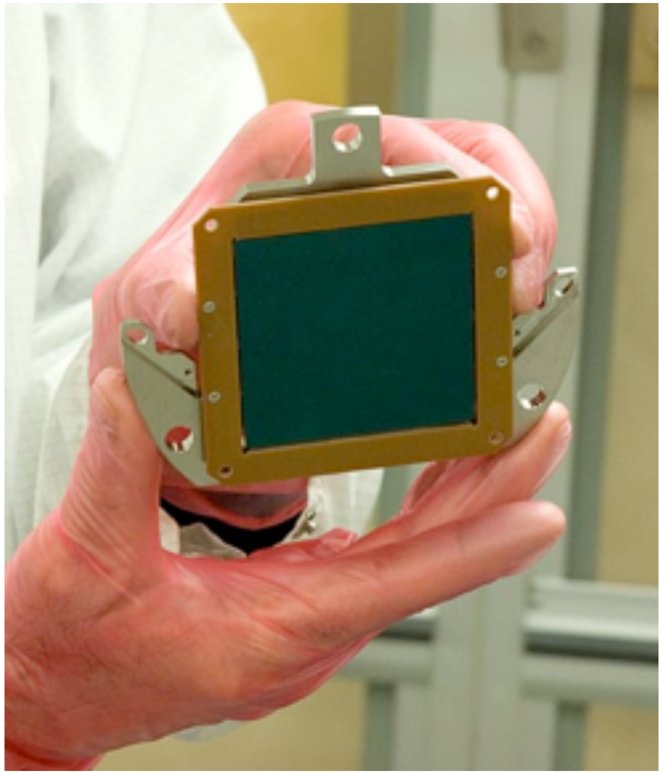
Response in red to 1.04 micron

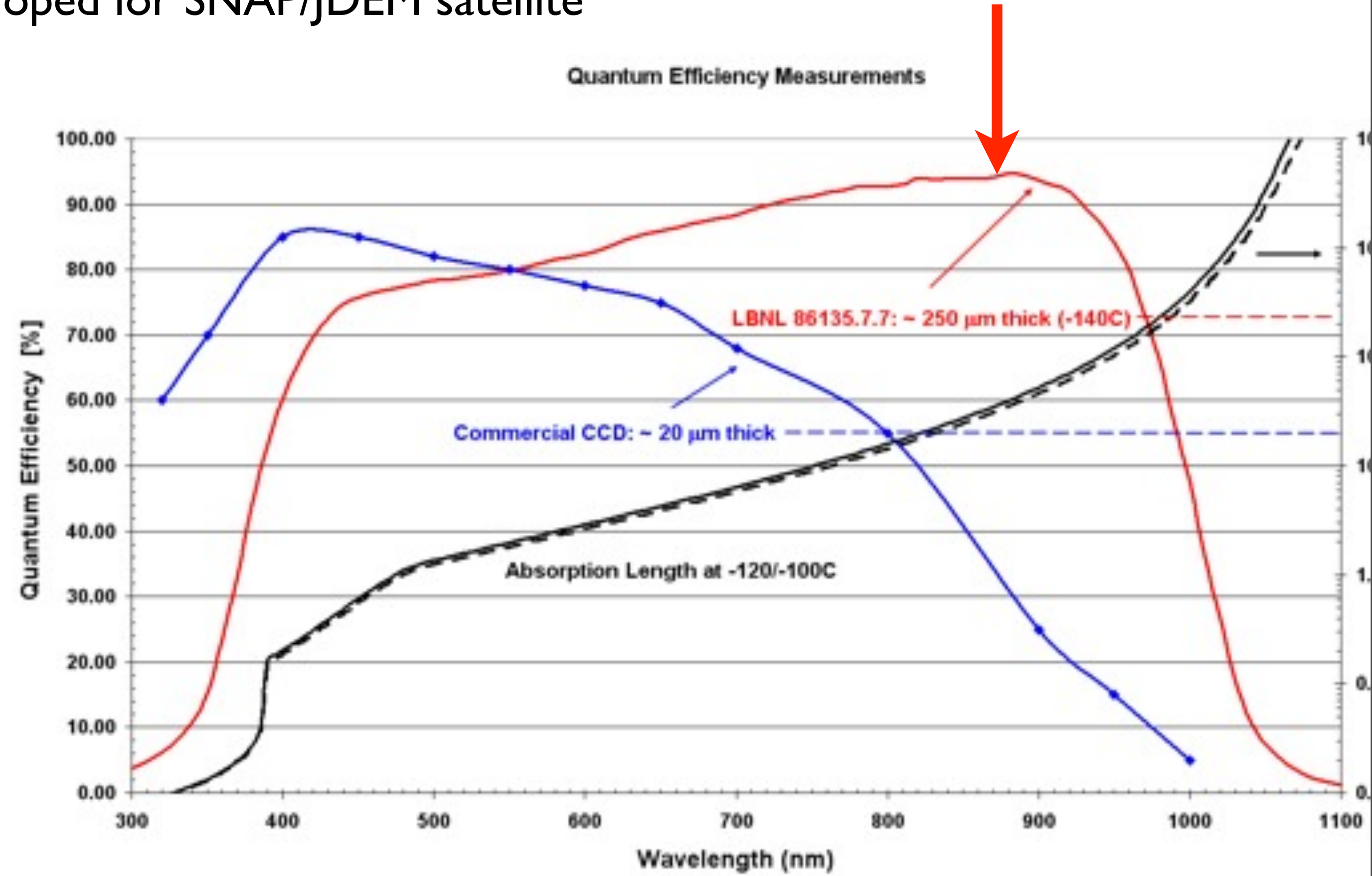
Lawrence Berkeley National Lab (LBNL) red-sensitive CCDs

4k x 4k devices in current use for BOSS

+ Integrated circuit electronics

Compact, in cryo, also developed for SNAP/JDEM satellite





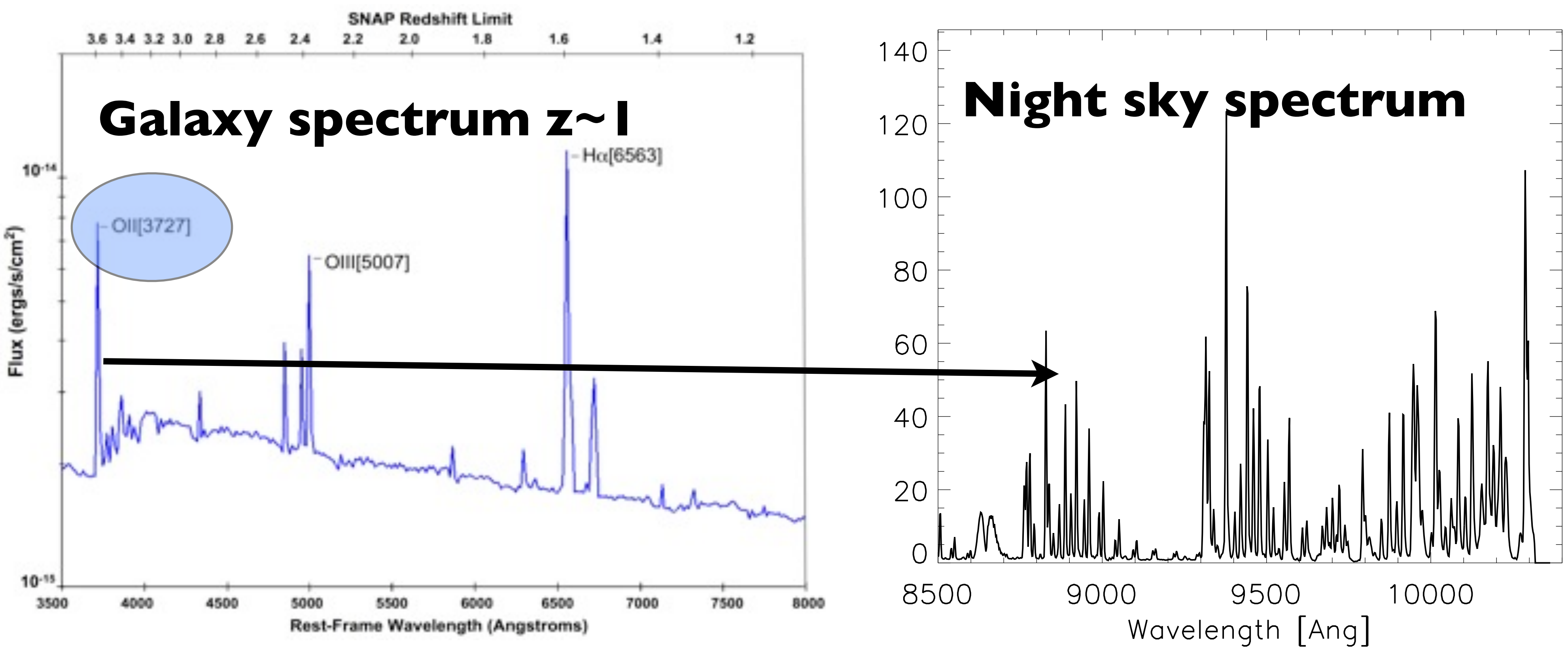
The BigBOSS Instrument: the Data Reduction Part

(Adam Bolton will give more detail)

BigBOSS Data Reduction

Modern view of the data:

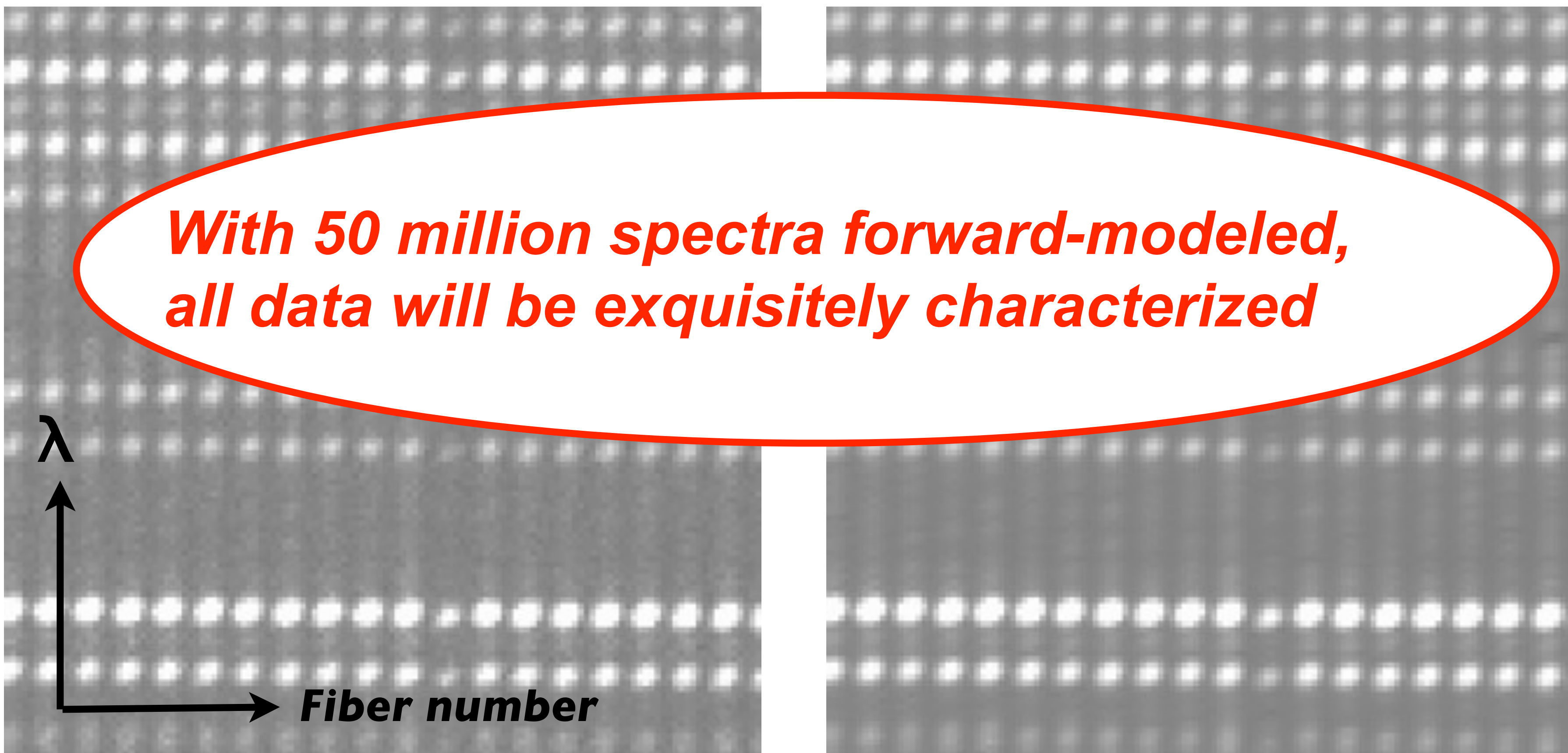
- **Resolution model per measurement (~pixel) + covariances**
- **Design for recovering low S/N and understand contamination**



BigBOSS Data Reduction

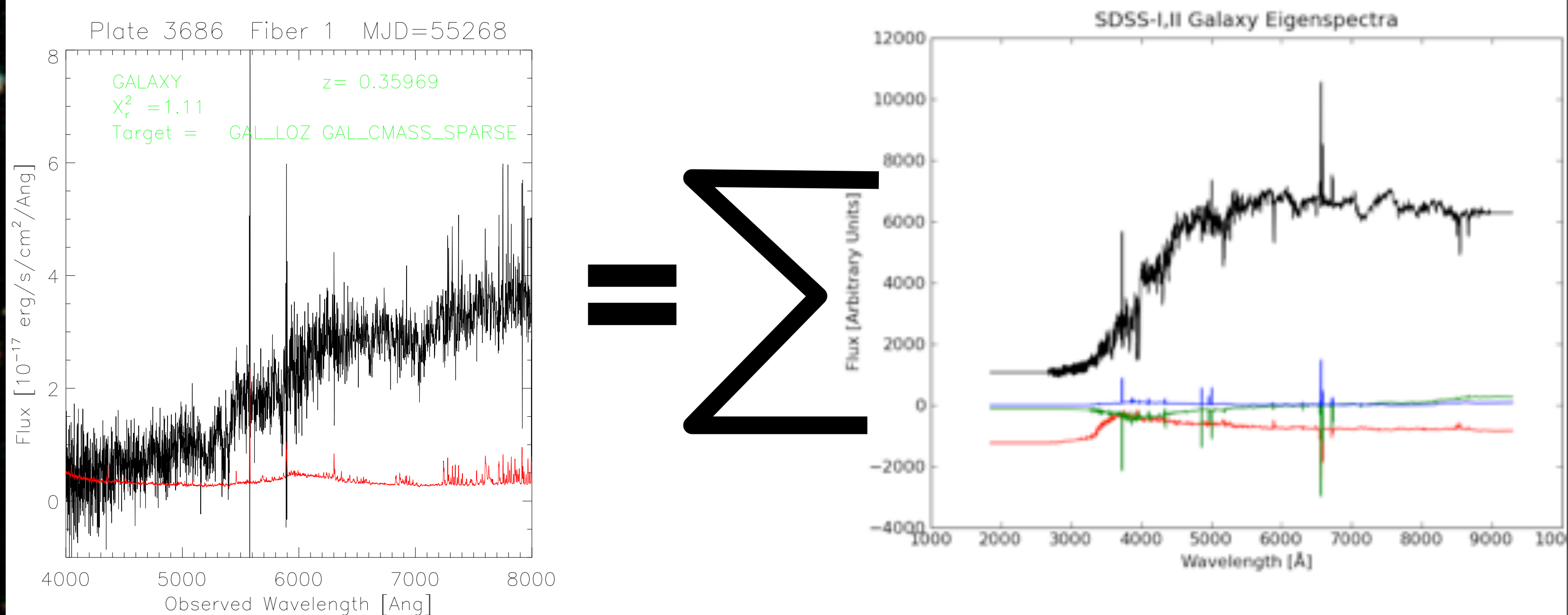
BigBOSS Key Project will be low-S/N, 20 min exposures
- **Devel. on SDSS/BOSS data**

Other modes? Shorter/longer exposures, lower/higher S/N?
- **Devel. on which data??**



BigBOSS spectra → redshifts

Optical fiber collects all photons within 2-arcsec



Hypothesis test:

Search all possible objects + redshifts
("Computers are cheap")

How capable is BigBOSS?

SDSS I+II galaxy survey = 929,000 redshifts

BigBOSS equivalent?

180 exposures / (30 exp/night) = 6 nights !

+ rest on the 7th night

The fine print:

*** Still need 2000 pointings to cover 10,000 deg2**

*** Fiber positioners not as flexibly-assigned as plug-plates -- 30% inefficiency**

BigBOSS Instrument Summary

Instrument

3 deg diameter FOV prime focus corrector
5000 fiber positioner
10x3 spectrographs, 3600-10,400 Ang

Operationally *(Arjun Dey's talk)*

ADC allows observing to airmass 2
Fiber reconfiguration in 1 min., every 20 min.
ToO?
Spectrographs fixed wavelength coverage, resolution

Data Reduction *(Adam Bolton's talk)*

Design for redshifts of faint galaxies in Key Project
Deep (or shallower!) exposures also possible