Accelerated expansion of the Universe through DESI

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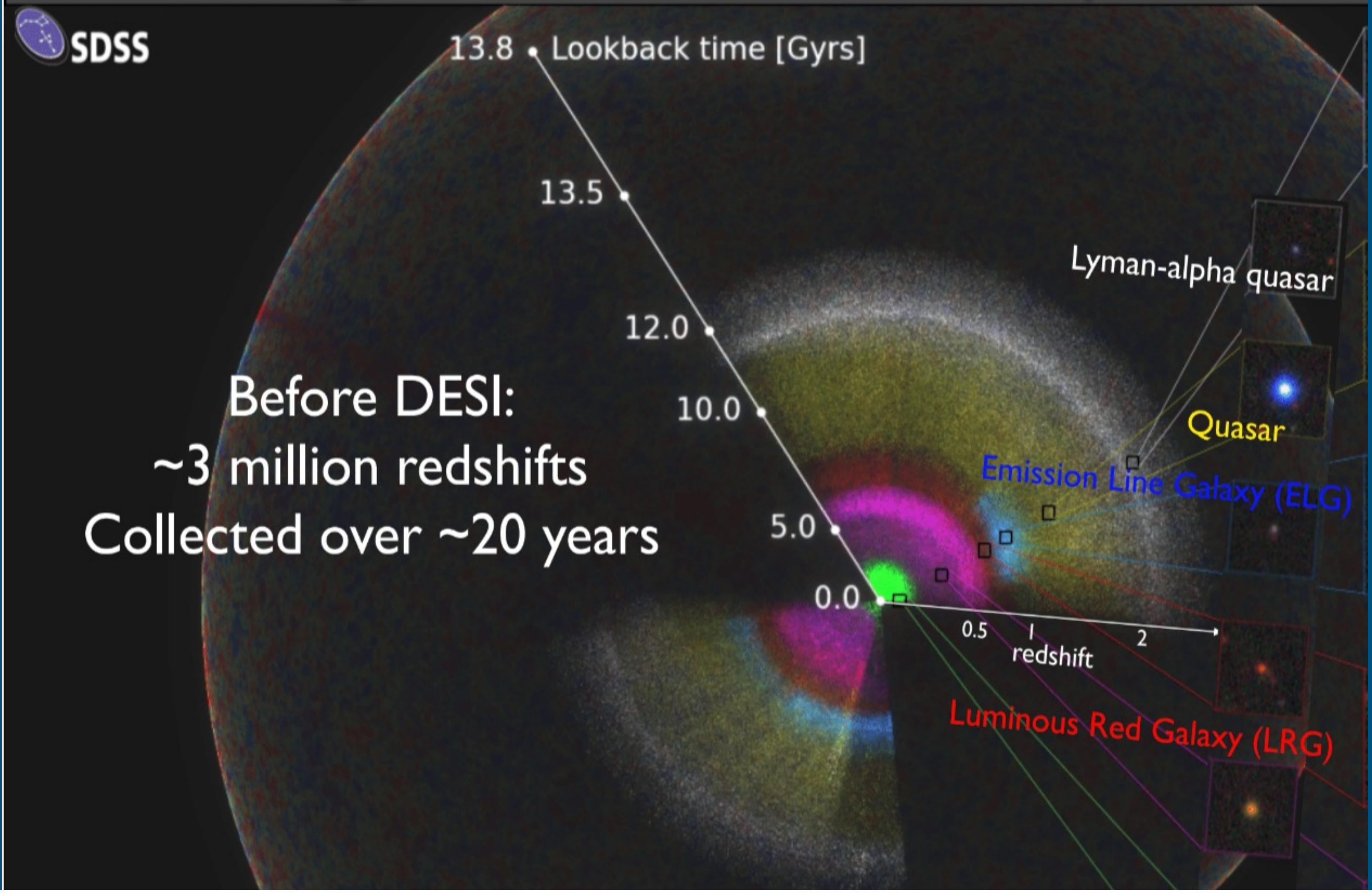
RPM, LBNL
Nov 3 2022

DARK ENERGY SPECTROSCOPIC INSTRUMENT

BERKELEY LAB
Lawrence Berkeley National Laboratory

OHIO UNIVERSITY

Large-scale Structure Maps



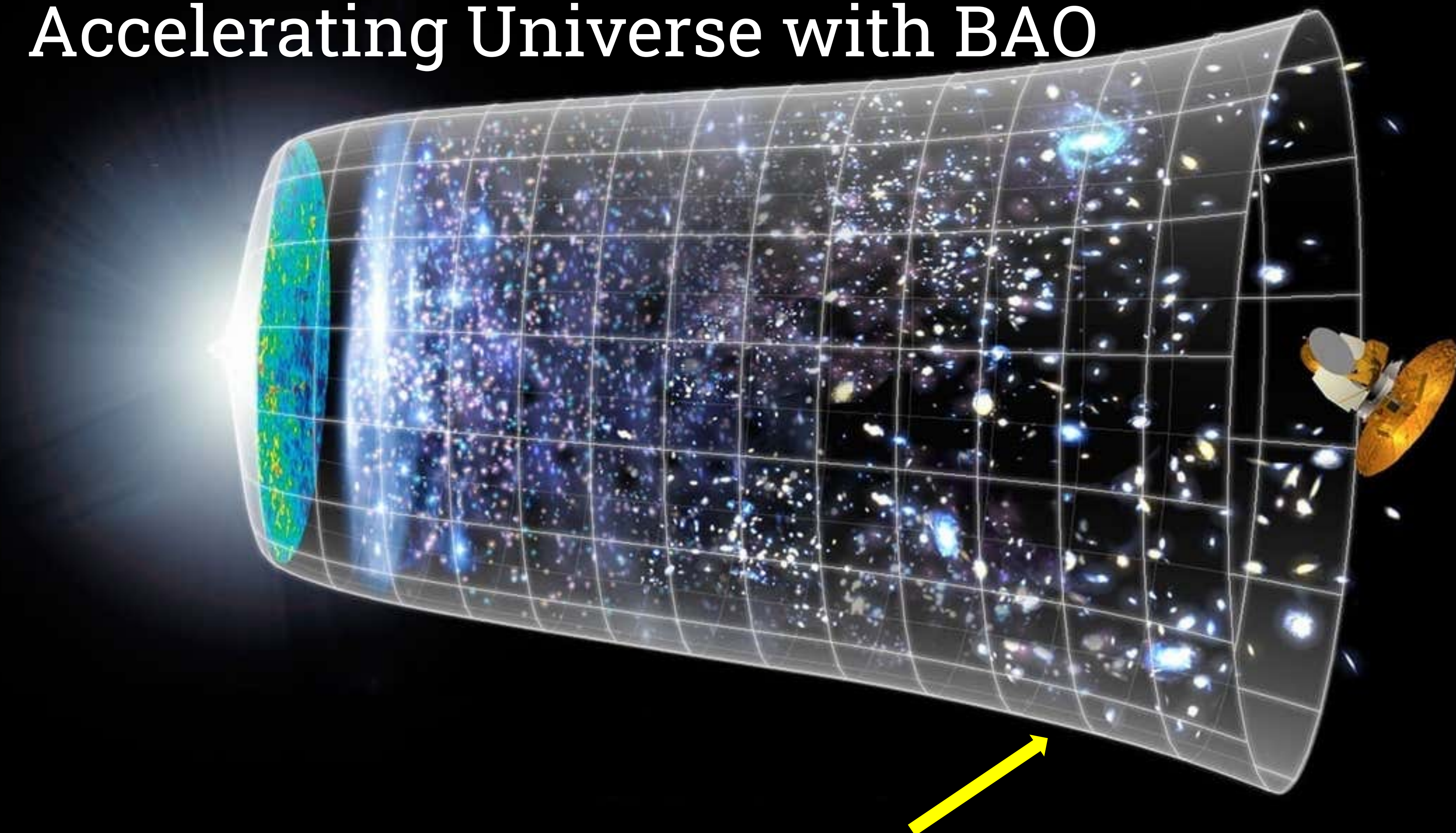
Science drivers of LSS

- Why does the expansion of the Universe accelerate?
- What is the nature of gravity on the cosmological scale? What is dark Matter?
- What was cosmic inflation like?
- More recently, what is the source of the tensions in s8 and H0?
- And many more

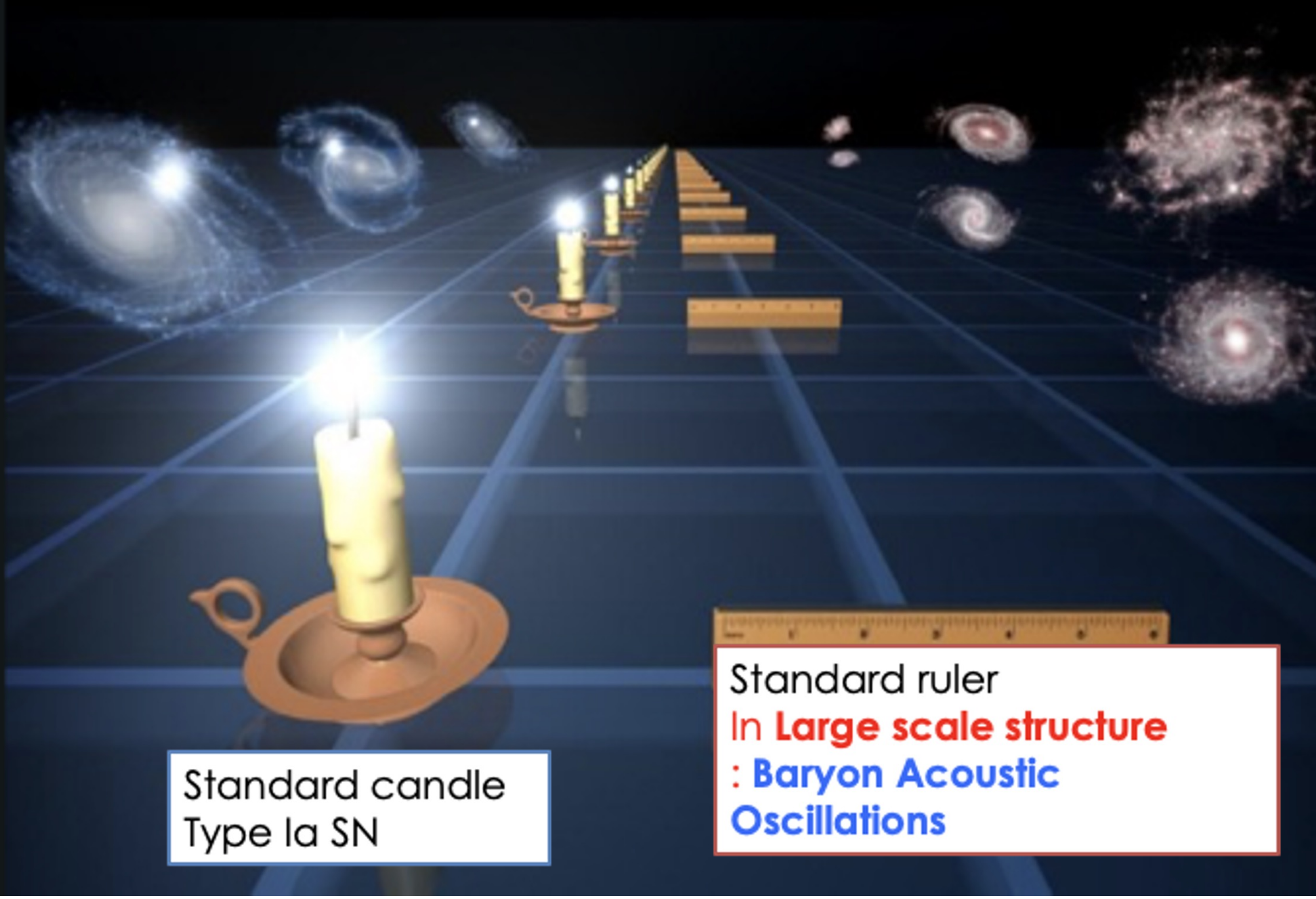
Outlines

- Why does the Universe accelerate? -> DESI will use the BAO feature.
- What is the nature of gravity on the cosmological scale? What is dark Matter?
- What was cosmic inflation like? -> Can use the very large scale, but after beating systematics
- More recently, what is the source of the tensions in s8 and H0?
- And many more

Accelerating Universe with BAO

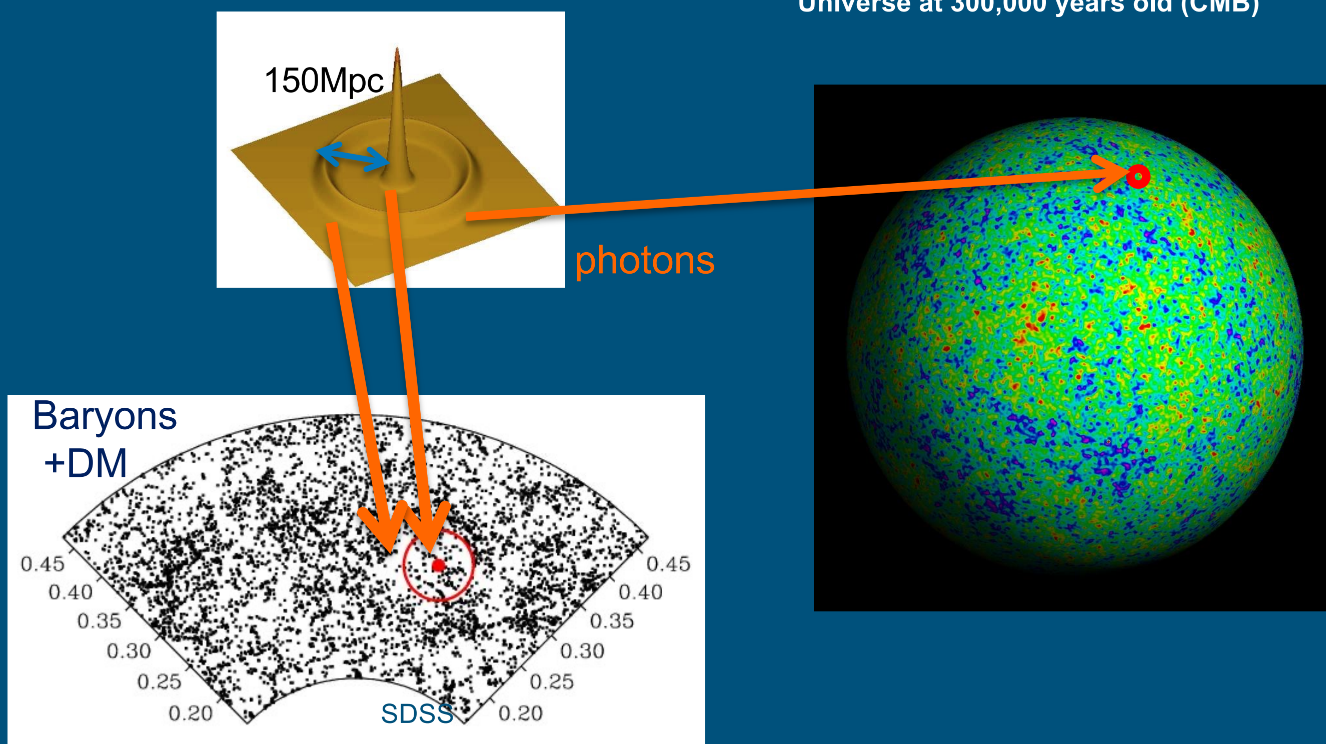


BAO as a Geometric Dark Energy probe



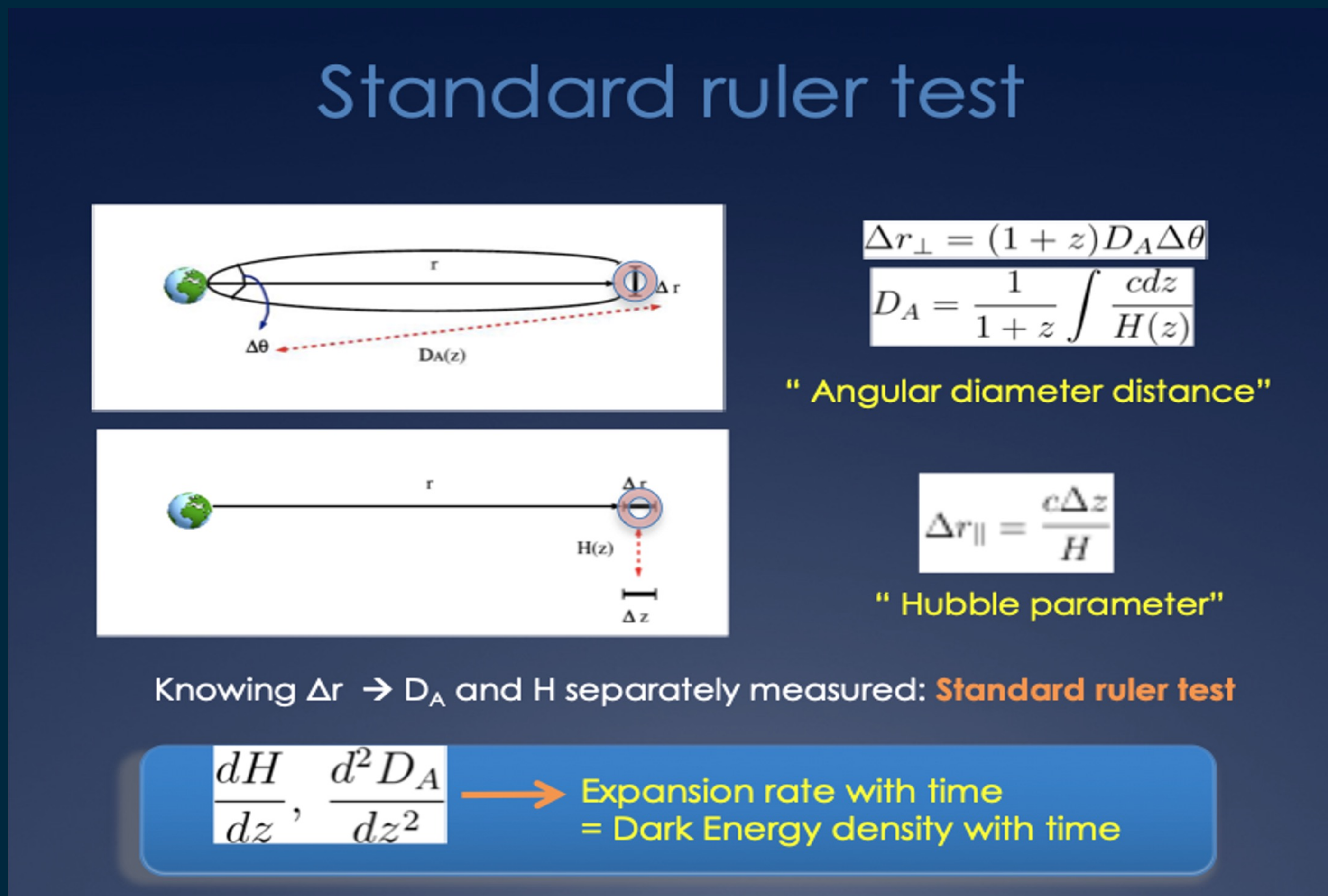
Baryon Acoustic Oscillations (BAO)

Universe at 300,000 years old (CMB)

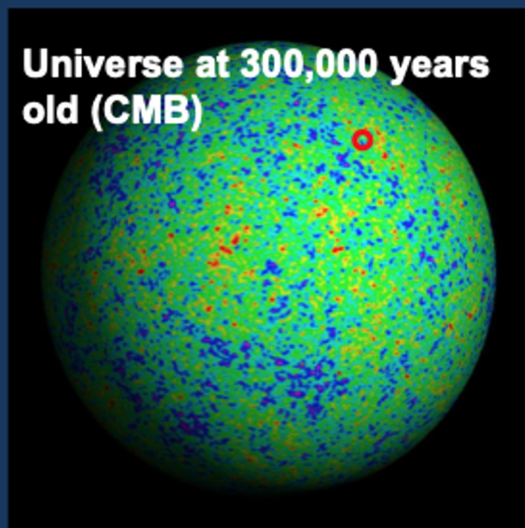


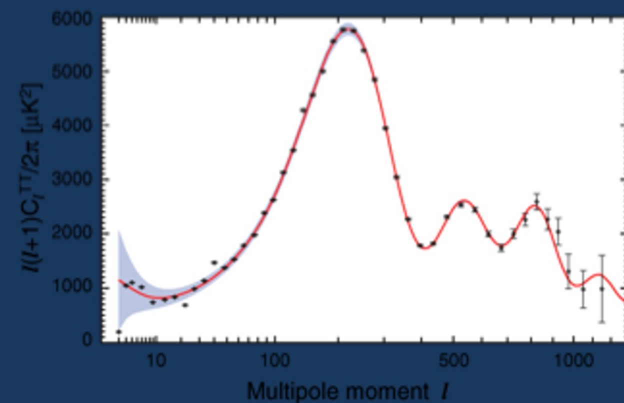
Galaxy surveys (e.g., SDSS, 2dF, WiggleZ, 6dF)

Premise: There is a feature with a known physical scale



BAO calibrated by the CMB



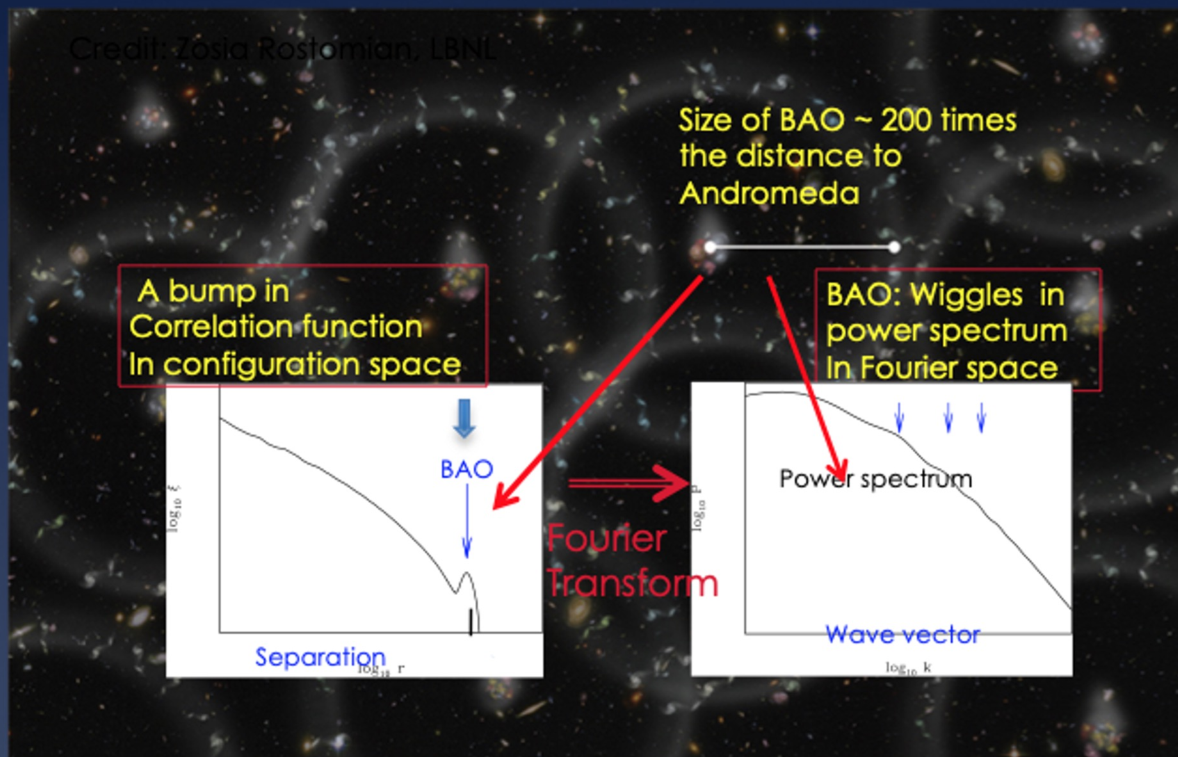


The shape of the initial power spectrum as well as the size of the BAO is precisely determined by analyzing CMB

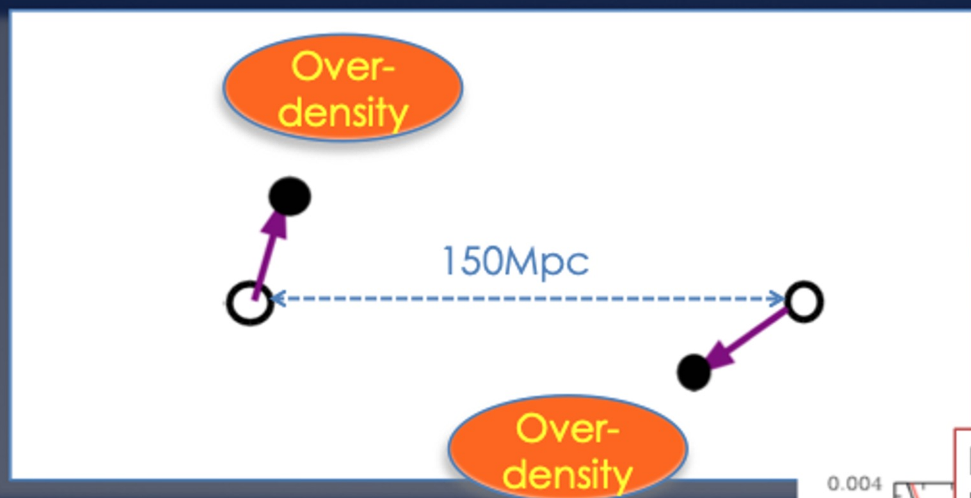
Sound horizon scale

~150Mpc -> 153.19 Mpc

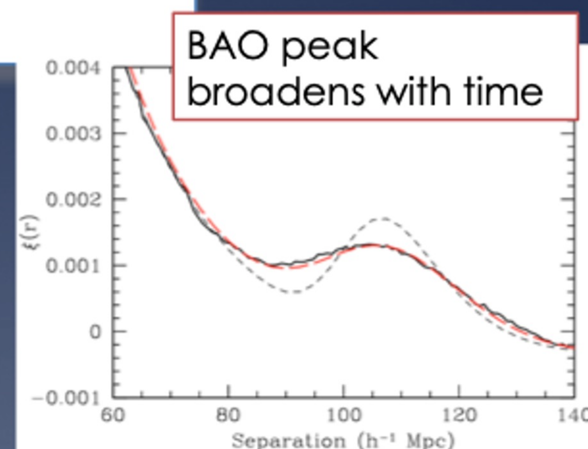
BAO measured in galaxy surveys



BAO broadening (damping)



Displacement of mass elements
During structure formation
(e.g., Eisenstein, HS, White ApJ. 2007)

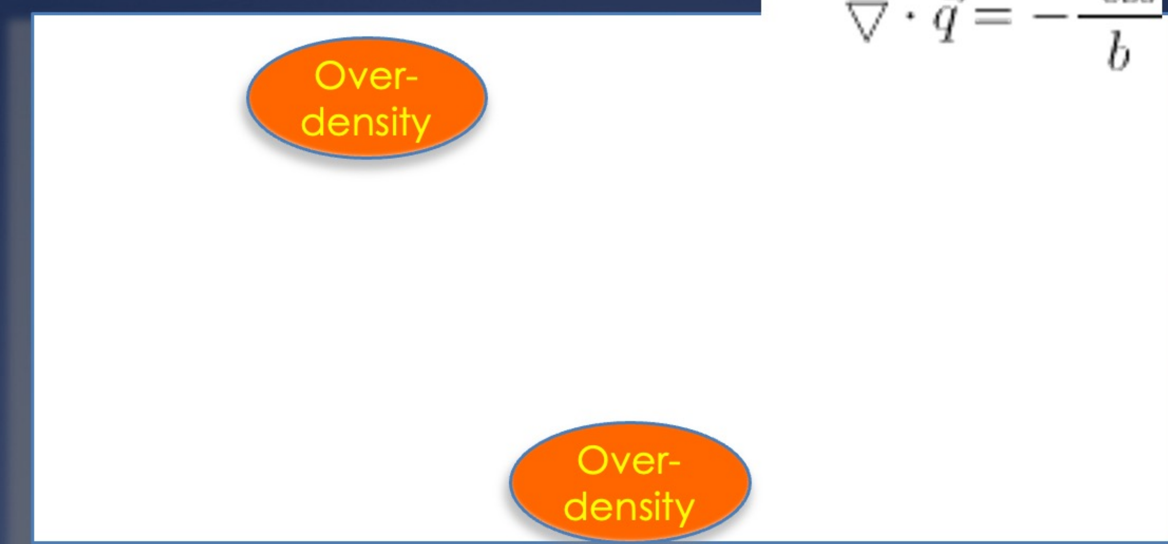


BAO reconstruction
(Eisenstein, H-JS, Sirko, & Spergel 2007)

Observed (nonlinear) density fields

Apply the linear continuity equation backward

$$\nabla \cdot \vec{q} = -\frac{\delta_{\rm obs}}{b}$$



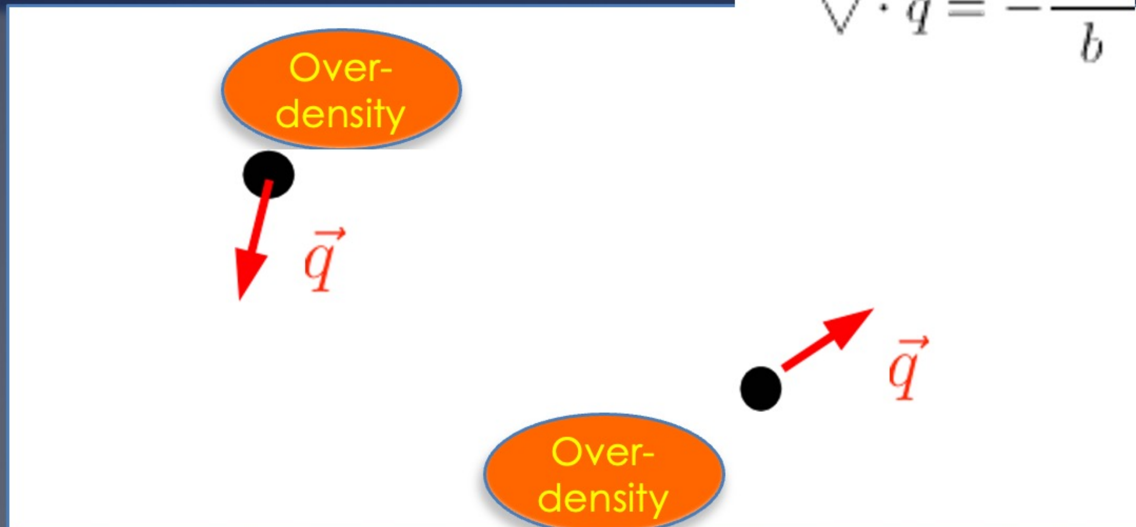
BAO reconstruction
(Eisenstein, HS, Sirko, & Spergel 2007)

Observed (nonlinear) density fields

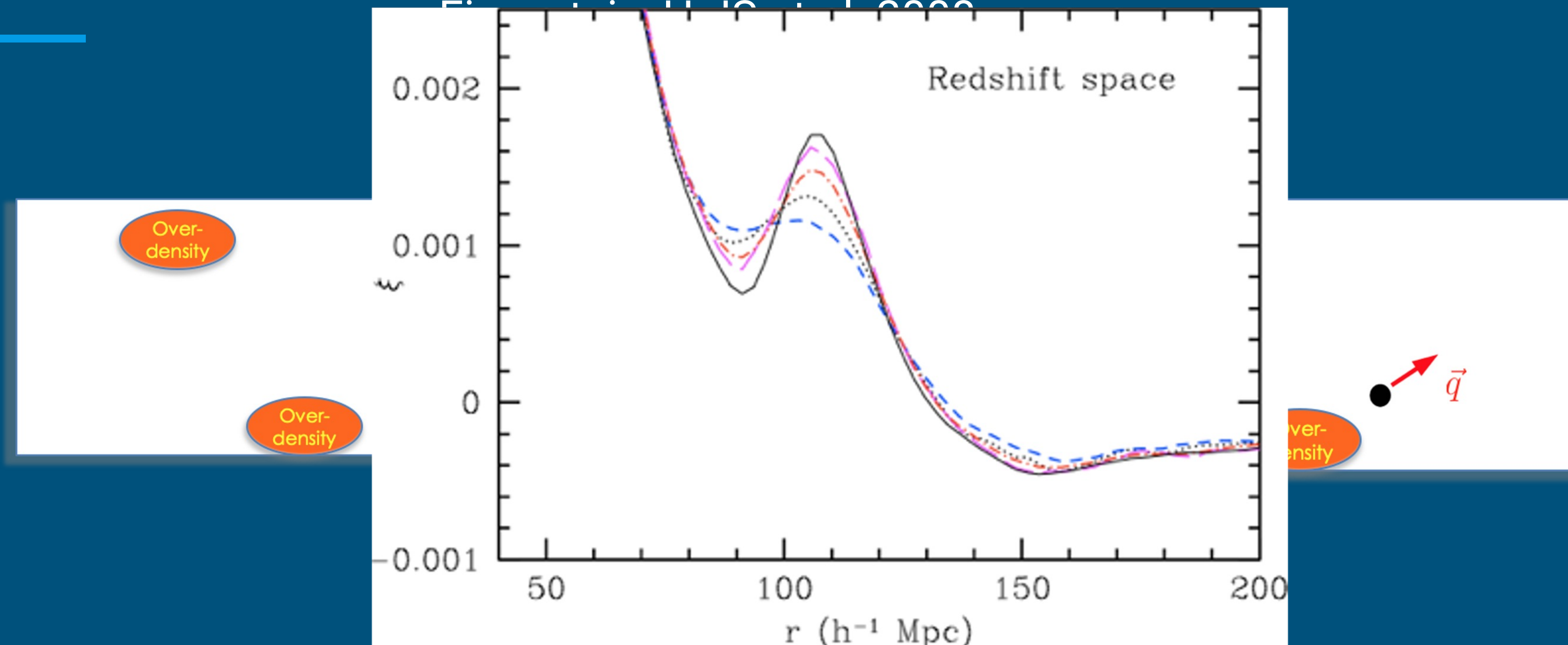
Apply the linear continuity equation backward

Move mass/galaxies BACK!

$$\nabla \cdot \vec{q} = -\frac{\delta_{\rm obs}}{b}$$

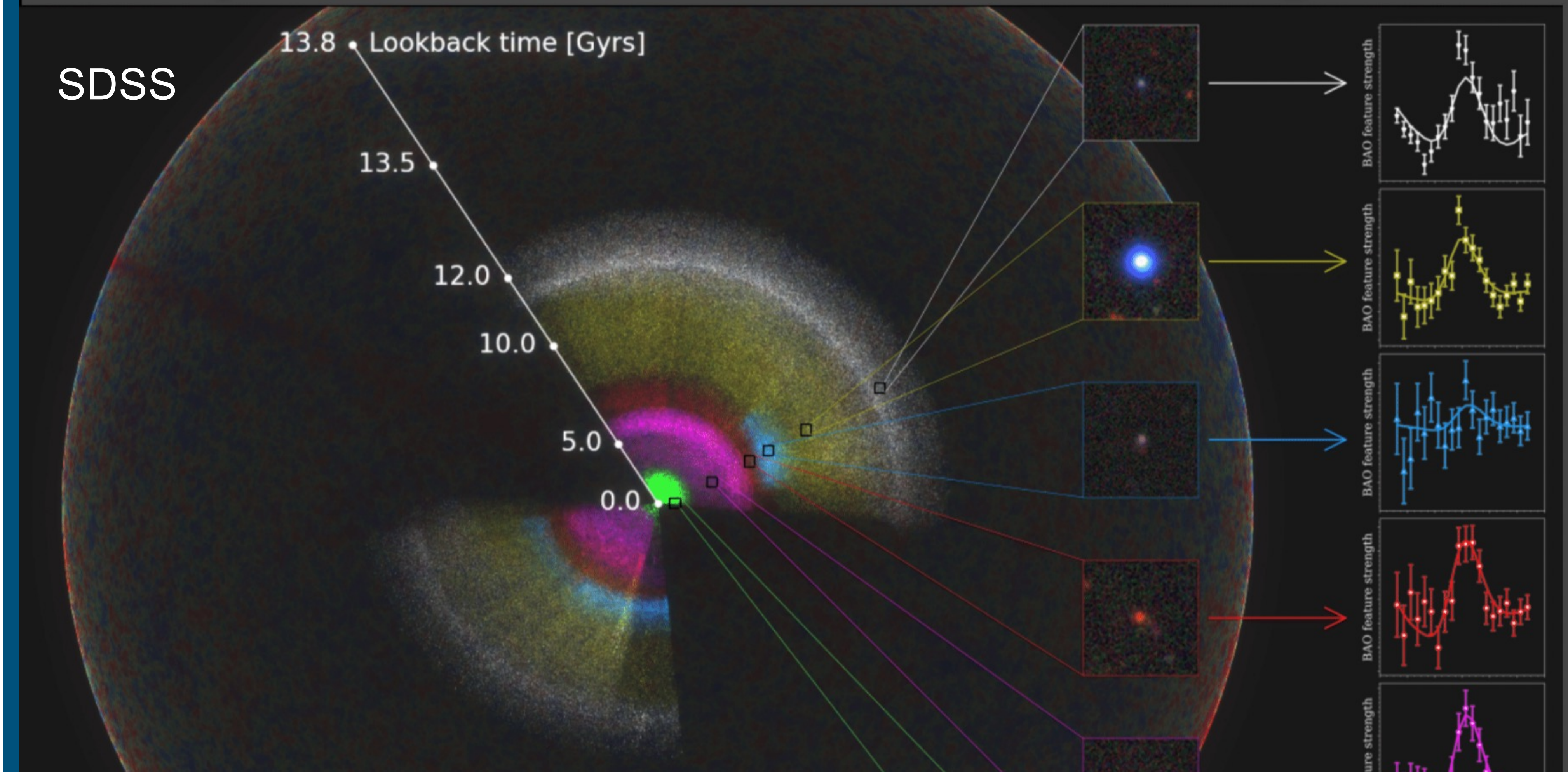


Good news!
The density field (or BAO) reconstruction

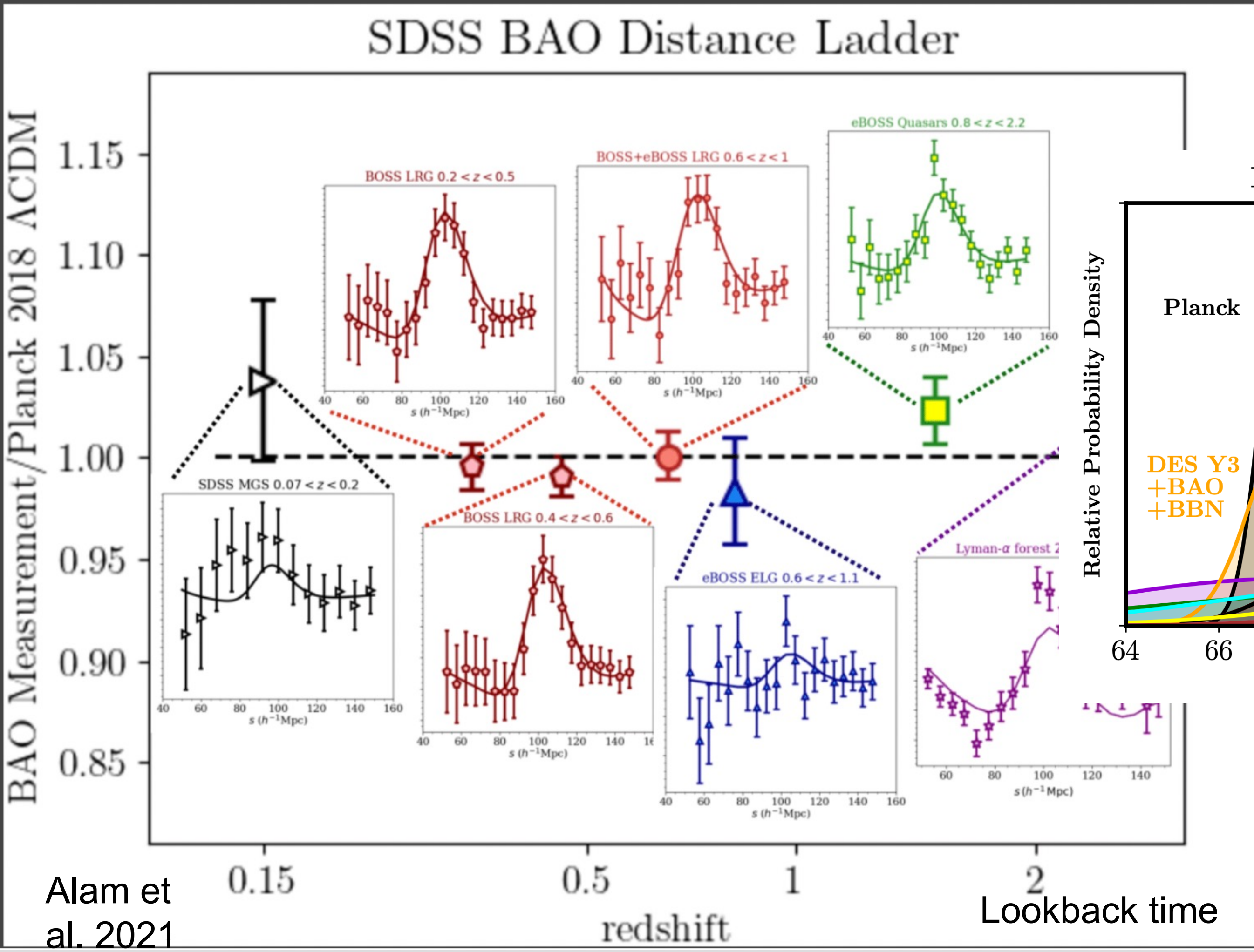


Most robust cosmological standard ruler!

Baryon Acoustic Oscillation Signal

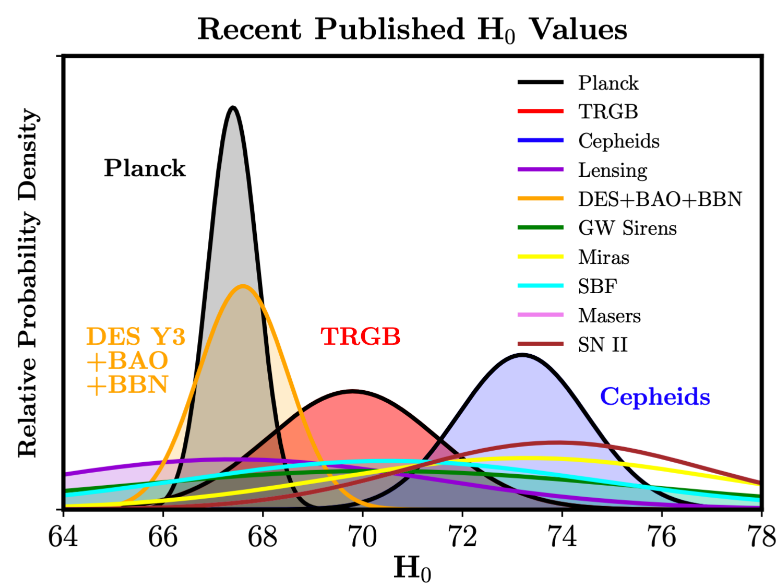


BAO from SDSS



Alam et al. 2021

Testing for any confirmation bias?

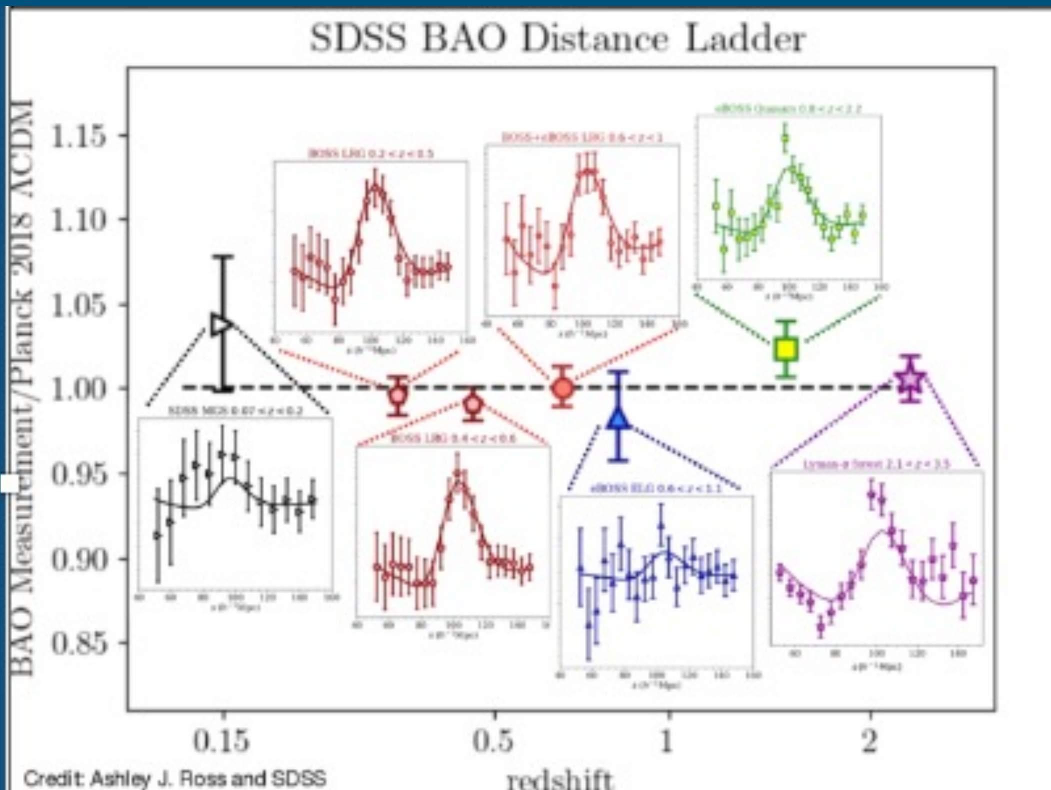


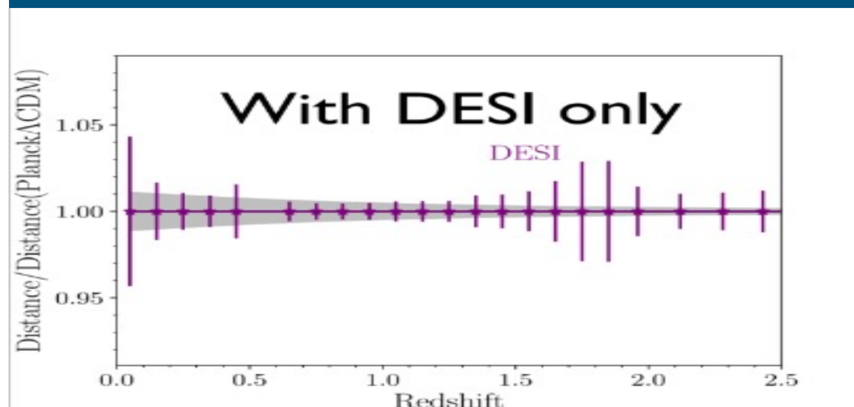
Freedman 2021
arixv2106.15656

What we care

- We need a bigger and bigger volume to have more independent samples of BAO.
- Want to limit shot noise as we want to trace the matter distribution
- Therefore we need a bigger survey with high enough number density.

DESI is here!

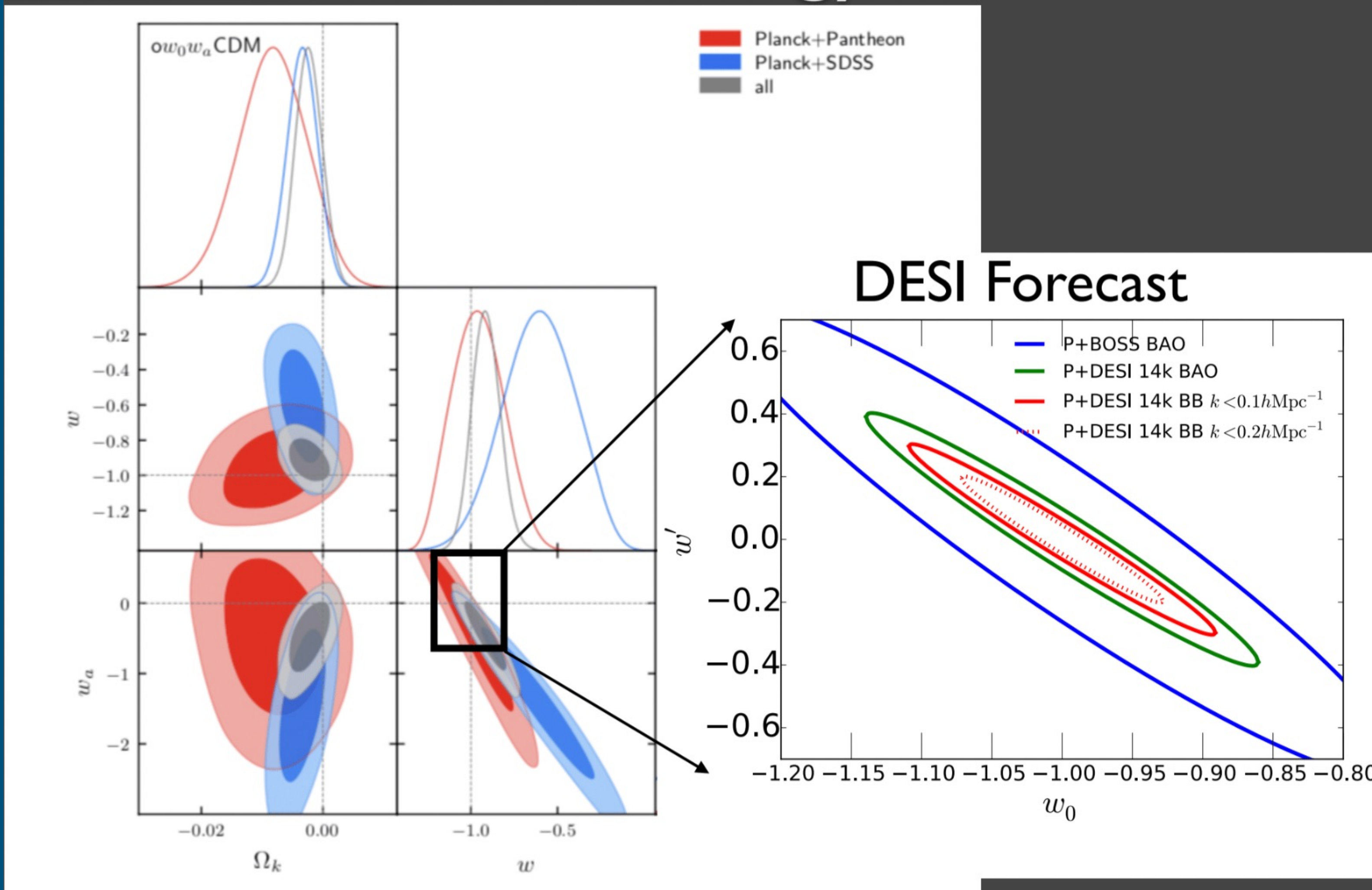




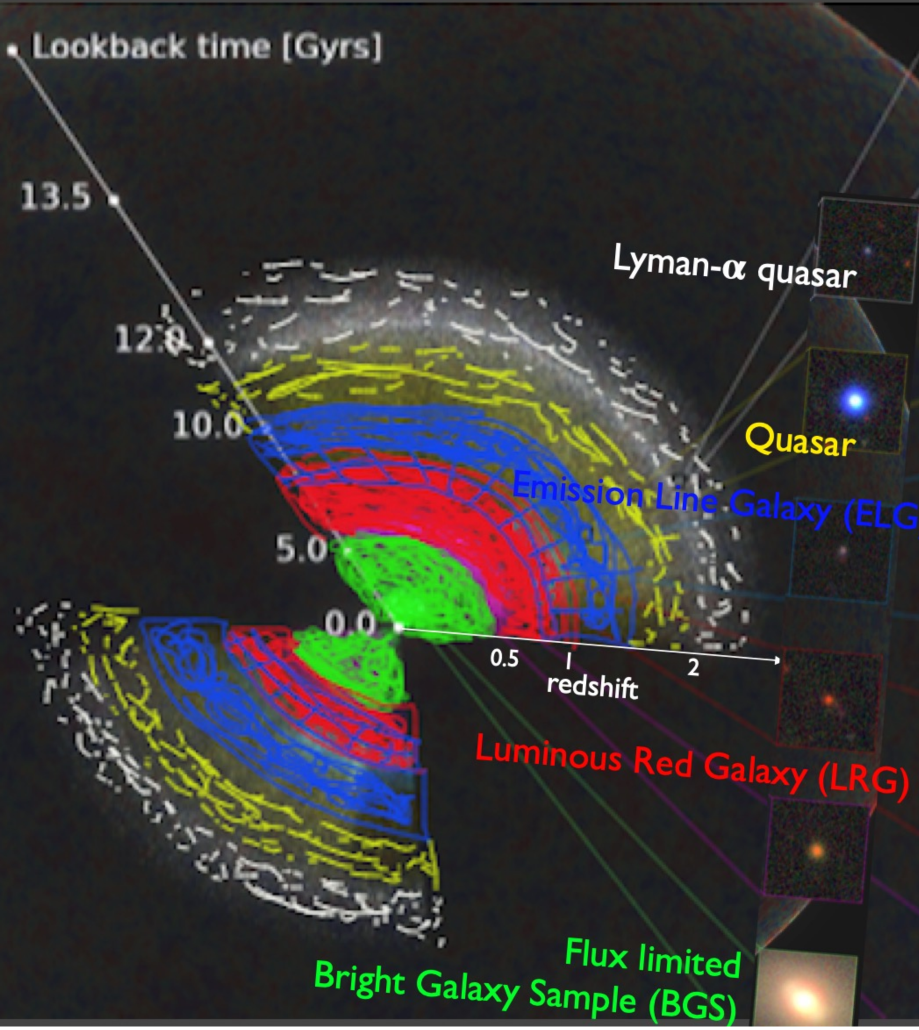
DESI: Aggregate BAO precision expected ~ 0.2 %

SDSS: Aggregate BAO precision ~0.7 %

DESI: Dark Energy Forecast

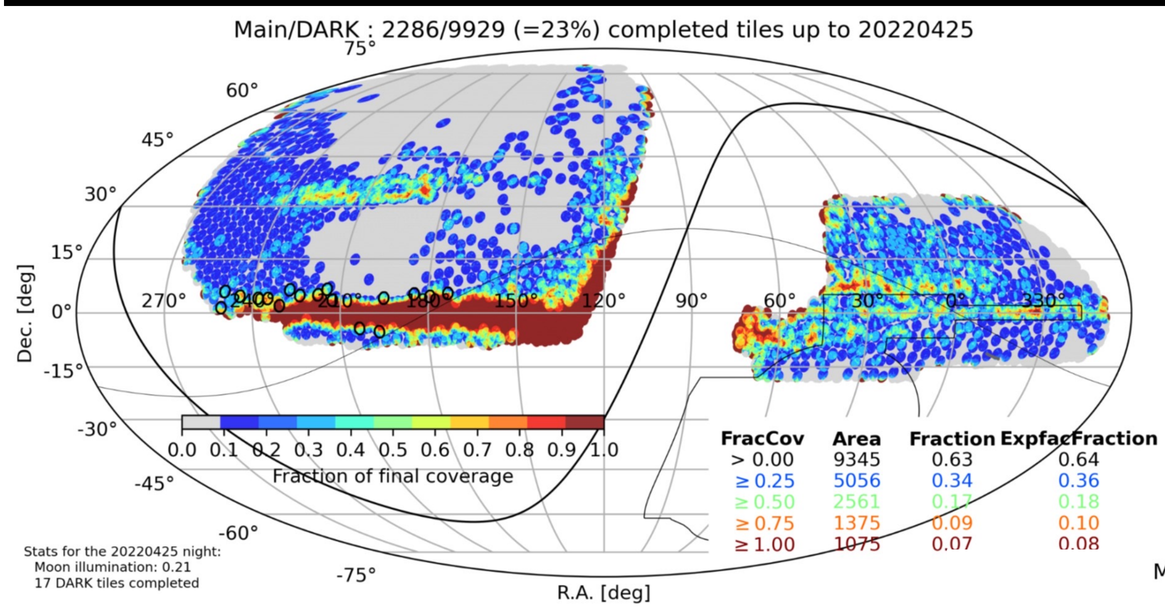


Large-scale Structure Maps



DESI will collect
~35 million redshifts

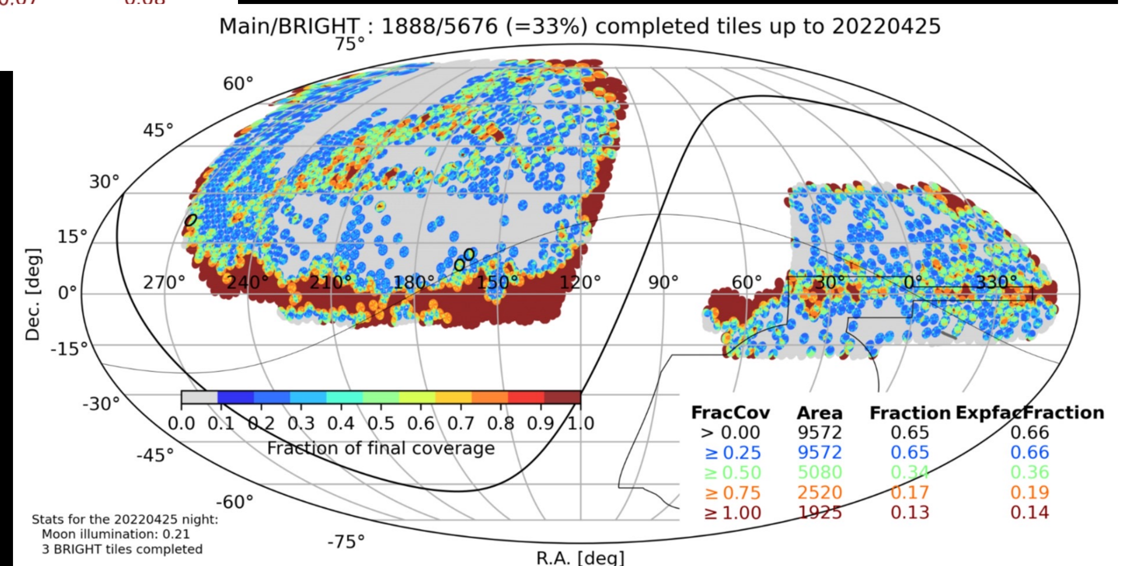
First blinded BAO analysis



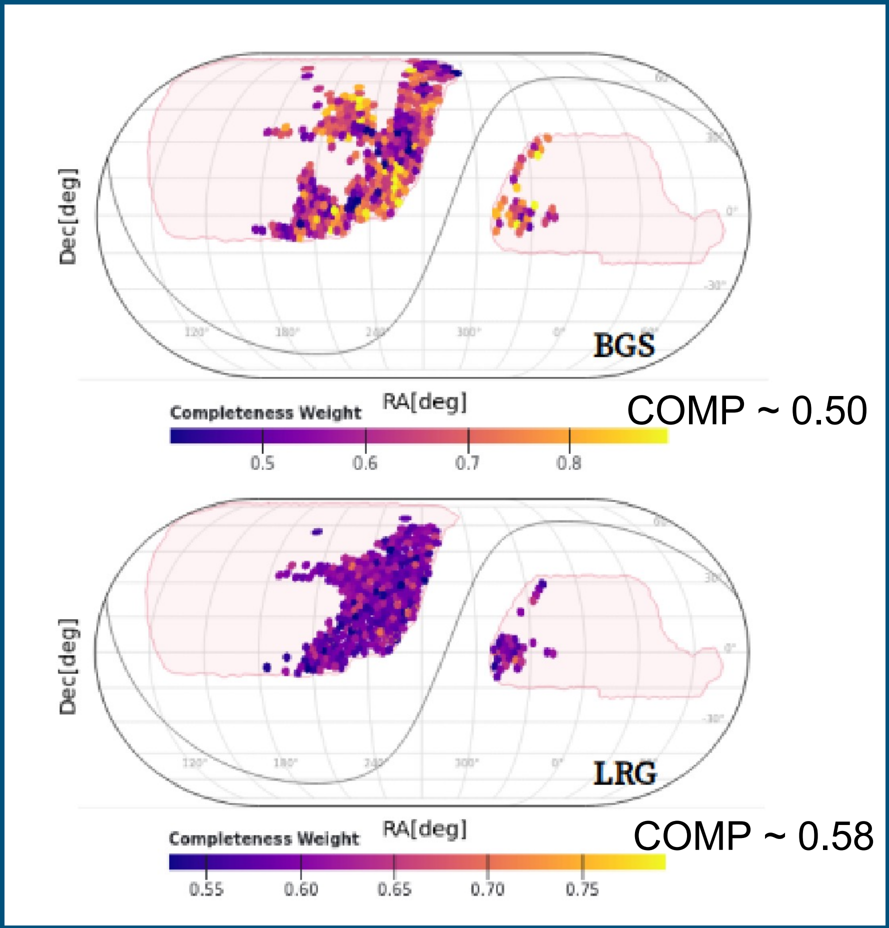
May 2022: Y1
These are being all blinded
at the catalog level.

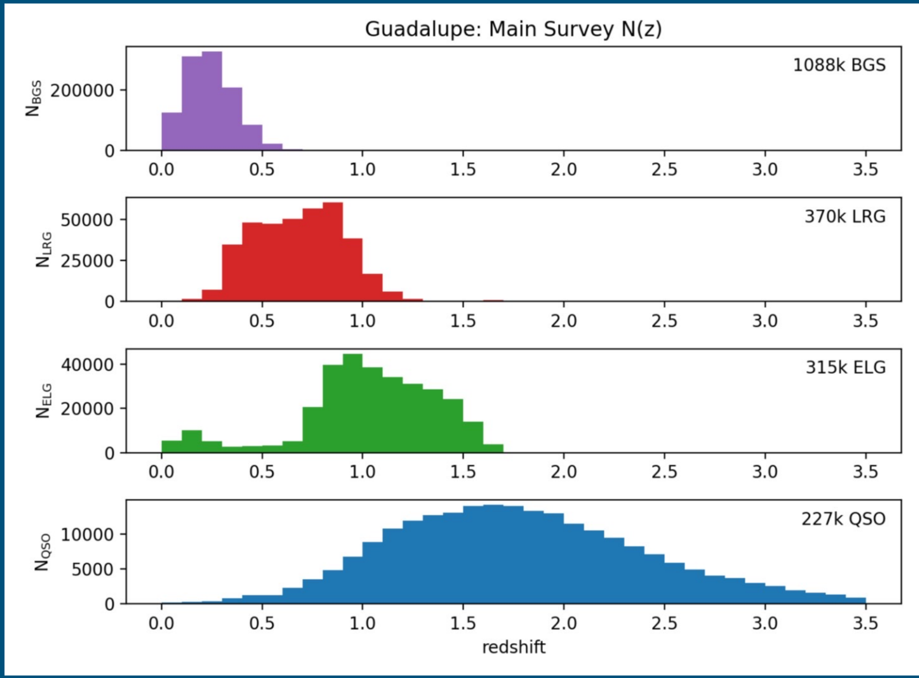
Credit: Anand Raichoor

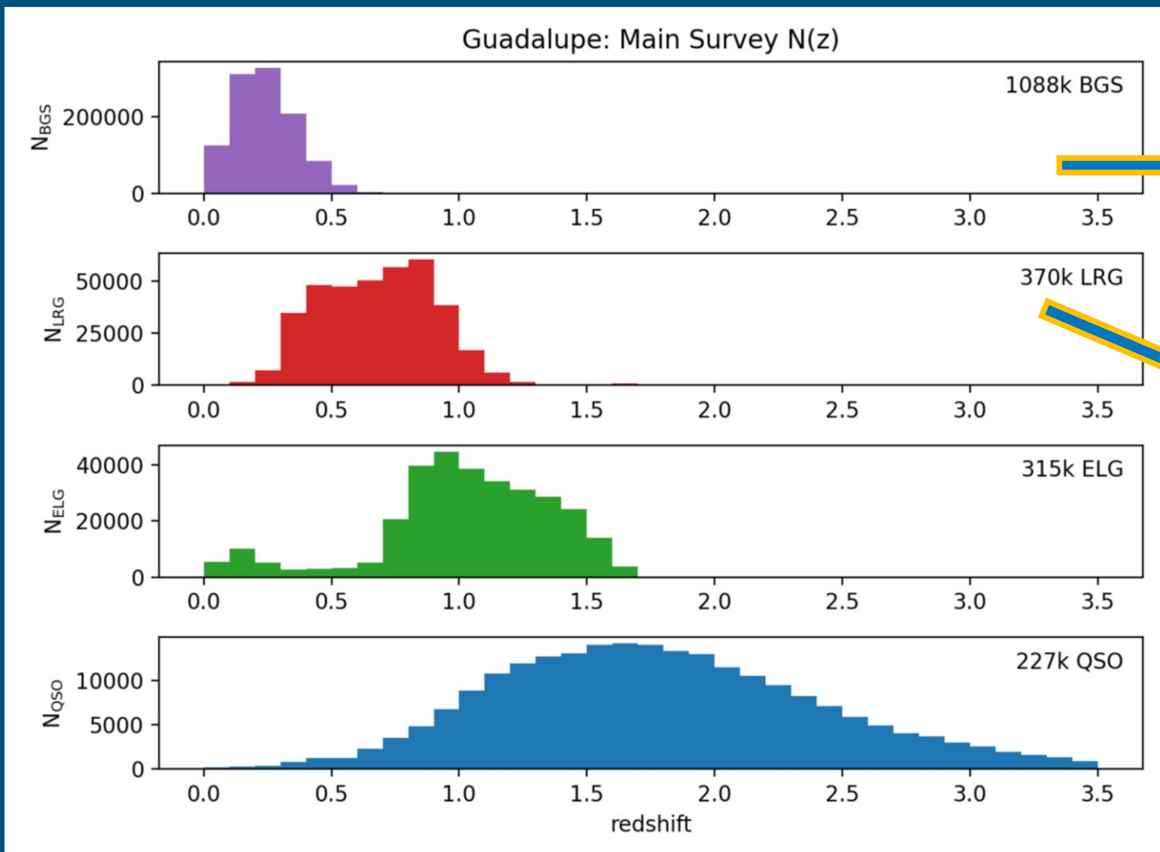
DESI will perform the first
blinded BAO analysis at the
catalog level
to minimize a confirmation bias.

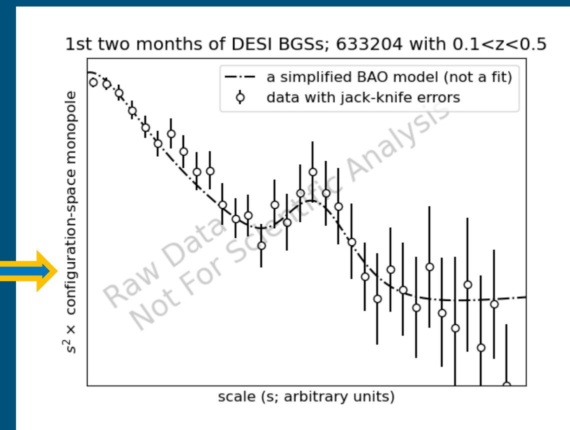


The first ~ 2 months of DESI (unblinded)









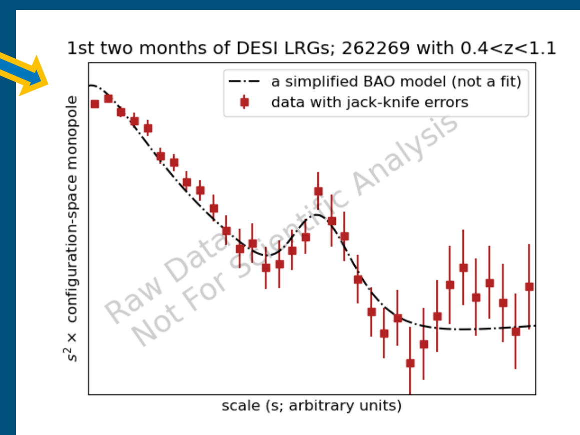


Figure credit: Ashley Ross

After a lot of work to convert the plots to some numbers!

Constructing mocks…

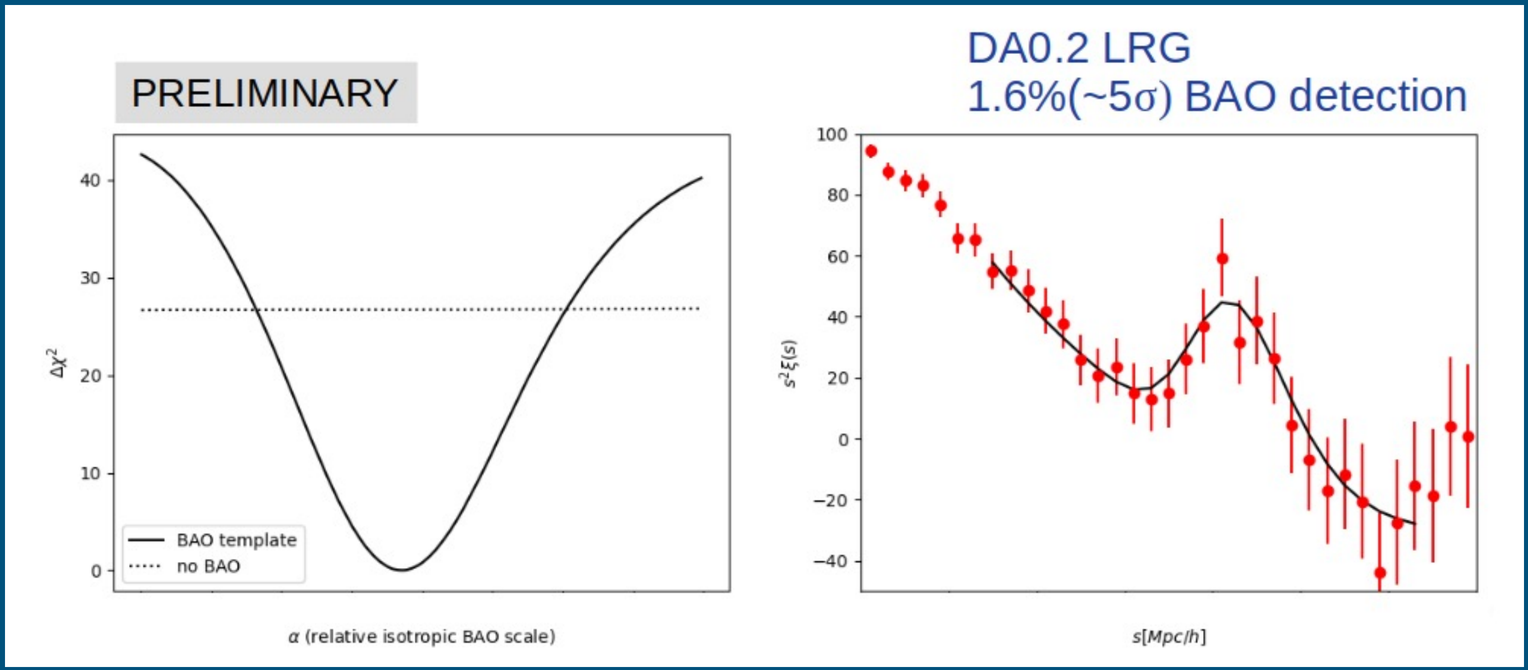
Constructing mock covariance matrices…

Calibrating analytic covariance matrices…

Testing BAO constraints with mocks

DA0.2 BAO task group

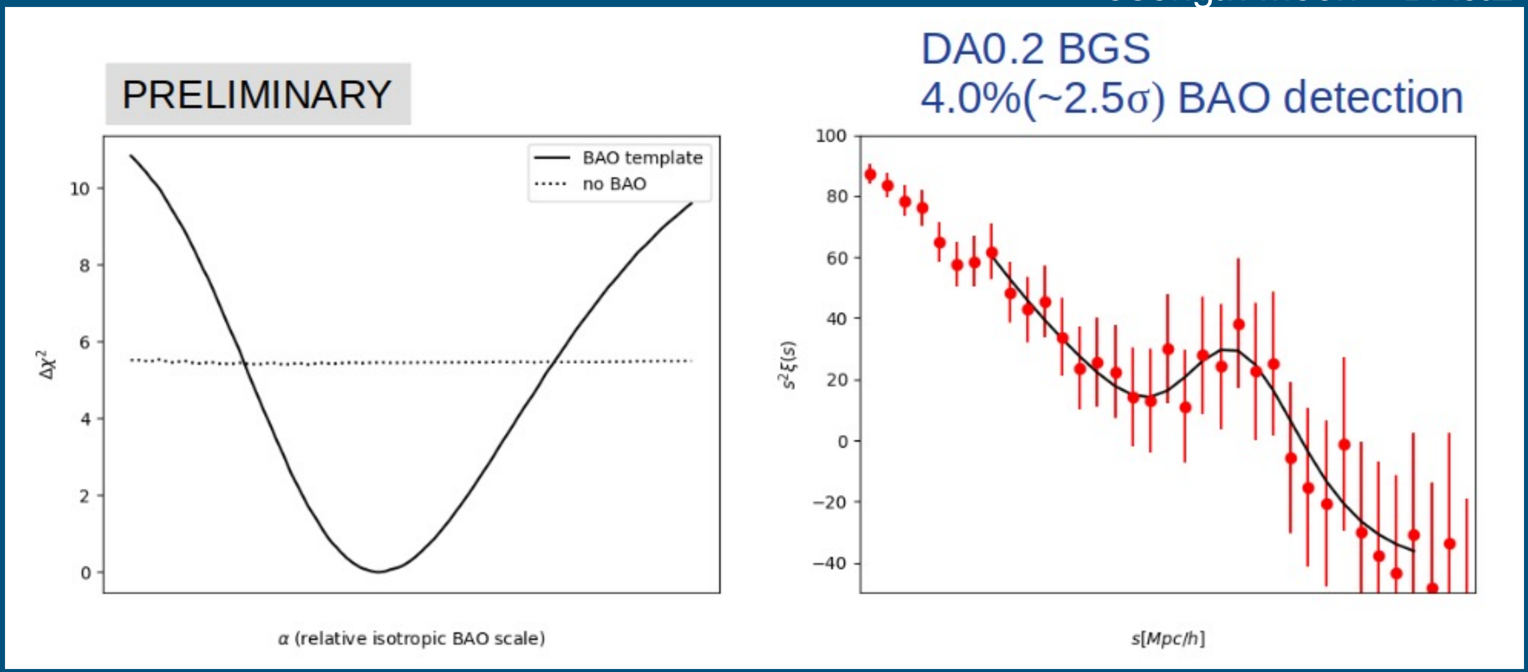
The first DESI BAO detection!



JeongIn Moon + DA0.2 BAO team

The first DESI BAO detection!

JeongIn Moon + DA0.2 BAO team

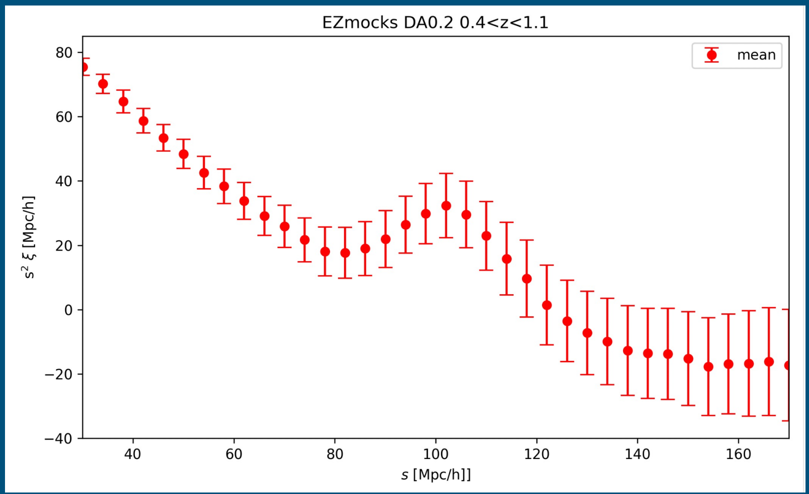


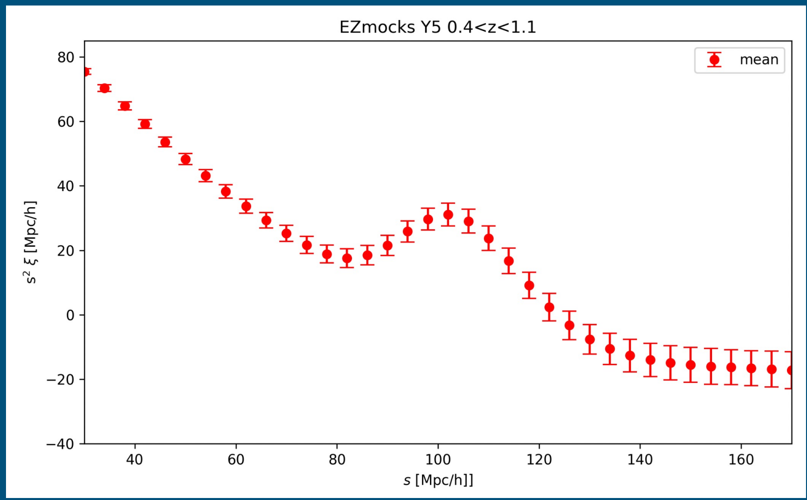
A collaboration paper being prepared to report this result. Plan to circulate in this Nov.

No cosmology will be inferred in this paper!

Are we in a good shape?
Yes, we think so.

Forecast based on mocks





DA0.2 LRG 0.4<z<1.1

1.6%

Expected Y5 LRG 0.4<z<1.1

0.35-0.4%

Figure credit: Christophe Saulder, Alejandro Perez+DESI

Y1 is planned to be released in Summer 2023

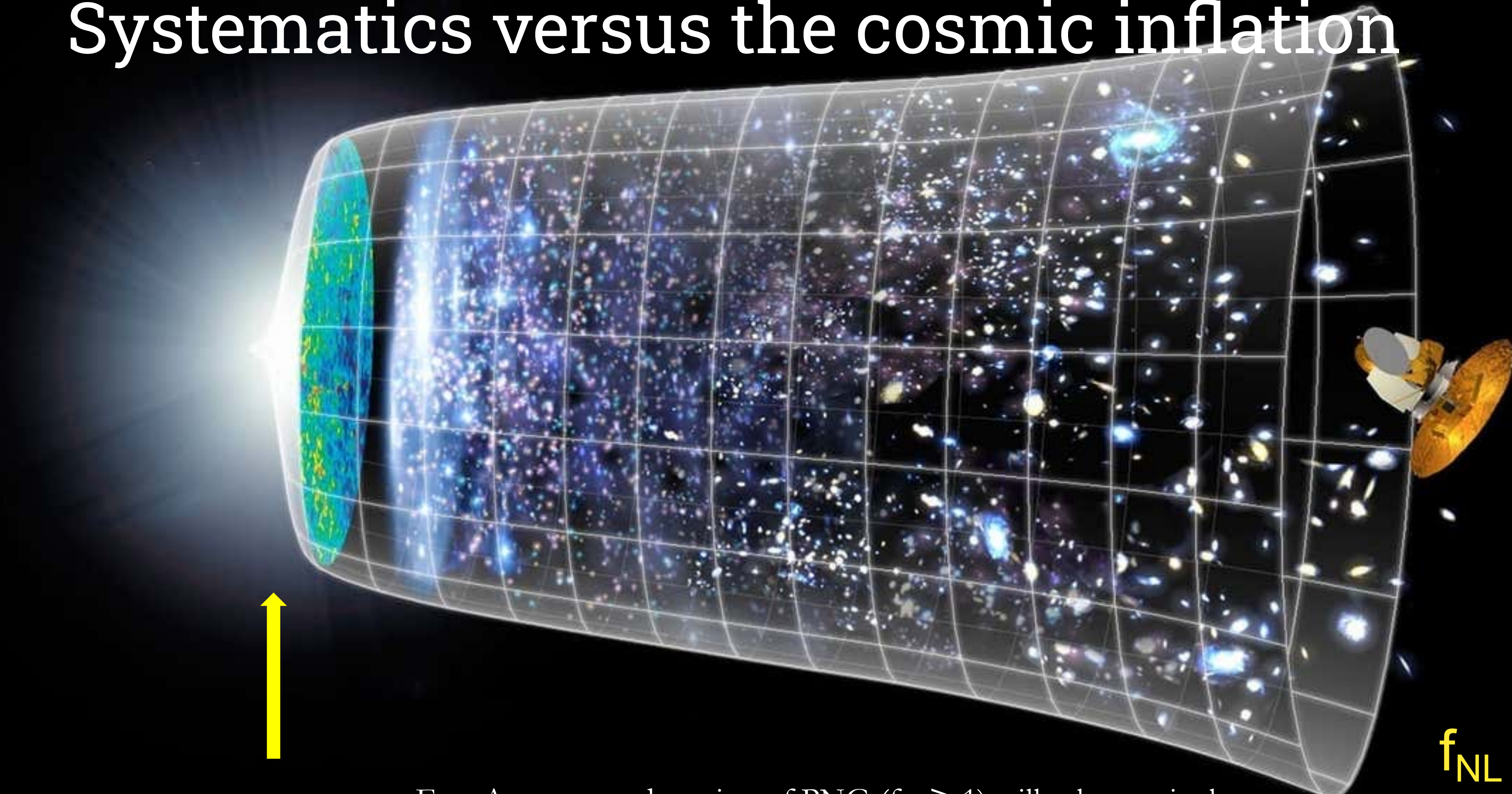
BAO at the level of aggregate precision of ~0.4% from all tracers at z<2. Better than all combined BAO redshift surveys so far with just the first-year DESI data.

A very stringent theoretical as well as observational systematic test is required.

Currently a rigorous mock challenge for estimating various systematic budgets and for the BAO analysis pipeline, not just for Y1 and beyond.

The first catalog-level blinded BAO distance scales in order to reduce a confirmation bias!

Systematics versus the cosmic inflation

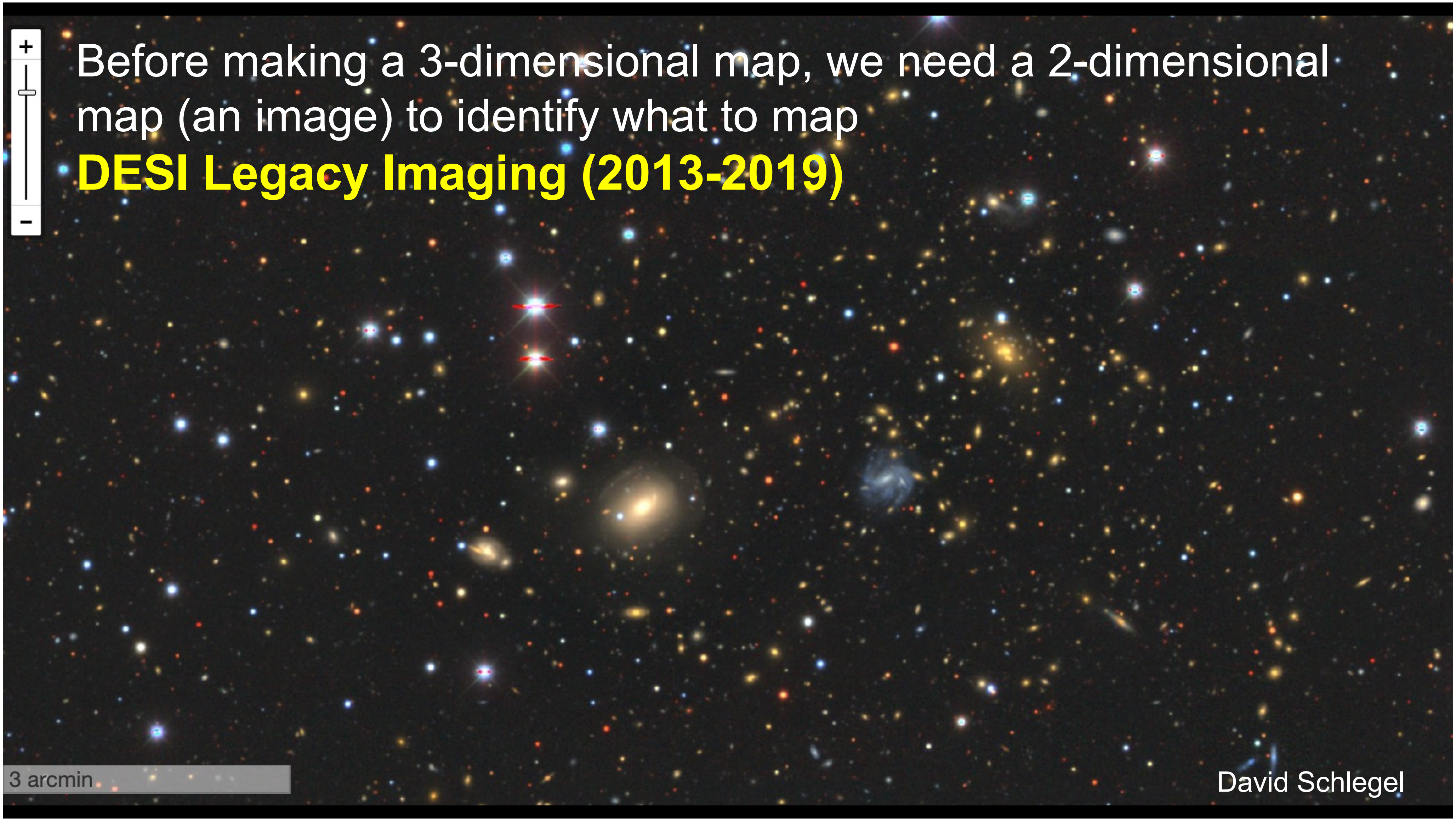


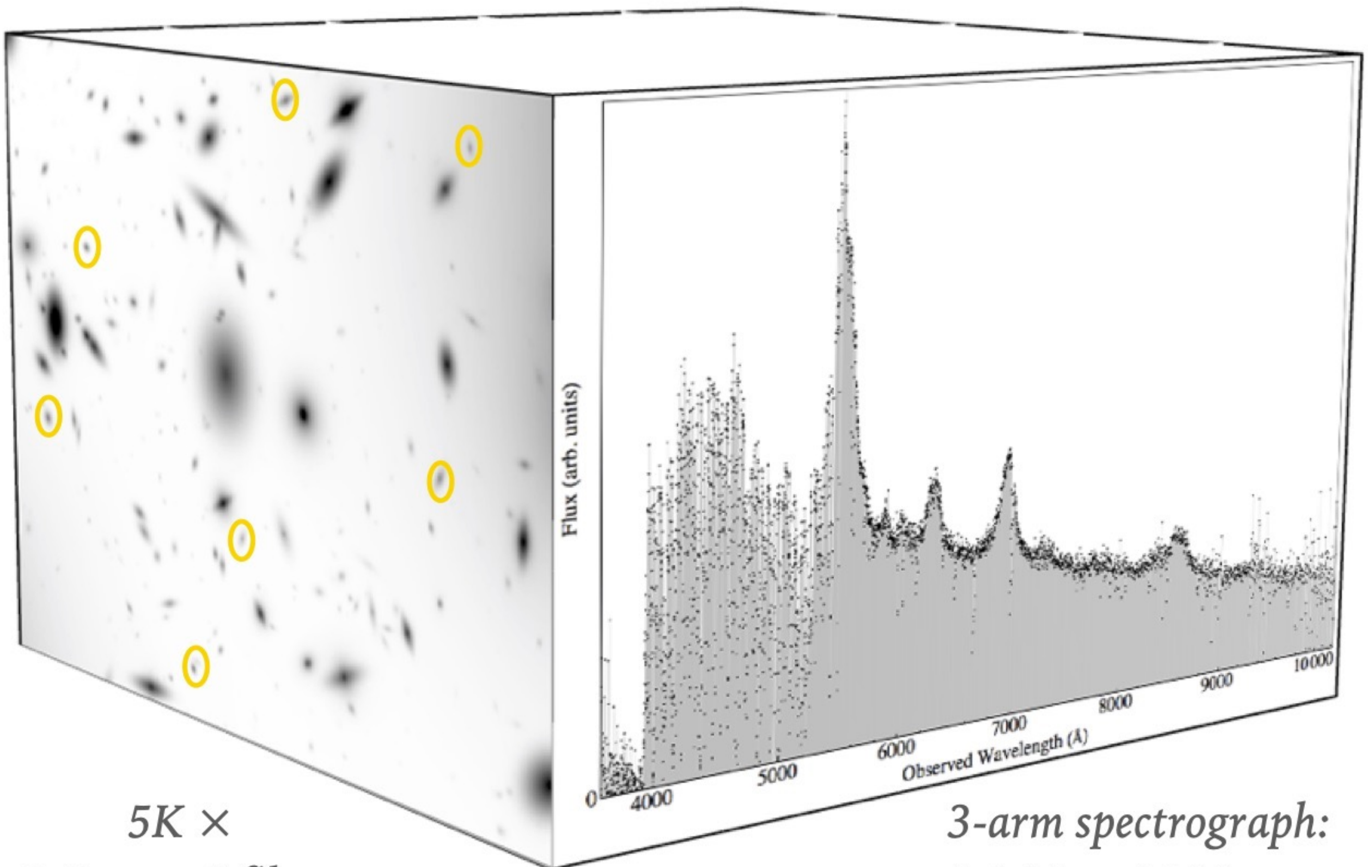
E.g., A non-zero detection of PNG ($f_{NL} \gtrsim 1$) will rule out single-field inflationary models (see e.g., Alvarez et al. 2014)

"...in any catalog of extragalactic objects the apparent density almost invariably varies across the sky because of the variable effects of galactic obscuration and confusion. This "coherence" of large angular scale is to be expected, and, if observed, must be treated with caution **unless one can make a reliable correction for it**."

P. J. E. Peebles, 1973, ApJ, 185, 413

Credit: Rongpu Zhou, the Blanco telescope, Chile


Before making a 3-dimensional map, we need a 2-dimensional map (an image) to identify what to map
DESI Legacy Imaging (2013-2019)
+
−
3 arcmin
David Schlegel



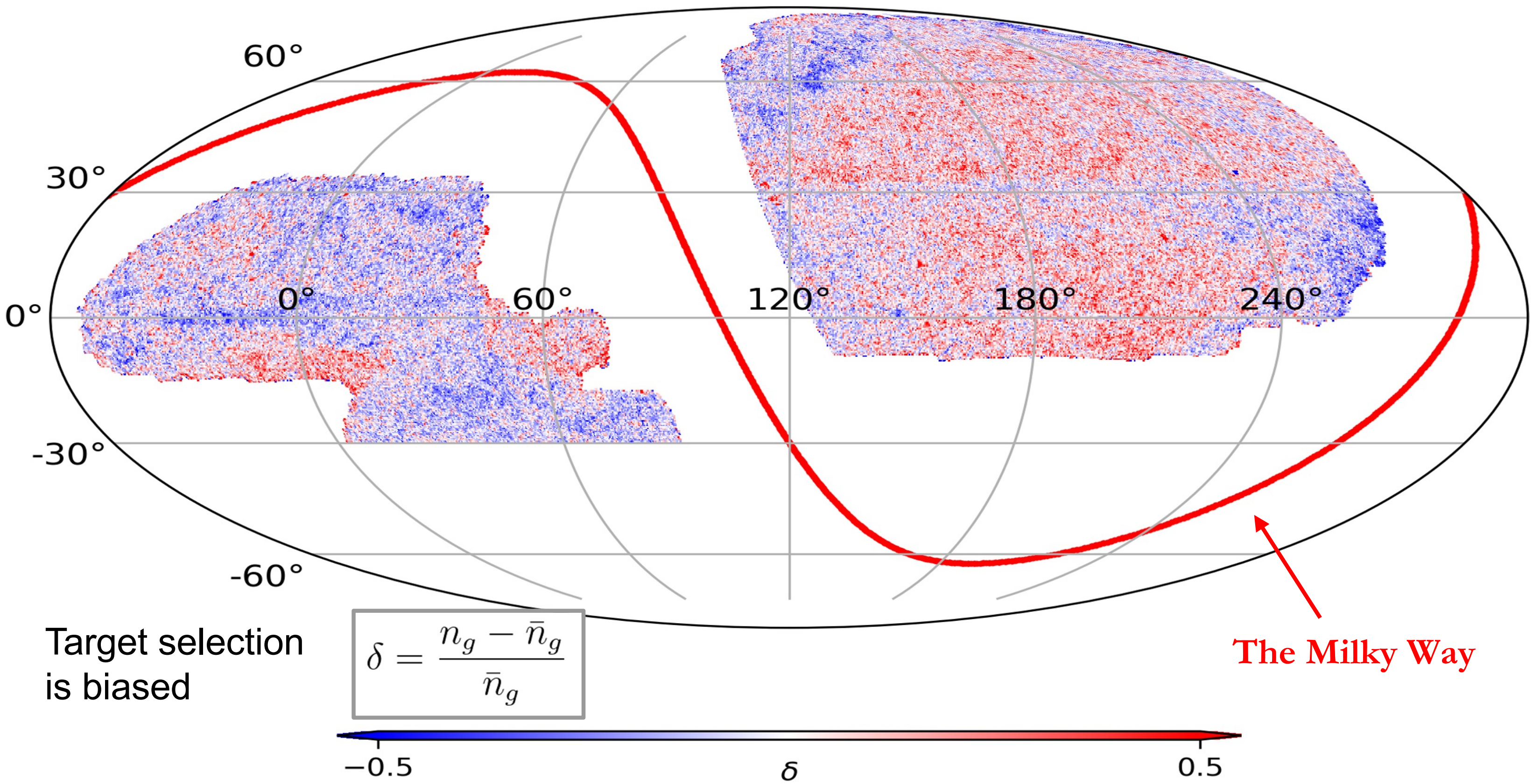
5K ×
1.8 arcsec² fibers

3-arm spectrograph:
$\lambda / \Delta\lambda \sim 4000$

Galaxy survey spectroscopy, e.g. DESI

Credit: David Kirkby

DESI Emission Line Galaxies (0.6<z<1.5)

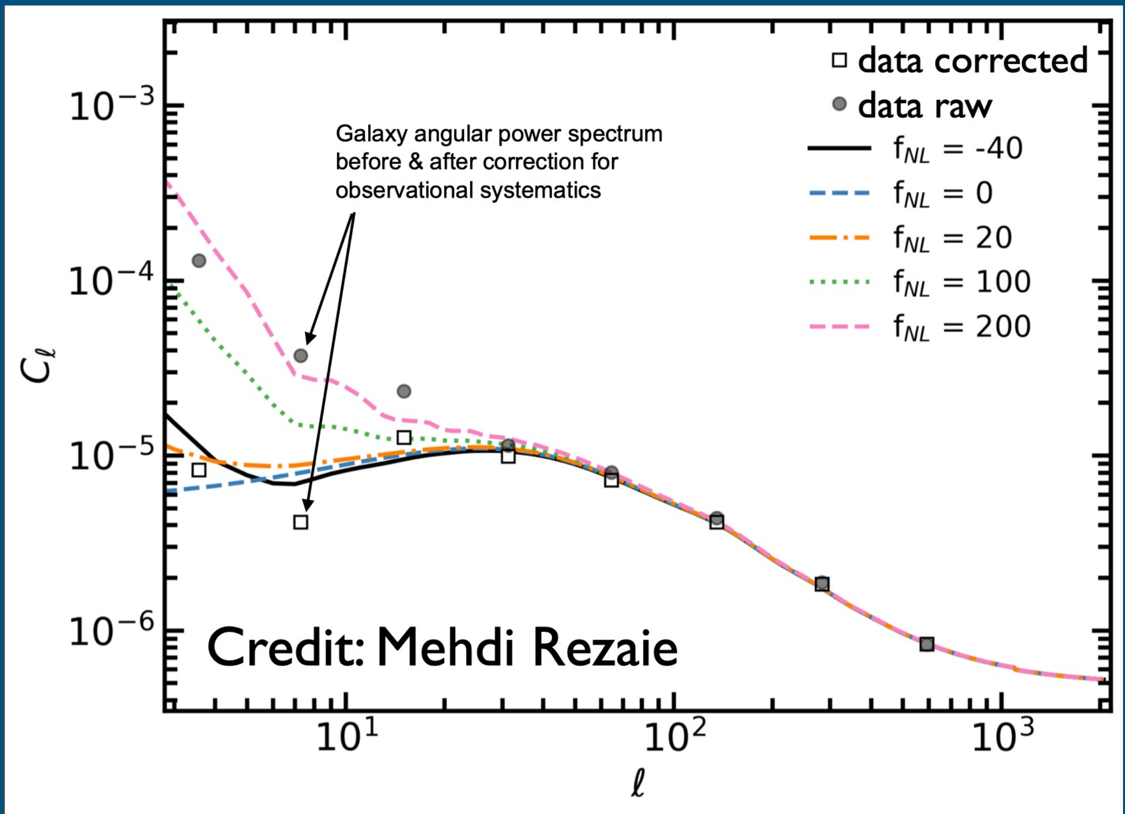


Target selection is biased

$$\delta = \frac{n_g - \bar{n}_g}{\bar{n}_g}$$

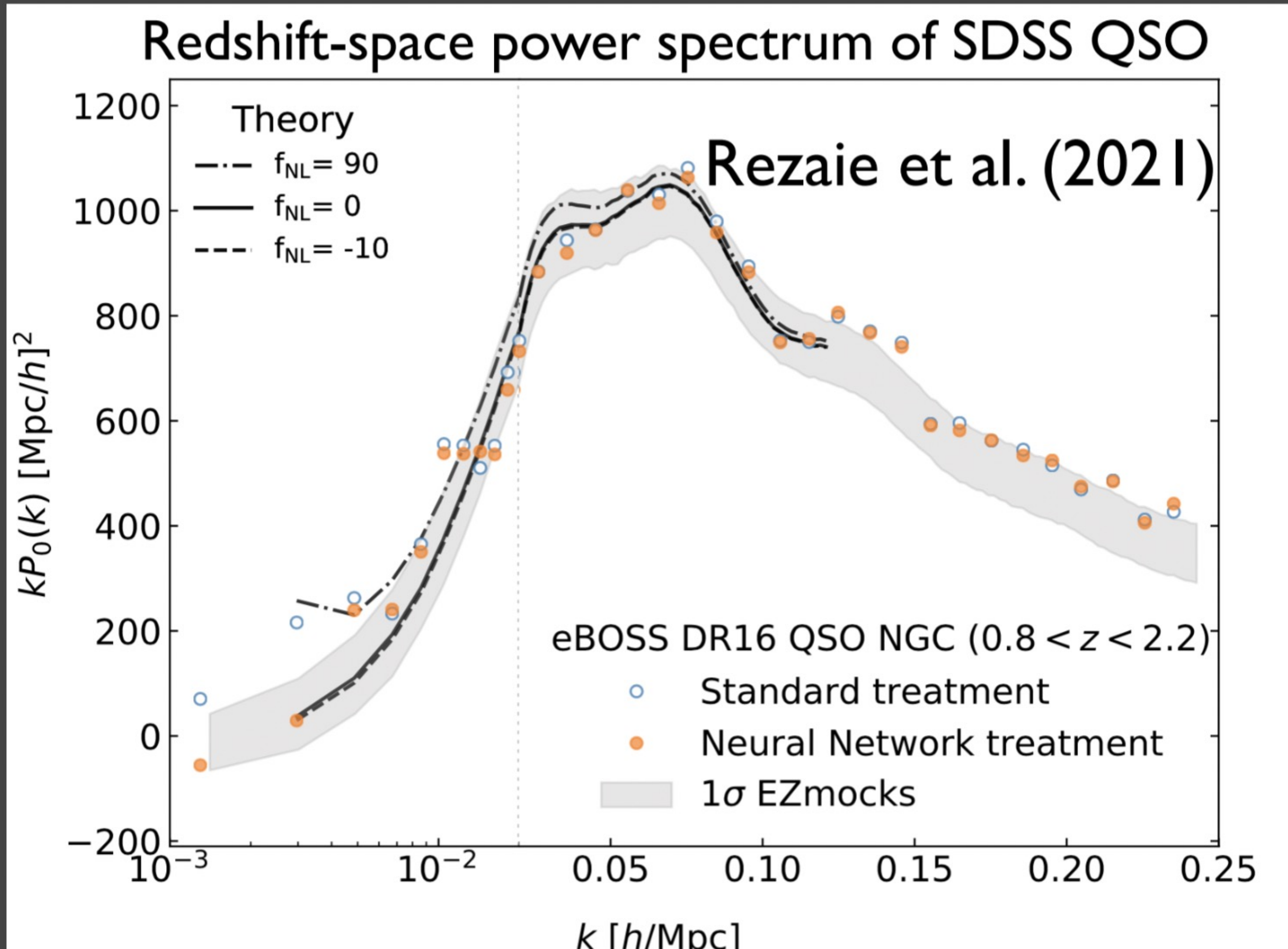
Target Selection by Daniel Eisenstein, "Alternative Emission Line Galaxies"
DESI Legacy Imaging Surveys Data Release 8

Observational systematics and local f_{NL}

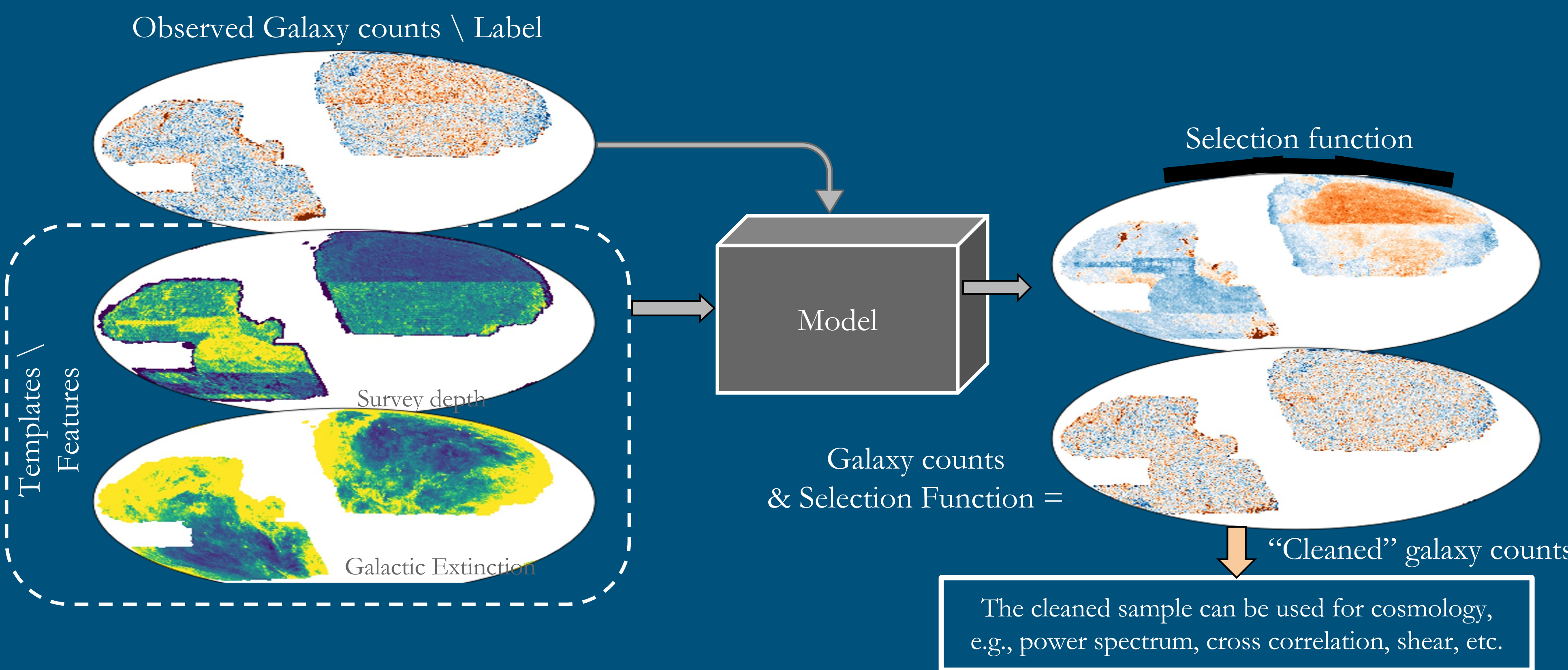


DESI Legacy Survey
DR9
BASS/MzLS LRG

Observational Systematics and local f_{NL}

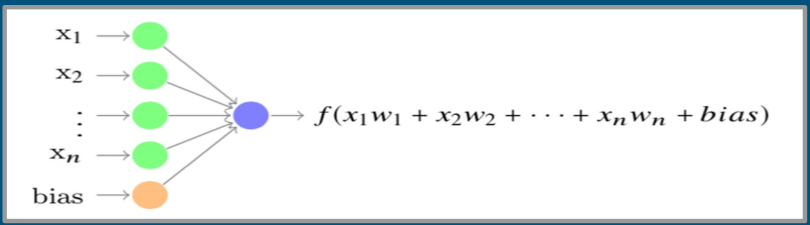


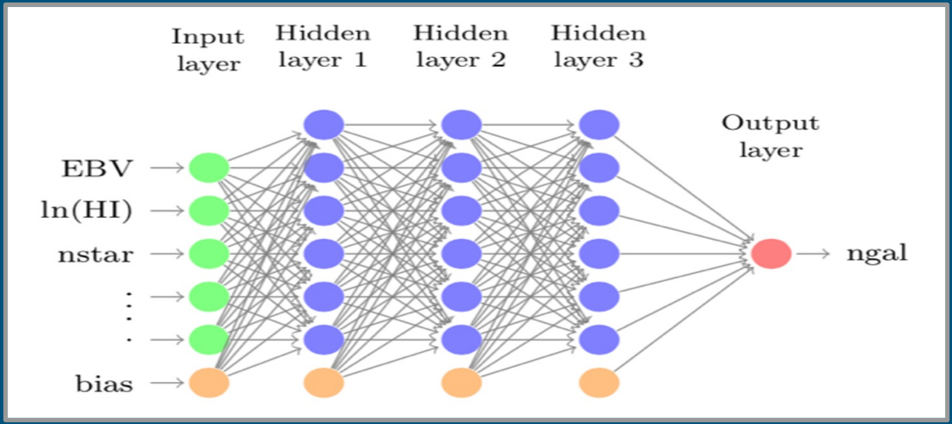
Regression-based Mitigation of Systematics



Fully Connected Neural Networks

(Rezaie, Seo, Ross, Bunescu 2020)





Advantage:

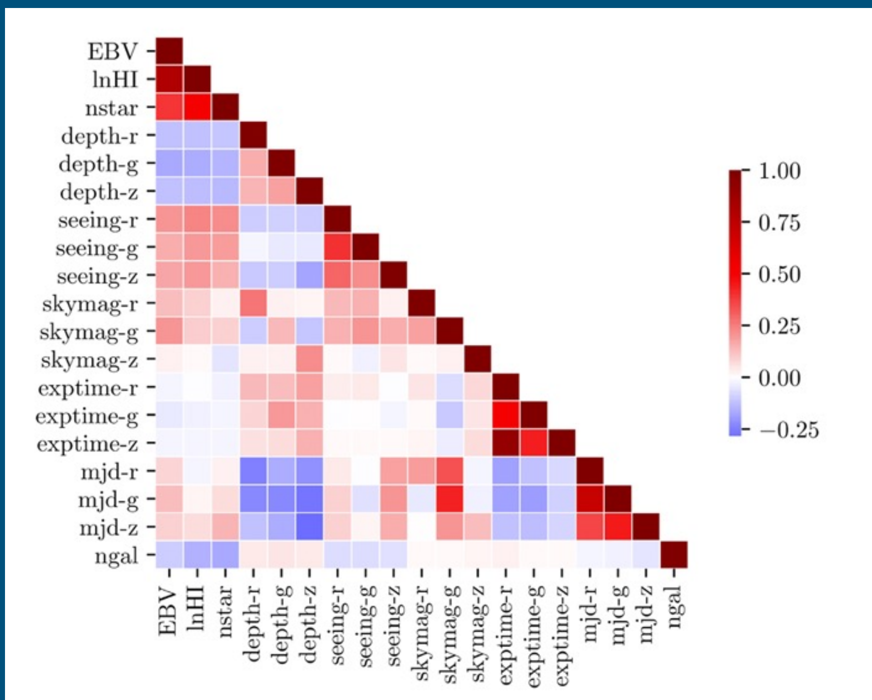
Both linear and nonlinear effect can be modelled.

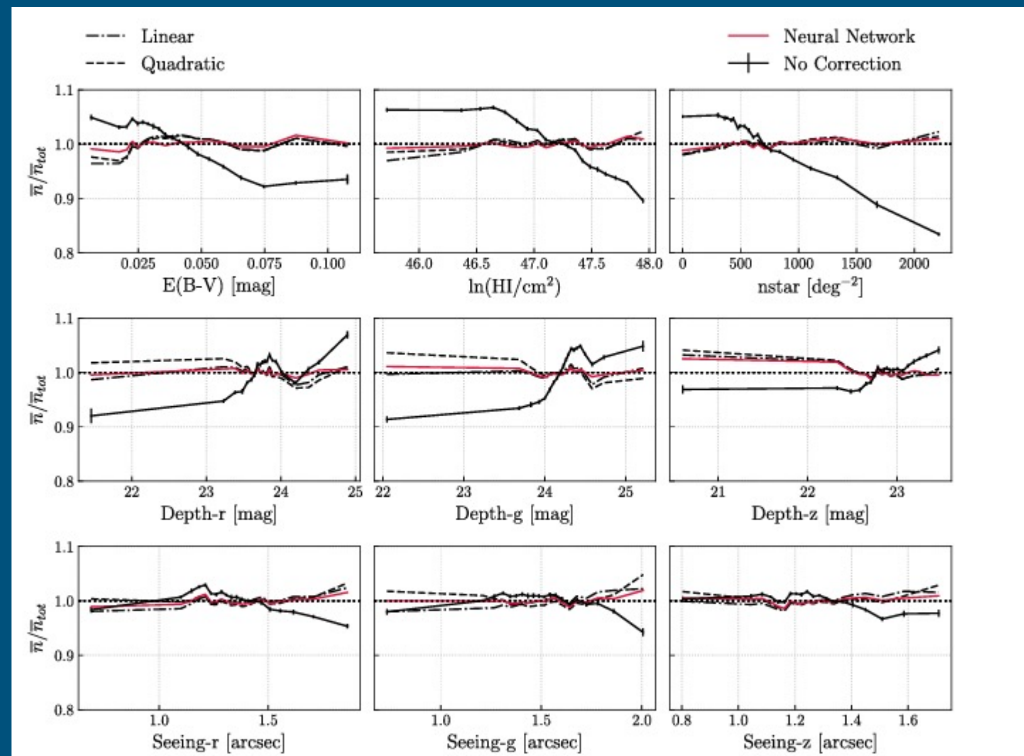
Training/validation/test sets can help overfitting (some caveats, though!)

The network learns the mapping from imaging attributes to galaxy counts.

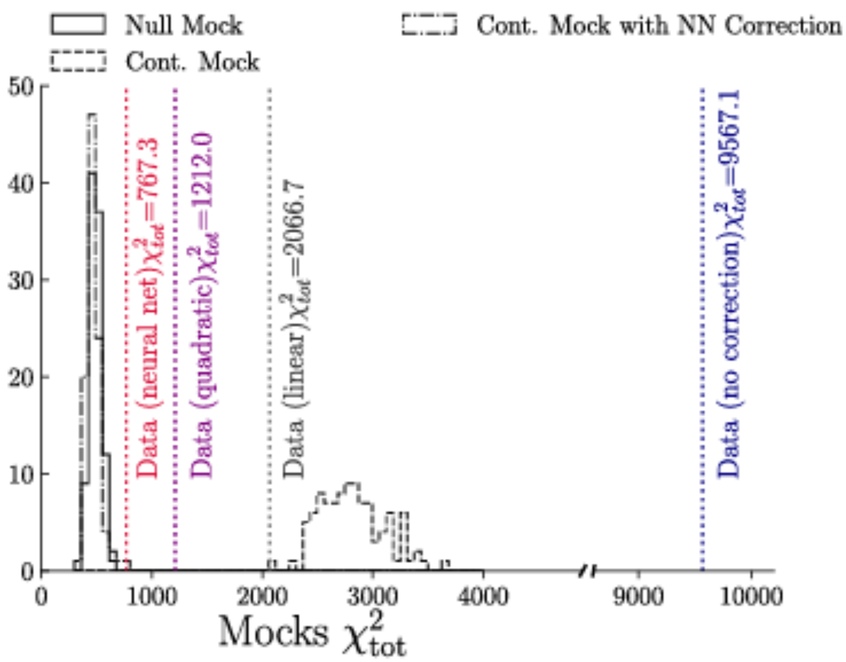
The parameters are trained by minimizing a 'cost' function $n(\vec{x},\vec{p})/f(\vec{p}) - \bar{n}(\vec{x})$

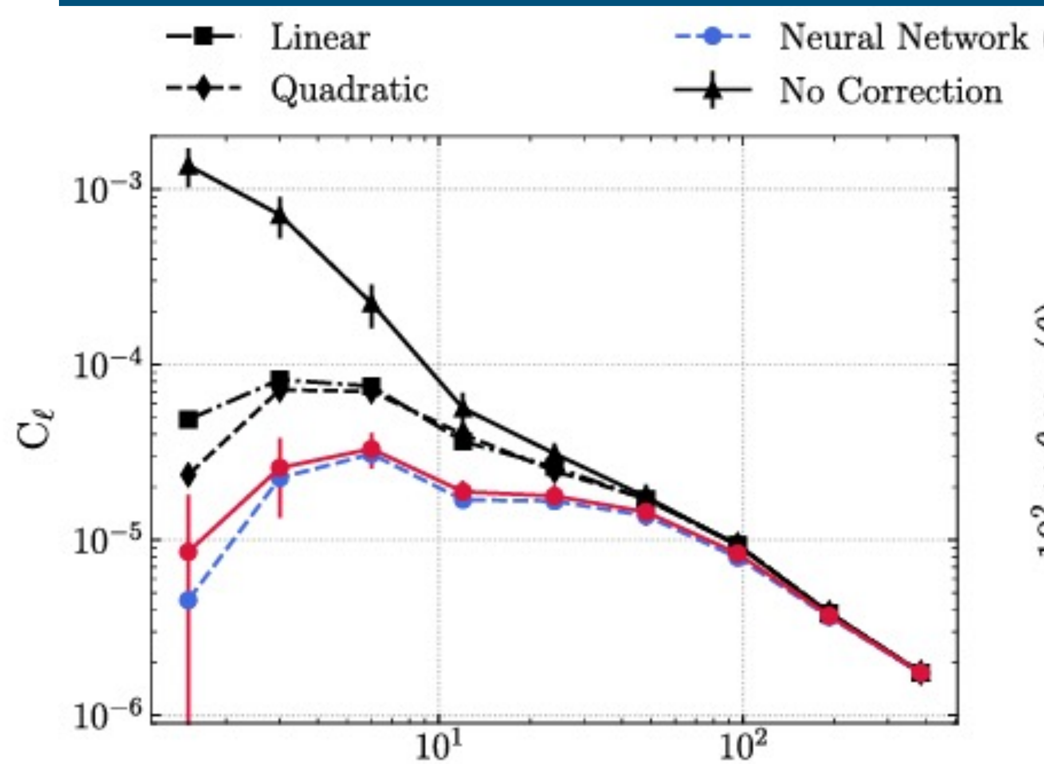
Strong correlations with imaging attributes





DESI Legacy survey DR7 ELG
Rezaie, H-JS, Ross et al. 2019

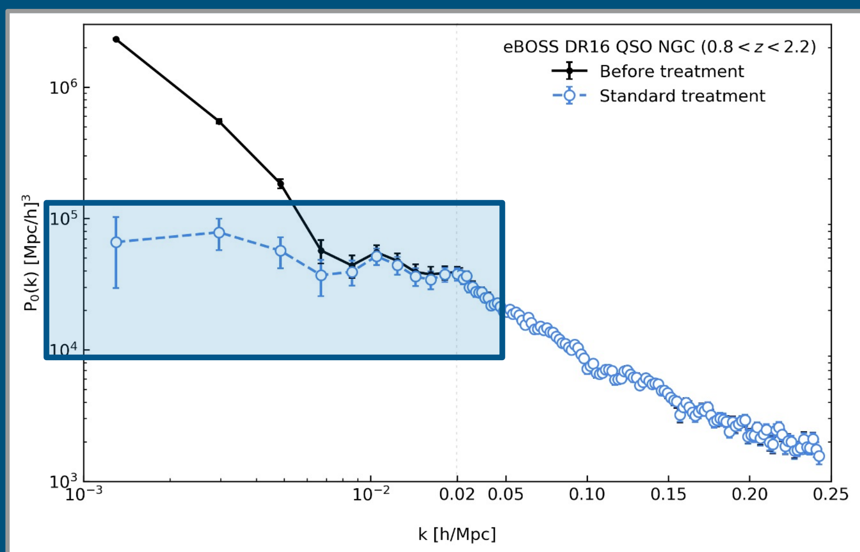


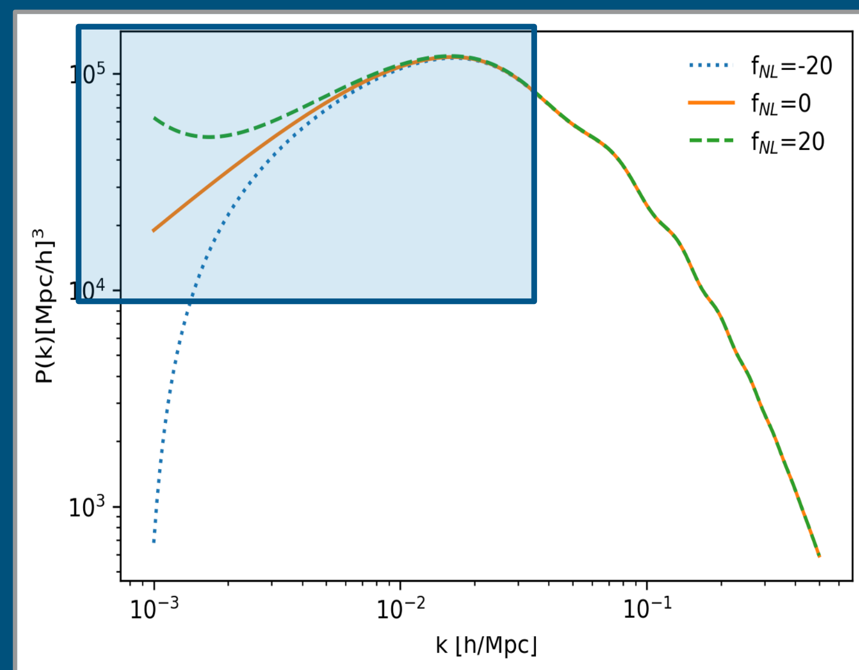


NN seems to outperform!

Final sample of Quasars from SDSS eBOSS DR16

Is this sample clean enough to allow an accurate measurement of cosmological parameters?



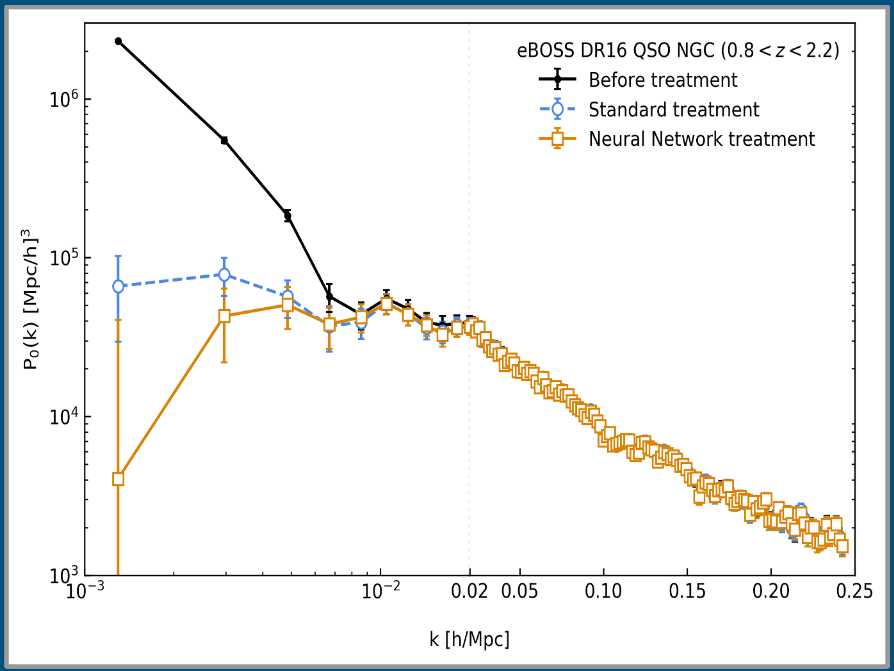


The public SDSS-IV eBOSS
Data Release 16 Quasar Catalog (summer 2020)

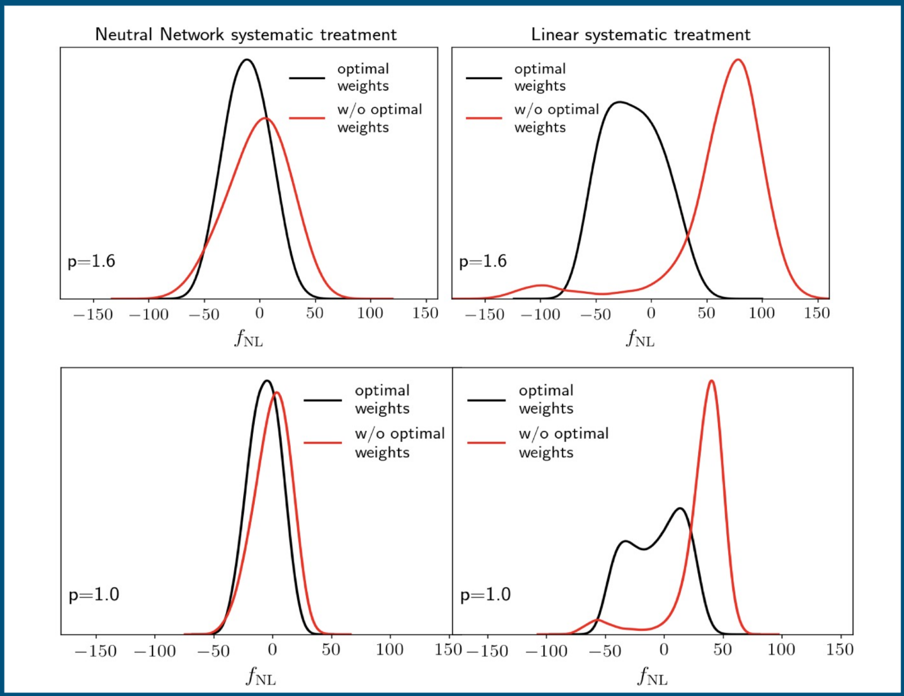
A non-zero detection of PNG ($f_{NL} \gtrsim 1$) will rule out single-field inflationary models (see e.g., Alvarez et al. 2014)

Final sample of Quasars from SDSS eBOSS DR16

We used the same set of templates to derive the selection function (systematic weights)

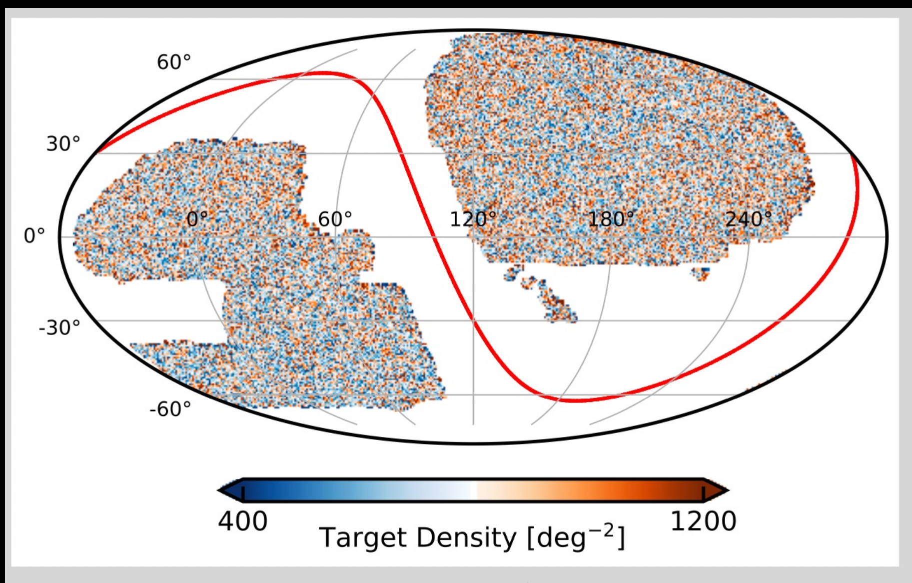


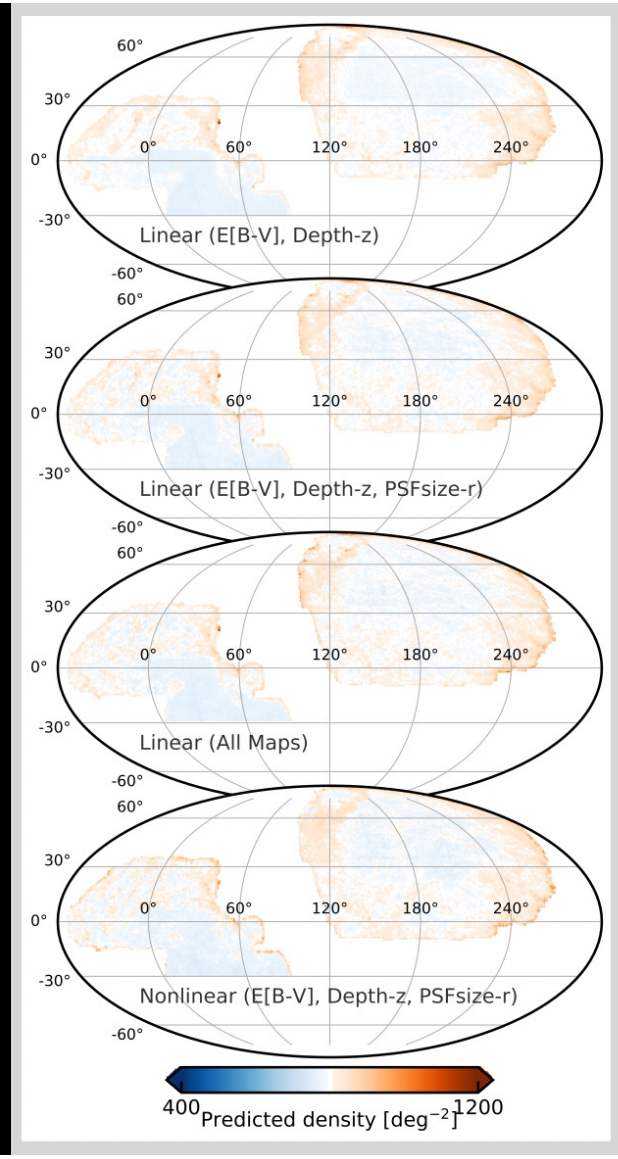
Rezaie, Ross, H-JS et al. 2021



Mueller, Rezaie et al. 2022

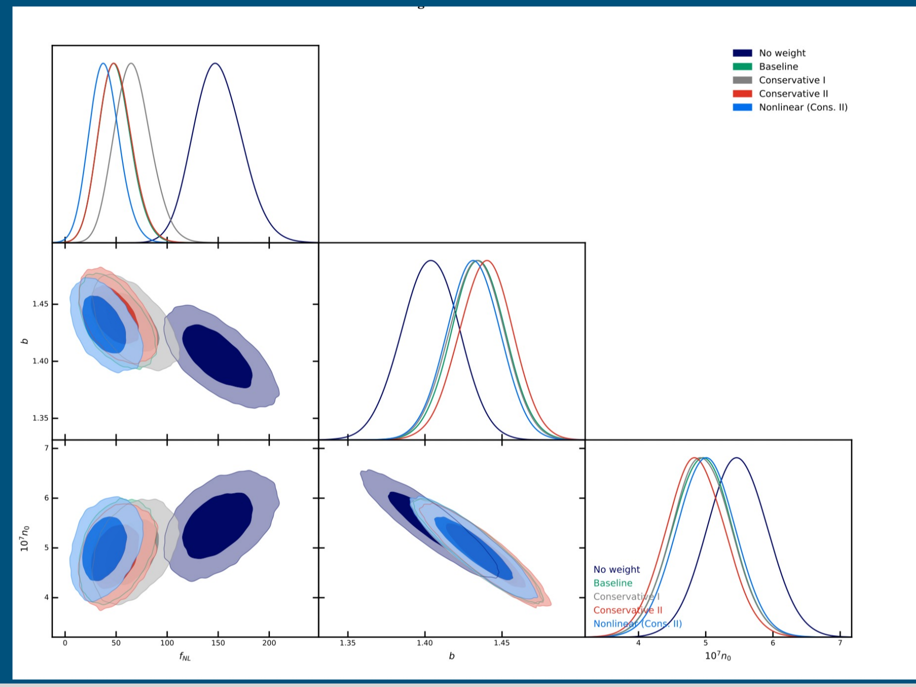
Currently, LRG from DESI Legacy Survey DR9





Rezaie, Ross, H-JS et al. prep

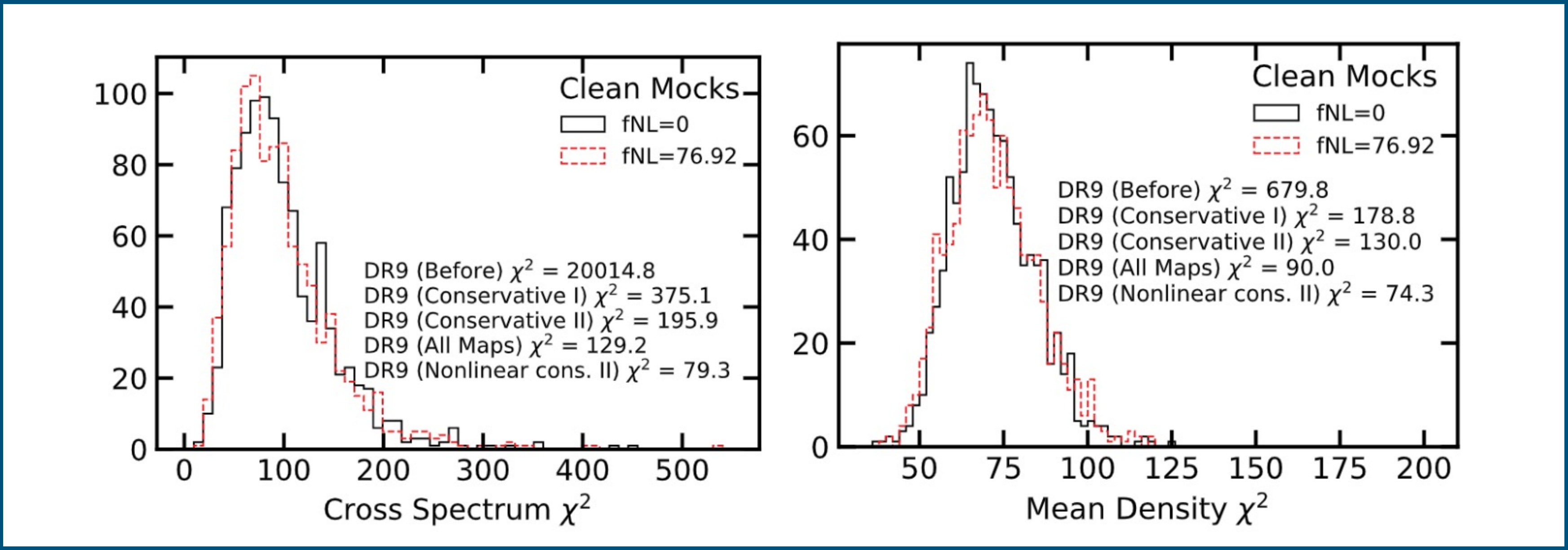
Preliminary:



$$f_{NL}/1.3 = f_{NL,CMB}$$

Footprint	Method	Best fit	Mean	68% CL	95% CL	χ^2
DESI	No Weight	147.13	150.13	$127.58 < f_{\rm NL} < 172.76$	$108.56 < f_{\rm NL} < 197.07$	44.4
DESI	Linear (all maps)	46.87	49.04	$33.97 < f_{\rm NL} < 63.98$	$21.21 < f_{\rm NL} < 81.00$	41.1
DESI	Linear (Conservative I)	64.46	66.69	$49.67 < f_{\rm NL} < 83.63$	$35.64 < f_{\rm NL} < 102.59$	38.8
DESI	Linear (Conservative II)	47.62	49.54	$34.21 < f_{\rm NL} < 64.81$	$21.27 < f_{\rm NL} < 82.06$	39.6
DESI	Nonlinear (Conservative II)	37.15	38.73	$24.58 < f_{\rm NL} < 52.77$	$12.32 < f_{\rm NL} < 68.55$	34.6
DESI (imaging cut)	Nonlinear (Conservative II)	37.91	39.74	$24.77 < f_{\rm NL} < 54.84$	$11.71 < f_{\rm NL} < 71.25$	35.8

Chi2 residuals indicate the correction is already reasonable



This motivates against introducing more flexibility in the mitigation: otherwise, a confirmation bias will be introduced.

Challenges: map-based limitations

- Are maps complete? Regression cannot mitigate unknown systematics
- Are maps contaminated? E(B-V) CIB is correlated with real LSS
- Regression also removes some true clustering modes. The real LSS and the systematic maps will have some chance correlation. Common LSS is in training/validation/test sets.   A larger degree of freedom will make such overcorrection worse.
- Mock tests needed for estimating the expected bias due to chance correlation for each scheme.

Forward model approach (Image simulations)

- Complementary to backward model such as regression
- Inject galaxies into real images and make target selection
- DES ‘Balrog’ (Suchyta et al. 2016). DESI ‘obiwan’ (Kong et al. 2020).
- Some dependences are well simulated (depth dependence).
- Not quite efficient.
- A hybrid between regression (eg NN) and the forward modeling is being pursued to compromise the efficiency of Obiwan and decrease the number of relevant input maps to NN (Alberto Rosado Marin at Ohio University).

Conclusion

- DESI is cool. The data is looking reasonable.
- DA0.2 BAO result will be published very soon.
- Stay tuned for DESI Y1 cosmology results next summer