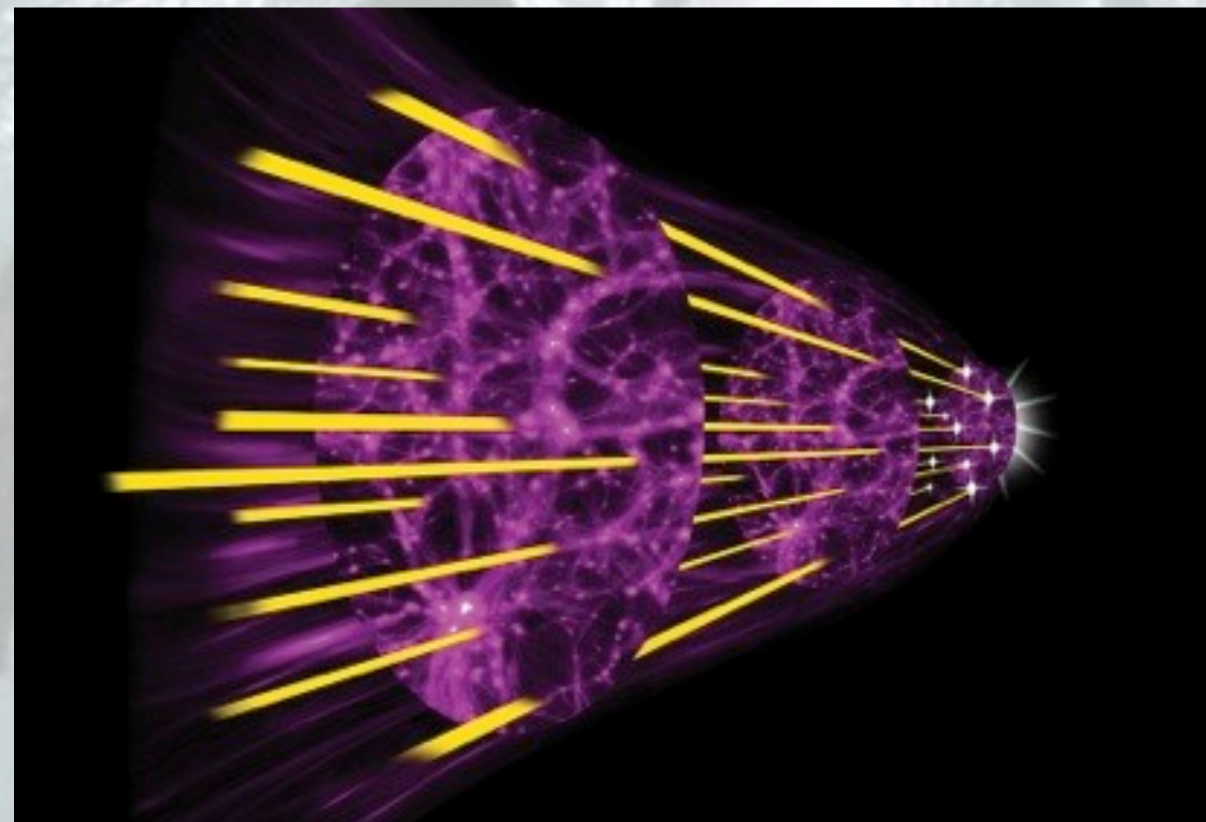


Status of QSO absorption cosmology

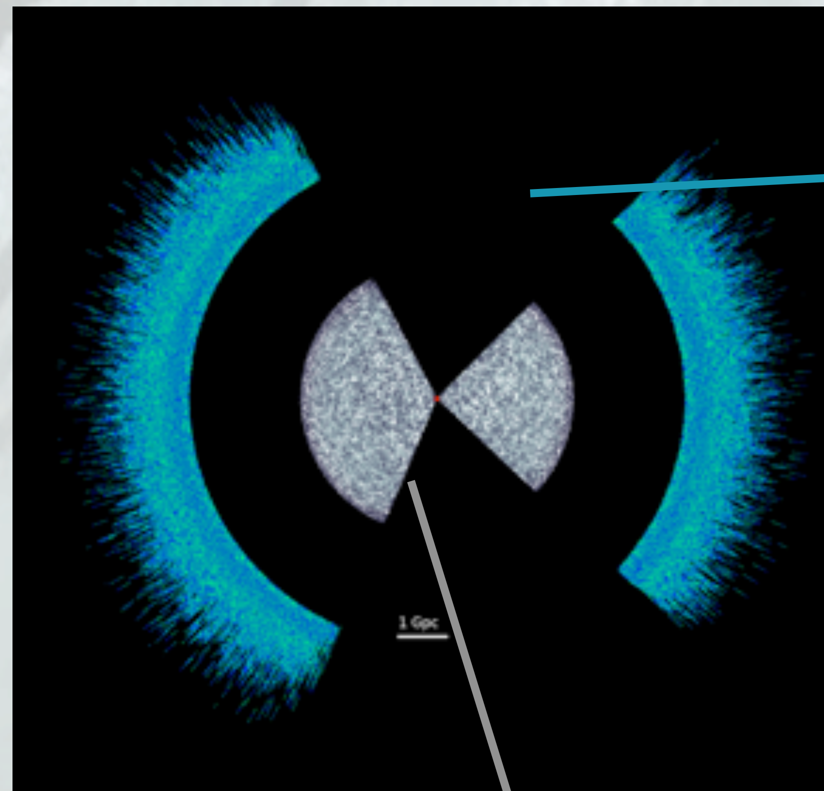
Mat Pieri

LAM QSO absorption cosmology team

- Lead: Mat Pieri
  - DESI absorption cosmology WG chair
  - DESI Science Committee member
  - WEAVE QSO survey lead
- Isabelle Paris
  - BOSS QSO science WG chair
  - QSO catalogue lead for BOSS, SDSS-IV (eBOSS, SPIDERS, TDSS), WEAVE
  - Early Career group lead fro SDSS-IV
- Michael Blomqvist
  - BOSS and eBOSS core team member
- Debopam Som
  - Public BOSS & eBOSS data. Likely external collaborator

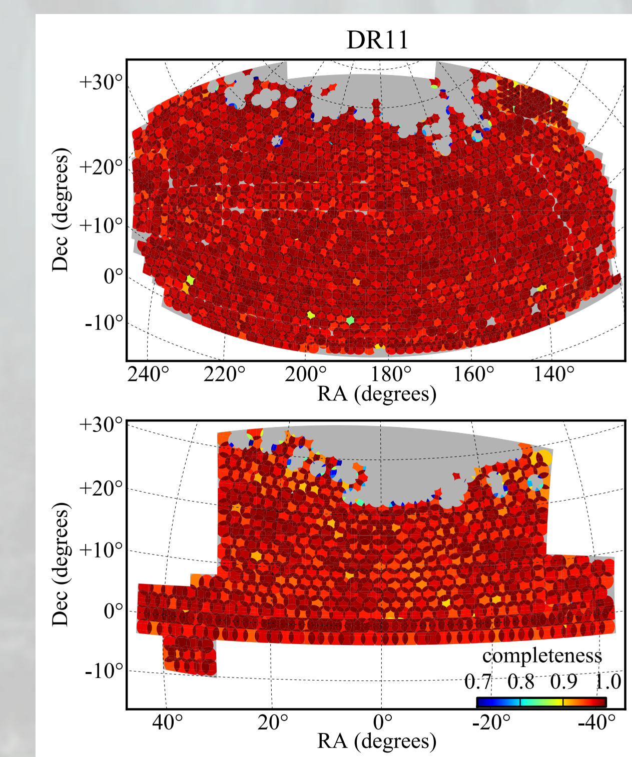
Current Science Status (BOSS)

- 1 of 4 in SDSS-III 2009-2014
- 10k deg^2
- Goal: 1.6M galaxies and >150k forest quasars
- Resolution R = 2000



2<z<3.4 forest

z<0.7 galaxies



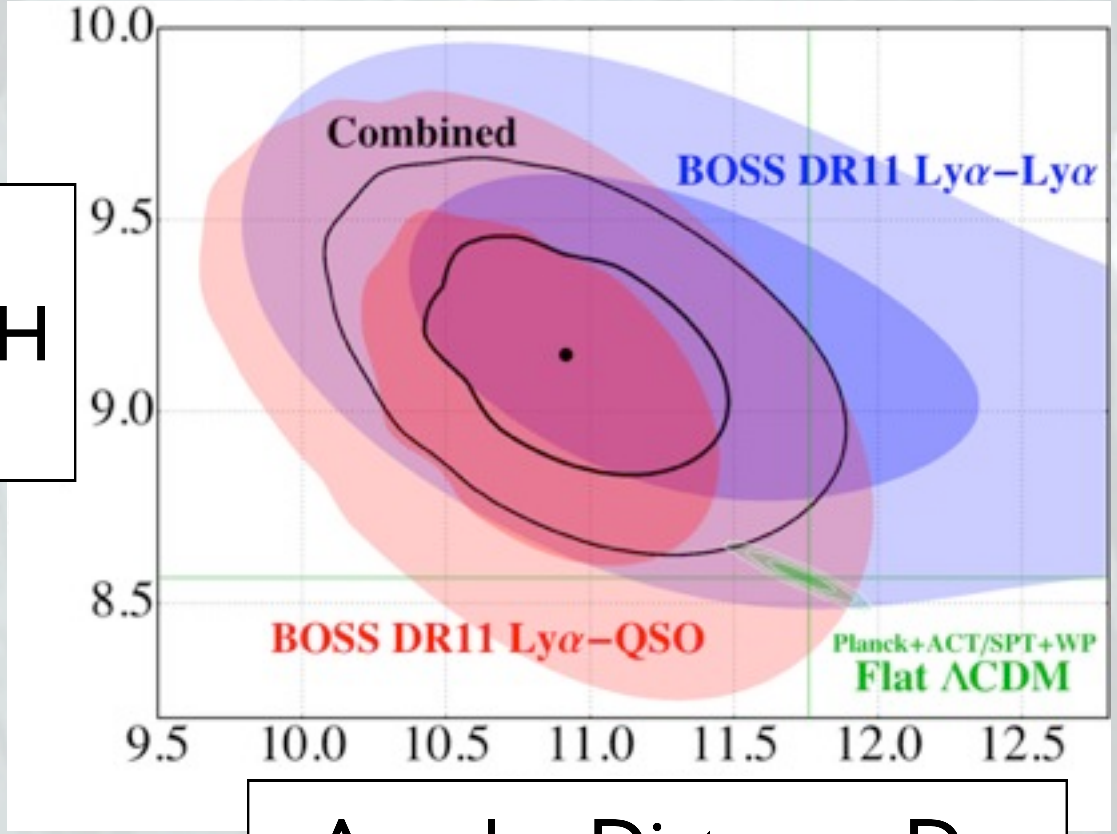
DR11 results out with ~140 QSOs

DR12 results on the way with 158k QSOs

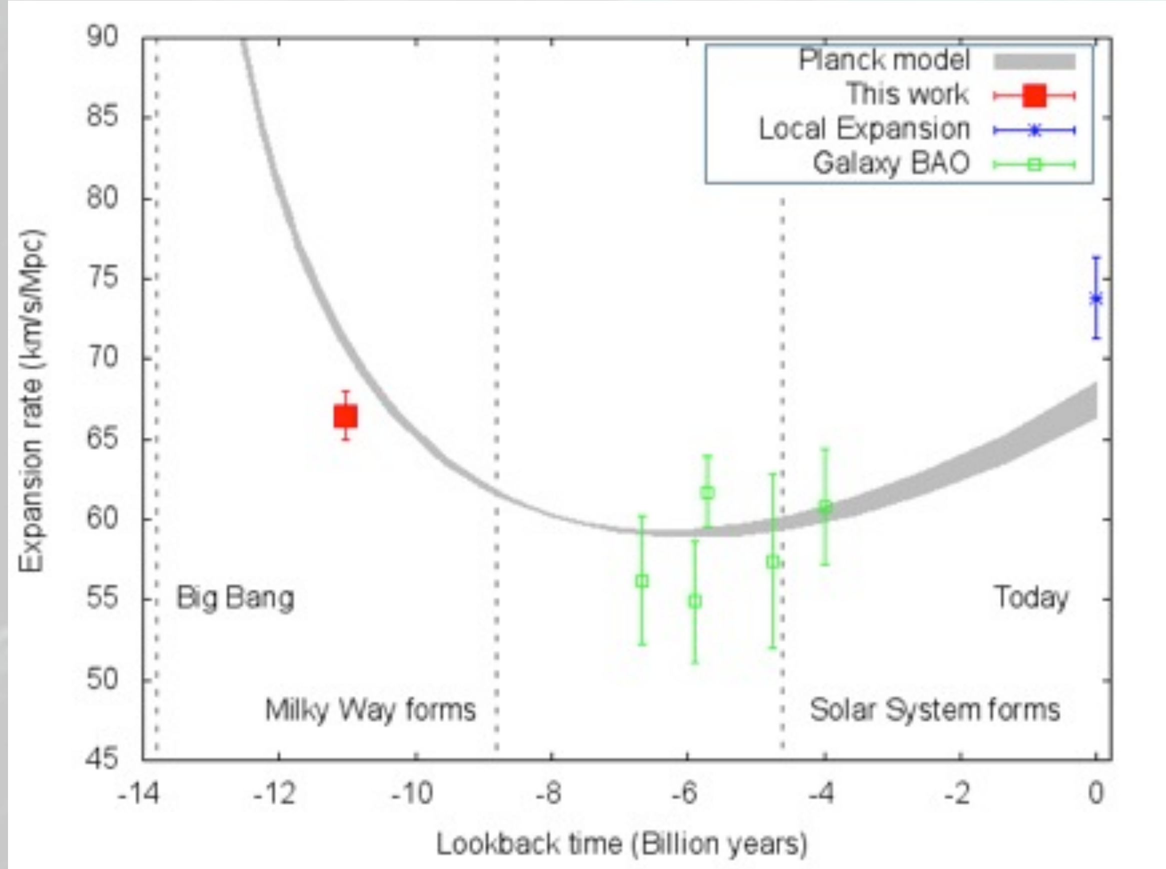
BOSS BAO Cosmology

2.5σ tension with concordance models based on Planck ...

$D_H = c/H$



Angular Distance, D_A



- Highest precision on expansion rate
- Highest z observation of BAO peak (at z ~ 2.3)
- 1st measurement of high-z deceleration

Delubac et al (2015)

Current Results

Stacking Lyα forest ⟹ high precision (0.5%) on metals

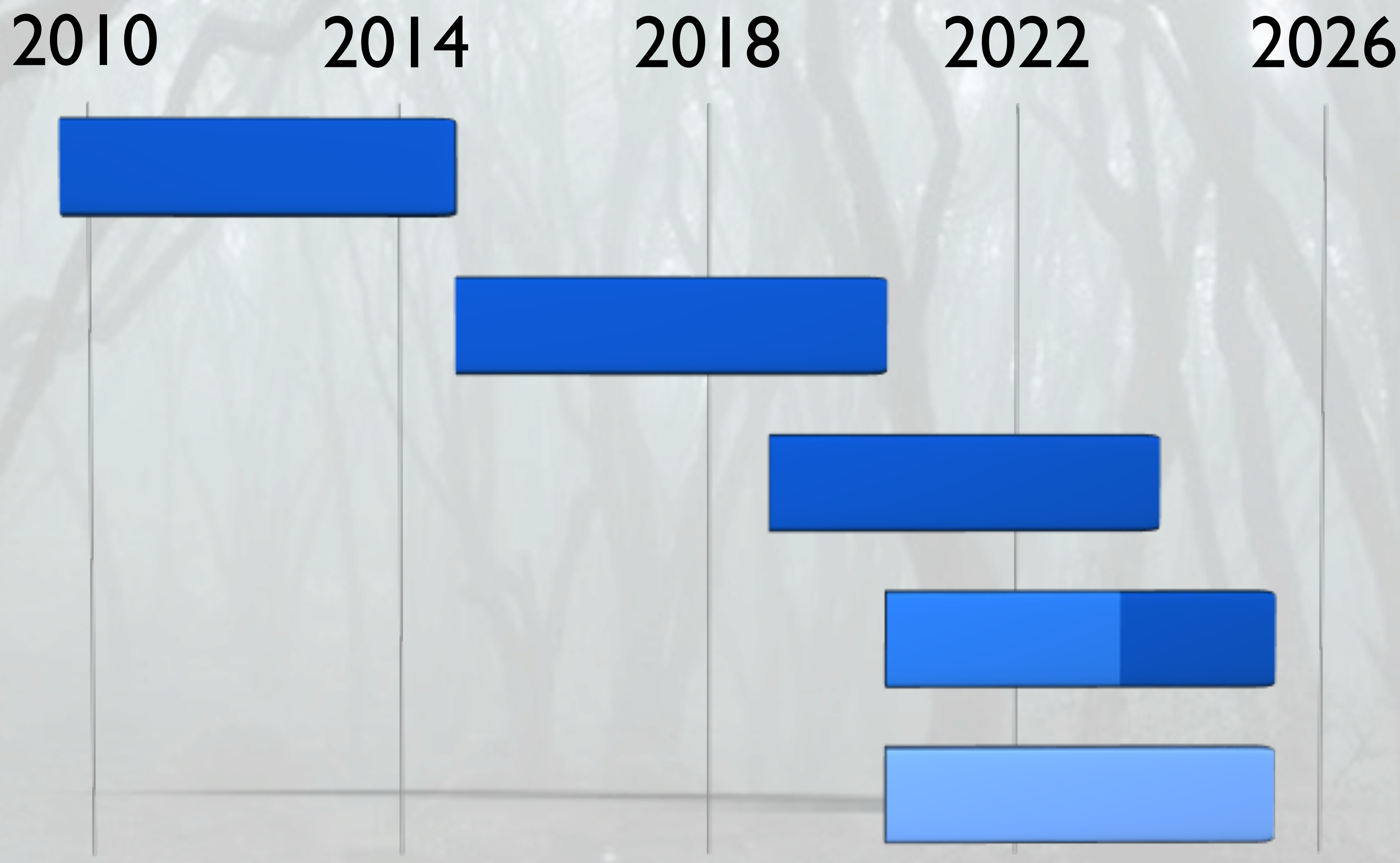
- Studied ~40k CGM regions and find signal of 30pc structure
- UVB, stellar populations + detailed outflow properties to explore

BAO from Lyα forest works

- ~2% precision on line of sight BAO
- Novel: redshift, type of probe ⟹ surprises?
- Perhaps seeing this in our 2.5σ tension with Planck
- Final BOSS DR12 results coming Lyα auto-corr (systematics tests)
- Lyα-QSO x-corr taking longer. Mostly due to lack of mocks

Growth of Massive IGM Surveys

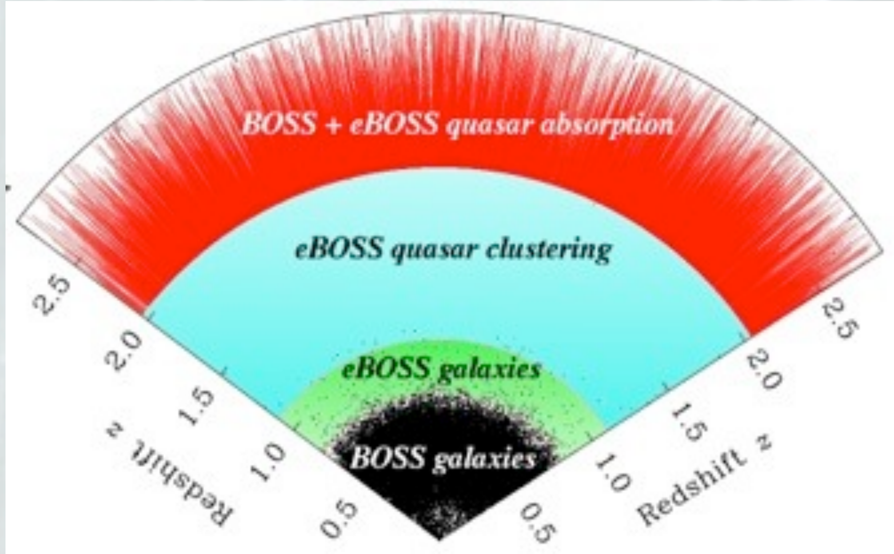
	N	Size
BOSS	160k	10k deg^2
eBOSS	220k	7.5k deg^2
WEAVE	400k?	10k deg^2?
DESI	600k	14k deg^2
4MOST	?	? deg^2

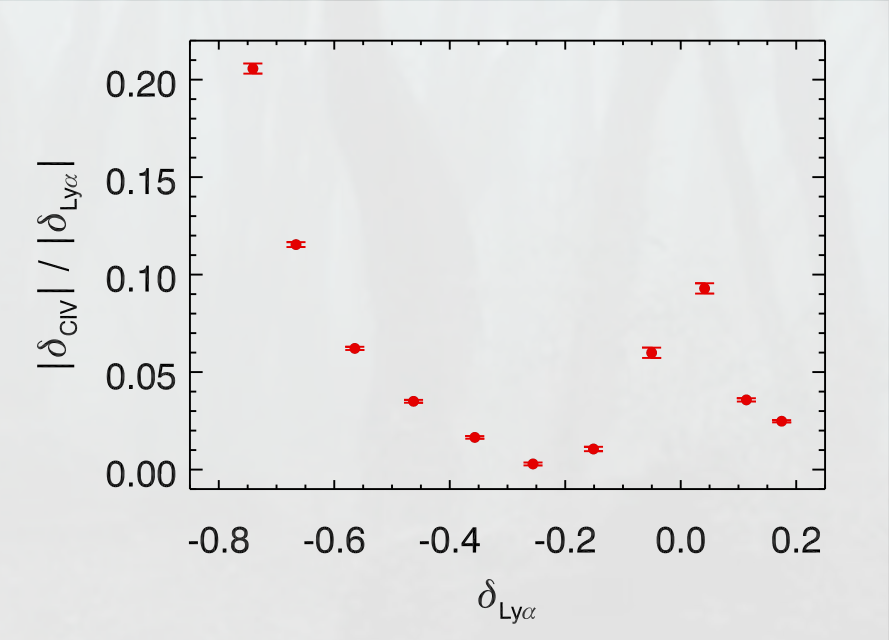


High-z quasars from N ~15k ⇒ N~0.6M

Growth of Massive IGM Surveys: eBOSS

- Improved Lyα forest BAO
  - 60k new spectra and 60k reobserved
- Fill z gap between galaxy and LyαF with clustering of ~600k quasars
  - No Lyα forest - use the carbon forest (MP 2014)
  - Weaker signal than LyαF offset by x4 more quasars compared to BOSS
  - ~2% QSOs & carbon: x-corr is 1%
- Effectively turns 1 survey into 3 surveys
- Metal BAO a contaminant of LyαF BAO





MP (2014)

eBOSS QSO Absorption Activities

- Current:
  - QSO catalogue building (Isabelle) and connection to target selection
- Planned:
  - Carbon BAO at $1.3 < z < 2$ (Michael, Mat)
  - Improved Lya BAO constraints at $z > 2$ (Mat, Michael)
  - Improved metal contamination (Debopam)
  - Void AP in absorption (Isabelle and Alice)
  - BAO AP + other corr function cosmo (Michael + ...)

Growth of Massive IGM Surveys: DESI

- Mayall (4m) - Kitt Peak Arizona, USA
- Resolution R=2000, 14k deg^2
- 4 x 15 min. 1 pass for z and 4 passes for absorption
- 600k high-z (Lyα forest) quasar spectra
- 1.4M intermediate-z quasar spectra
- 20M+ galaxies with z<1.6
- ~0.5% precision on high-z BAO in 2025
- Potential to cross-correlate quasars, galaxies and carbon absorption at z~1.5
  - Effectively ~6 BAO measurements
- X-Corr with Euclid

DESI QSO Absorption Activities

- Science Readiness Plan

DESI QSO Absorption Activities

11 Lyman α Forest and Other IGM Absorption Studies

11.1 Data and pipeline

Our use of intervening absorption involves treating the transmission in the spectral pixels themselves as a tracer of structure, therefore intergalactic medium (IGM) based cosmology is more sensitive to pixel level artefacts and systematics than other science goals in DESI. As a result our science preparedness involves more tests of the pipeline and data quality than any other science teams. The following science preparedness milestones will be addressed in close coordination with the Science Pipeline and Data working group. We expect these tasks to be on going with improving data models, and then science verification data.

Task 11.1: Set DESI tolerance to spectroscopic artefacts. We must asses the acceptable level of erroneous flux collaboration, sky subtraction residuals, the impact of the point spread function (or deviations from Gaussian in the resolution matrix), flux bias and fibre cross-talk. Furthermore we must determine knock-on effects in the pipeline reduction and survey planning.

Subtask 11.1.1: Quicksim tests. We will initially perform tests using model spectra with the quicksim codeset in addition to quasar spectral energy distributions, and pipeline reduction with and without mock forests in the spectra. We will then compare the two-point correlation functions and covariance that results. The mocks without forest data will be particularly useful for exploring what effects impact upon our primary analysis techniques: estimators of the two-point correlation function and error covariance. Once we have placed limits on our tolerance we will aid in the improvement of the pipeline, should this be necessary.
Target date: June 2016

Subtask 11.1.2: Full pixel-level simulation tests. In addition to tests with quicksim, we will also confirm the quality of the reductions after the above process, by applying our tests to the full pixel-level simulation of the DESI survey. This will allow us to confirm that the point-spread function has been characterised satisfactorily.
Target date: June 2017

Task 11.2: Provide astrophysical templates to pipeline working group. Toward the production of data models, we will aid the pipeline working group by assembling template spectra of damped Lyman-α systems, metal absorption, broad absorption line quasars and spectra of objects incorrectly identified as quasars (in coordination with the target selection working group).
Target date: December 2015

Task 11.3: Contribute to pipeline quasar identification. All high redshift quasars will be observed in all five passes, so these quasars (and any quasar targets requiring re-observation) must be identified between passes.The working group will aid in the production of a quasar identification (and redshift) algorithm, which will be integrated into the pipeline reductions.
Target date: December 2015

Task 11.4: Define sample. Choices such as the inclusion of damped Lyman-alpha quasars, whether to include input from the Lyman-beta forest, the desirable redshift range for quasars of a given redshift must be justified.
Target date: December 2016

Task 11.5: Determine optimal quasar co-addition or analysis given potential variability between observations. Observed quasars may vary to a significant extent between observations of the same field (which may be years apart), as a result combining these observations into a naive co-added spectrum may introduce biases in the absorption field. The working group must assess the optimal approach to combining multi-epoch quasars observations either at the co-add stage or

at the analysis stage
Target date: June 2016

11.2 Analysis Methods

Task 11.6: Develop/refine of analysis code.

Subtask 11.6.1: Develop and make public a continuum fitting code. One of the basic steps in Ly-α analyses is the *continuum fitting*, necessary to go from the observed quasar spectrum to the cosmological fluctuations that we are interested in. While some Ly-α analyses are very sensitive to this step (i.e., PDF studies), most clustering analyses are quite insensitive, as shown in recent BOSS analyses. Even though each specific analysis might use a different continuum fitting method, the working group would benefit from having a baseline fitting code publicly available.
Target date: mid-2019

Subtask 11.6.2: Develop estimators of the flux correlation function and covariance matrix. In order to address the effect of potential systematics on the data, we would like to see their impact on our final measurement, the large scale clustering.
Target date: mid-2019

Subtask 11.6.3: Model large scale clustering measurements. In order to extract cosmological information from the large scale clustering results (mainly BAO scale) we need to develop an accurate model and a fitting code. This model will probably be based on perturbation theory, with the broadening of the BAO peak and potentially deviations from linear theory on small scales. It should also be able to describe and fit other large scale effects, like fluctuations of the UV background, correlations with metal lines or the distortion caused by the continuum fitting step.
Target date: end of 2019

Subtask 11.6.4: Model non-linearity of small scale clustering measurements. The one-dimensional power spectrum of Ly-α provides competitive constraints on the small scale clustering of the primordial density field. On these scales the clustering can not be modeled with a perturbative approach, and the measurement has to be directly compared to a fully non-linear model based on hydrodynamical simulations, discussed in Task 11.9. The cosmological constraints obtained from this analysis will be combined with those from the rest of the collaboration.
Target date: end of 2019

Subtask 11.6.5: Develop Fisher-matrix forecasts.
Target date: Done

Subtask 11.6.6: Diagnostics of potential systematics. Several potential sources of systematic errors exist, and will be tested with data models as described in Task 11.1. This task will be complemented with tests on real observed data, which are particularly valuable where the systematics are astrophysical in nature such (e.g. metal line contamination). For this purpose, will design and refine a set of further set of diagnostic tools such as spectral stacking, null tests, data splits. These will be applied to public BOSS, eBOSS data in preparation for DESI analyses.
Target date: end of 2018

11.3 Simulations and Analysis Mocks

Task 11.7: LyaF mocks suitable for DESI LyaF cosmology goals.

Subtask 11.7.1: Develop/refine production of realistic overdensity skewers for BAO mocks. The approach to producing density skewers defined by the BOSS collaboration is currently

considered sufficient for our needs, but further refinement will be necessary (in particular, accommodating a greater density of skewers). While this task will be addressed sufficiently in mid-2016, we are likely to continue to refine these mocks until the end of 2019 (in part due to improved computing resources).
Target date: mid-2016

Subtask 11.7.2: Develop mocks capable of reproducing the quasar-forest cross-correlation for BAO mocks. Current Ly-α forest BAO mocks data produced by the BOSS team include no correlations between quasar positions and the intervening absorption, so they are inadequate for studying the quasar-Ly-α cross-correlation. Since this correlation is a key goal for the working group we are working to correct this for DESI mocks.
Target date: mid-2106

Subtask 11.7.3: Assess requirements for broadband power mocks. Does we require dedicated mocks or can we achieve the required small scale power by refining BAO mocks?
Target date: mid-2016

Subtask 11.7.4: Refine addition of astrophysical signatures in mocks.
Target date: mid-2017

Task 11.8: Maintain awareness of the latest relevant IGM science developments. While the measurement of BAO in absorption is thought to be resistant to the details of IGM physics (subject to ongoing testing in the mocks above), this is not true of the interpretation of structure on other scales. Extracting cosmology form the broadband correlation of absorbers (particularly on smaller scales and typically along line of sight) requires an understanding of IGM temperature, pressure, hydrogen/helium reionization, fluctuations in extragalactic background radiation, outflows, high column density lines and metals. In light of this we must stay up to date with the latest advances in the IGM science community.

Subtask 11.8.1: Presence at IGM science meetings.
Target date: ongoing

Subtask 11.8.2: Workshop bringing together the working group and the IGM science community.
Target date: mid-2016

Task 11.9: Coordinate simulation activities. More than one team will be performing hydrodynamic simulations associated with this working group. These are necessary in order to marginalise over intergalactic medium nuisance parameters. In order to maximise the scientific output of this working group it is desirable that these teams work in a collaborative manner.
Target date: end of 2016

Subtask 11.9.1: Develop common parameter grid. To this end, we are developing a working group simulation parameter grid, allowing us to make effective use of computational resources by covering this space in a coordinated manner (after some concordance tests). This includes both cosmological and simulation parameters such as box side and resolution, As part of fixing this parameter grid we must build consensus on what parametrisation to employ (e.g. $z = 0$ standard or $z >$ k-bin modulation).
Target date: end of 2016

Subtask 11.9.2: Standardize simulation/analysis interfaces. We will generate a standardised interface between working group and simulation activity, by setting a standard simulation output format and a χ^2 test tool to compare these outputs with the observed forest power.
Target date: end of 2016

11.4 Survey Planning

Task 11.10: Contribute to schedule planning for repeat tiling. As stated in Section 11.1, only a subset of those objects targeted as quasars will be re-observed in repeat tiling and all quasar targets must be analysed ahead of subsequent targeting of those fields. A number of survey planning tasks relevant to this working group arise as a result. These survey planning tasks are directly tied to pipeline tasks.

Subtask 11.10.1: Assess time required between passes to test then routinely apply quasar identification and redshift measurements. This task is closely connected to Task 5.16 and also requires Task 5.13.
Target date: January 2018

Subtask 11.10.2: Set signal-to-noise requirements. Varying degrees of limiting signal-to-noise ratio (SNR) will be required on quasar targets, which in turn indicates the number of survey passes needed on those targets. In order of increasing demands we must; confirm a quasar, determine redshift with sufficient precision, and finally perform absorption cosmology.

For the latter, we plan to obtain the maximum SNR possible by re-observing these quasars in every pass. However, what is the minimum SNR considered acceptable for absorption cosmology? This limit is expected to be met by all quasars observed in all passes, but further tests with degraded BOSS data will be performed to confirm this.

We must further determine what SNR is required in order to identify which objects are not quasars, and which quasars have sufficiently precise redshifts for quasar clustering BAO studies. If multiple passes are required to obtain quasar confirmation and redshifts this must be taken into account as an additional fiber overhead to the survey. These questions will be addressed with the models described in Section 11.1.

This task is closely related to Task 5.33, and will be finalised on the same time scale.
Target date: June 2019

Subtask 11.10.3: Assess other re-observation criteria. The value of a quasar for absorption cosmology must be addressed by this working group. Do we wish to (continue to) re-observe broad absorption line quasars once they are identified and their redshift is determined, even though they are not desirable for absorption cosmology? What is the blue-end quality of the spectrographs and what limit does this entail for our desirable redshift range for absorption cosmology. Do we wish to set SNR requirements on quasars with $1.3 < z < 2.1$? These quasars are not viable for Ly-α cosmology, but may be used for triply ionized carbon (CIV) absorption BAO cosmology. We anticipate that the eBOSS team will demonstrate whether this cosmology is sufficiently valuable.
Target date: December 2016

Task 11.11: Plan early science.

Subtask 11.11.1: Determine when a sufficiently large sample is obtained in order to start addressing our main science objectives. It will take some time for a large survey of quasars to build up both in terms of number and SNR. What easily science can be achieved in this context? This will being with Task 5.12 and the be completed for Task 5.14.
Target date: June 2017

Subtask 11.11.2: Determine what early science might we pursue making use of the peculiarities of science verification data. In particular what might we achieve with high signal-to-noise fields. In line with Task 5.29, working group projects will be defined, and then in line with Task 5.30 any selected working group projects will enter the program. This process will take place throughout 2017.
Target date: January 2018

11.5 Data, catalog, code & documentation dissemination

Task 11.12: What working group related data, value-added catalogs, simulations, mocks and code should be shared both internally and externally.
Target date: End of 2018

Task 11.13: Determine what internal documentation is needed. This will facilitate WG expansion and in some cases may become draft text for publications.
Target date: End of 2016

11.6 Milestones for Lyman α Forest

Milestone M11.1: End of 2015 — Templates provided to pipeline WG

Milestone M11.2: End of 2015 — Signal-to-noise requirements established

Milestone M11.3: End of 2016 — 1st (partial) pass at tolerance to spectroscopic artefacts

Milestone M11.4: End of 2016 — BAO mocks with quasar-forest cross-correlations

Milestone M11.5: End of 2016 — Set common parameter grid for simulations

Milestone M11.6: End of 2016 — Defined value of carbon forest BAO intermediate and requirements of intermediate redshift QSOs

Milestone M11.7: End of 2017 — Plan science from science verification data

Milestone M11.8: End of 2017 — Plan early science from survey mode data

Milestone M11.9: End of 2017 — 2nd (complete) pass at tolerance to spectroscopic artefacts

Milestone M11.10: End of 2018 — Developed broadband power mocks (potentially as a refinement to BAO mocks)

Milestone M11.11: End of 2019 — Defined analysis and diagnostic methods

Milestone M11.12: End of 2019 — Test previous 5 milestones and the data flow between them on public BOSS/eBOSS data

Milestone M11.13: End of 2020 — Early science using science verification data

Milestone M11.14: End of 2021 — Early science using science survey mode data

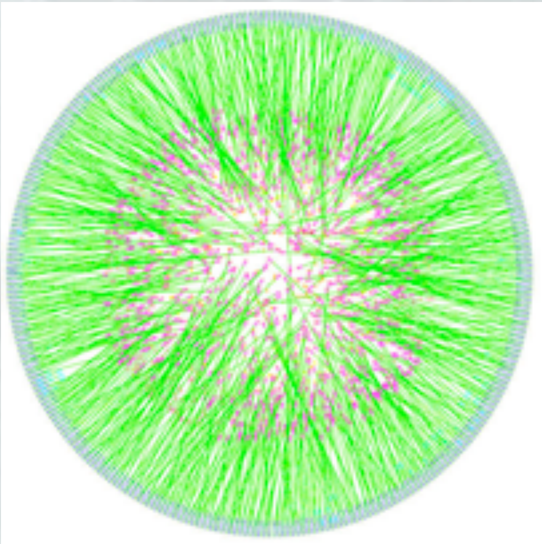
Milestone M11.15: End of 2022 — First DESI LyaF BAO science paper complete

Milestone M11.16: End of 2022 — First DESI LyaF broadband power science paper complete

DESI QSO Absorption Activities

- Science Readiness Plan
- Current:
  - WG planning (e.g. writing the SRP)
  - QSO mocks: tests of 1st pass (15 min) information for faint (g~23) QSOs for z-precision on QSO clustering and z>2 ID for repeat obs
- Planned
  - QSO fitter and catalogue
  - Test impact of DESI spectro artefacts on correlation function (on going)
  - Define carbon value and impact on intermediate-z S/N requirements
  - Cross-correlate carbon with QSO z and ELG z
  - Cross-correlate with Euclid at high-z

Growth of Massive IGM Surveys: WEAVE



- William Hershel Telescope (4m) - La Palma
- Access to all INSU labs
- >400k Lyα (z_Q>2.1) quasar spectra over 10k deg^2
- Novel target selection from J-PAS (efficient and directed)
- Resolution R=5000 or 20000 (4040-4650 Ang)
- BAO: 4x BOSS at z>2.1
  - < 1% error on BAO in 2023
- High S/N spectra for IGM properties
- Status: Challenging external review: 'not sufficiently different from DESI', 'potential time slip', 'J-PAS targeting data uncertainty'
- Entered 6 month 'refocus and rescope': narrow z focus

Growth of Massive IGM Surveys: WEAVE

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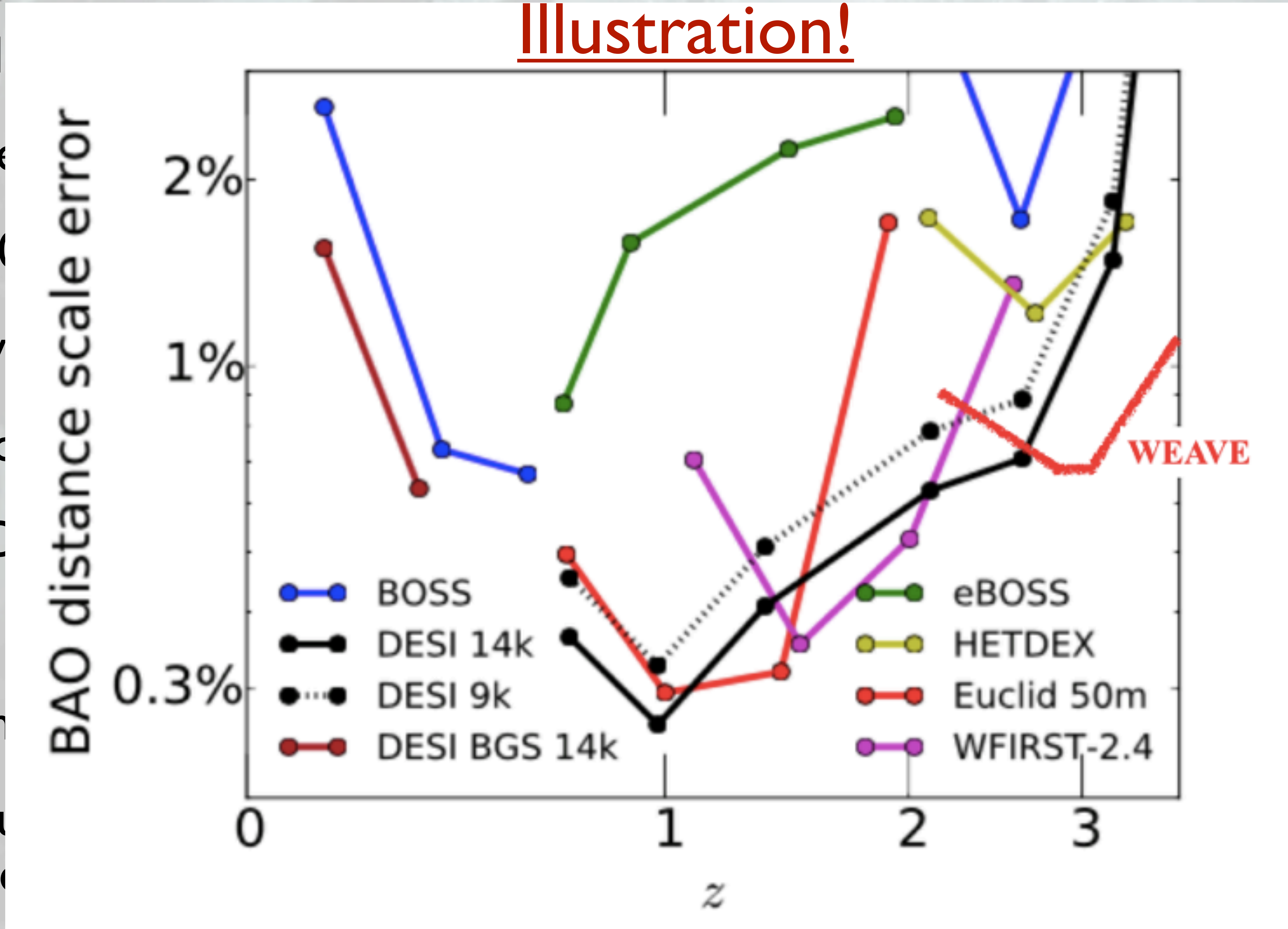

- Entered 6 month 'refocus and rescope': narrow z focus

WEAVE QSO Absorption Activities

- Current:
  - QSO mocks for WEAVE simulations
  - QSO mocks for J-PAS projections
  - Definition of desired WEAVE survey to the g~23 limit based on and J-PAS targeting quality at optimal redshift
- Planned:
  - Refine targeting using other data
  - Define survey plan and targets
  - BAO Lyα auto and QSO-Lyα cross-correlation
  - Cross-correlate with J-PAS and Euclid imaging