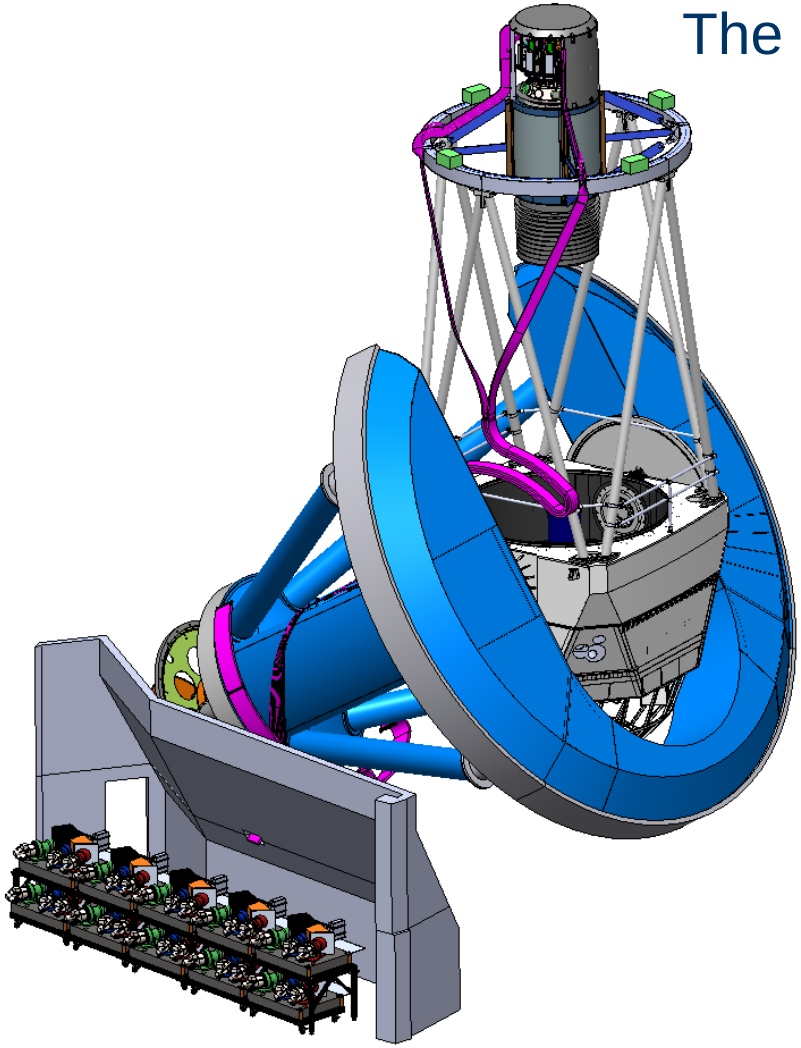


DESI

The Dark Energy Spectroscopic Instrument

Construction status
Cosmological distances
with Lyman-alpha forests

Julien Guy (LBNL)

Feb 27, 2018

Outline

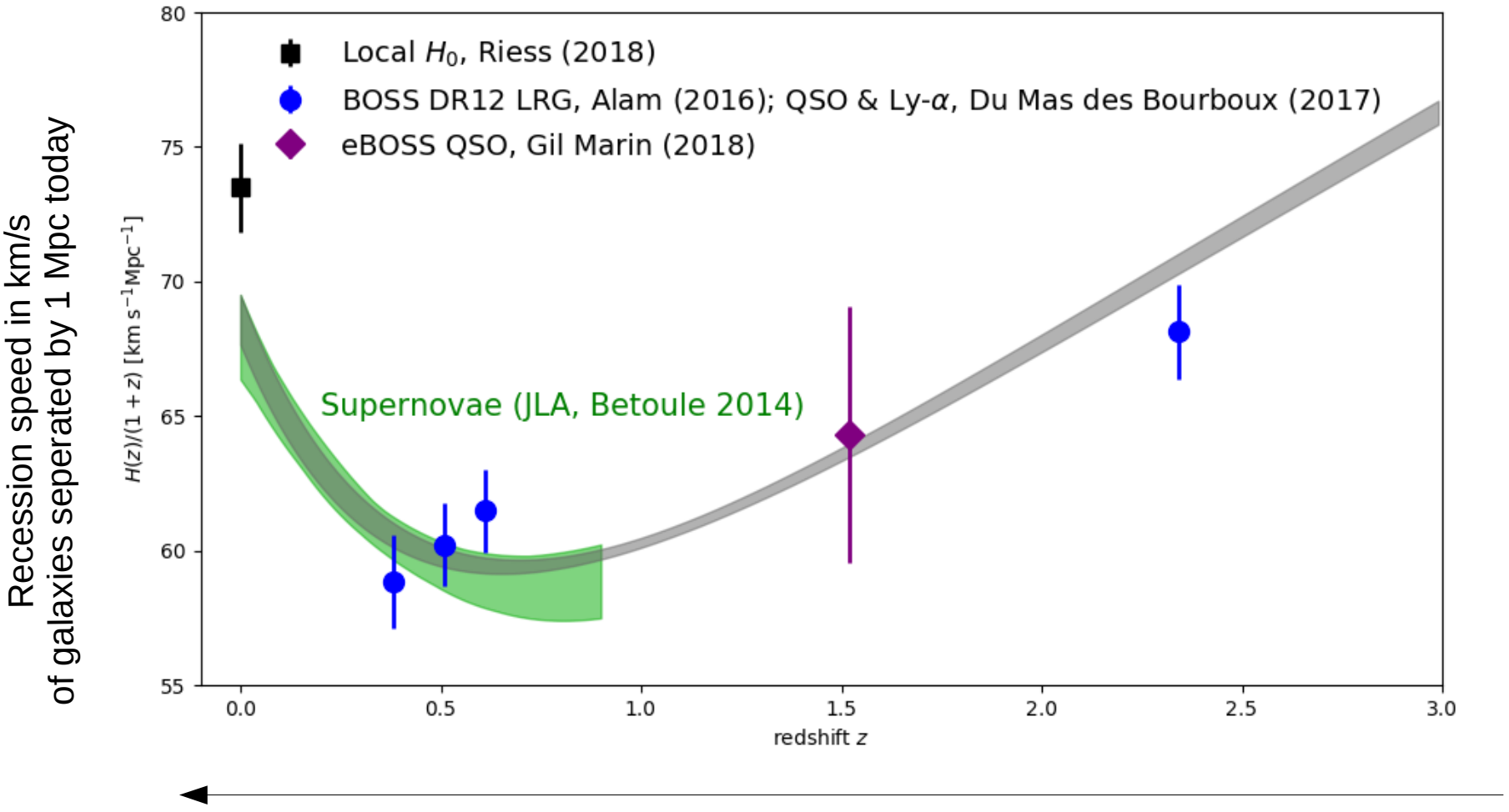
Overview of DESI science

DESI instrument and construction Status

BAO with Lyman-alpha forests

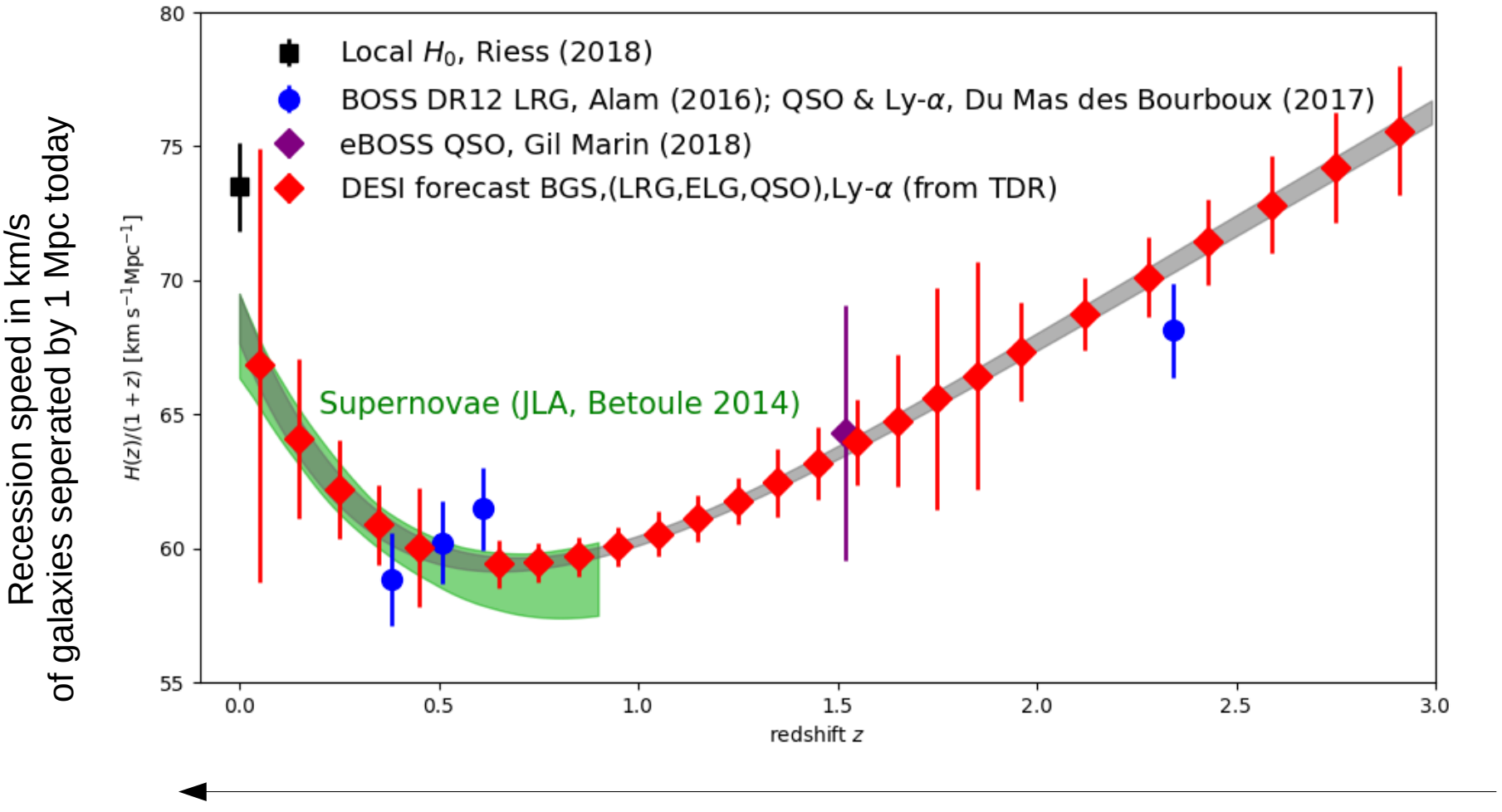
DESI science case: test of LCDM

Constraints on H(z)

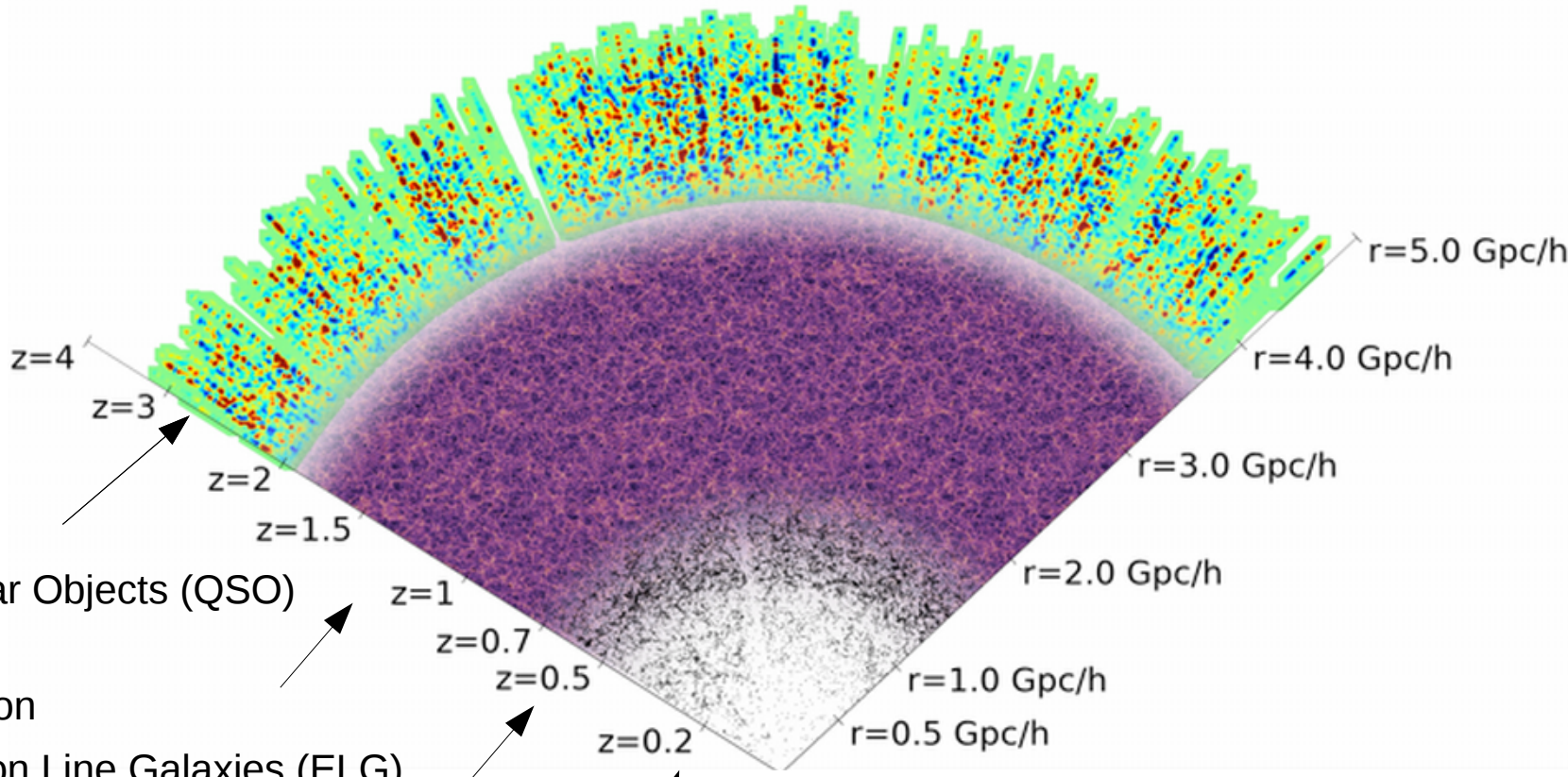


DESI science case: test of LCDM

Constraints on H(z)



DESI: redshift and spectra of more than 30 million galaxies and quasars



2.4 million
Quasi Stellar Objects (QSO)

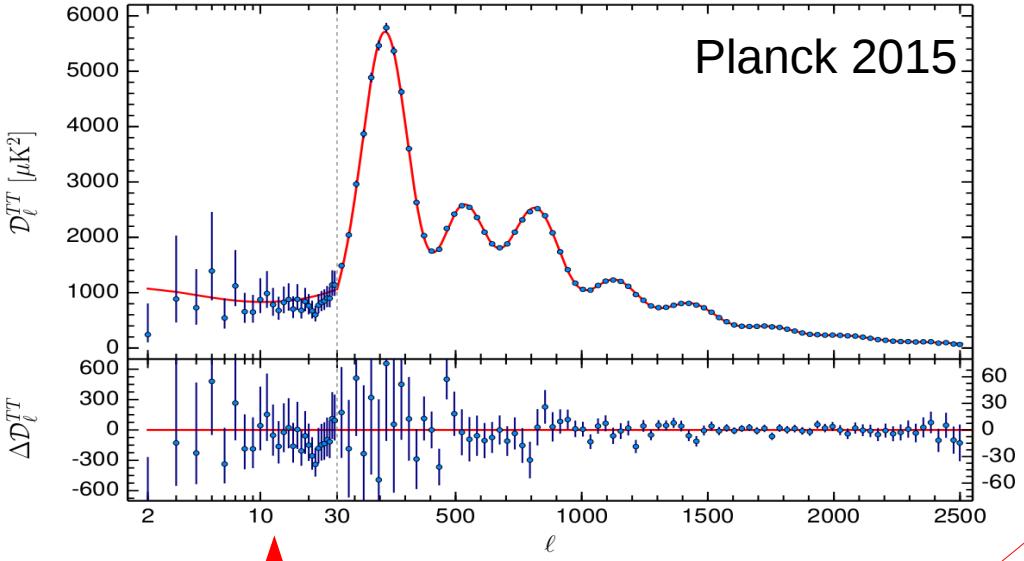
17 million
Emission Line Galaxies (ELG)

4 million
Luminous Red Galaxies (LRG)

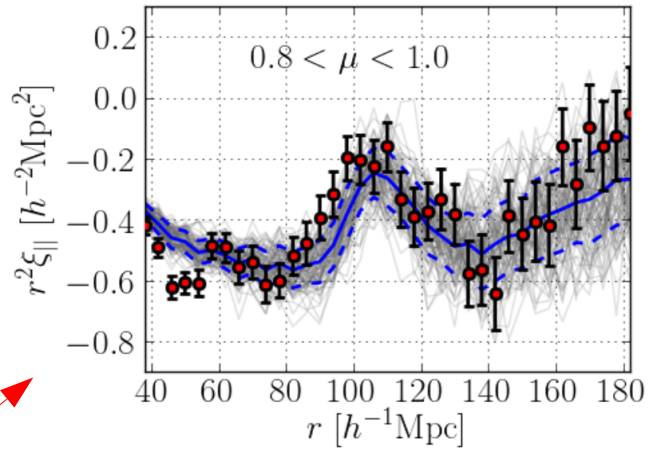
10 million
brightest galaxies

Baryon Acoustic Oscillations

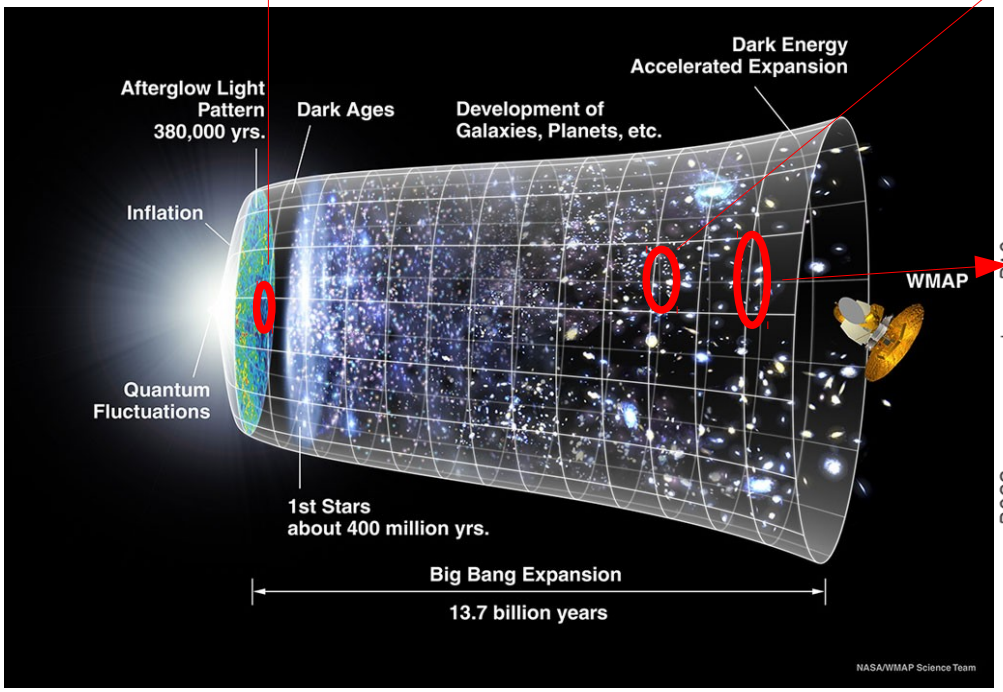
in the CMB at z~1000

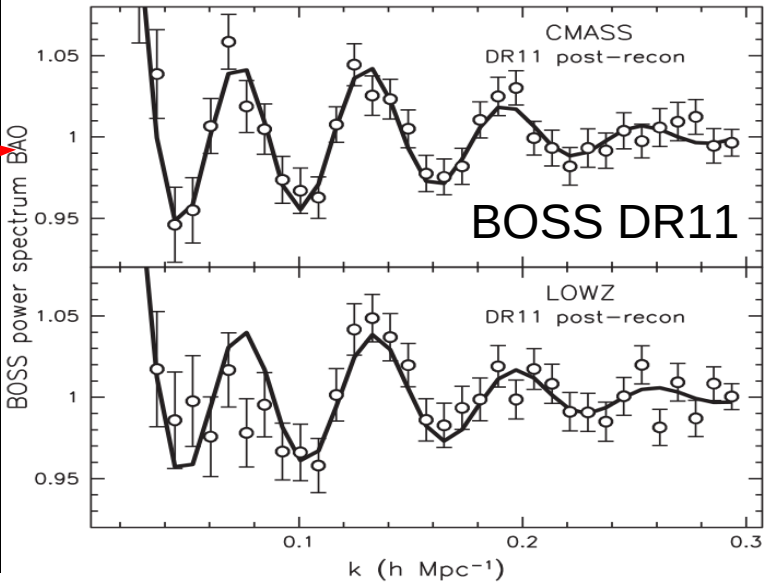


in Lyman-alpha forests at z ~ 2.3



in the galaxy density field

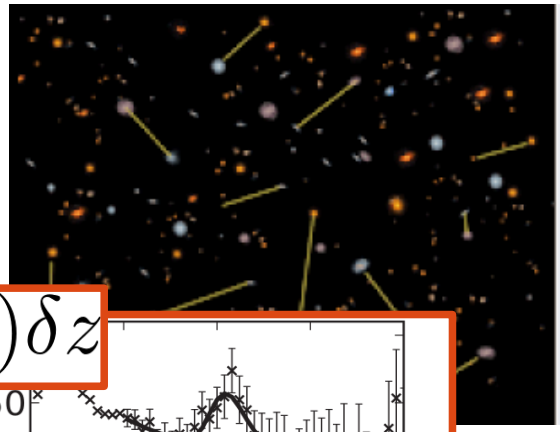


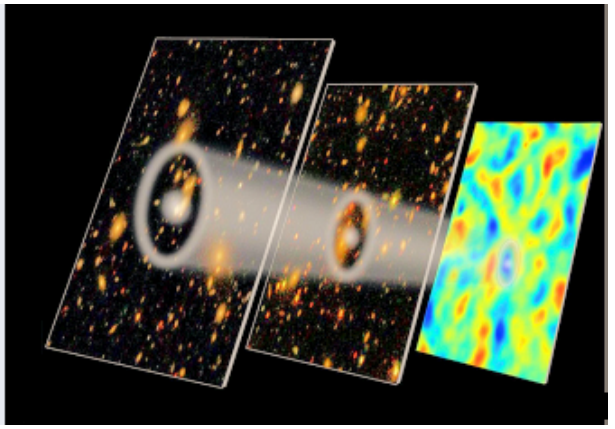


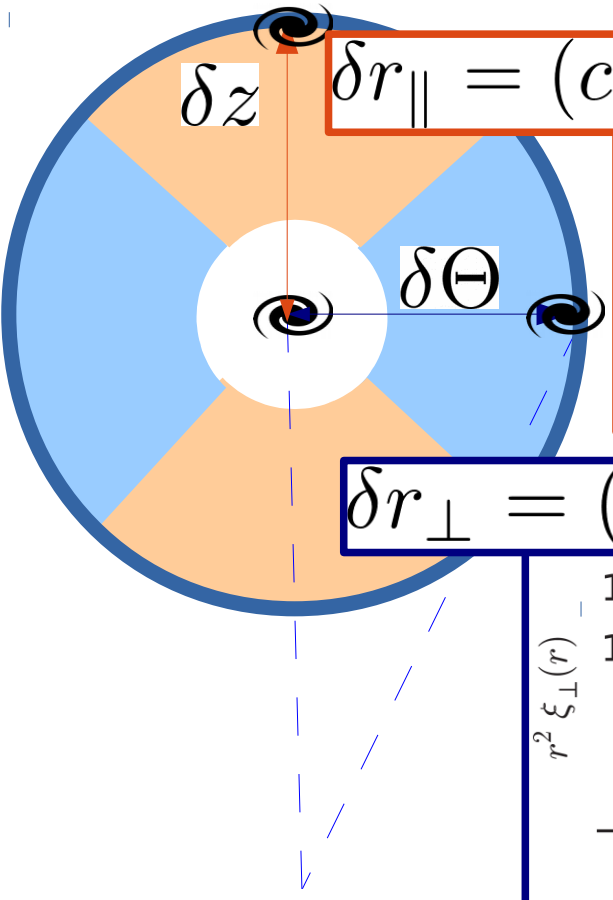
Baryon Acoustic Oscillations

r ~ 150 Mpc : cosmological probe

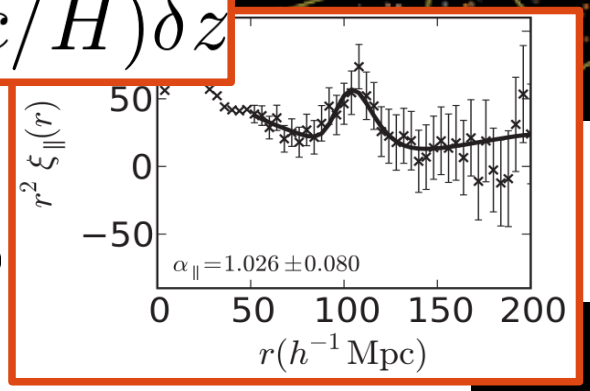
2 measurement
- angular (transverse)
- redshift (radial)



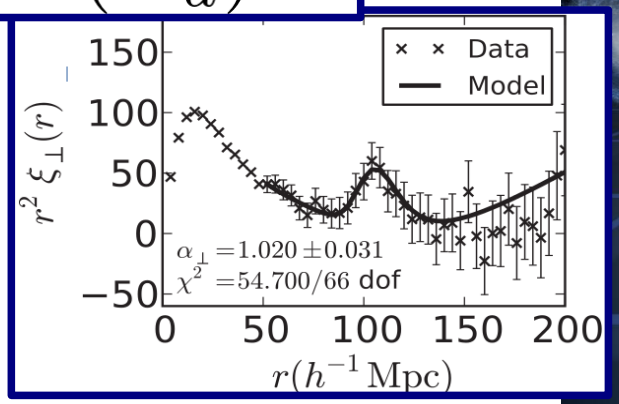


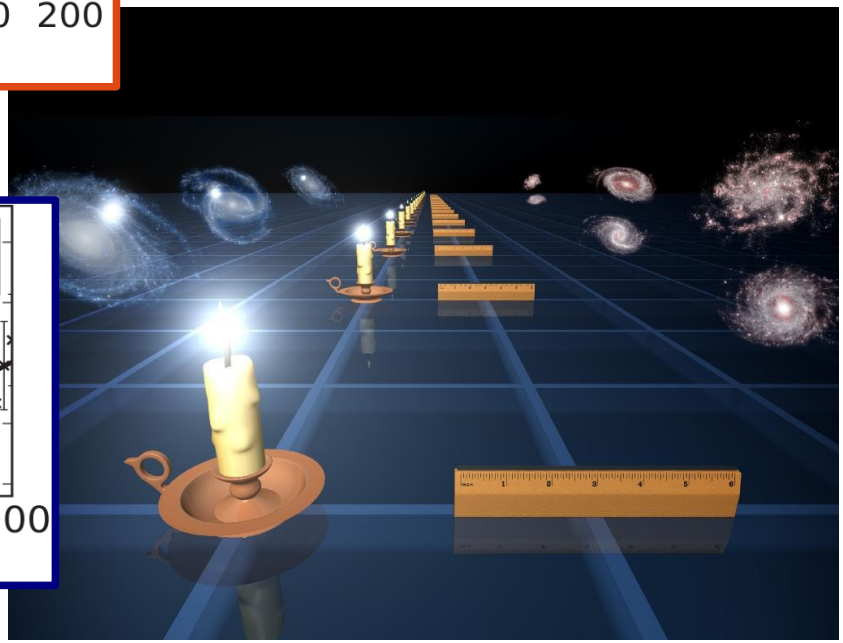


$$\delta r_{\parallel} = (c/H)\delta z$$



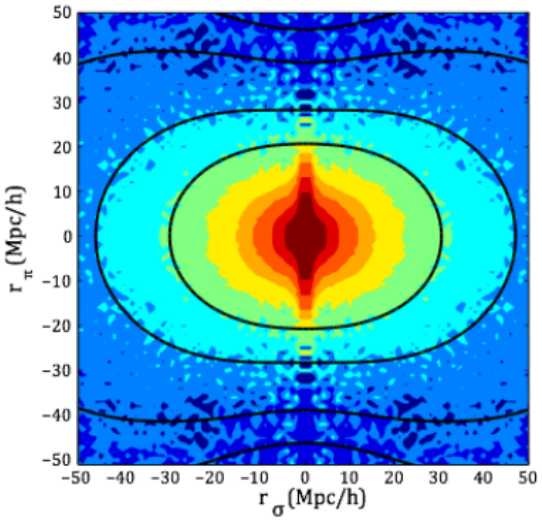
$$\delta r_{\perp} = (D_a)\delta\Theta$$



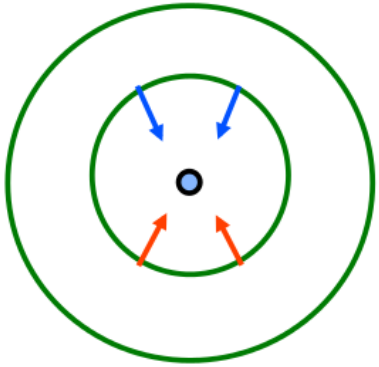


Beyond BAO

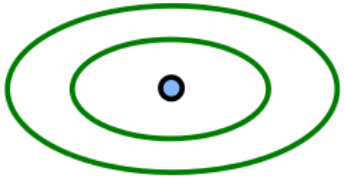
- There is significantly more information in the galaxy power spectrum than just the information from BAO
  - Growth rate
  - Neutrinos
  - Inflation



observed redshift space distortions from BOSS



"real" space



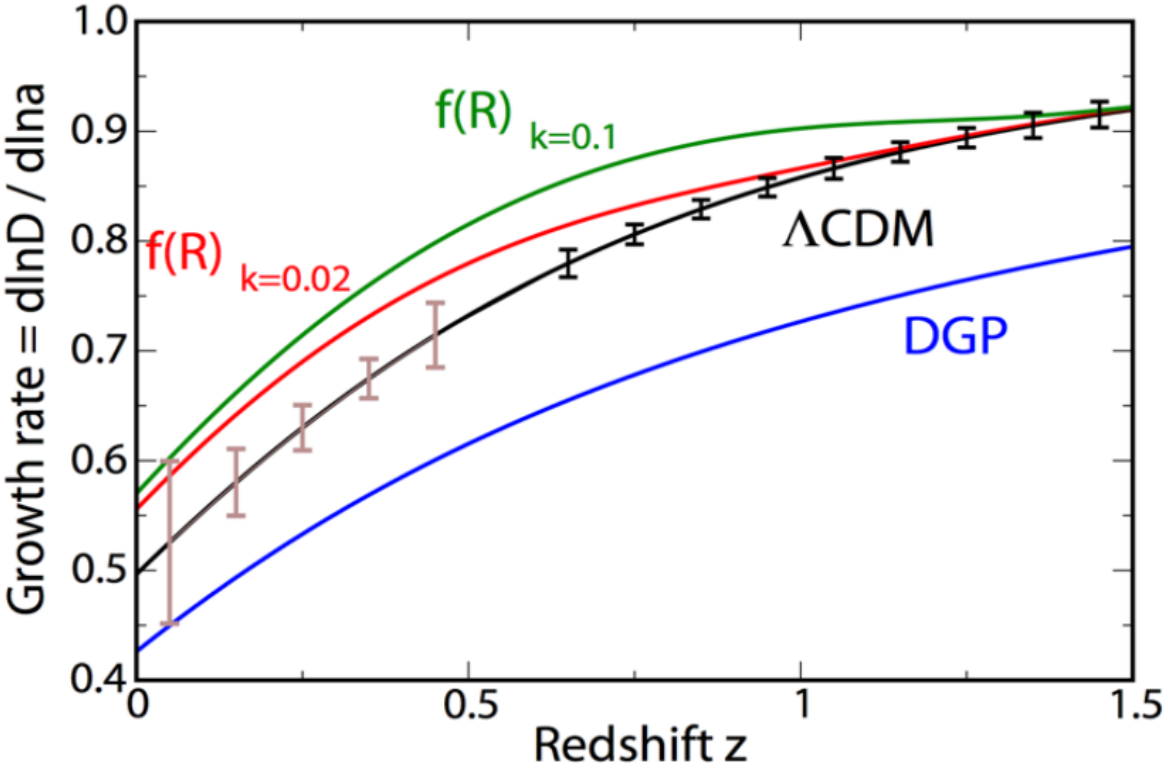
"redshift" space

- Anisotropy in the correlation function constrains fσ8, where f is the growth rate
- Produces a test of GR
- DESI will measure the growth rate <1% over 0.0 < z < 1.4

(slide from R. Weschler)

Growth Complements Distance

- Combining distance measurements with growth of structure measurements distinguishes between dark energy and modified gravity as the source of cosmic acceleration.



TDR Figure 2.12

(slide from R. Weschler)

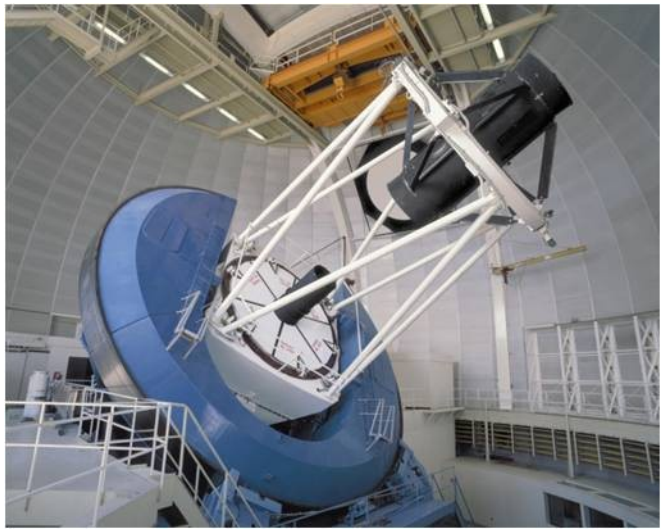
DESI instrument overview

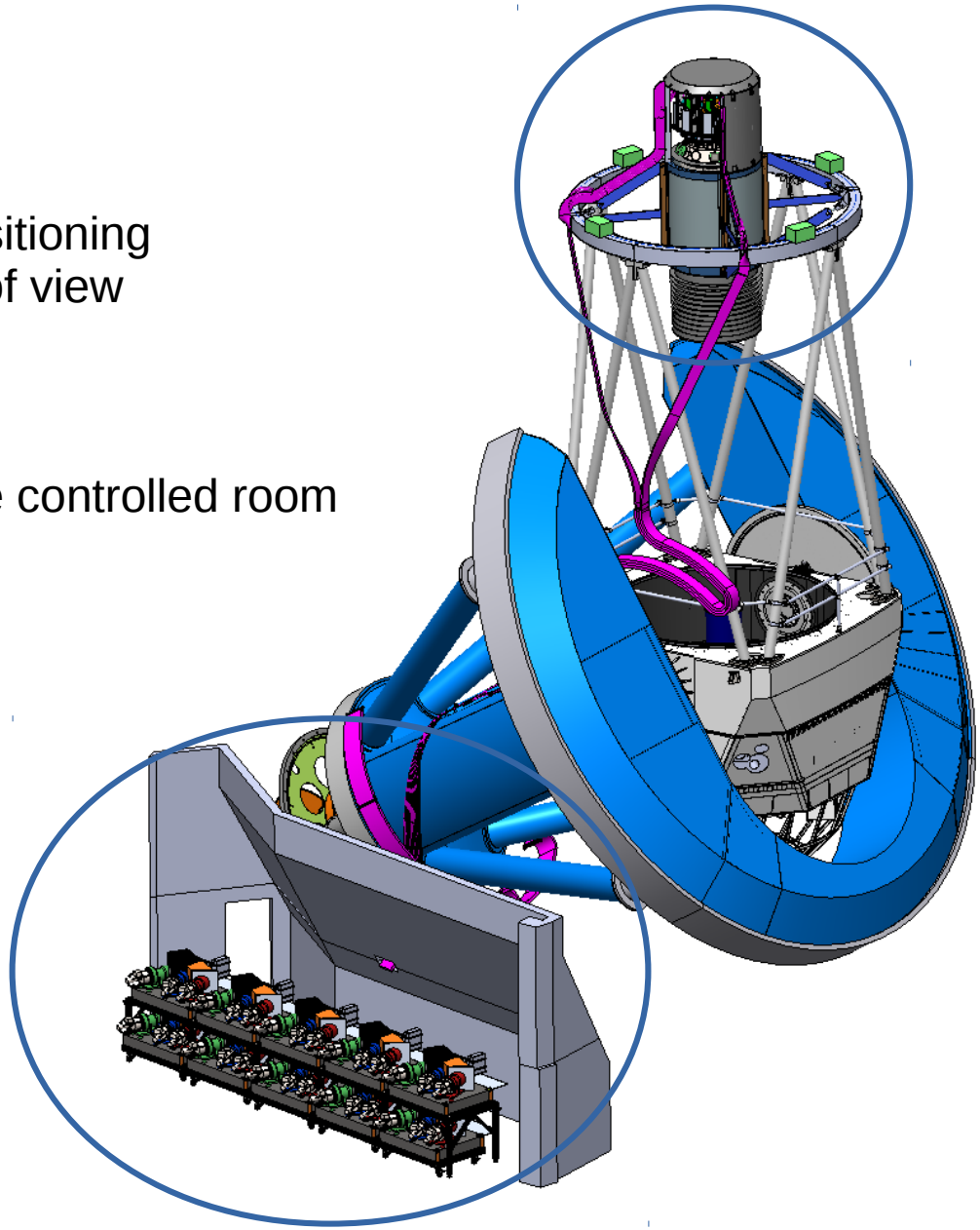
- on Mayall 3.8 m telescope

- new prime focus instrument
    - new corrector
    - 5000 fibers, with robotic positioning
    - on a 8 square degree field of view

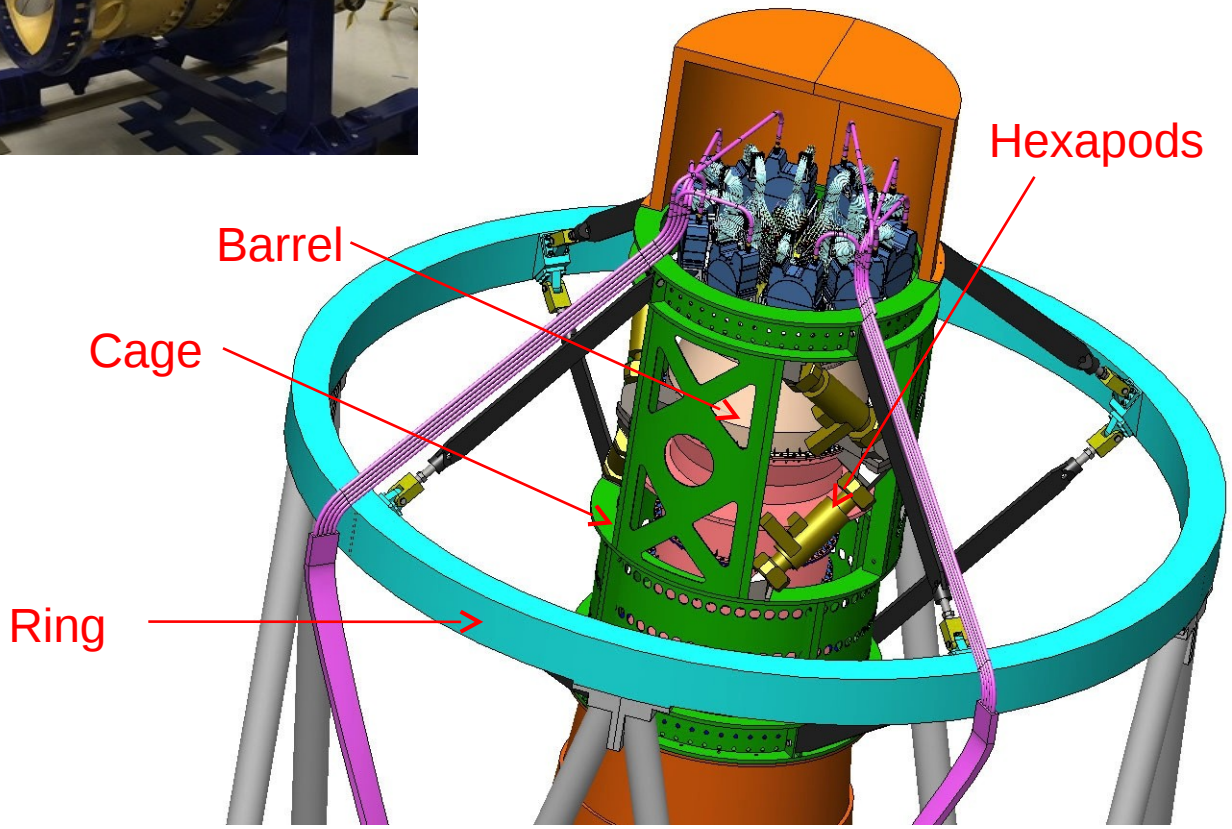
- 49m fiber cable

- 10 spectrographs in temperature controlled room



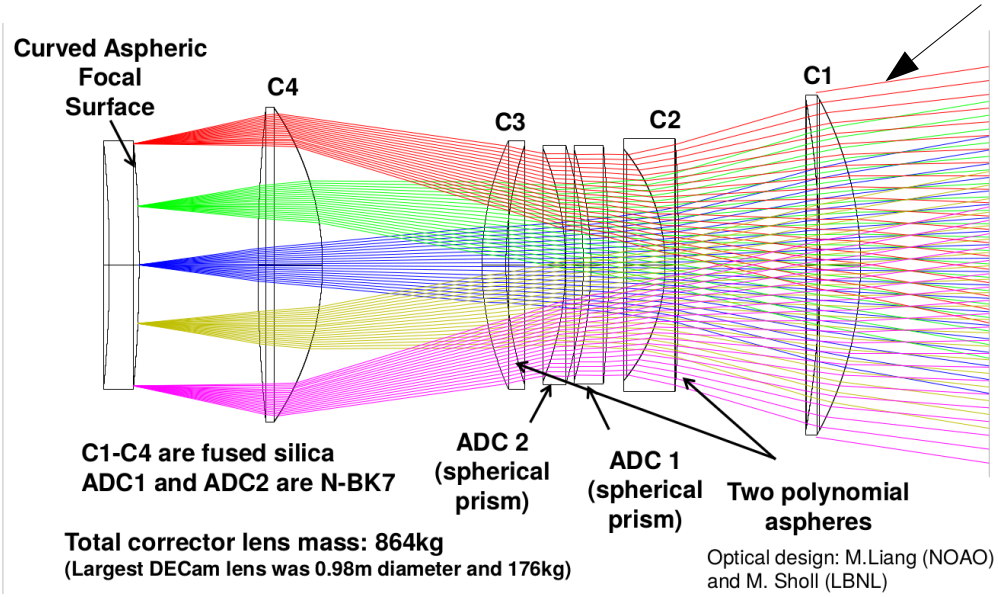


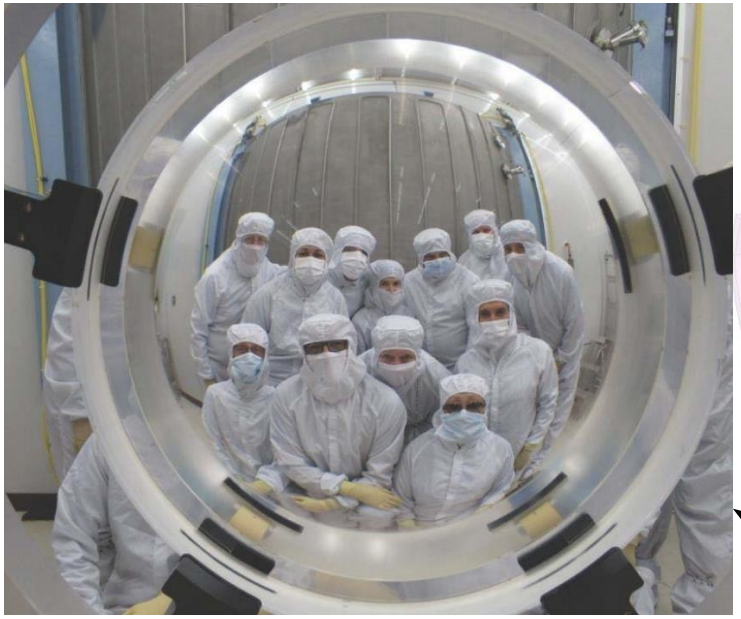
Barrel, Cage & Ring

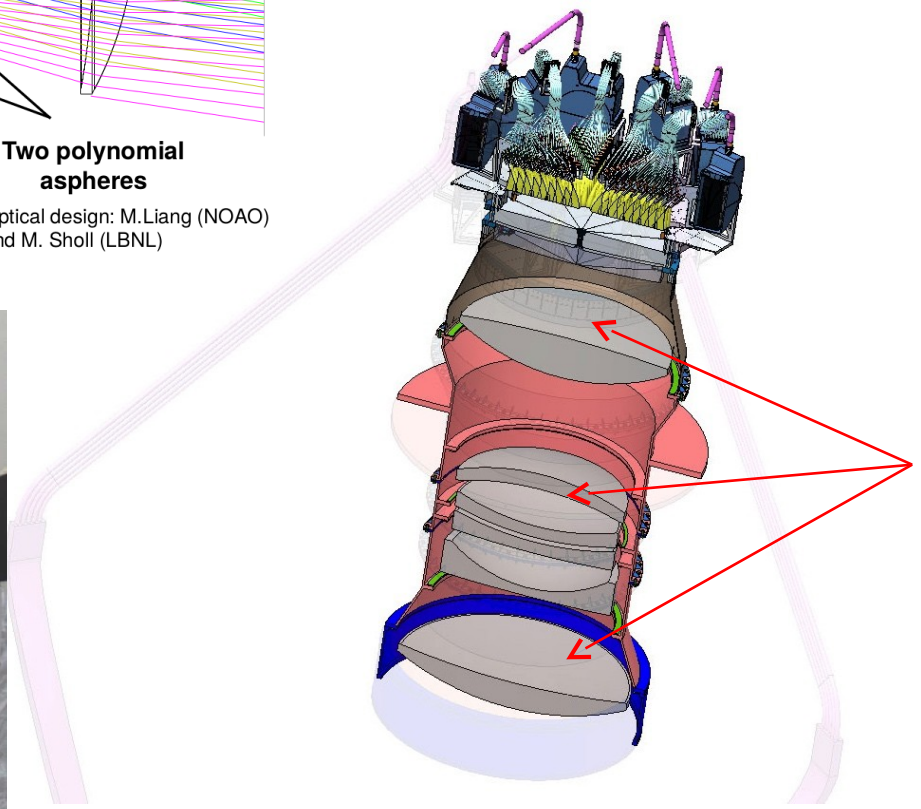


DESI Corrector

C1: 1.1m diameter

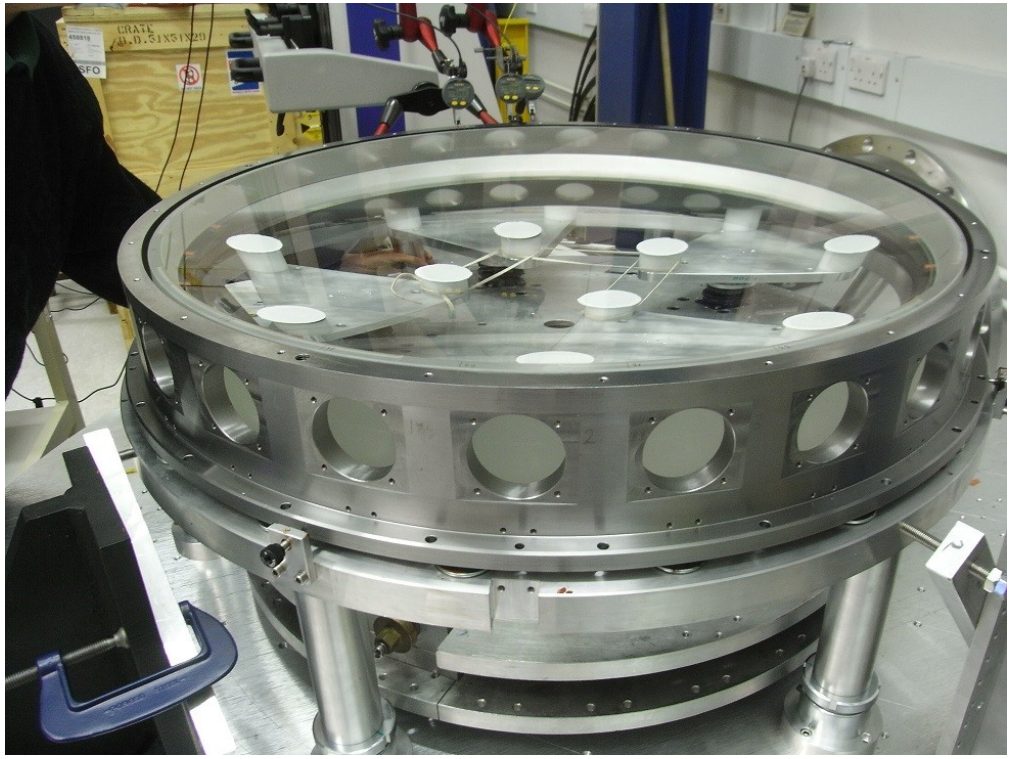




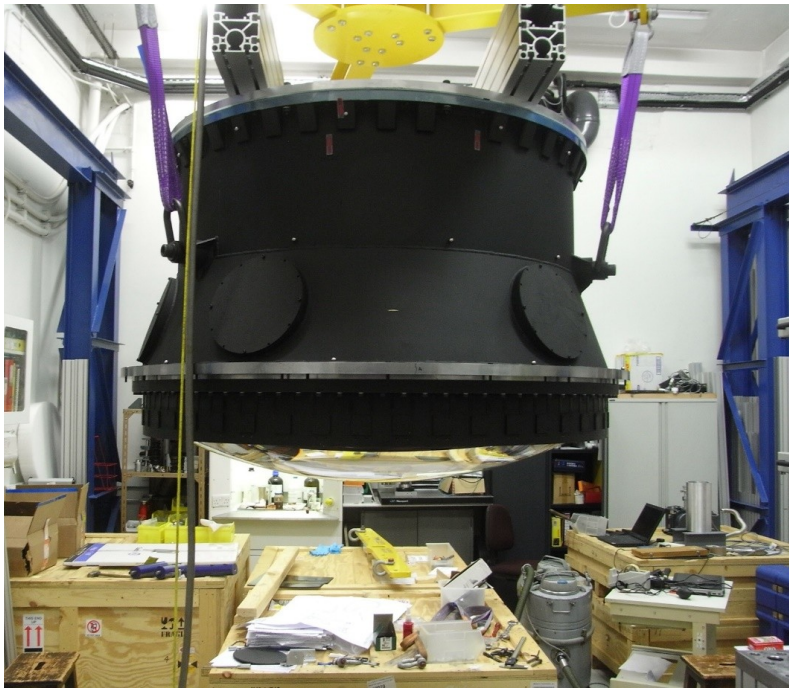


C2 polishing took 3 years (Sept 2014 – Sept 2017)

Lenses at UCL for integration



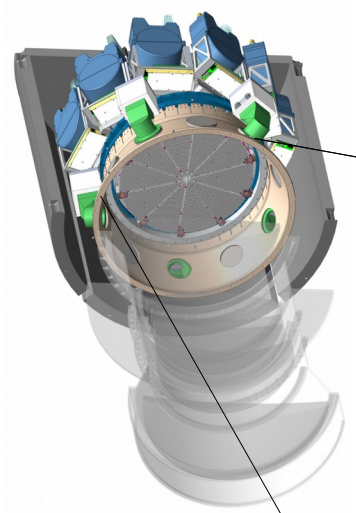
ADC1 lens being integrated last week to its cell at UCL



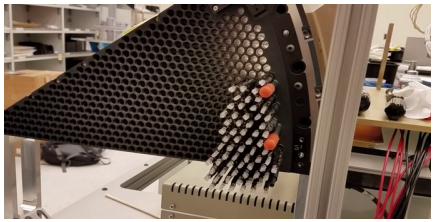
C1 integrated into the barrel

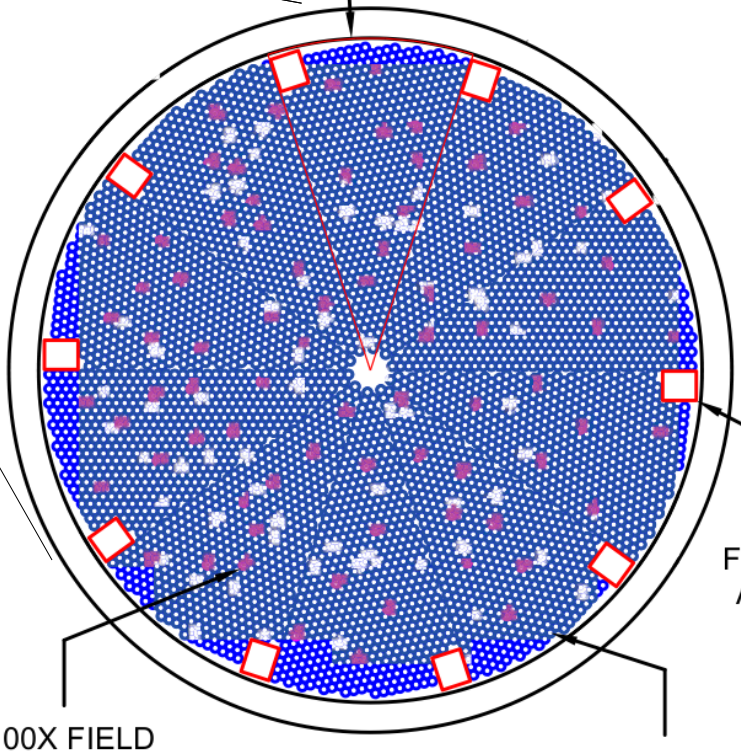
Corrector expected to be ready for installation in July 2018

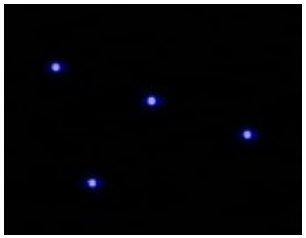
Focal Plane System



10X FOCAL PLATE PETAL:
ONE PETAL+ ONE FIBER
CABLE FOR EACH
SPECTROGRAPH



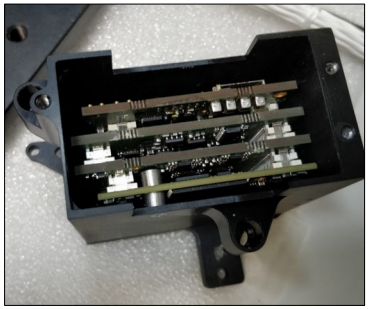


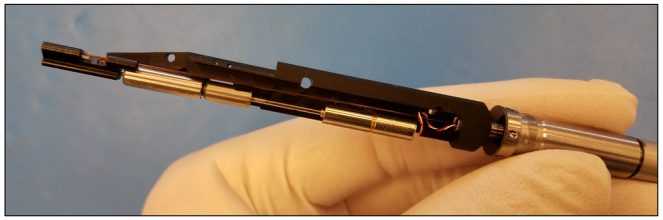


100X FIELD
ILLUMINATED
FIDUCIAL

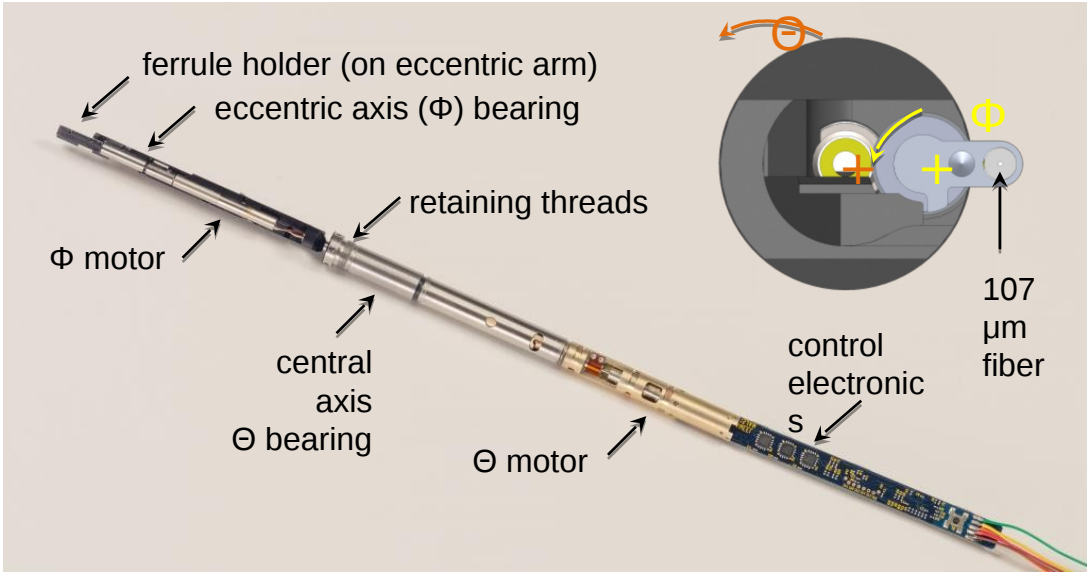
5000X
FIBER POSITIONER

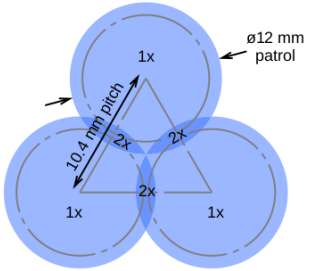
10X GUIDE
FOCUS ALIGNMENT
ASSEMBLY, EACH
WITH 2 GFA
ILLUMINATED
FIDUCIALS



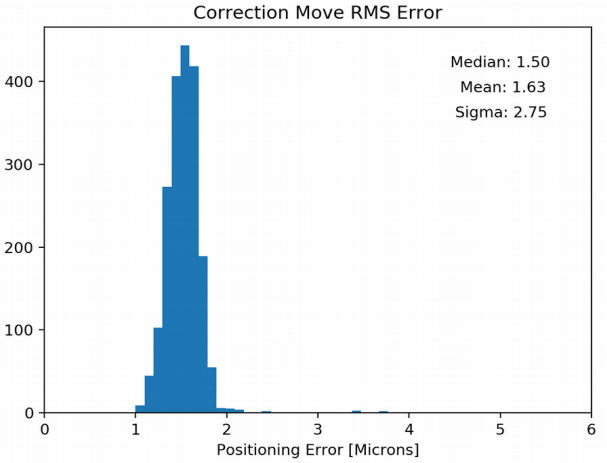


5000 fiber positioners



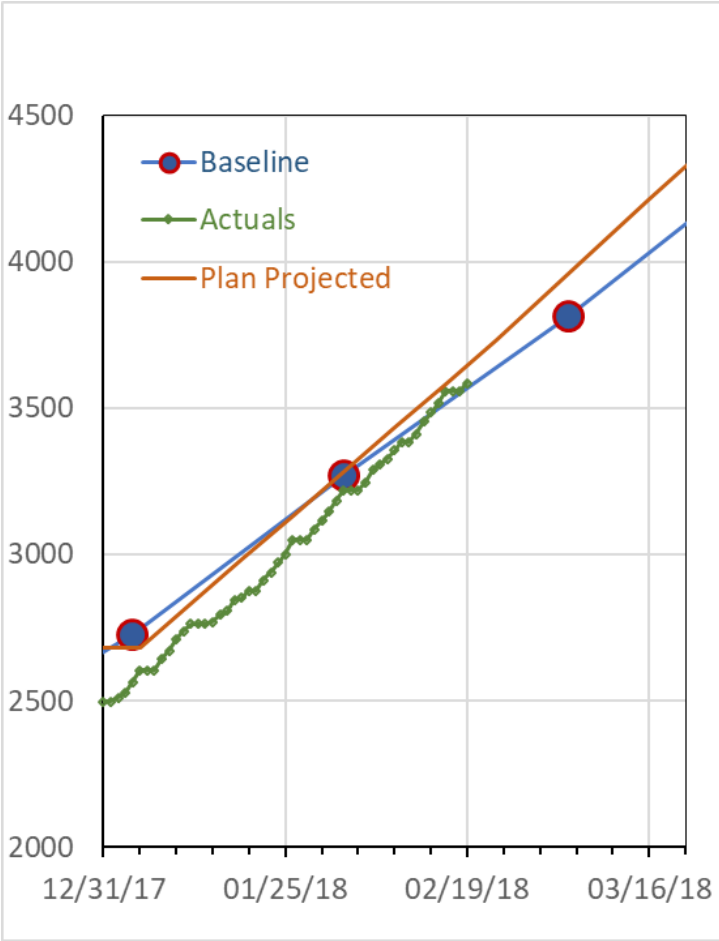


EXACT COVERAGE
R1 = R2 = 3 mm

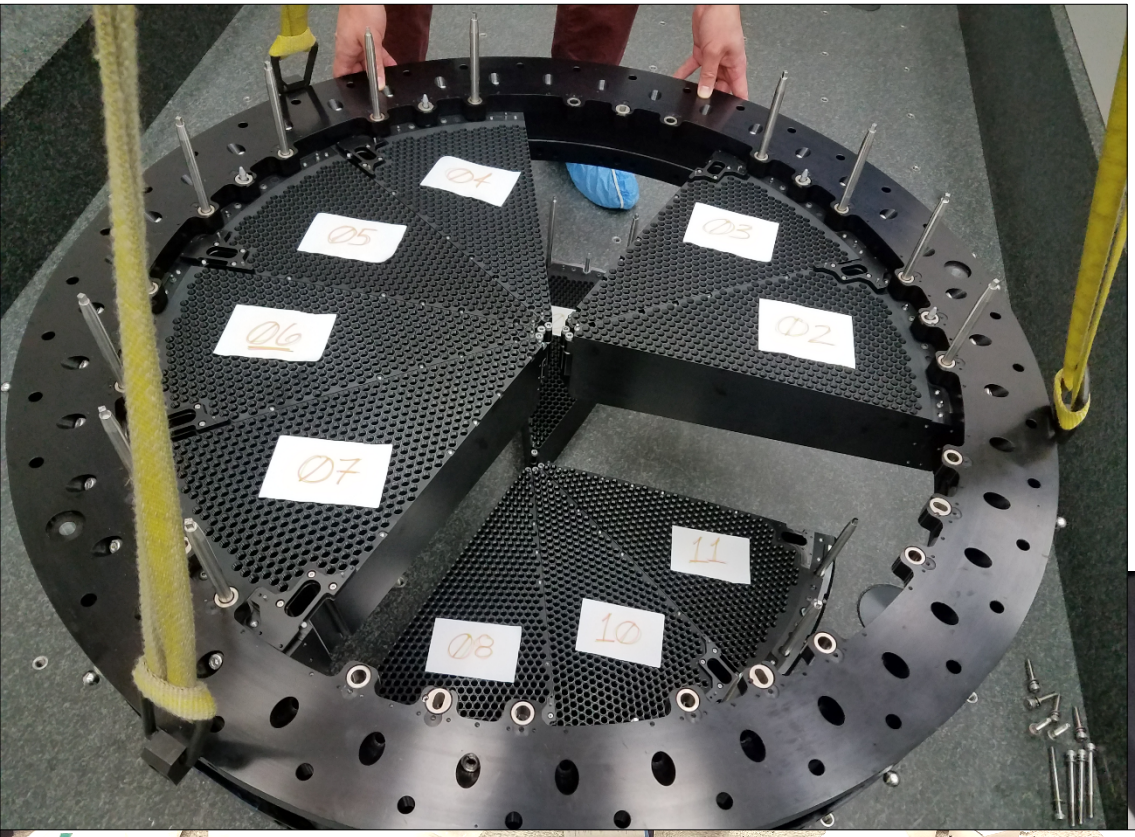


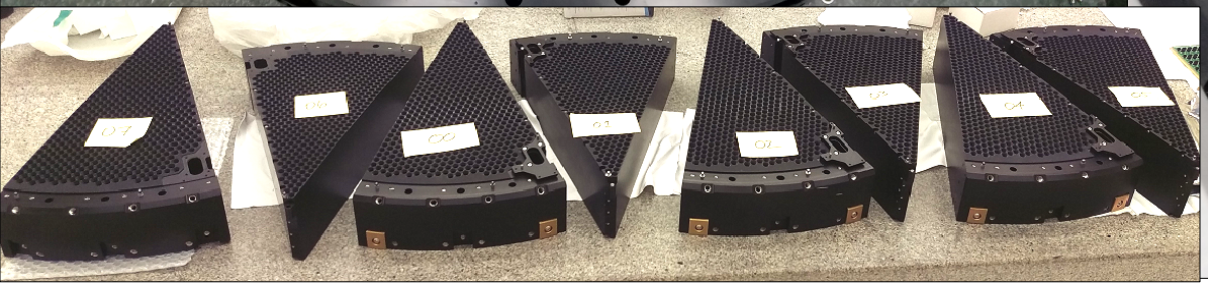
Precision of positioning 1.5 um, 0.02 arcsec
(fiber diameter is 107 um)

Production status

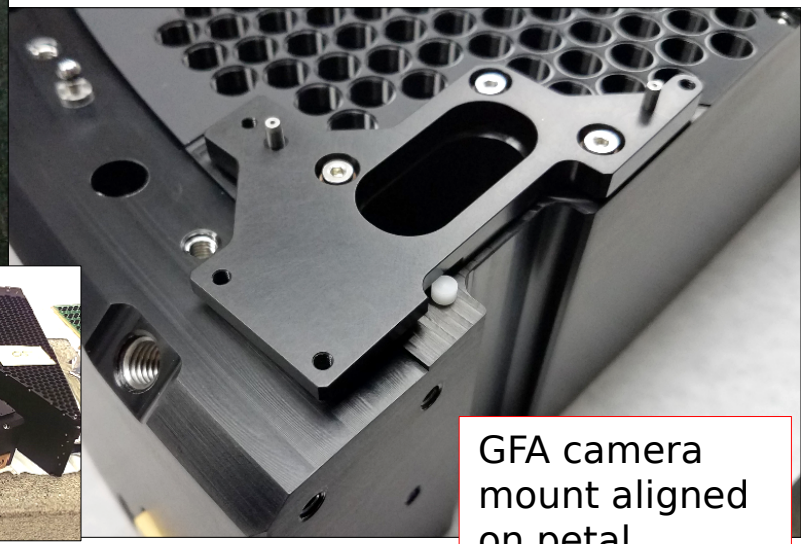


Petals have been aligned in integration ring





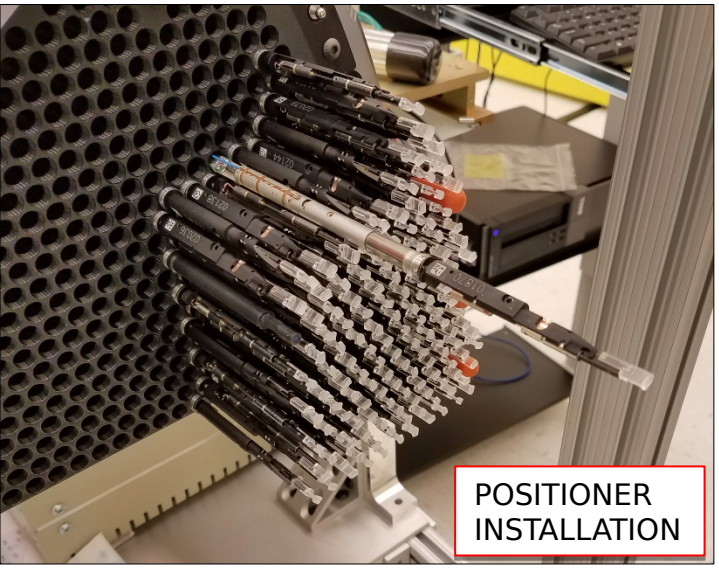
- Completes L2 Milestone: Focal Plate Structure Ready for Integration
- Achieved alignment error of 12 um RMS
- The petals fit together beautifully, no issues

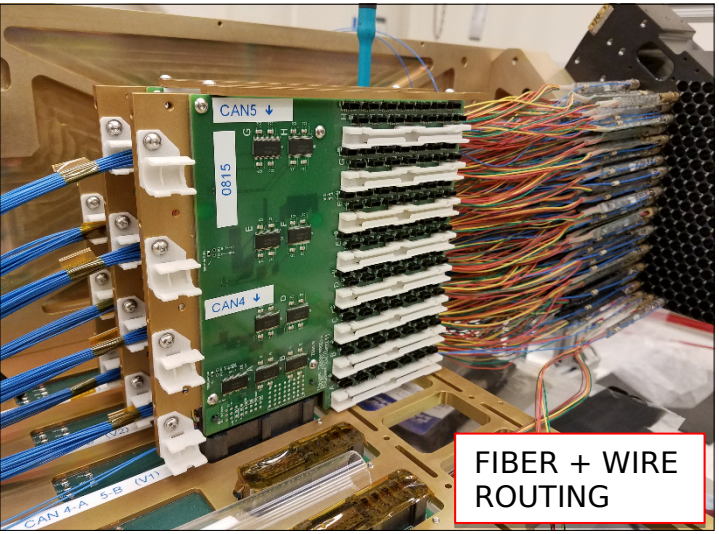


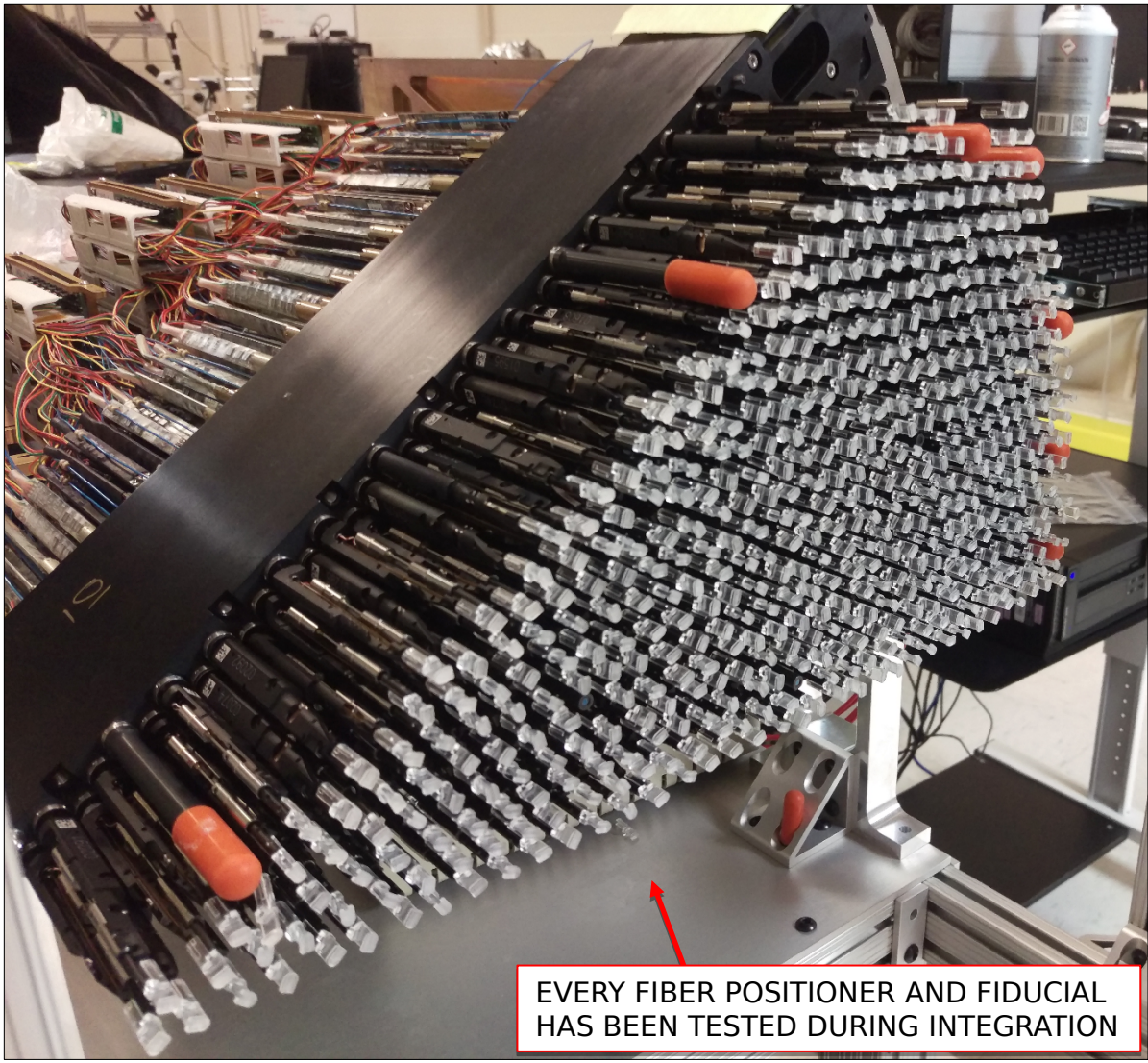
GFA camera mount aligned on petal

slide from J. Silber

19 Jan 2018: First production petal loaded with positioners and fiducials, and handed off for splicing!





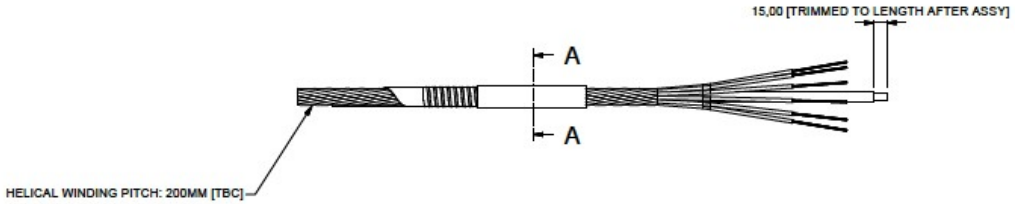


slide from J. Silber

10 x 49-m fiber cables (500 fibers each)
connecting one petal to a fiber slit-head

Cable cross-section

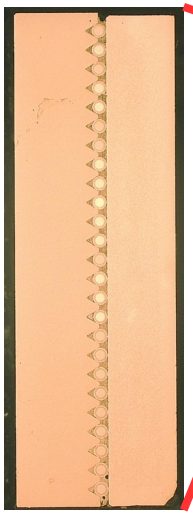
Cable winding

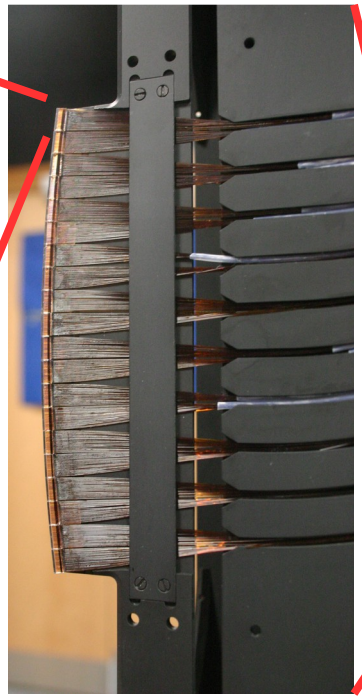


Miniflex insertion

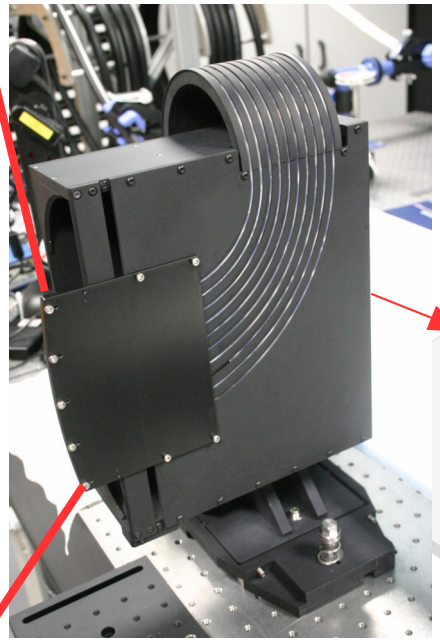
Miniflex insertion

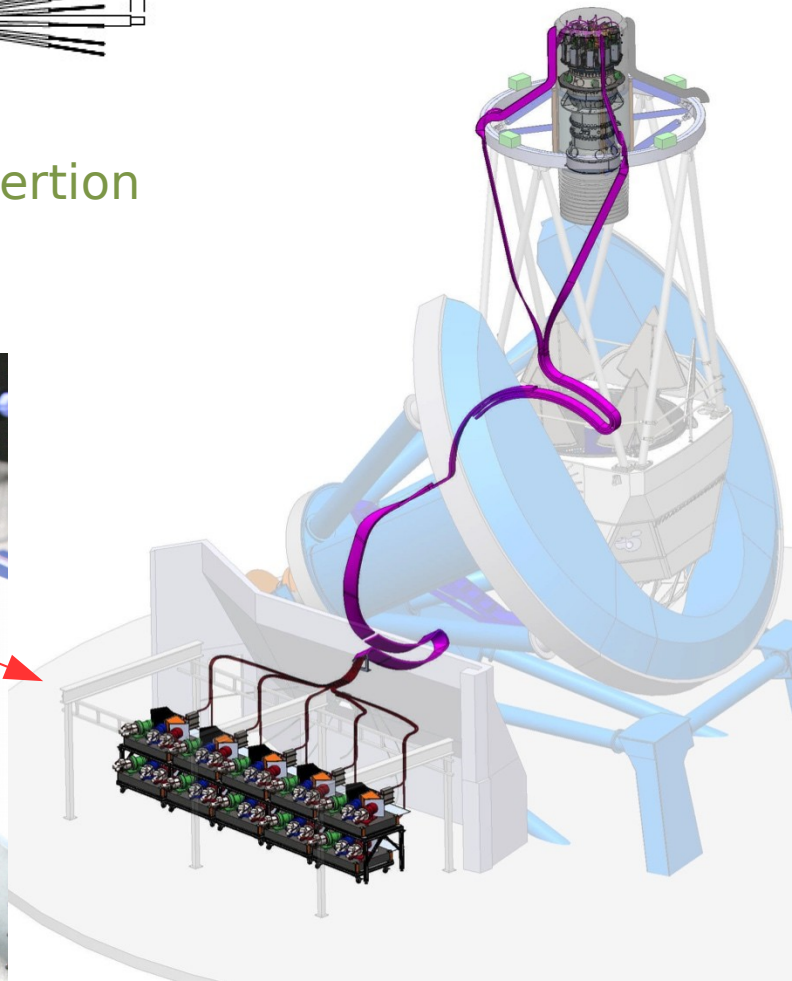
20 blocks of 25 fibers





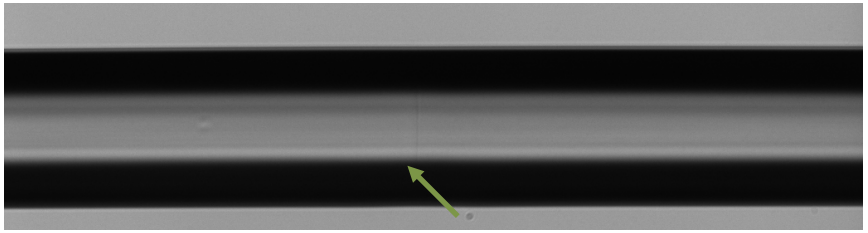
1 fiber slit-head



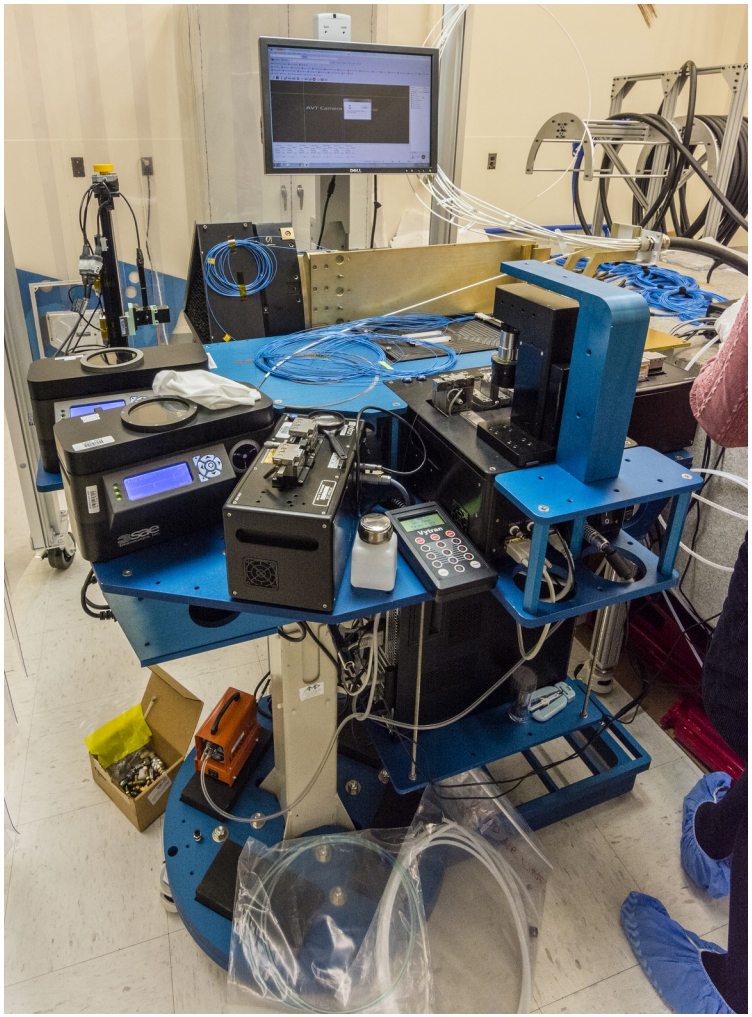


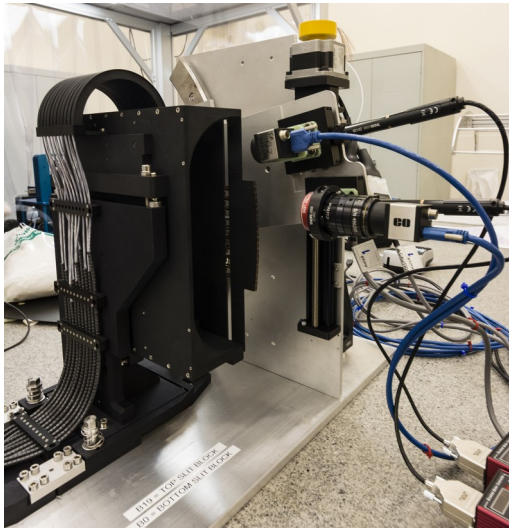
Petal and fiber cable is being integrated at LBNL (building 77)

Need to splice 5000 fibers!



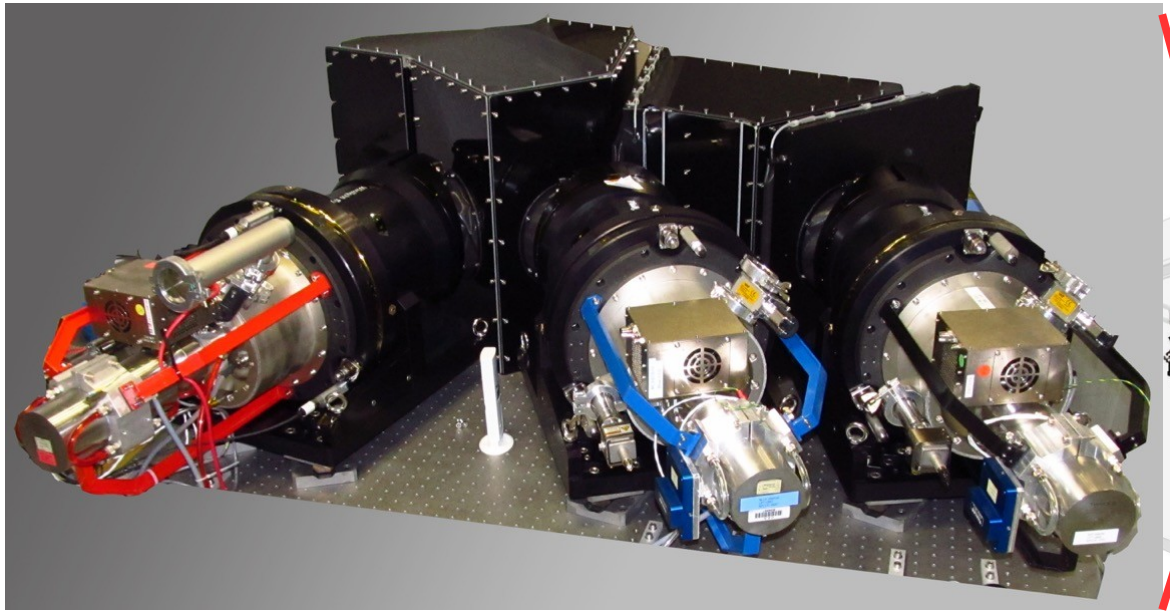
Splice is here (honestly!)

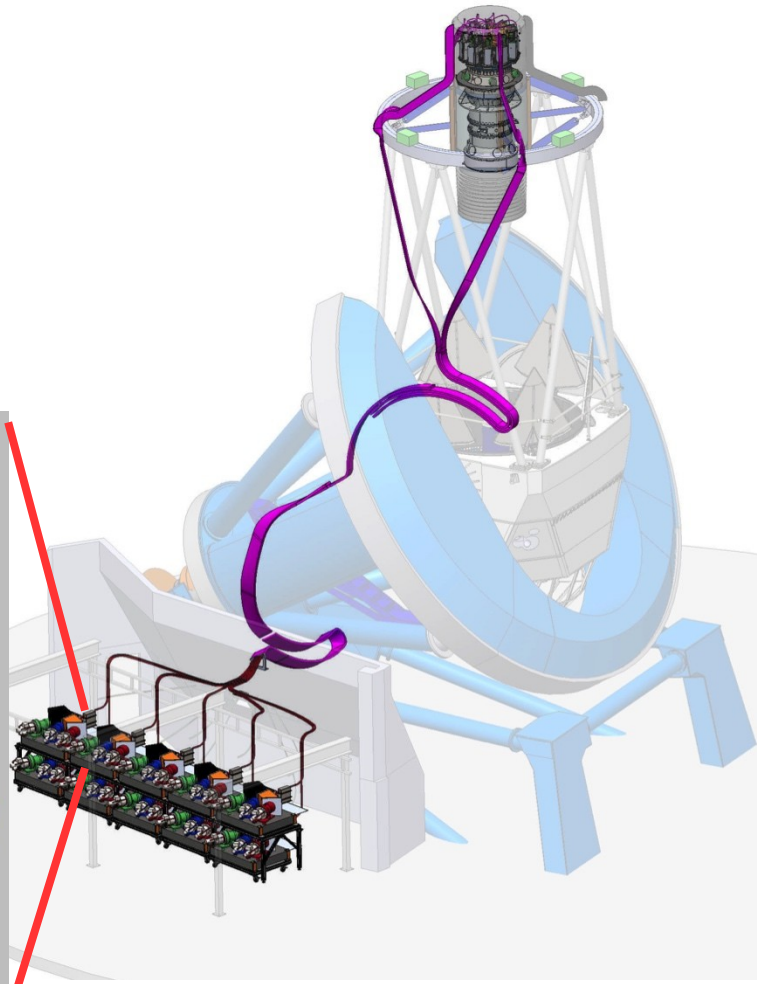


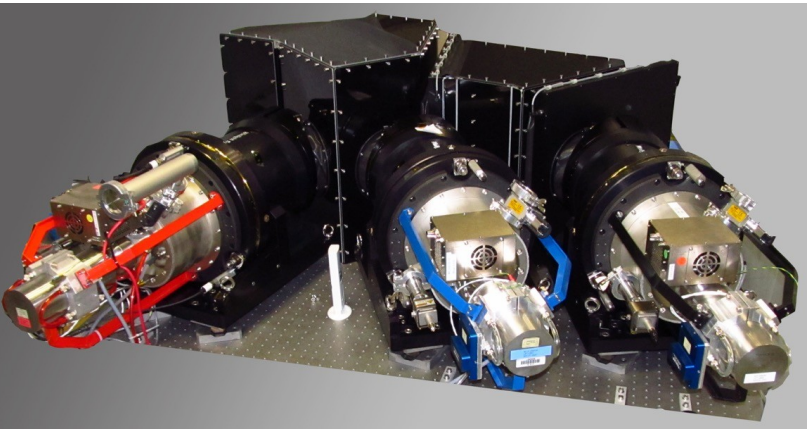


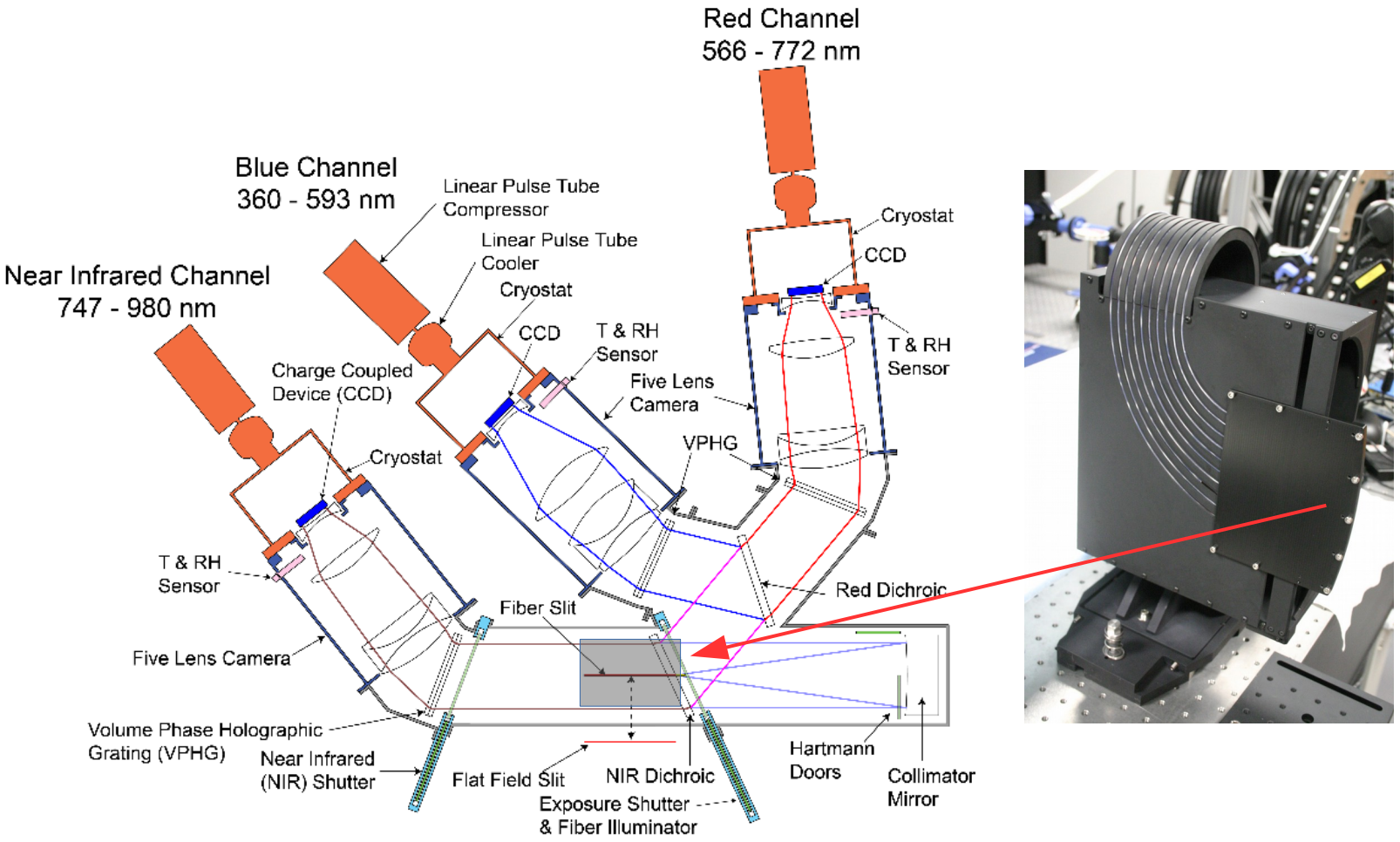
DESI spectrographs

- 10 spectrographs
- in Coude room, in a temperature controlled shelter

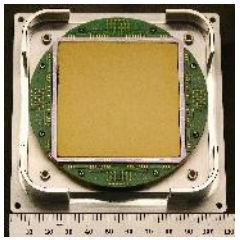






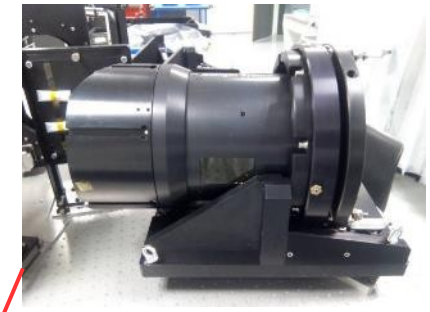

Red Channel
566 - 772 nm
Blue Channel
360 - 593 nm
Near Infrared Channel
747 - 980 nm
Linear Pulse Tube Compressor
Linear Pulse Tube Cooler
Cryostat
CCD
T & RH Sensor
Charge Coupled Device (CCD)
Five Lens Camera
VPHG
Red Dichroic
Fiber Slit
Volume Phase Holographic Grating (VPHG)
Near Infrared (NIR) Shutter
Flat Field Slit
NIR Dichroic
Exposure Shutter & Fiber Illuminator
Hartmann Doors
Collimator Mirror

Blue channel
ITL CCD

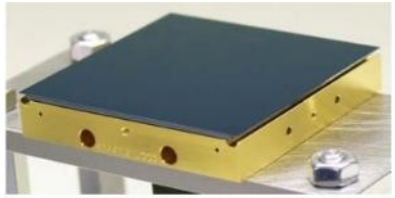


Red cryostat

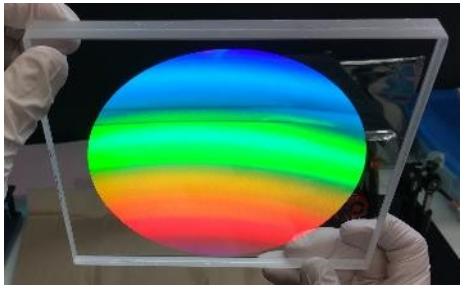
EM Red Camera (WL)

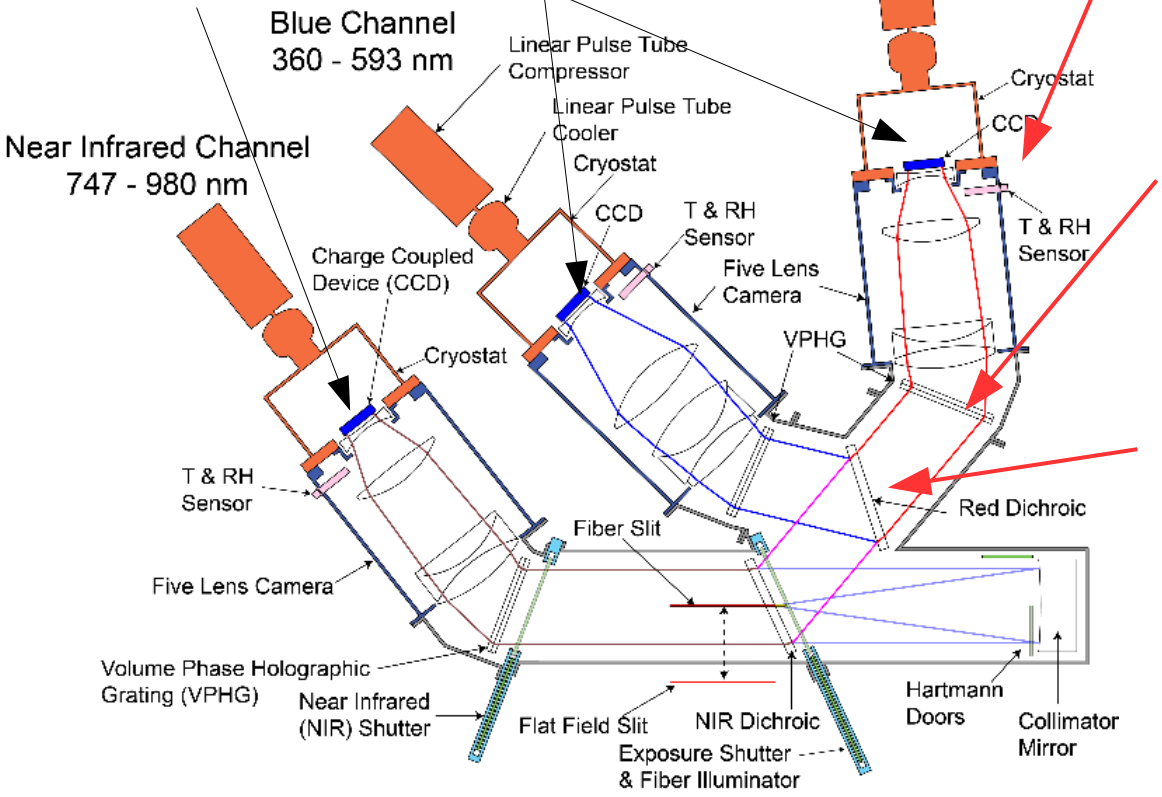


Red and NIR channels :
LBNL 250um CCDs



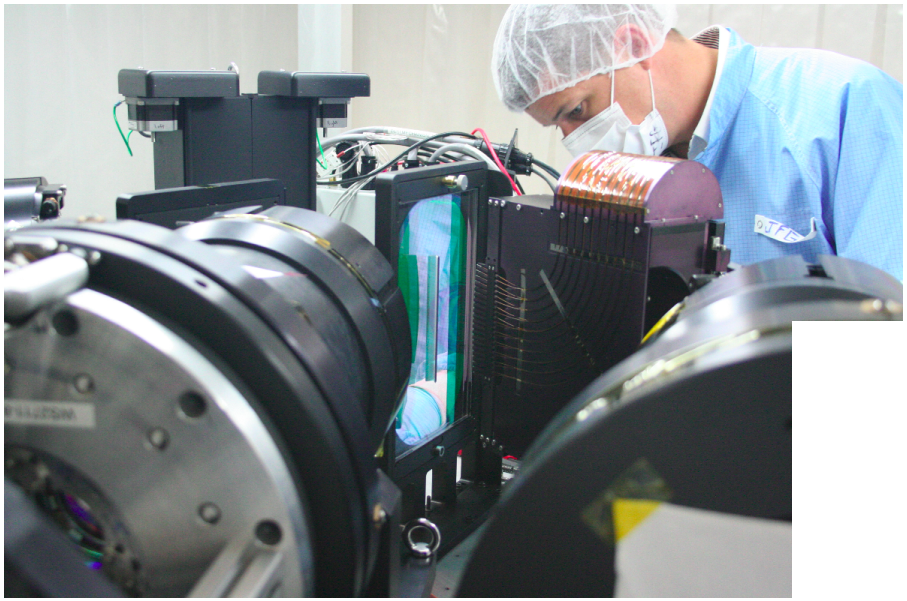
Red production VPH Grating

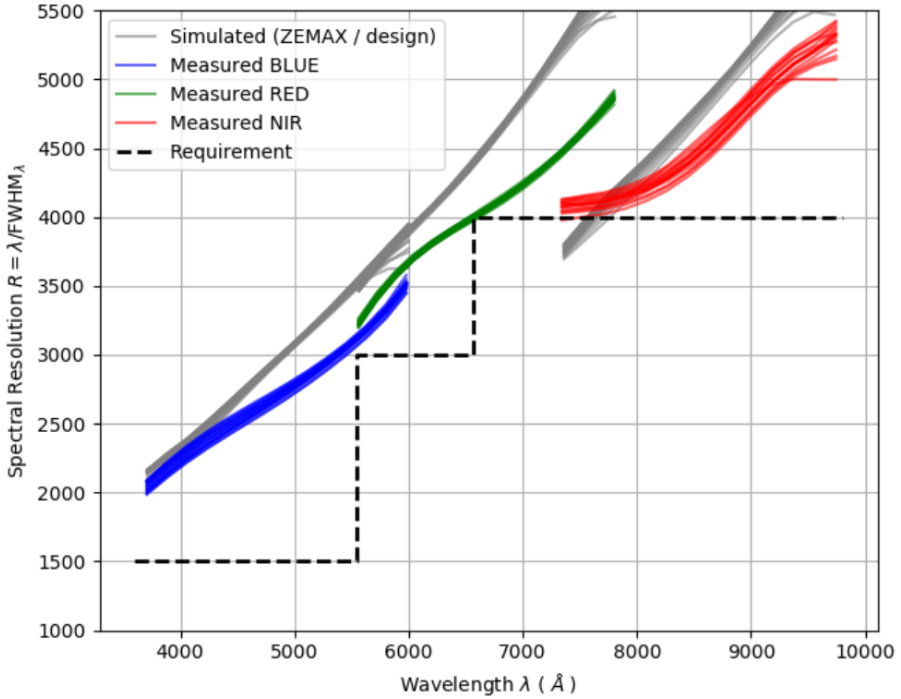




Red Pass Dichroic

Engineering Model Spectrograph was tested in France in 2016-2017





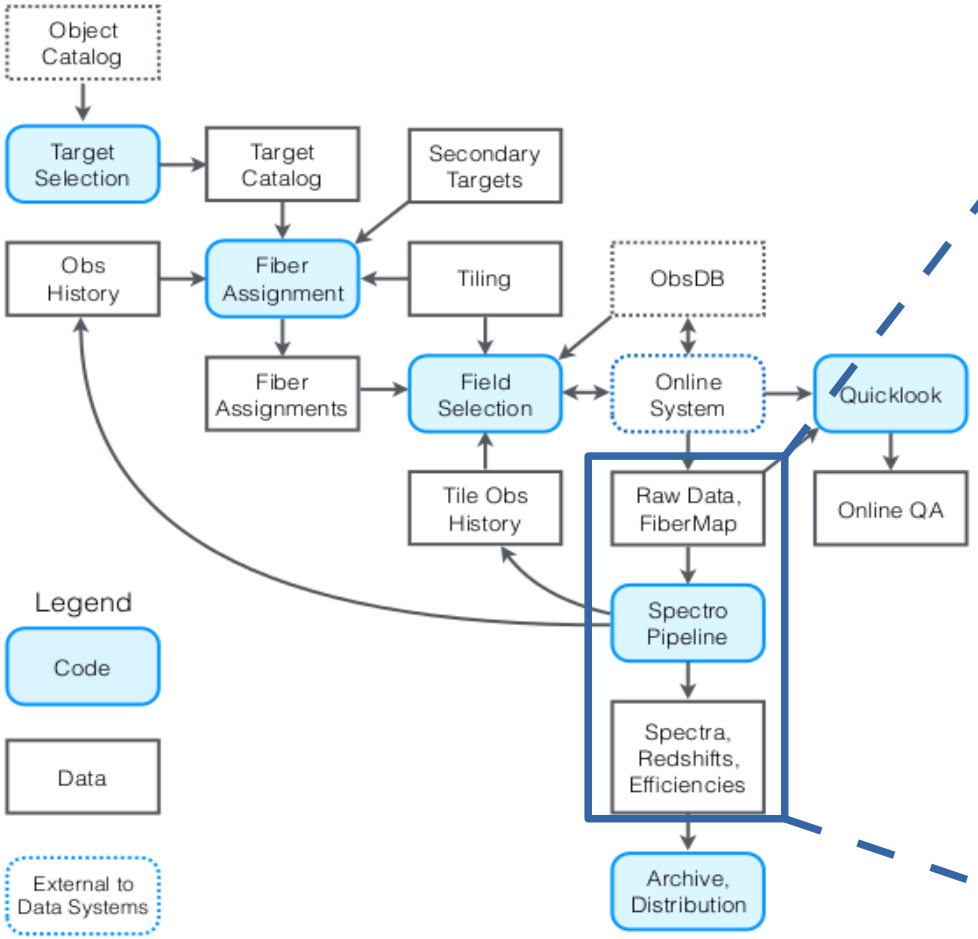
10 Science Model with be tested starting … this week

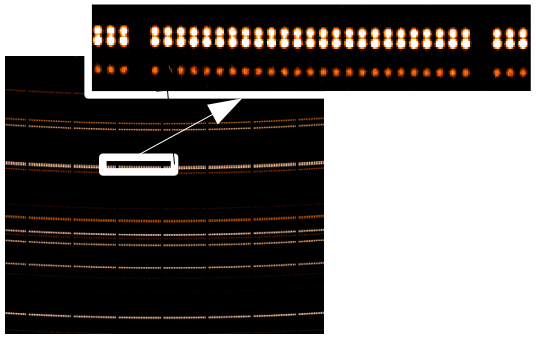
At Kitt Peak, work has started 2 weeks ago to dismount the upper end of the Mayall telescope.

Data systems (the software)

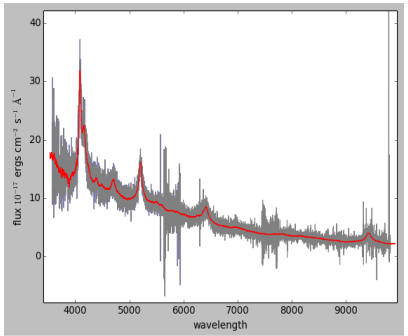
A relatively large data set
10,000 tiles to cover 14,000 deg2 in 4 passes (fov is 7 deg2)
> 300,000 CCD images of 4000x4000 pixels (without calibration)

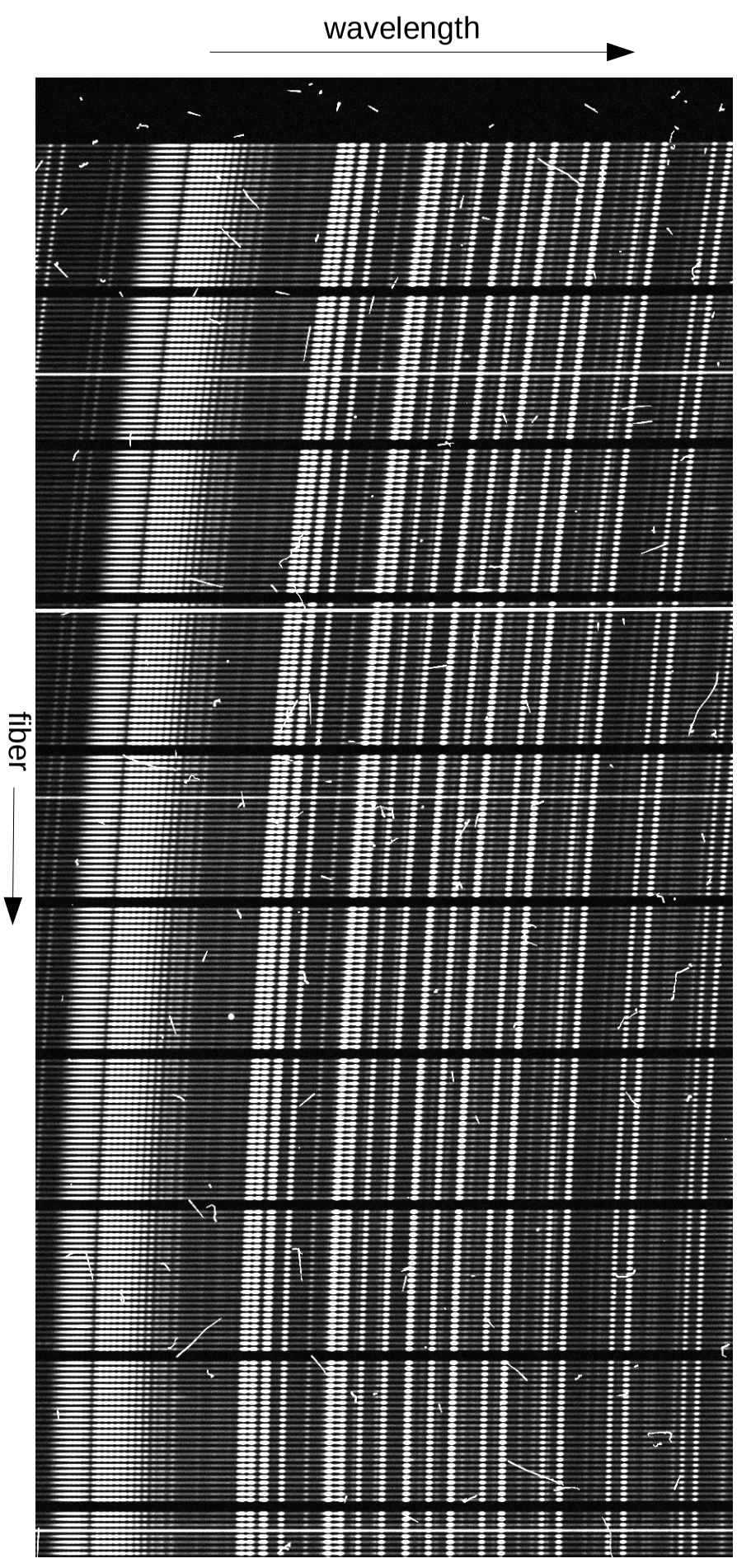
A complex data flow

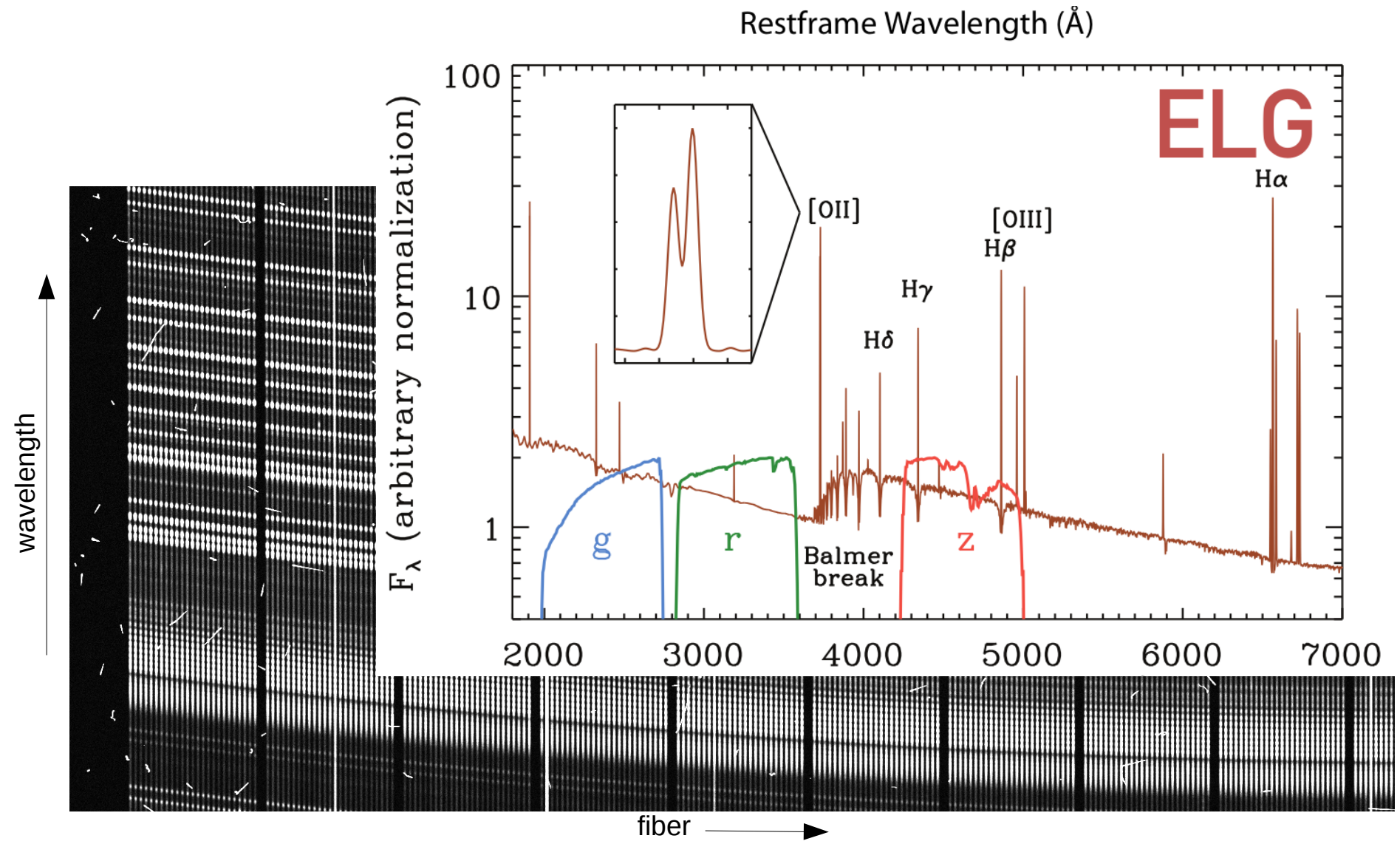


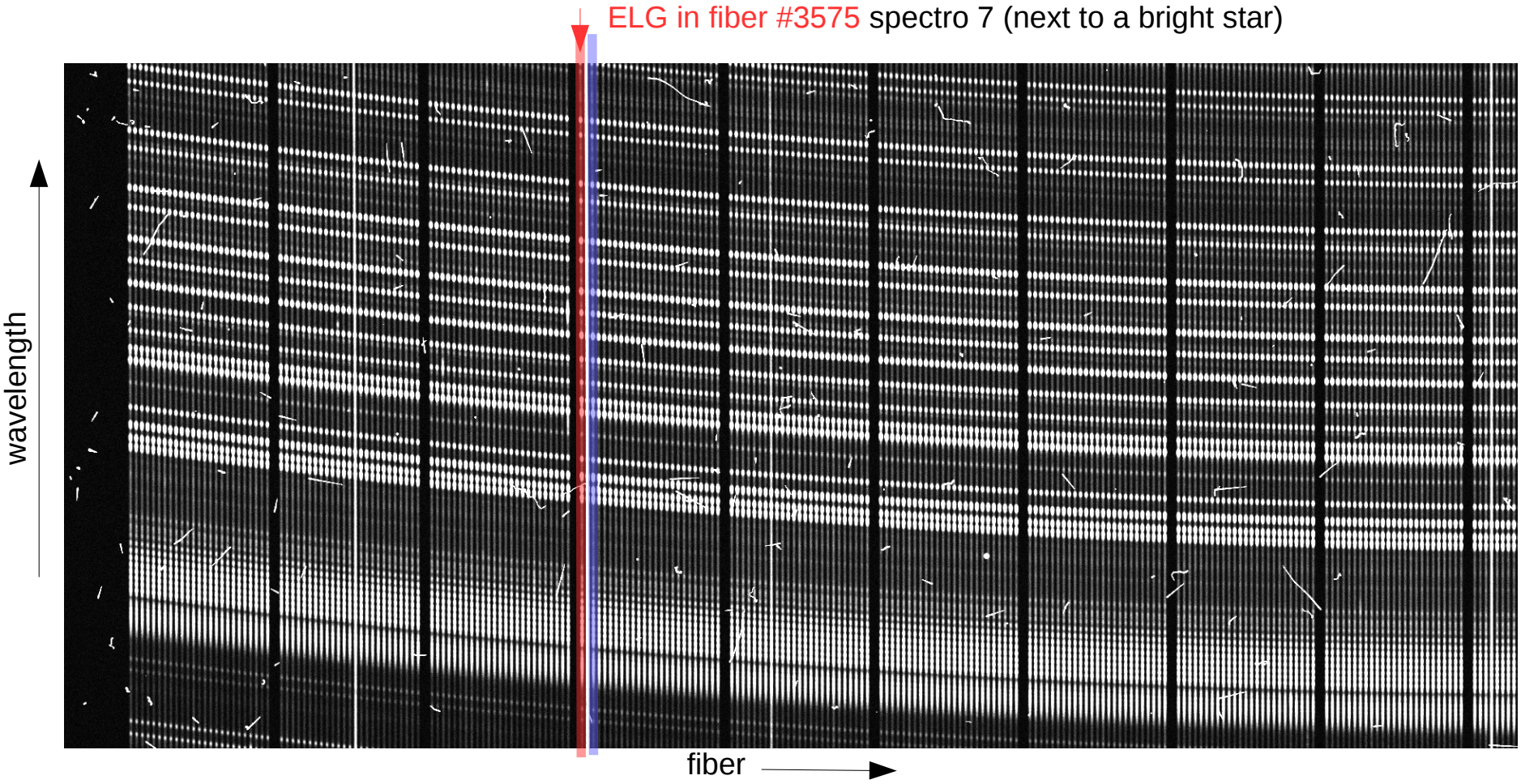


Spectroscopic Pipeline

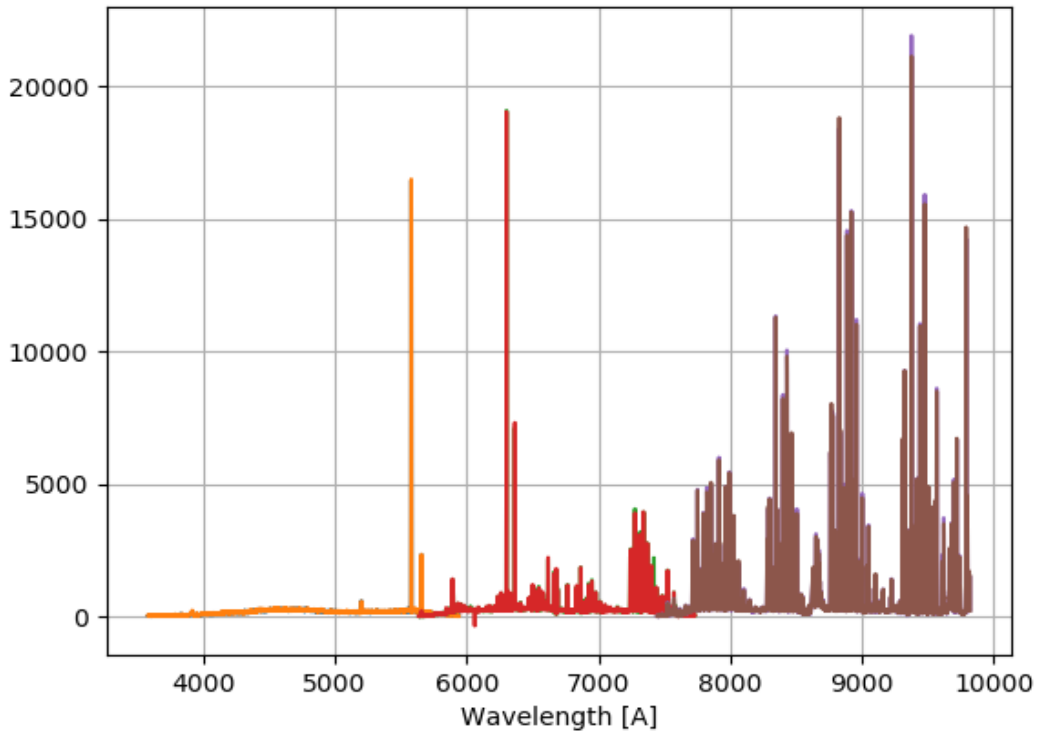



wavelength
fiber

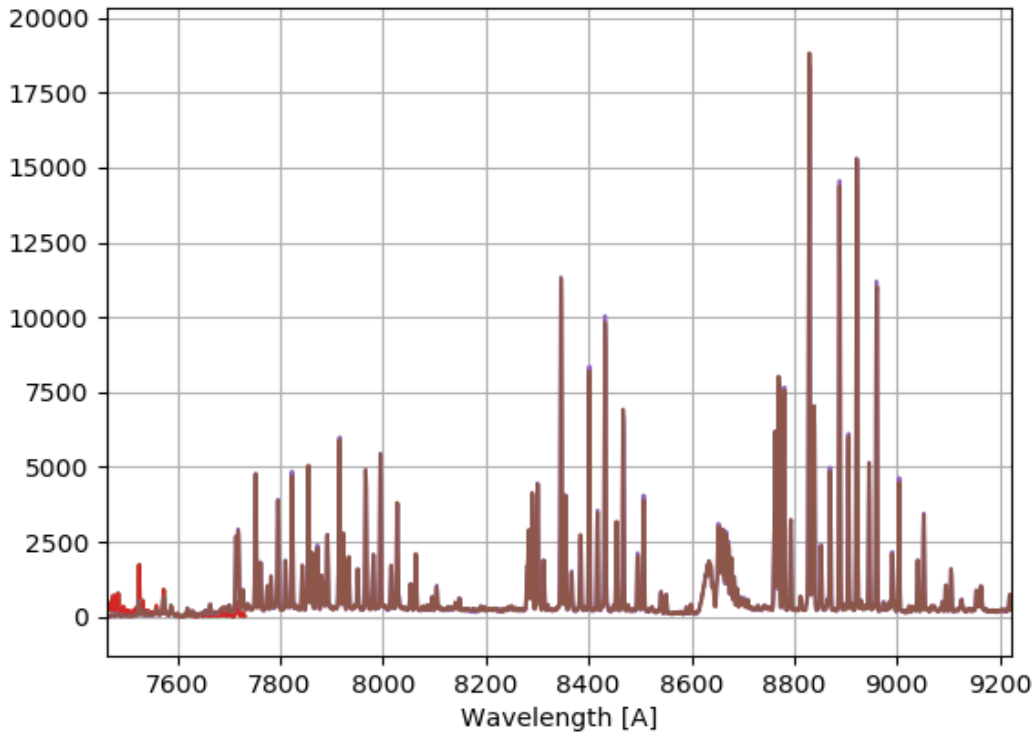

Restframe Wavelength (Å)
ELG
100
10
1
F_λ (arbitrary normalization)
[OII]
Hδ
Hγ
Hβ
[OIII]
Hα
g
r
Balmer break
z
2000
3000
4000
5000
6000
7000
wavelength
fiber


ELG in fiber #3575 spectro 7 (next to a bright star)
wavelength
fiber

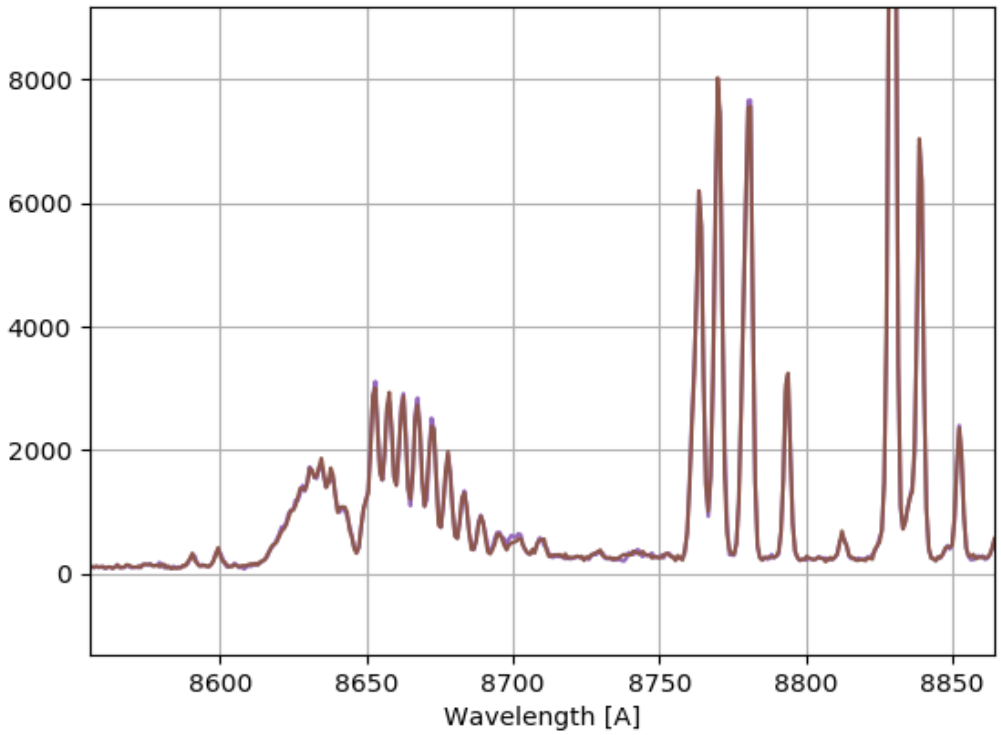
Extracted spectra of fibers #3575 and #3577 (3576 is a bright star)



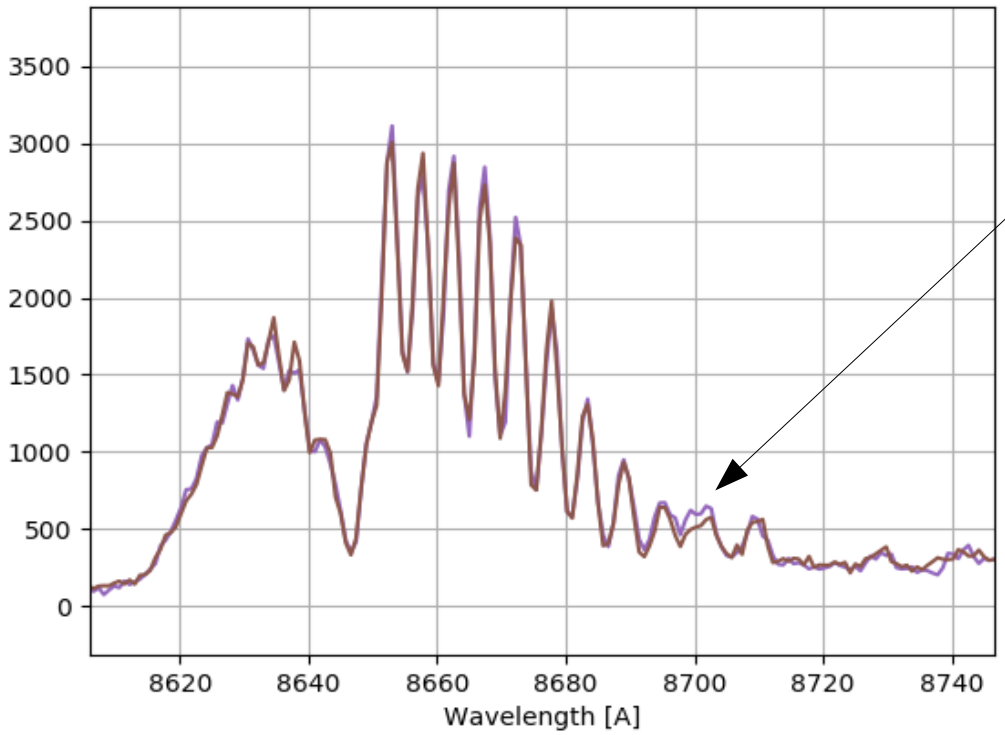
Extracted spectra of fibers #3575 and #3577 (3576 is a bright star)



Extracted spectra of fibers #3575 and #3577 (3576 is a bright star)

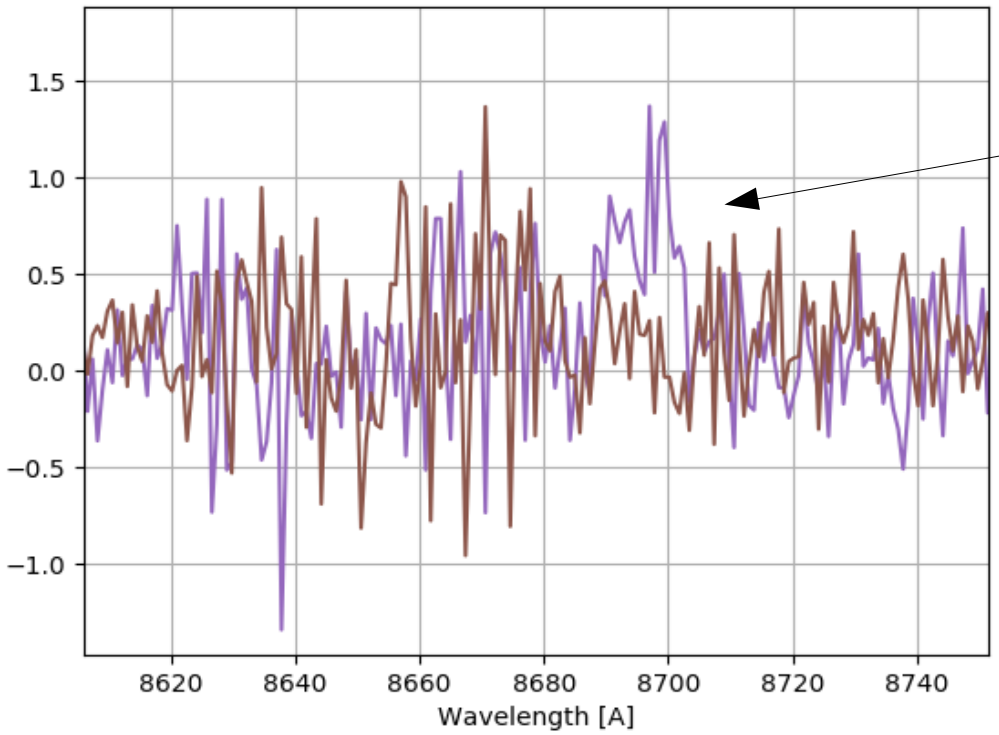


Extracted spectra of fibers #3575 and #3577 (3576 is a bright star)



Excess of flux

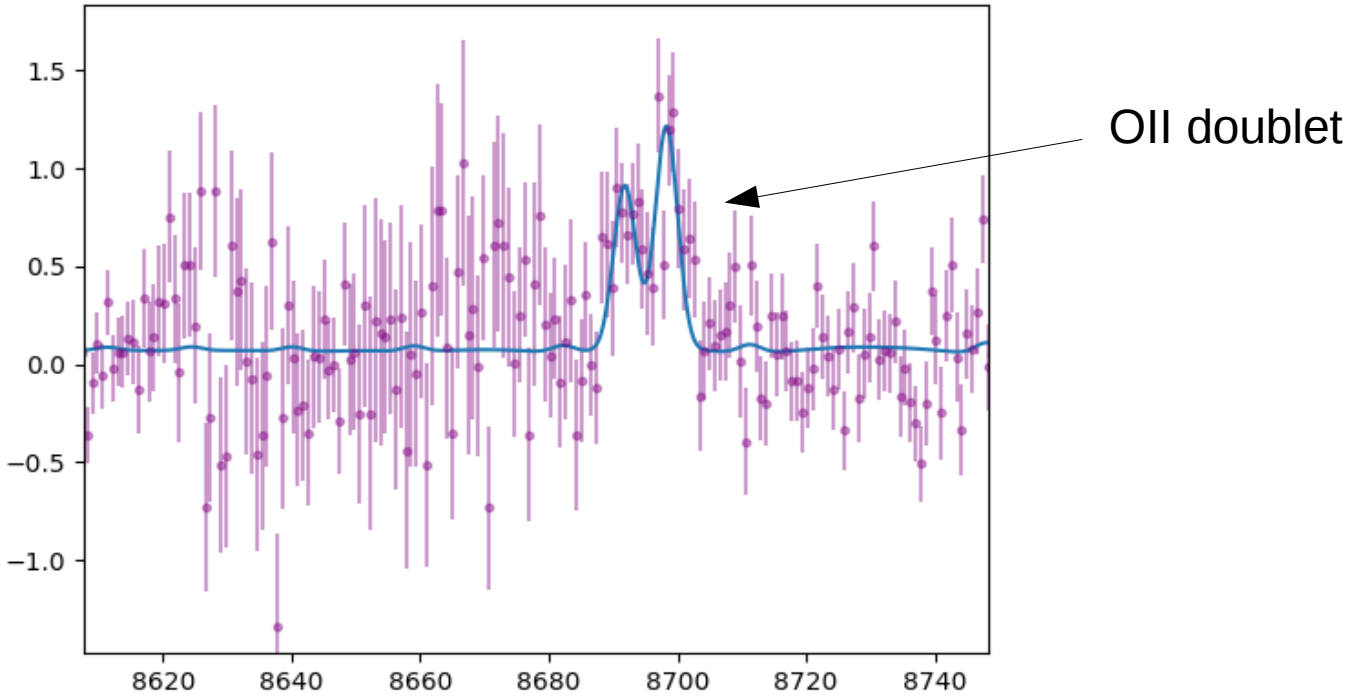
Calibrated spectra of fibers #3575 and #3577 (3576 is a bright star)



OII doublet

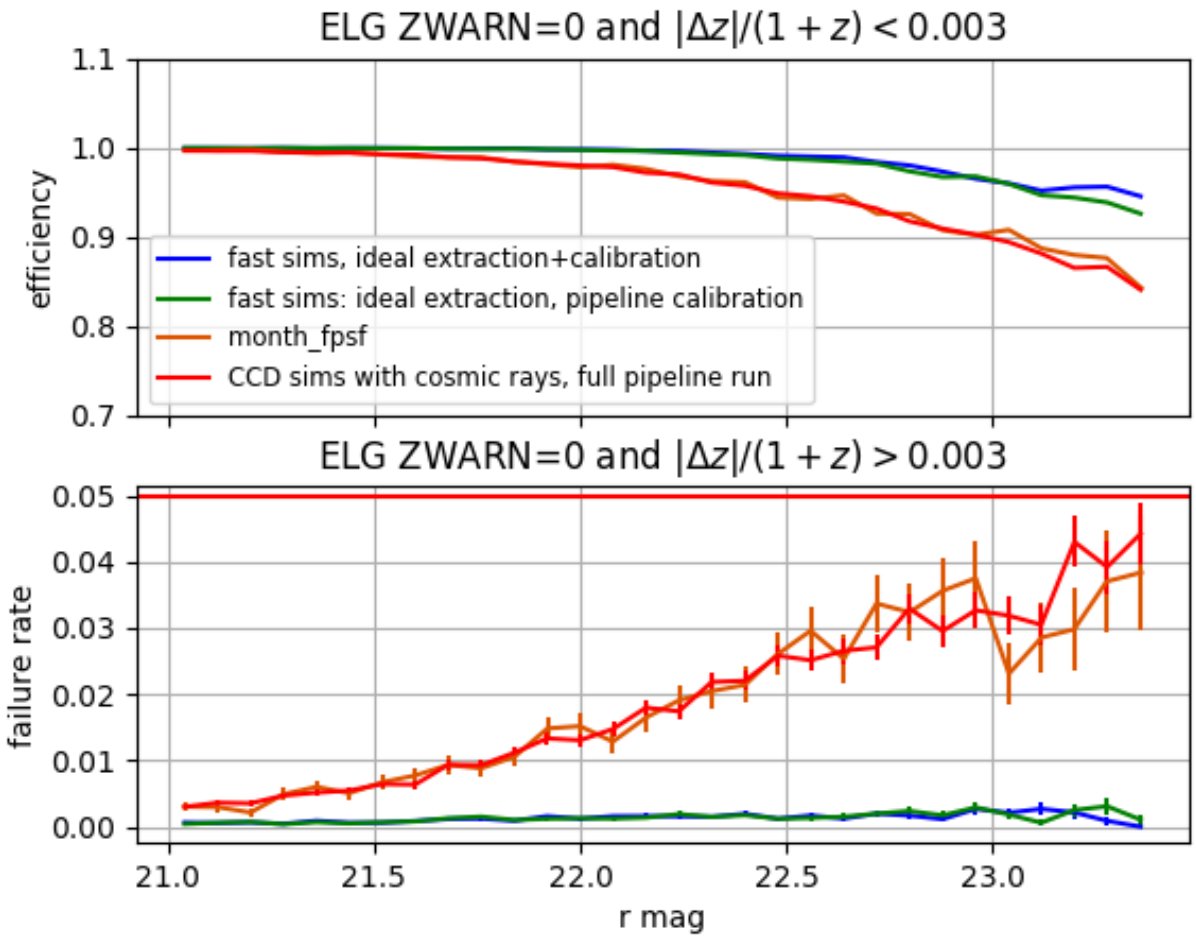
ELG r-mag=23 OII flux = 1.8e-16 ergs/s/cm2 at z~1.3
(efficiency of 90% in single exposure on simulations)

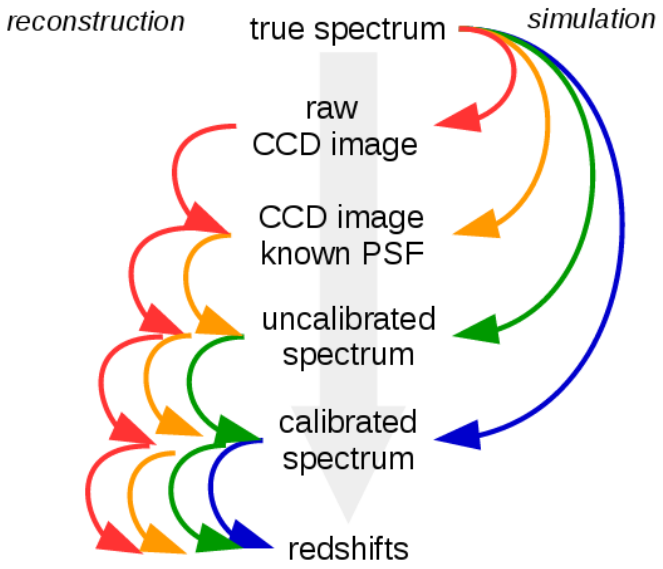
Calibrated spectrum and simulation input (convolved with resolution)



DESI simulations

used to test the spectroscopic pipeline

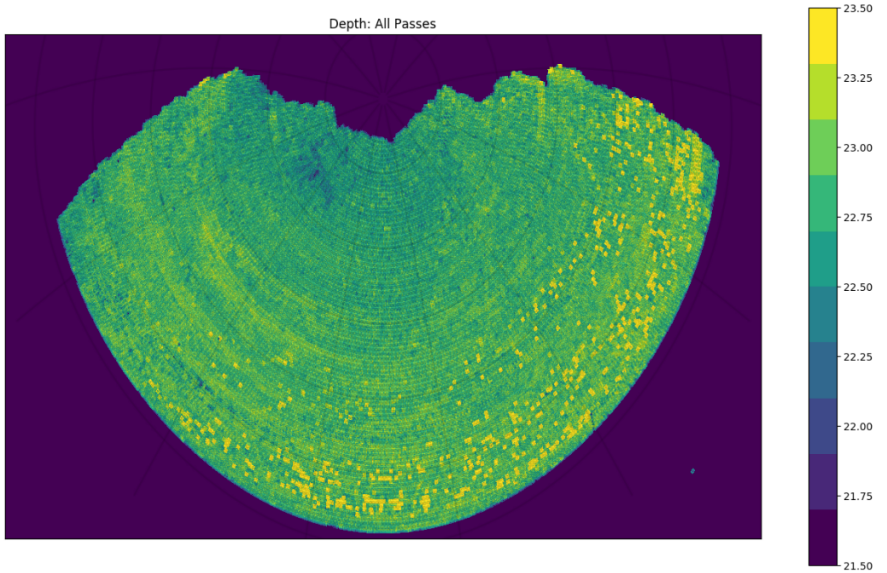


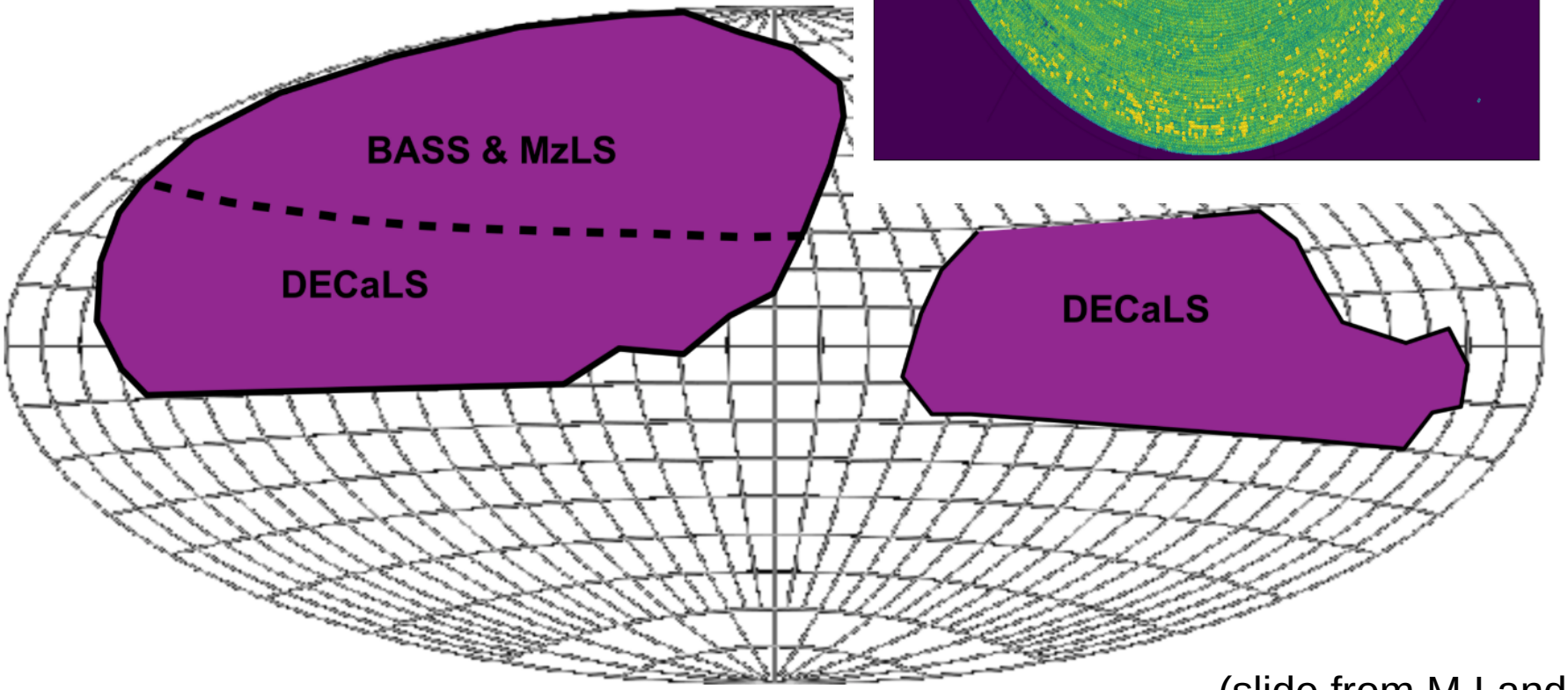


DESI Imaging surveys

Footprint: 14,000 deg2
MzLS: done!
DECaLS: 71% NGC, 53% SGC
BASS: 73.4%

MzLS is 100% complete as of 31 January 2018.



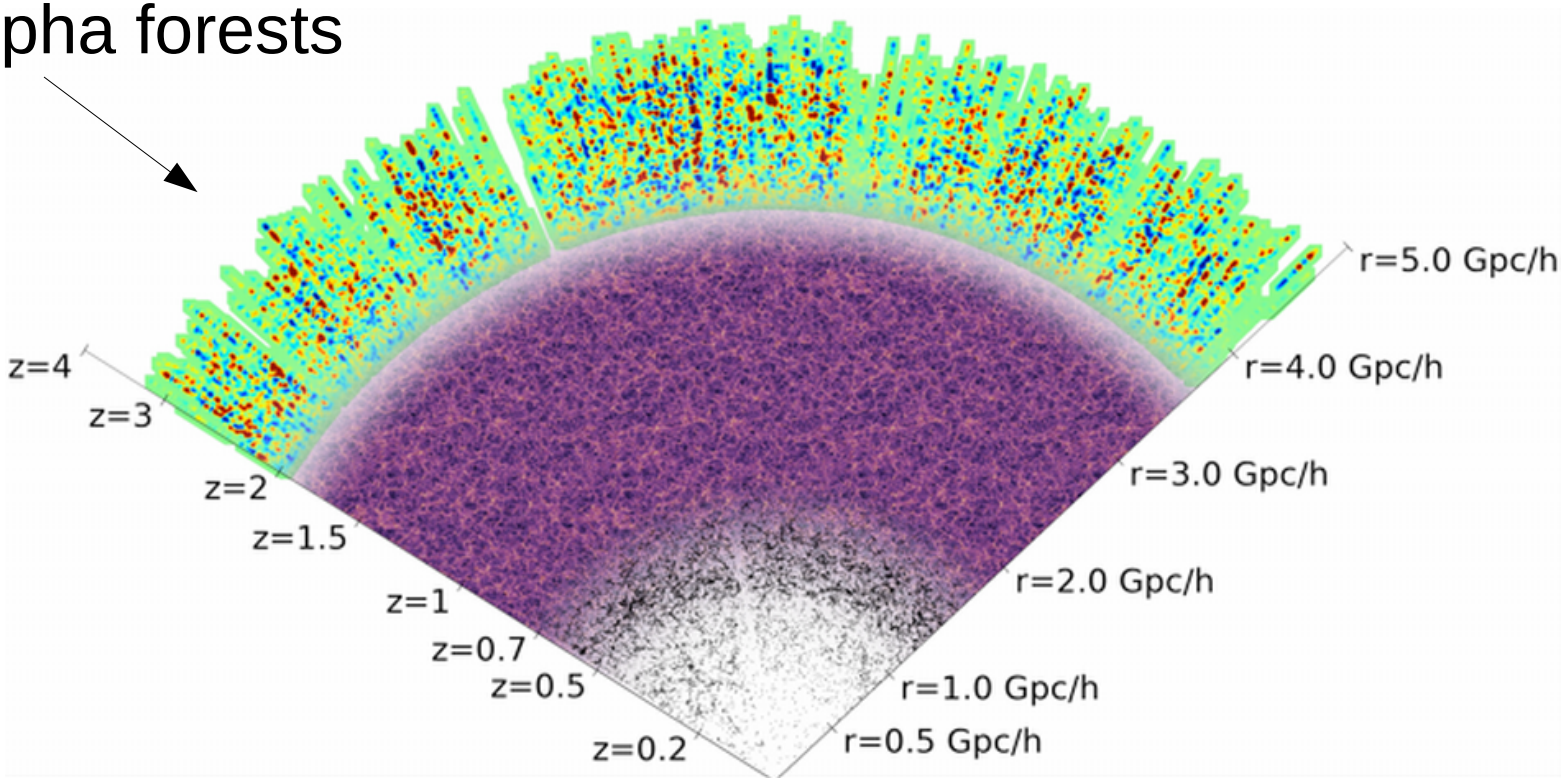


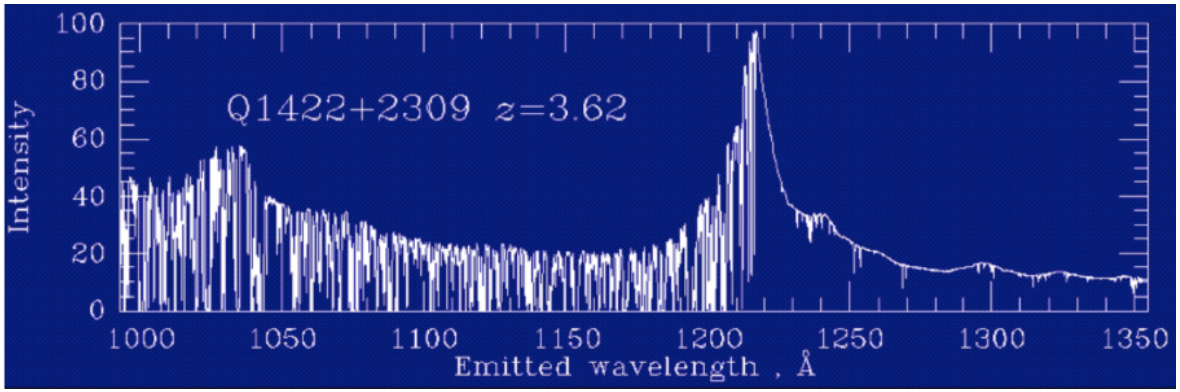
(slide from M Landriau)

Schedule

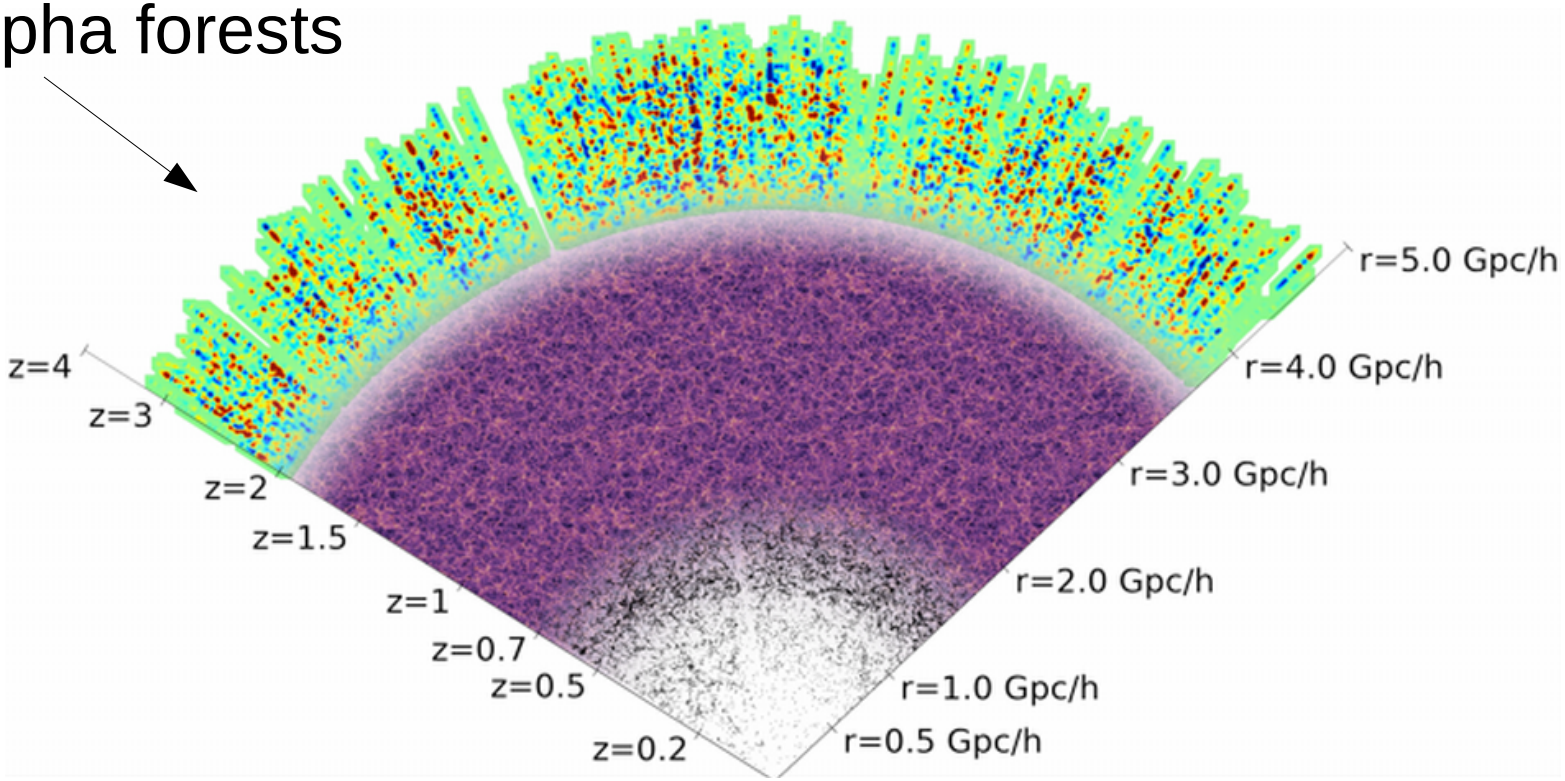
Milestones	Date
CD-0 Approval (mission need)	September 2012
CD-1 Approval (DESI selected)	March 2015
CD-2 Approval (baseline)	September 2015
CD-3 Approval (construction)	June 2016
Start of Installation	February 2018
Commissioning Instrument	October 2018
Focal Plane Installation	February 2019
Start of Commissioning	May 2019
End of Commissioning (ends MIE project)	September 2019

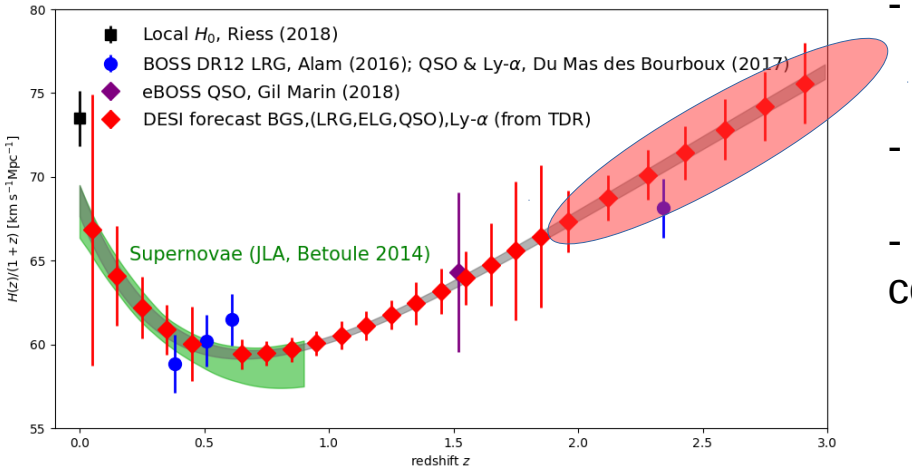
Lyman-alpha forests





Lyman-alpha forests





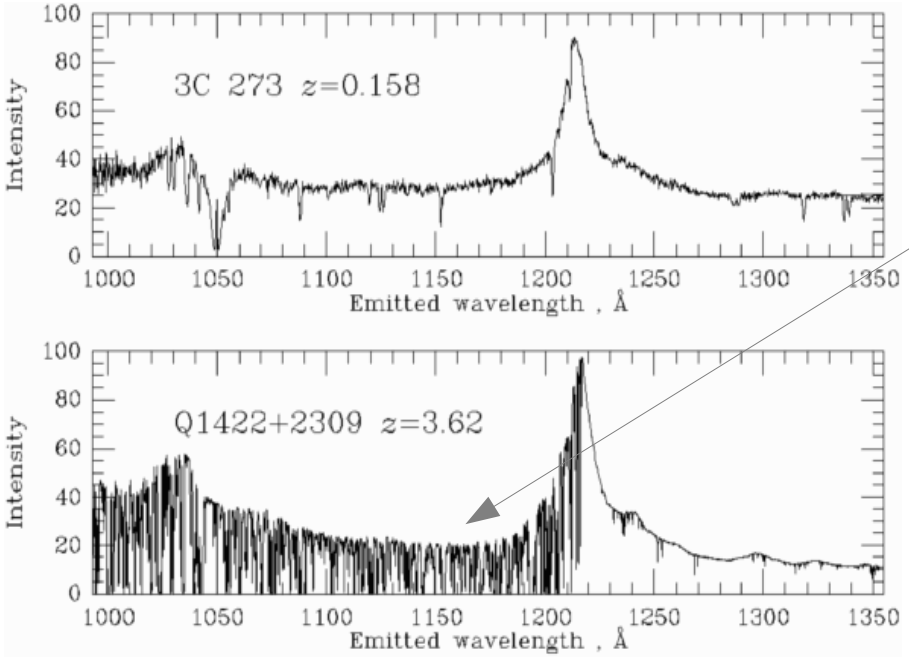
- highest redshifts before the CMB
  for distance measurements today

- matter dominated era, decelerated expansion

- test of the cosmological model in different conditions, where dark energy contributes less.

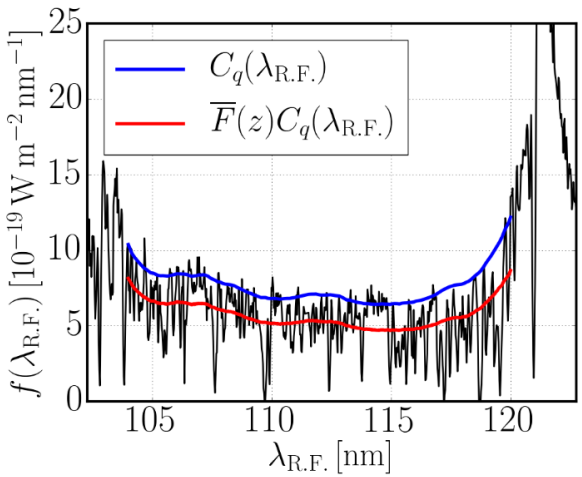
Lyman-alpha Forests

Neutral H absorption along the line of sight of distant quasars



$$\lambda_{Ly\alpha} = 121\,\mathrm{nm}$$

$$\lambda_{obs} = (1+z)\lambda_{Ly\alpha}$$



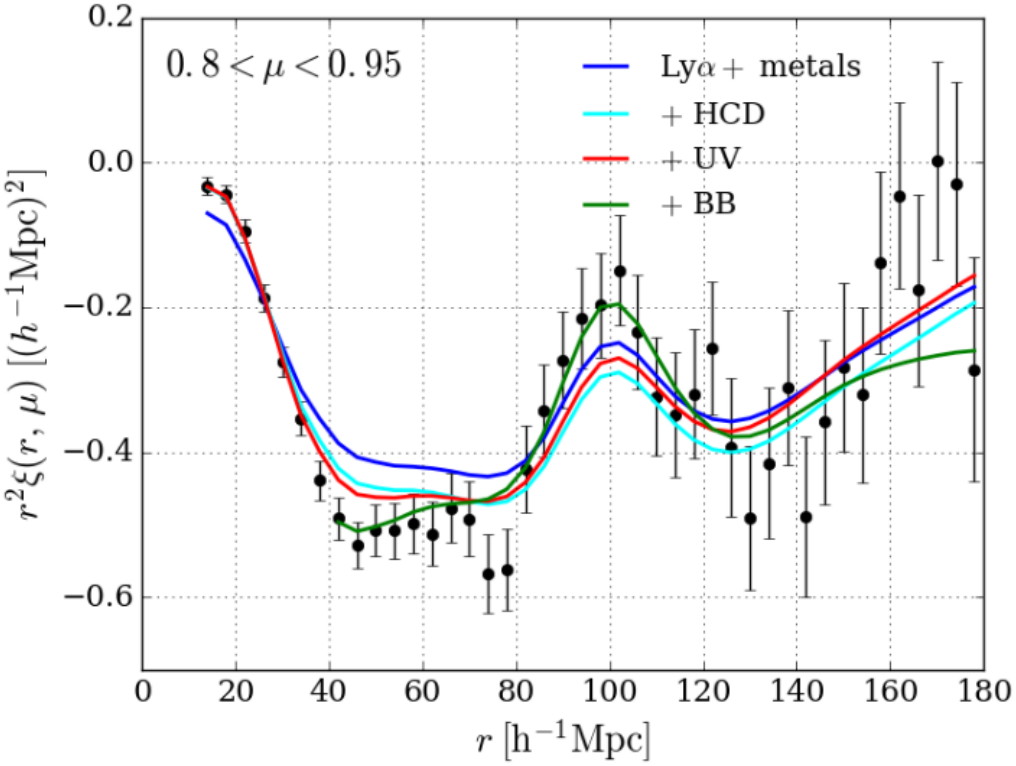
Flux decrement :

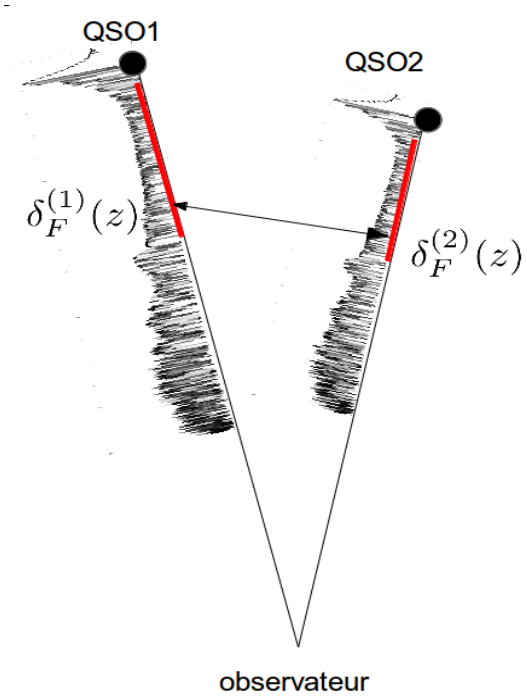
$$F(\lambda) \equiv \frac{f(\lambda)}{C_q(\lambda)} = e^{-\tau(n_{HI})}$$

$$\delta_F(\lambda) = \frac{F(\lambda)}{\bar{F}(\lambda)} - 1 = \frac{f(\lambda)}{\bar{F}(z)C_q(\lambda)} - 1$$

BOSS DR12 Lyman-alpha auto-correlation

Bautista et al. 2017



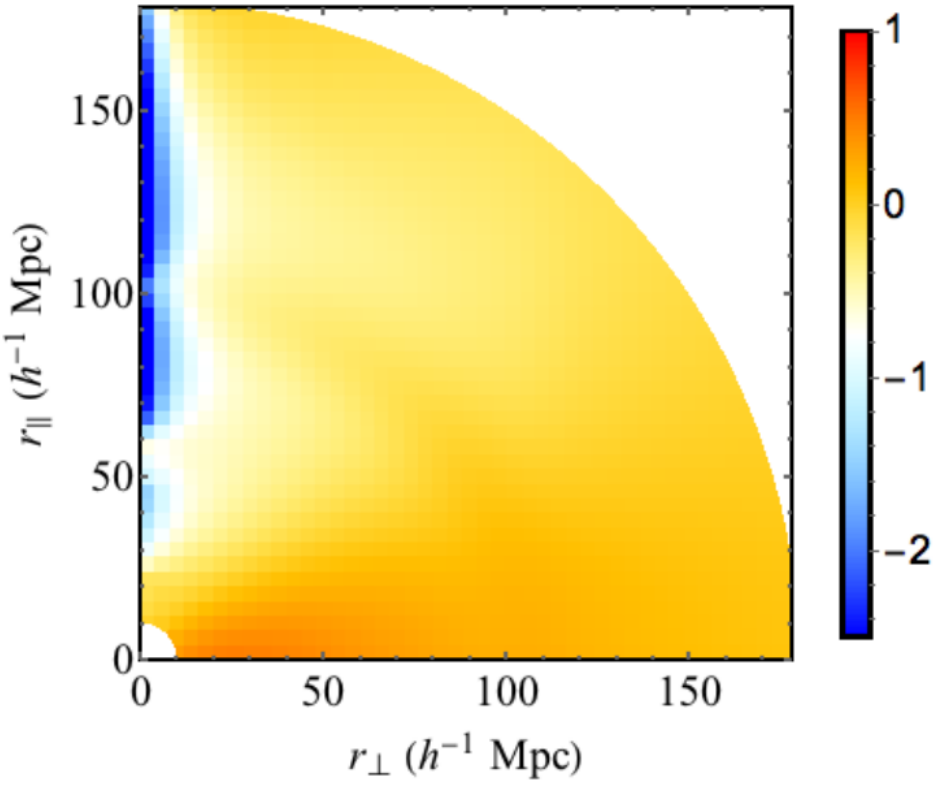


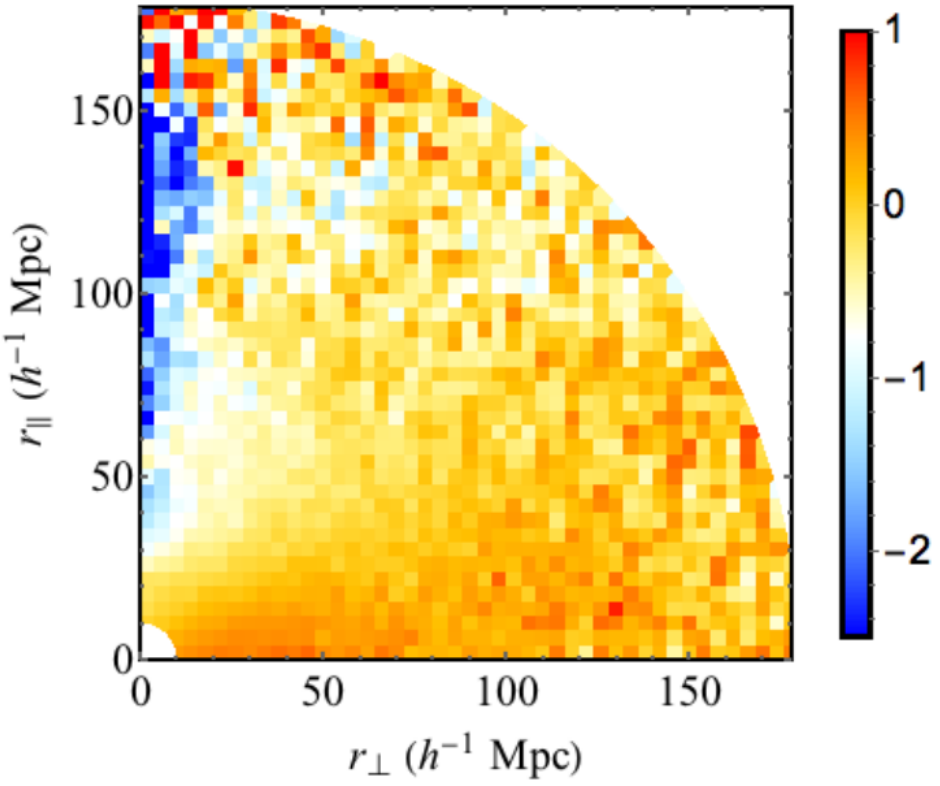
$$\xi(r_\parallel, r_\perp) = < \delta_1 \delta_2 >_{(\Delta r_{1,2} \in r\, bin)}$$

$$(\theta_{12}, z_1, z_2) \rightarrow (r_\perp, r_\parallel)$$

BOSS DR12 Lyman-alpha auto-correlation

Bautista et al. 2017

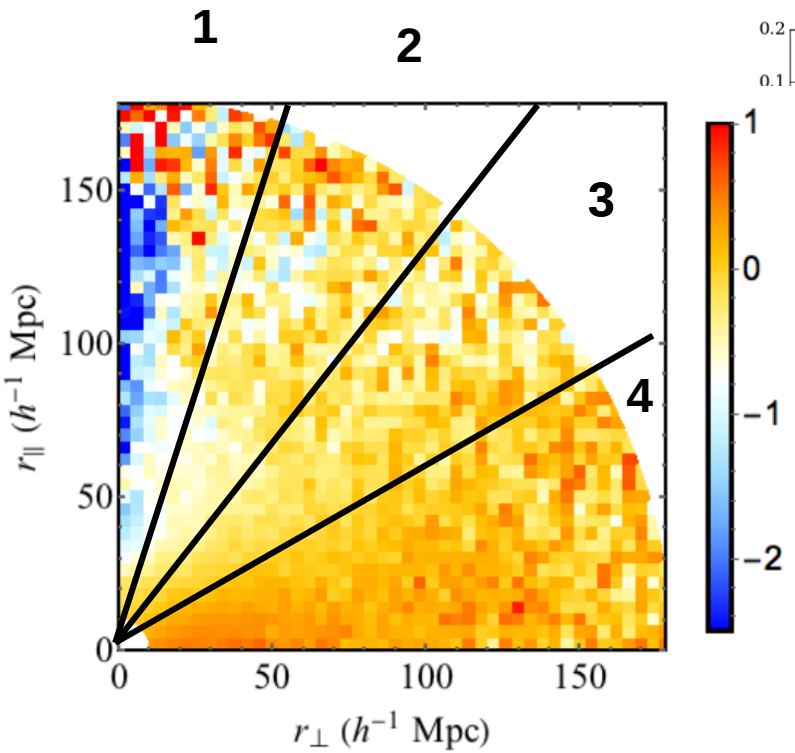


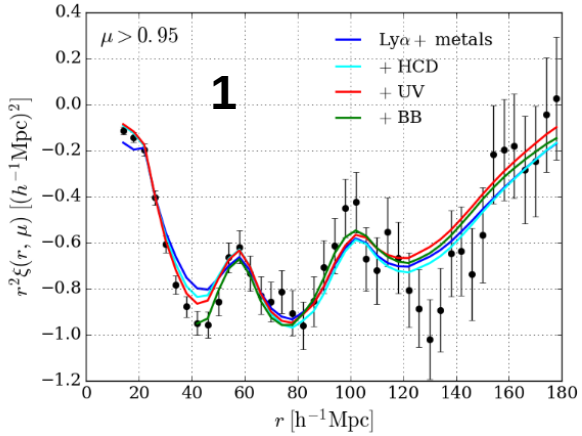


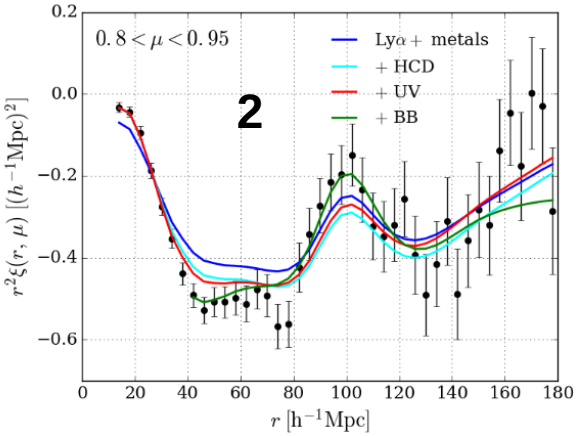
BOSS DR12 Lyman-alpha auto-correlation

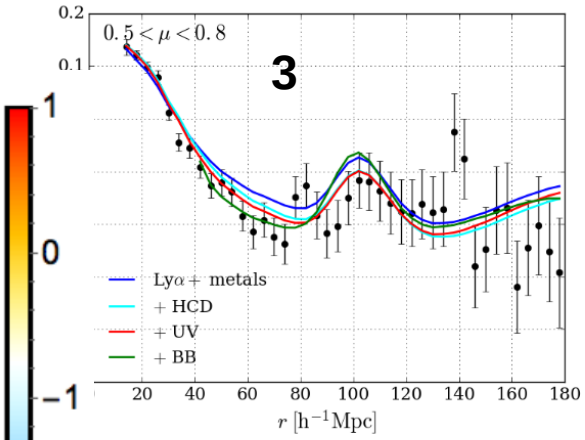
Bautista et al. 2017

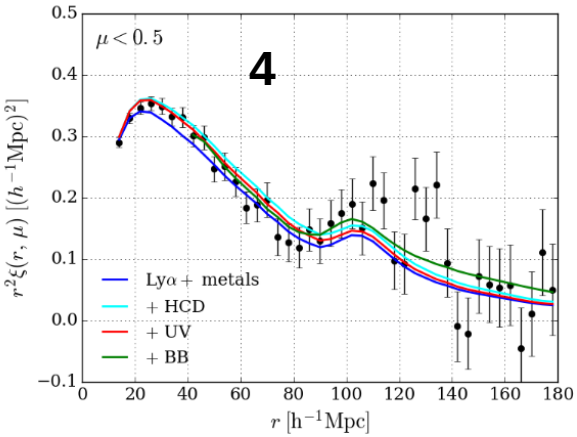
Wedges





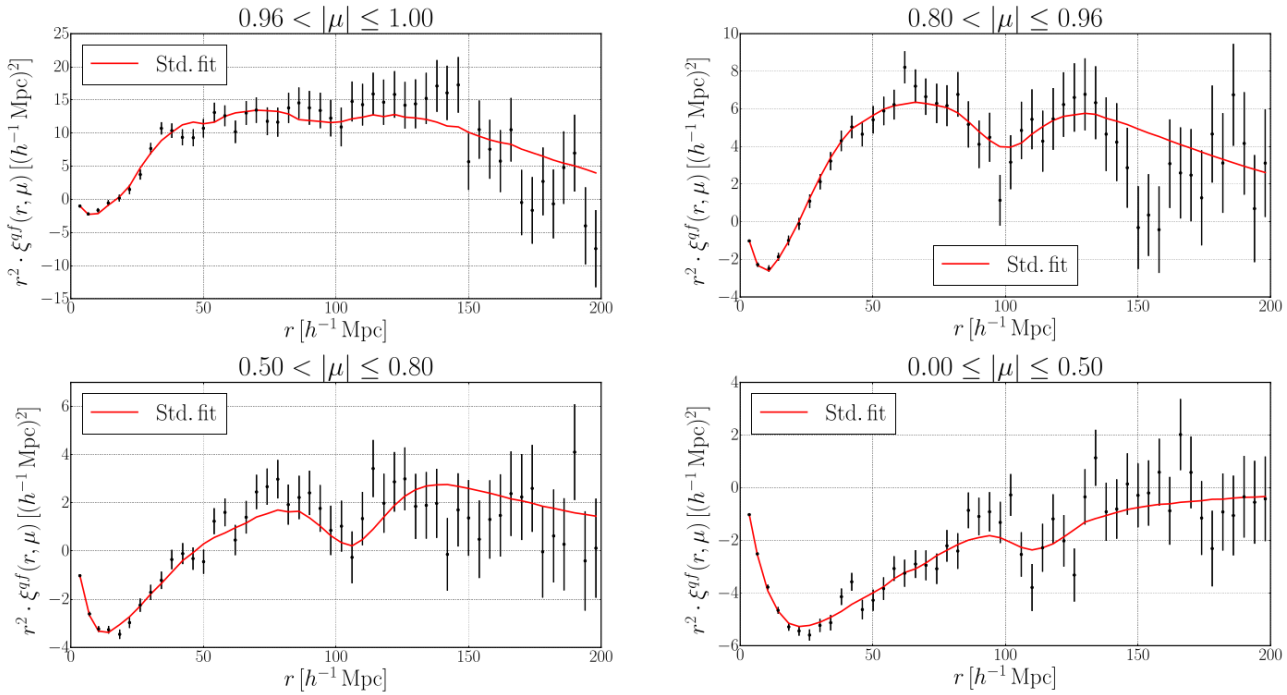


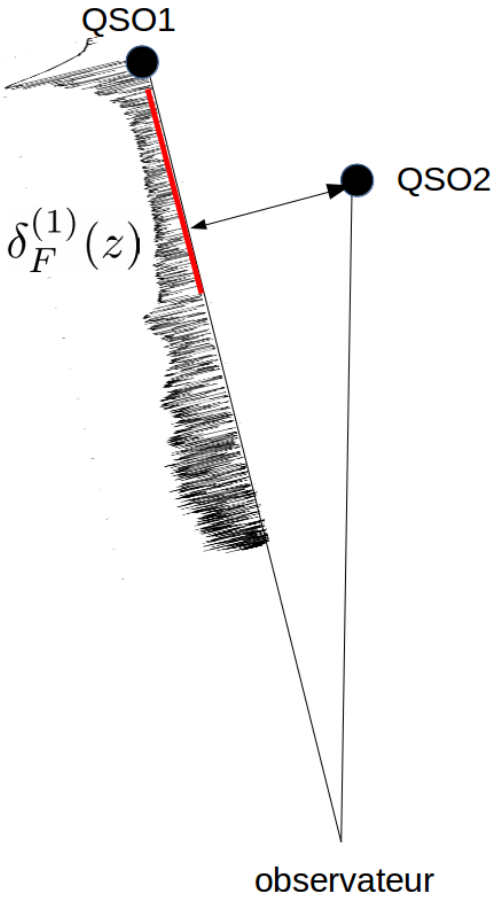




BOSS DR12 Lyman-alpha – QSO cross-correlation

Du Mas des Bourboux et al. 2017





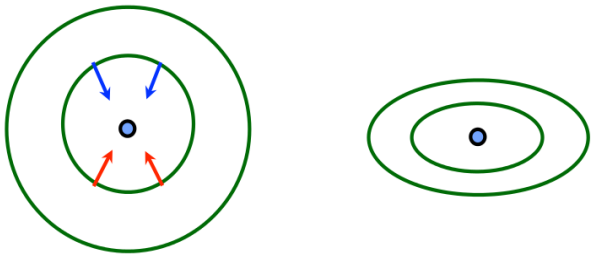
$$\xi(r_{\parallel}, r_{\perp}) = < \delta_i >_{(\Delta r_{i,q} \in r\,bin)}$$

$$(\theta_{12}, z_1, z_2) \rightarrow (r_{\perp}, r_{\parallel})$$

Modeling the Lyman-alpha correlation function

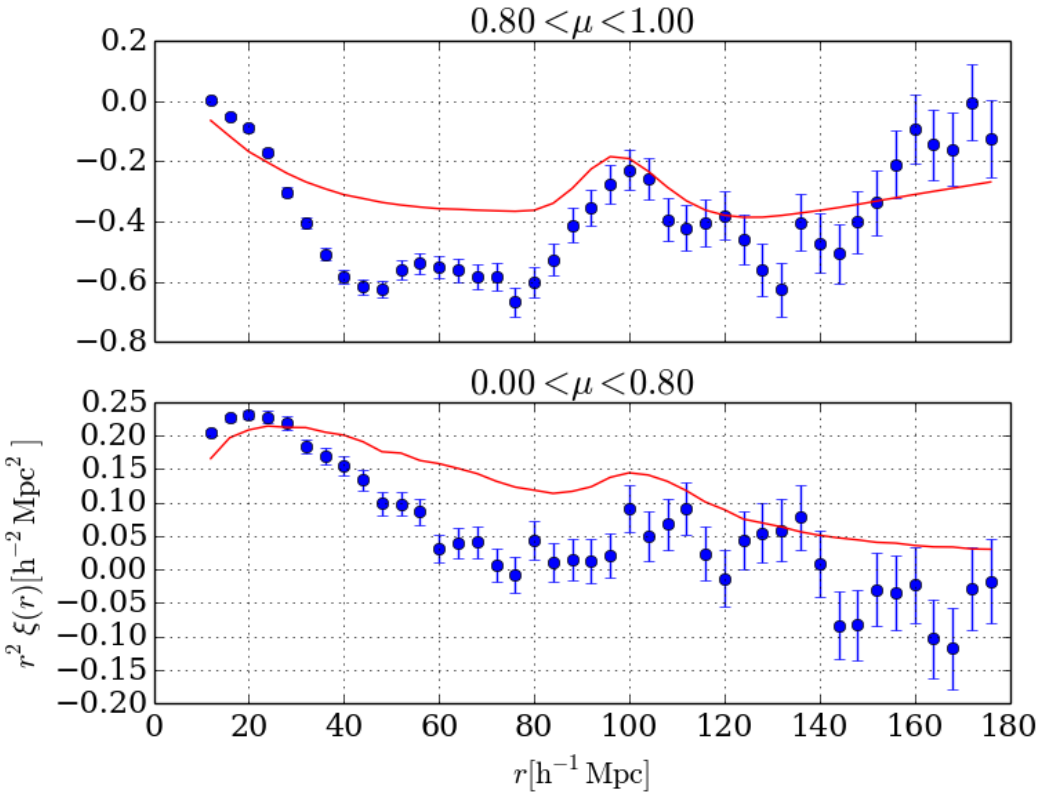
1) biais and redshift space distorsions

$$P_X(k) = b_X^2 (1 + \beta_X \mu_k^2)^2 P_{lin}(k)$$



"real" space

"redshift" space



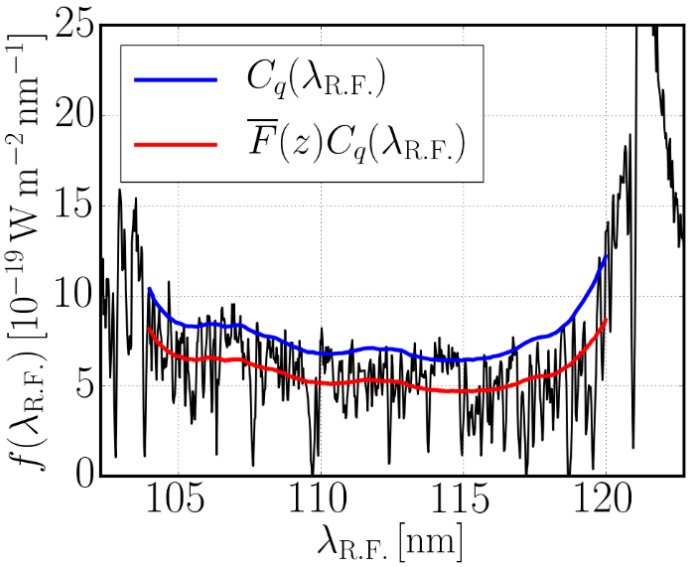
Modeling the Lyman-alpha correlation function

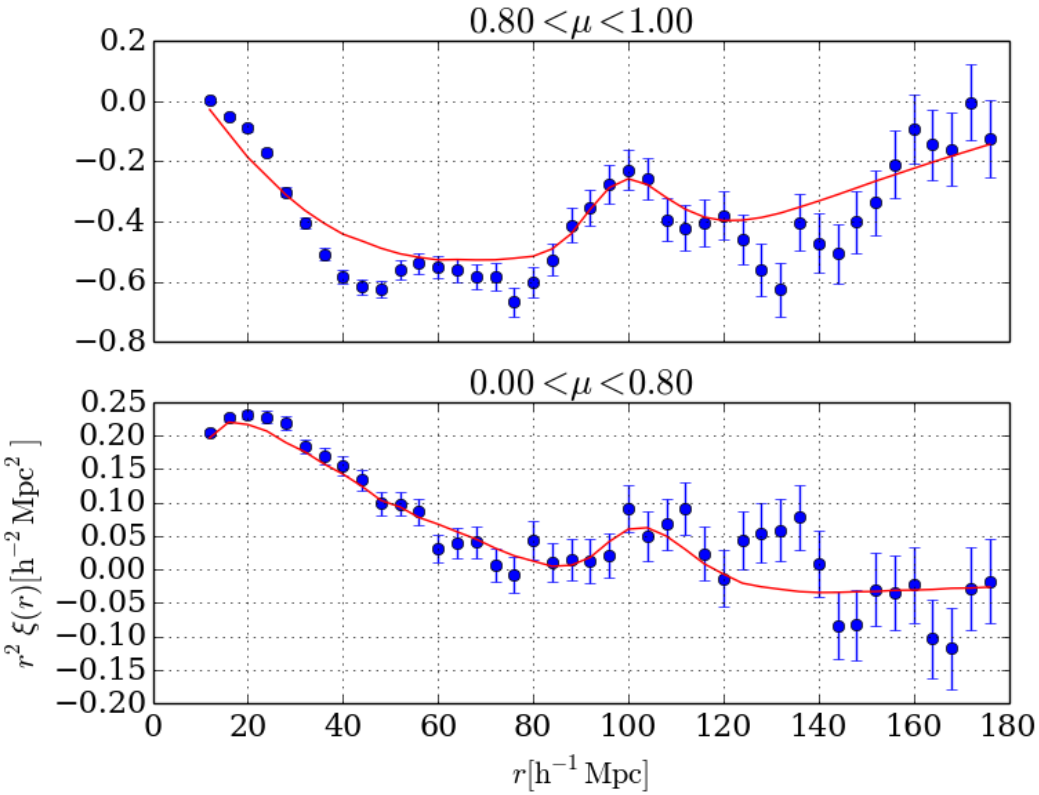
1) biais and redshift space distortions
2) distortions due to continuum fitting (Bautista 2017)

$$\delta_\alpha(\lambda) = \frac{flux_q(\lambda)}{C(\lambda)\bar{F}(z)} \times (a_q + b_q\lambda) - 1$$

$$a_q, b_q = func(\delta_{q,i}) \rightarrow \delta_{q,i}^{meas} = \sum_j c_j \delta_{q,j}^{true}$$

$$\xi^{meas} = M\,\xi^{true}$$





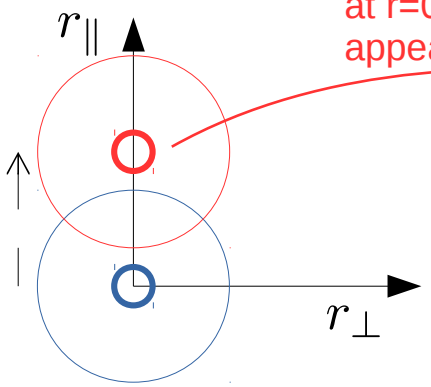
Modeling the Lyman-alpha correlation function

1) biais and redshift space distortions
2) distortions due to continuum fitting
3) contamination by other atomic transitions (Bautista 2017)

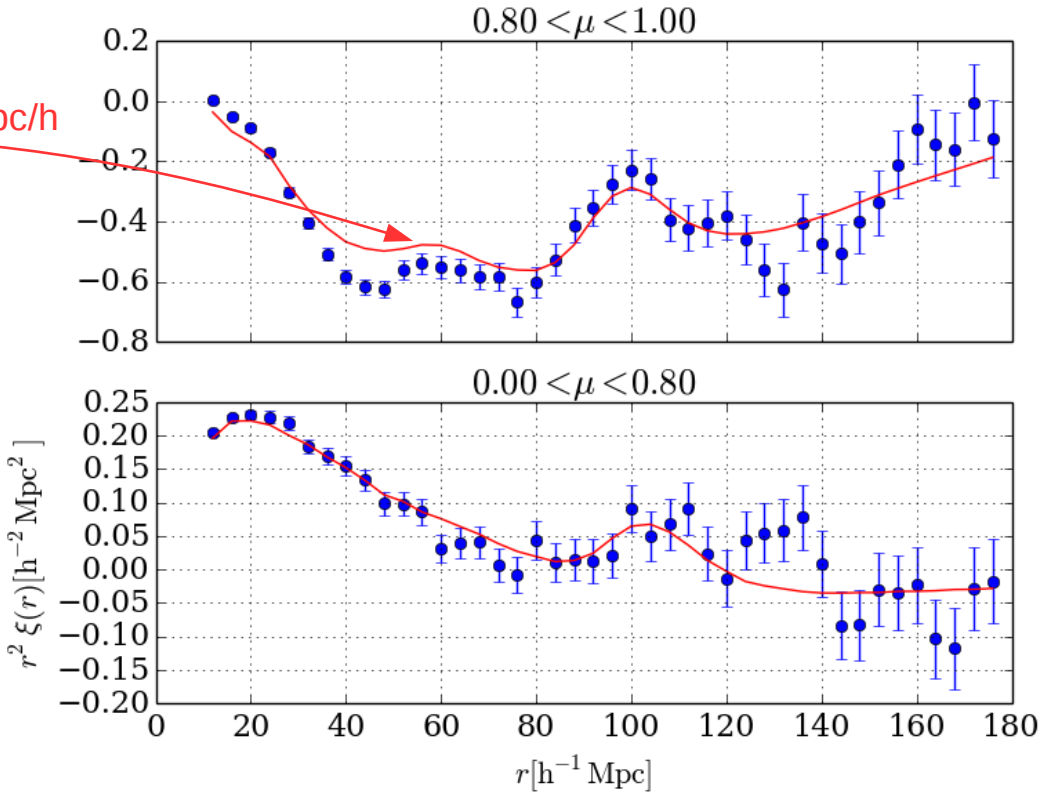
- Si II and Si III absorption lines in Lyman-forests
- Introduce spurious correlation :
  - wrong redshift when interpreting Si II absorption as Lya
  - wrong longitudinal separation r_parallel

$$\Delta_z = \lambda_{obs}/\lambda_\alpha - \lambda_{obs}/\lambda_i$$

$$\Delta r_\parallel \sim c\Delta z/H$$



SiII x Lya
at r=0
appears at r=60 Mpc/h



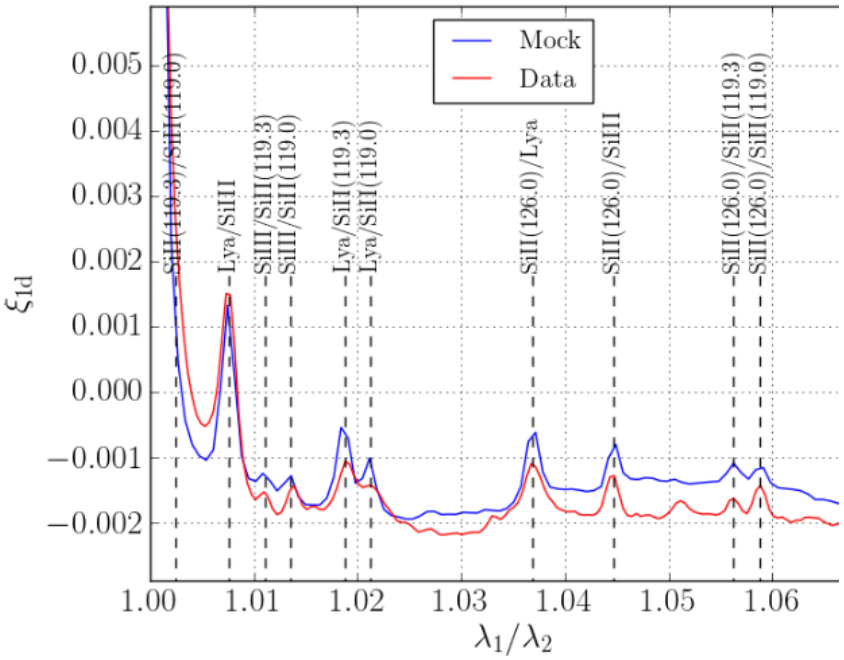
- Modeled using another distortion matrix
- Fit for biases of extra transitions

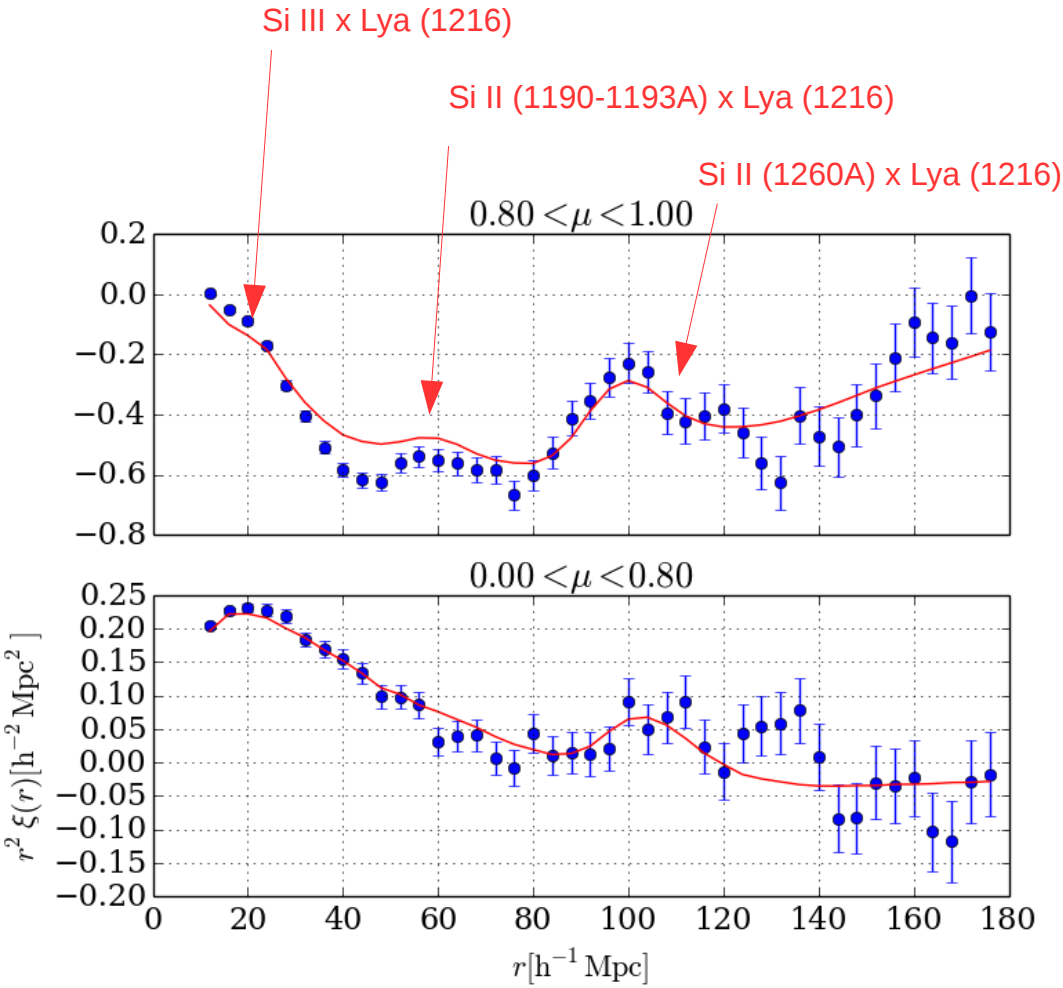
$$\xi^{meas} = M_{\alpha\alpha}\xi^{true}(\theta, b_\alpha, \beta_\alpha) + \sum_{i,j} M_{ij}\xi^{true}(\theta, b_i, \beta_i, b_j, \beta_j)$$

Modeling the Lyman-alpha correlation function

1) biais and redshift space distortions
2) distortions due to continuum fitting
3) contamination by other atomic transitions (Bautista 2017)

Transitions easily detected
in 1D correlation functions
(auto-correlation of the same quasar)

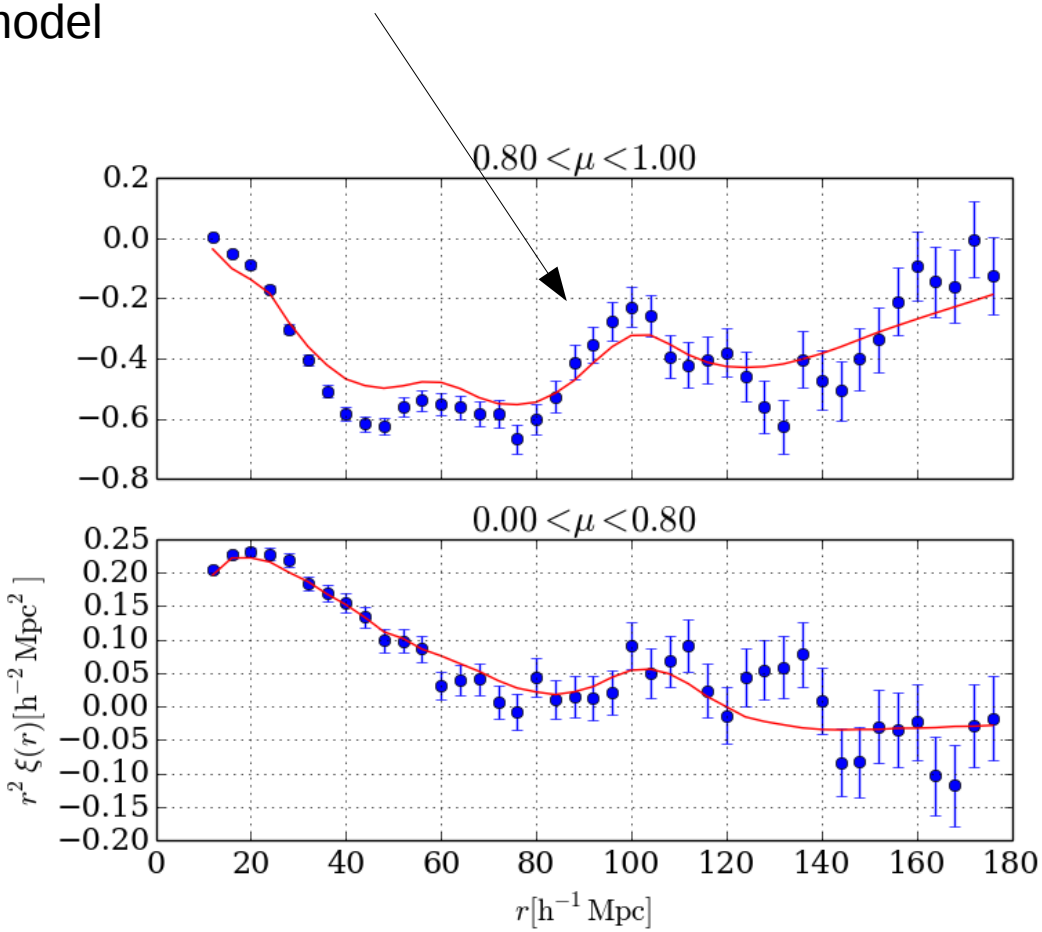




Modeling the Lyman-alpha correlation function

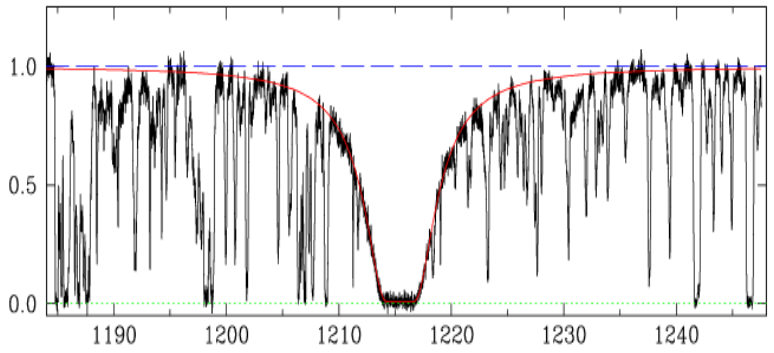
1) biais and redshift space distortions
2) distortions due to continuum fitting
3) contamination by other atomic transitions
4) non-linear clustering (McDonald 2003, Arinyo-i-Prats 2015)

- at small scale from models adjusted on hydro-simulations
- large scales : Gaussian broadening of BAO peak
- both terms included in the P(k) model

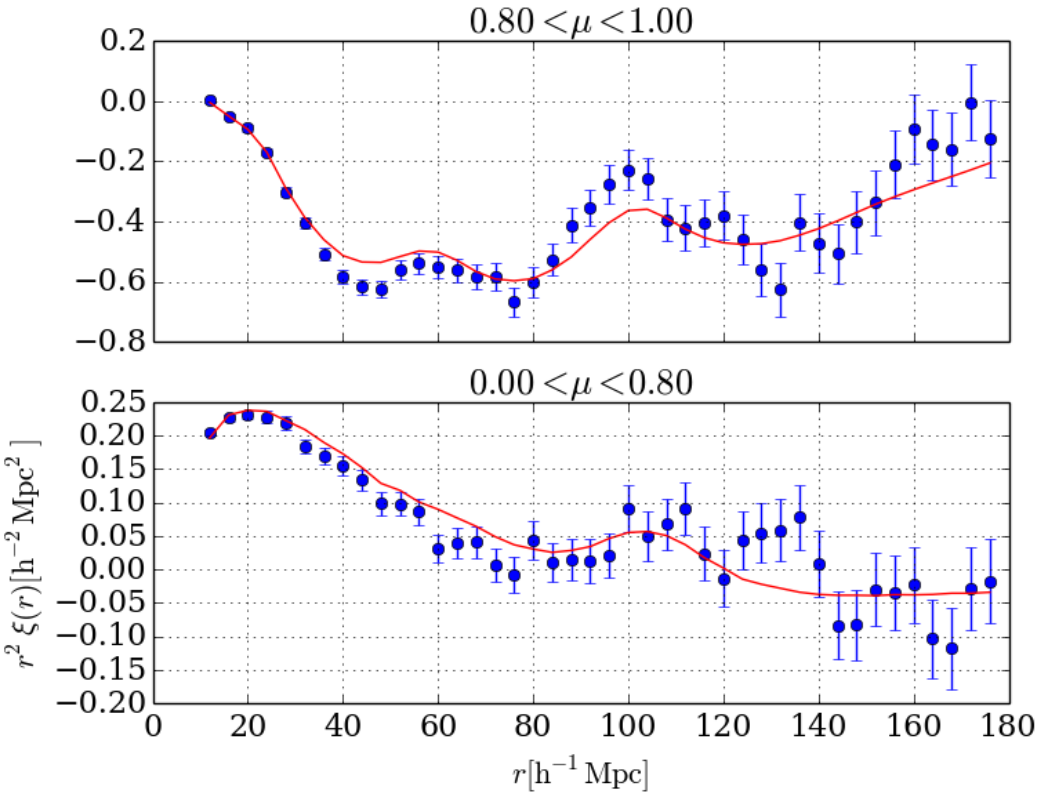


Modeling the Lyman-alpha correlation function

1) biais and redshift space distortions
2) distortions due to continuum fitting
3) contamination by other atomic transitions
4) non-linear clustering
5) distortion due to Damped Lyman-alpha systems
- simple model in Bautista (2017), checked on mocks,
but can do better (Rogers, 2018)

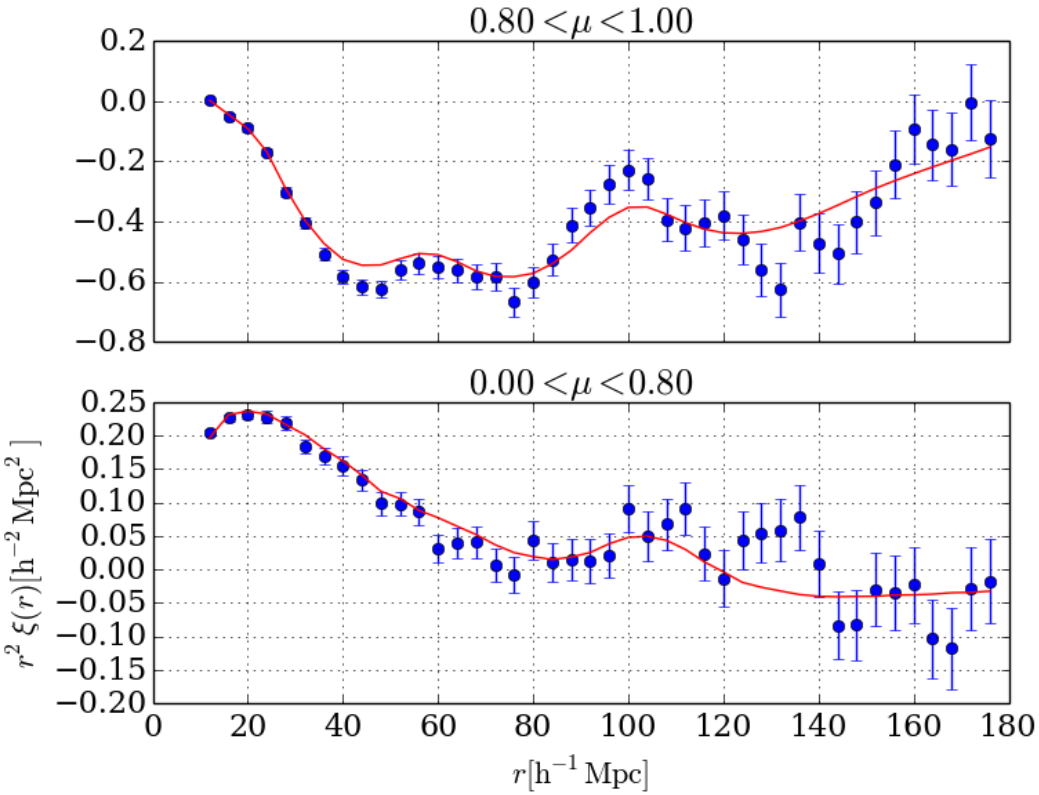


rest. wavelength (A)



Modeling the Lyman-alpha correlation function

1) biais and redshift space distortions
2) distortions due to continuum fitting
3) contamination by other atomic transitions
4) non-linear clustering
5) distortion due to Damped Lyman-alpha systems
6) UV background fluctuations (Gontcho A Gontcho 2014)
- variation of neutral H fraction
- correlated with UV sources, matter, Lyman-alpha



Modeling the Lyman-alpha correlation function

1) biais and redshift space distortions
2) distortions due to continuum fitting
3) contamination by other atomic transitions
4) non-linear clustering
5) distortion due to Damped Lyman-alpha systems
6) UV background fluctuations

Plus :
7) Auto-correlation of foreground absorbers (CIV, SiIV ...)
8) Interstellar Medium absorption (correlated with dust)
9) Instrumental effects (sky background subtraction, spectro-photometric calibration)

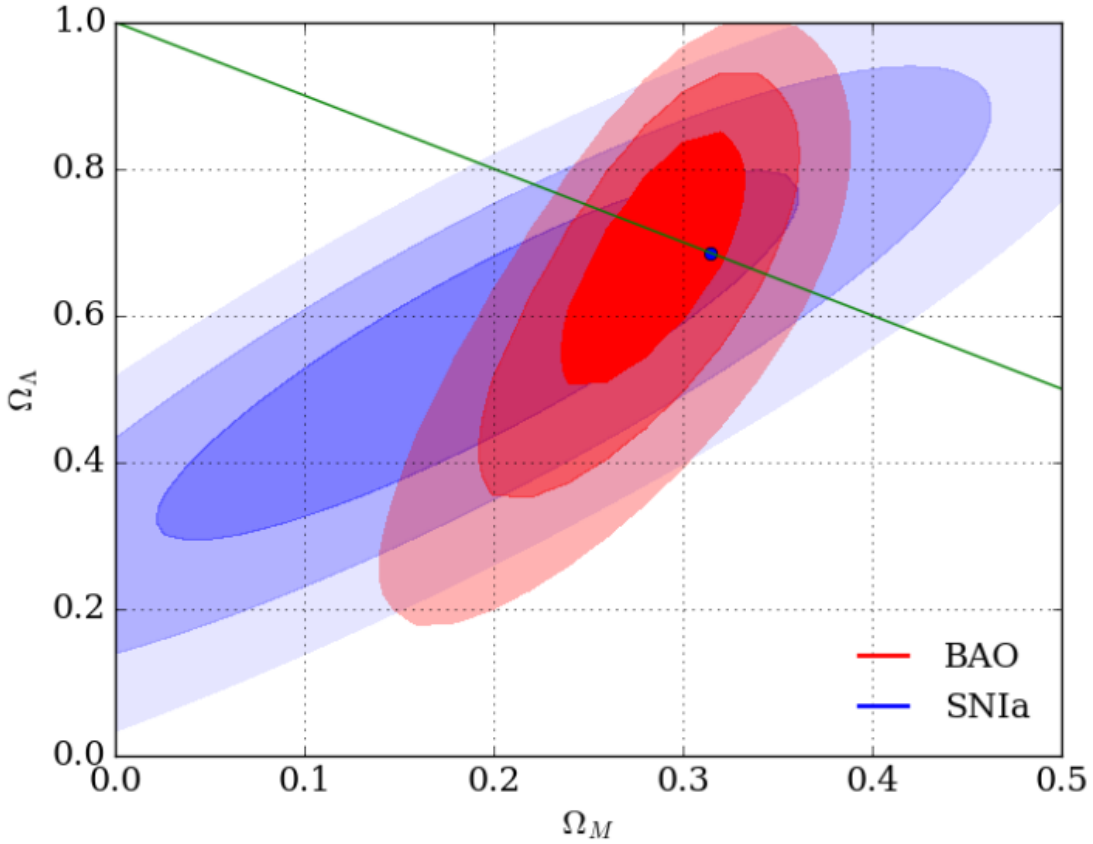
Maximum shift of BAO peak position ~ 0.3 sigma_stat (for BOSS DR12)

analysis	$\alpha_{\parallel}$	$\alpha_{\perp}$	$b_{\mathrm{Ly}\alpha}(1+\beta_{\mathrm{Ly}\alpha})$	$\beta_{\mathrm{Ly}\alpha}$	$\chi^2_{\mathrm{min}}/DOF$, prob
Lyα	1.040 ± 0.033	0.975 ± 0.056	-0.326 ± 0.002	1.246 ± 0.044	$1763.8/(1590-4)$ $p = 0.001$
+metals	1.050 ± 0.035	0.967 ± 0.054	-0.330 ± 0.002	1.275 ± 0.045	$1644.5/(1590-9)$ $p = 0.130$
+HCD	1.053 ± 0.036	0.962 ± 0.054	-0.321 ± 0.003	1.656 ± 0.086	$1561.4/(1590-12)$ $p = 0.612$
+UV	1.053 ± 0.036	0.965 ± 0.055	-0.326 ± 0.003	1.666 ± 0.085	$1556.5/(1590-13)$ $p = 0.639$

(table from Bautista 2017)

Cosmological results for BOSS (DR12)

Combined lyman-alpha autocorrelation, and lyman-alpha-QSO cross-correlation
Du Mas des Bourboux et al. (2017)

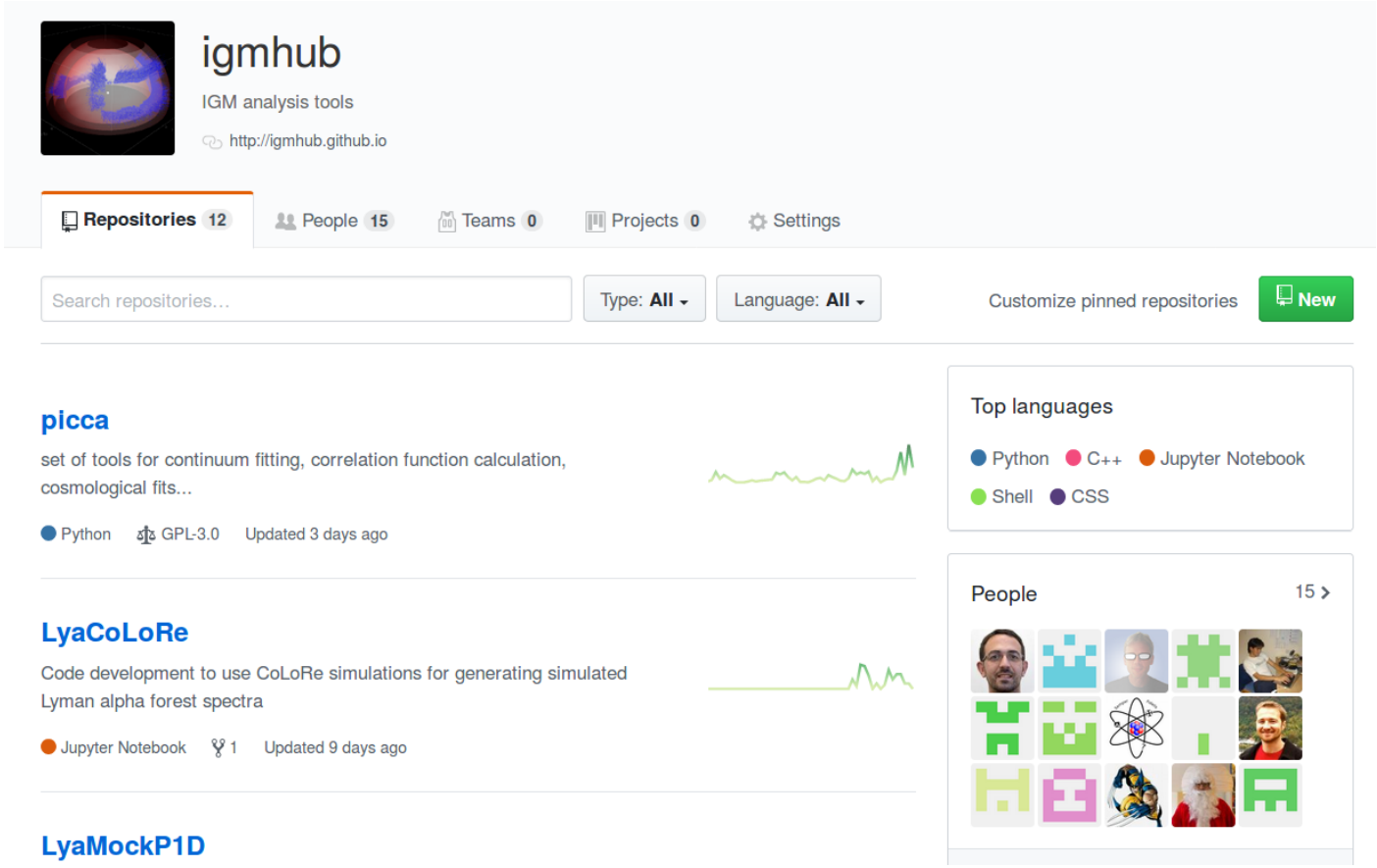


Red: BAO only (6dFGS, SDSS main, BOSS LRG, eBOSS QSOs, BOSS lyman-alpha auto- and lyman-alpha-QSO cross-correlation), without CMB.
Blue: Supernovae Ia (JLA, Betoule 2014)

Lyman-alpha analysis continues in eBOSS.
This is a preparation for DESI.

- eBOSS paper will be a combined fit of multiple tracers/absorbers
(Lya-Lya, Lya-Lyb, Lyb-Lyb, Lya-QSO …)

- All the code is public, on https://github.com/igmhub
co-addition (stacking), QSO continuum fit, (cross-)correlation function estimators, P1D(k), correlation function fit (as used in BOSS DR12 papers), mocks



White paper on DESI Lyman-α BAO systematics

DESI Lyman-α Working Group
White-paper conveners: Nicolas Busca (APC), Andreu Font-Ribera (UCL), Julien Guy (LBNL), Anže Slosar (BNL)

Conclusion

- DESI is in a very active construction phase.

- A lot of activities are taking place at the LBNL, both in hardware and software.

- Commissioning starts in May 2019, operations in September 2019.

- Potential of cosmological distance measurements with BAO in the lyman-alpha forests demonstrated with BOSS.

- There are contaminants to the lyman-alpha correlation function, but no identified blocking factor for precise measurements.

- DESI lyman-alpha work prepared with eBOSS analysis.