Present and future redshift survey

David Schlegel, Berkeley Lab

Redshift surveys = one of ~few probes of inflationary epoch

Inflation-era parameters: non-gaussianity, primordial Pk

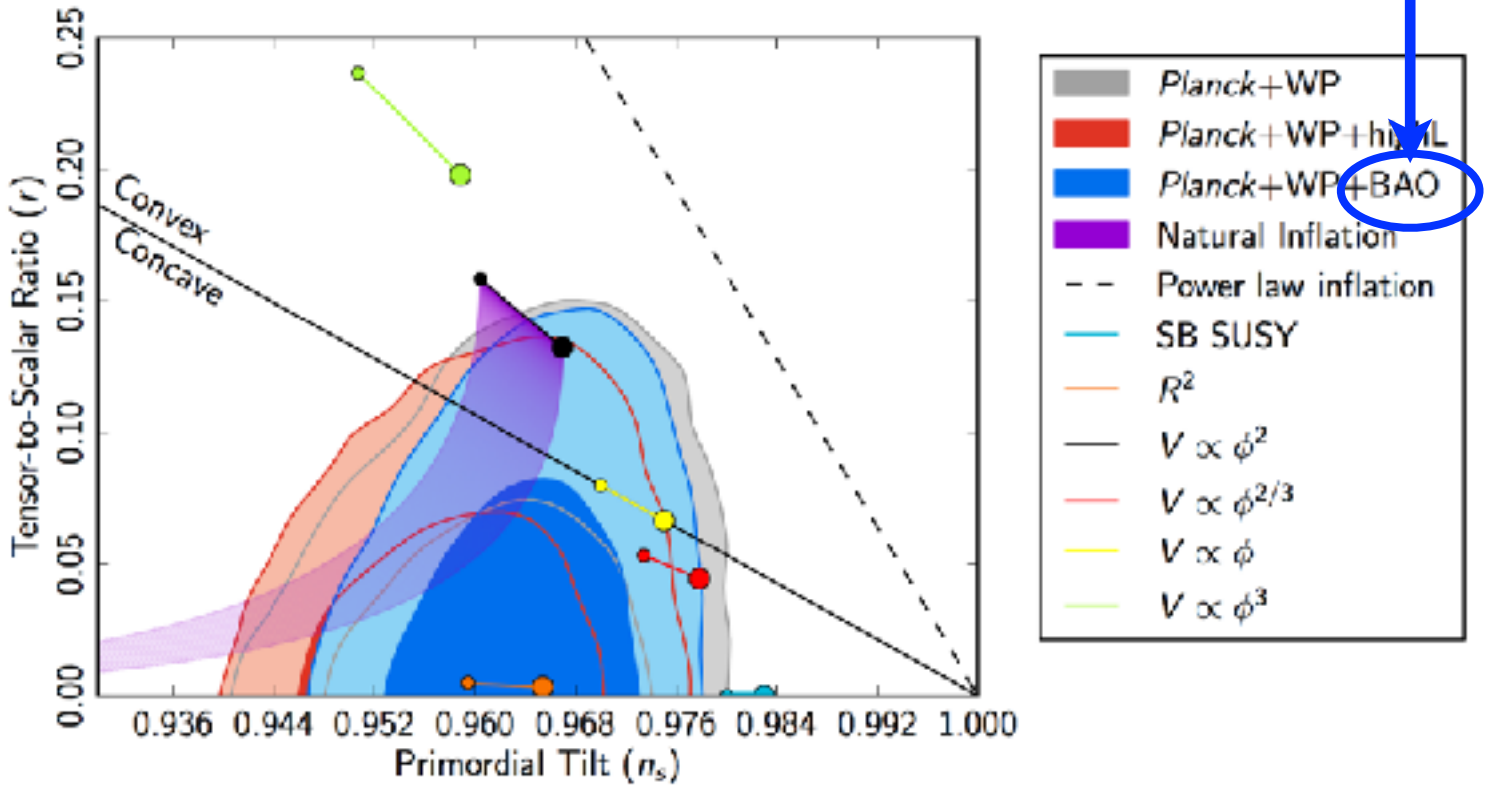
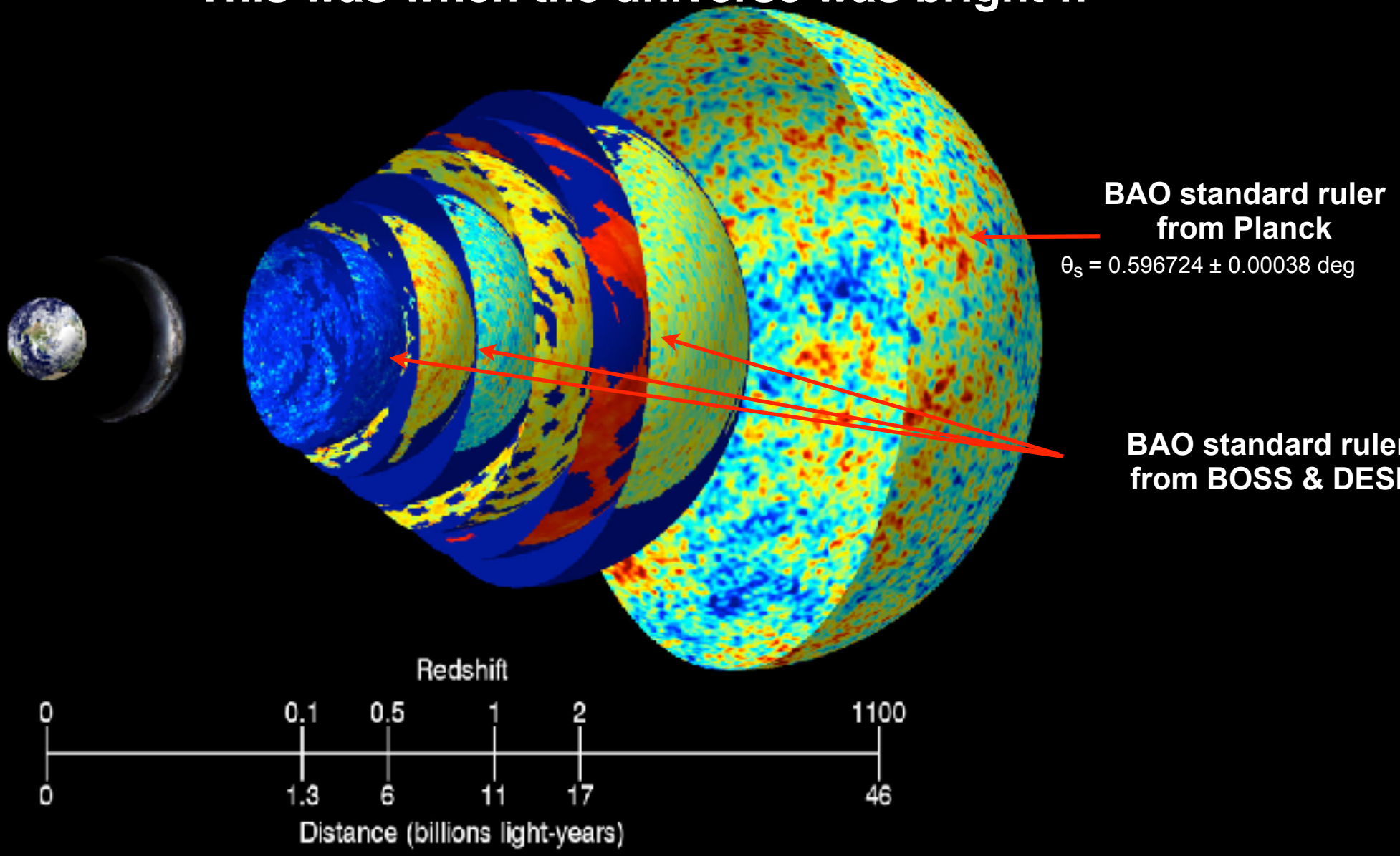


Fig. 26. Marginalized 68 % and 95 % confidence levels for n_s and r from Planck+WP and BAO data, compared to the theoretical predictions of selected inflationary models.

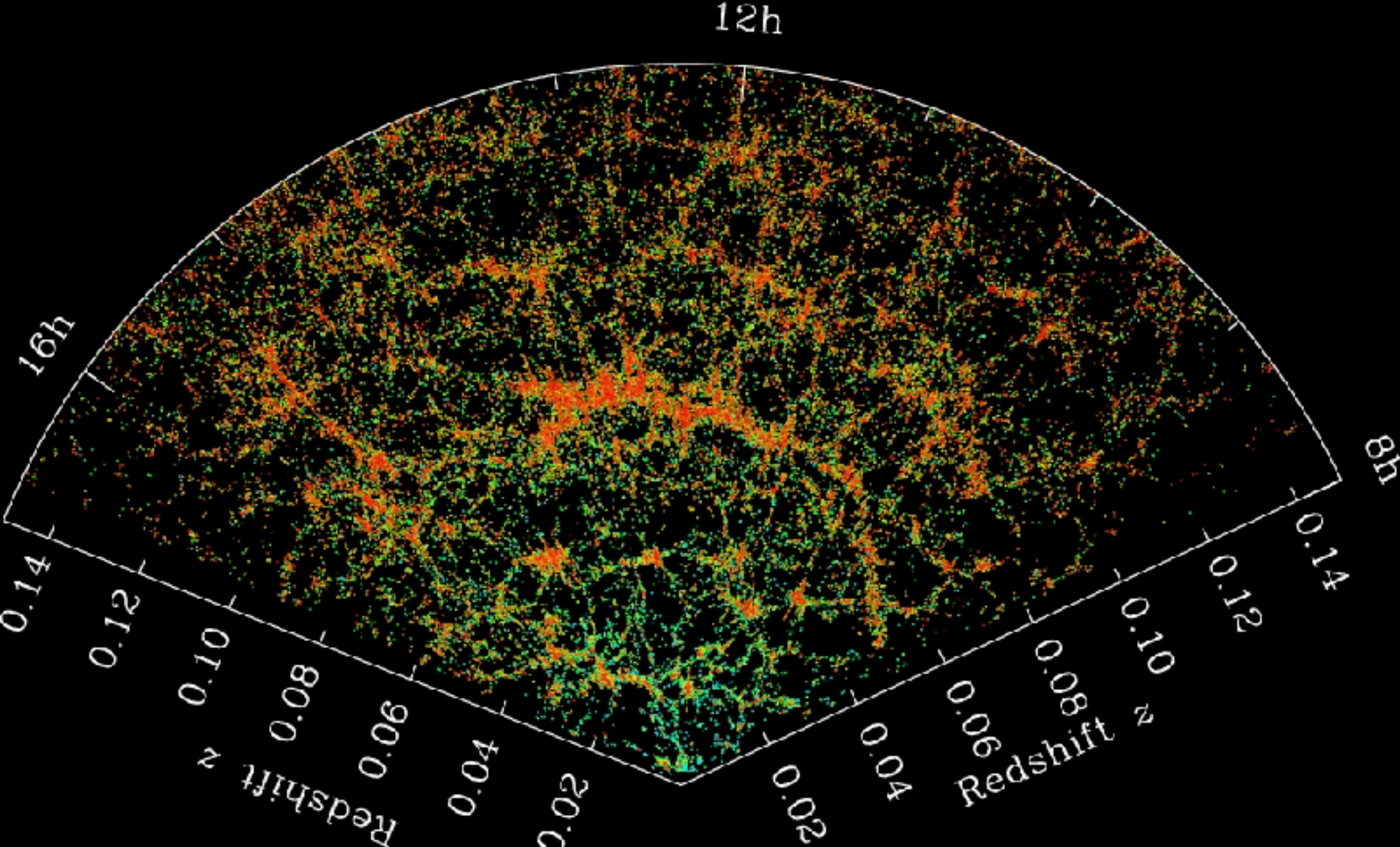
from Planck overview paper (2014)

Cosmological info scales as the # of modes mapped

Optical redshift surveys map linear modes from z=0 → 4
This was when the universe was bright !!

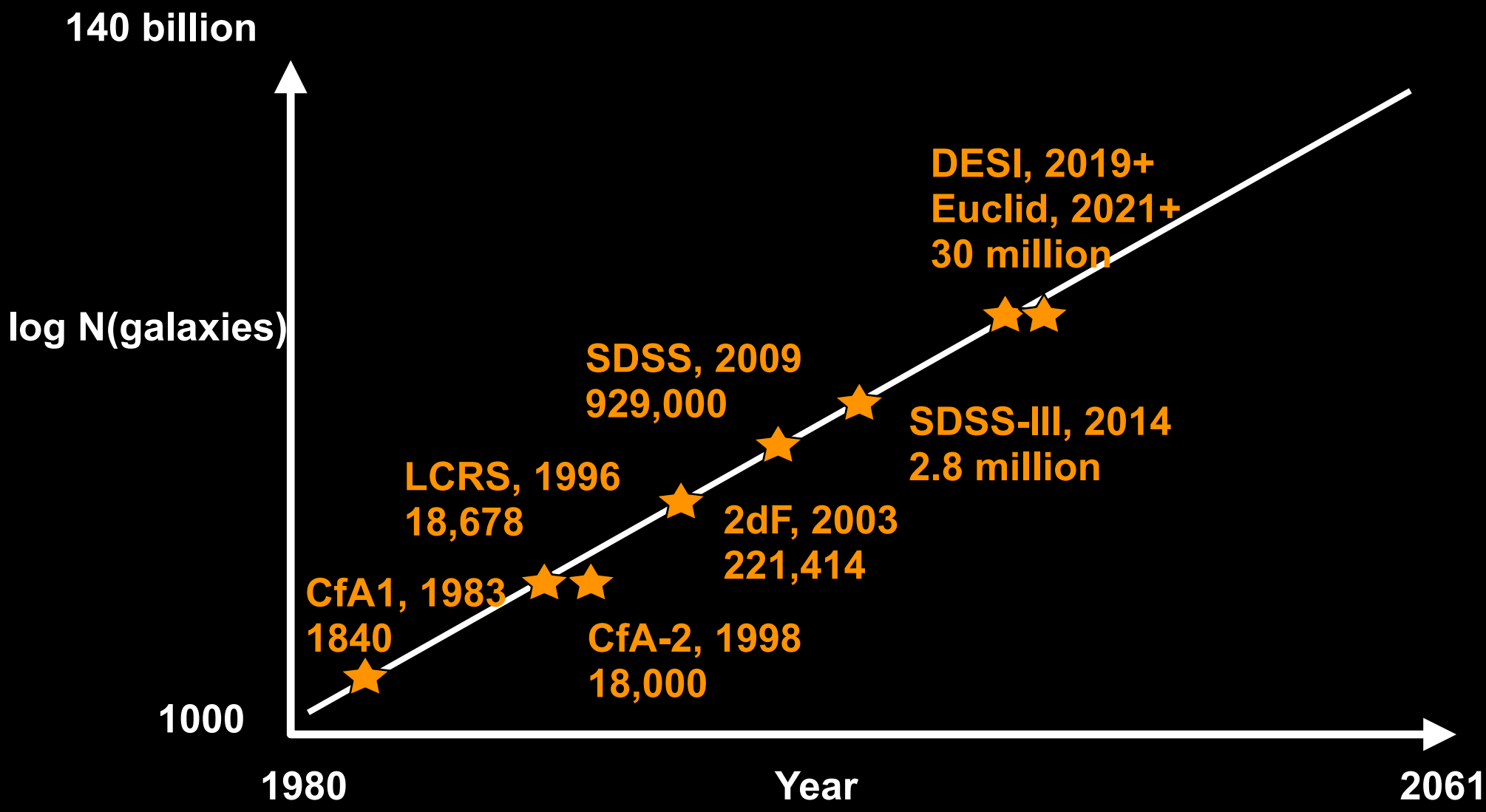


We’re in a golden age of redshift surveys



Redshift surveys larger by ~10X every 10 years

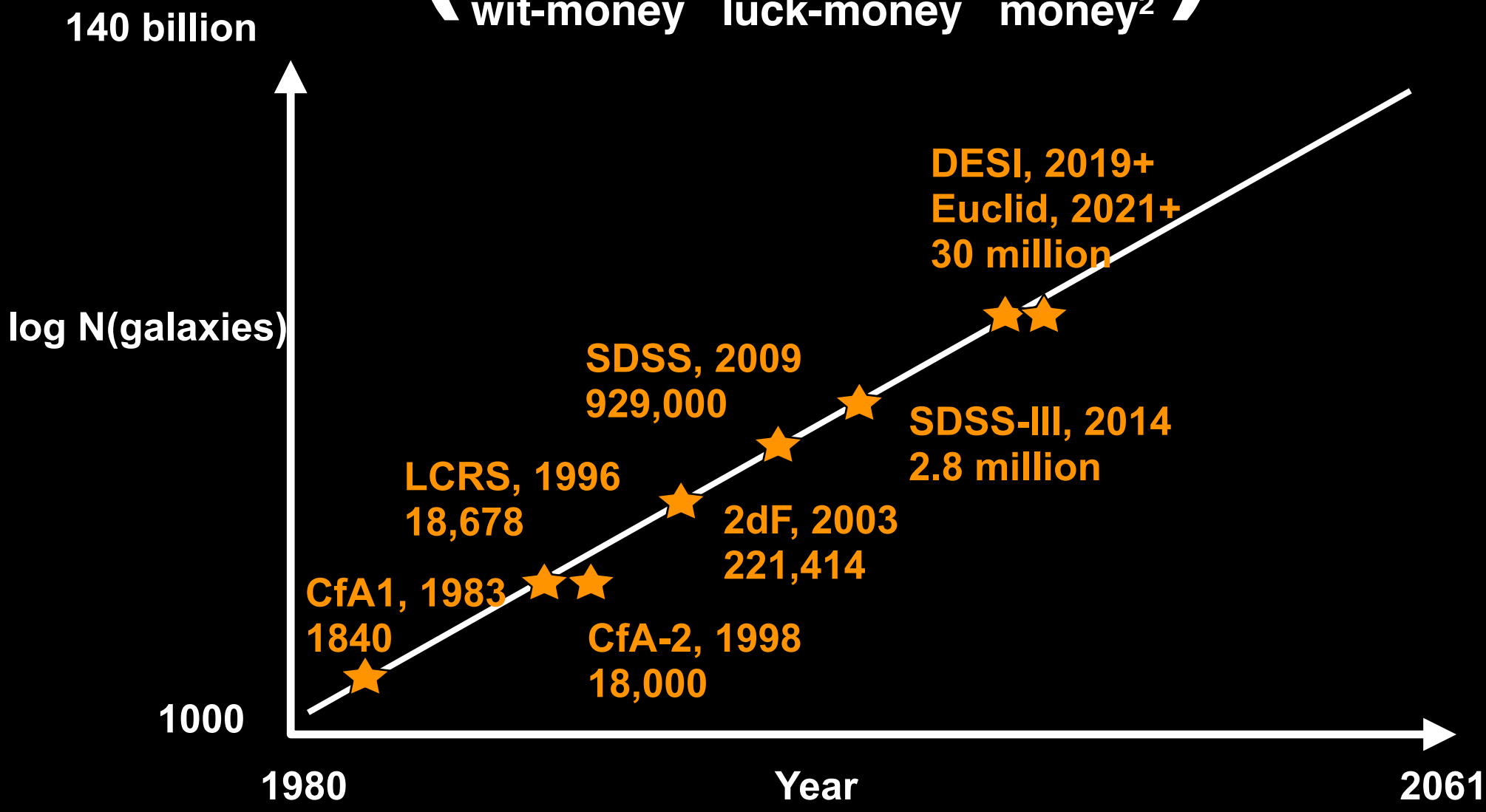
- Compare to Moore's Law in computing
- Redshift survey instruments improve, but need to look at fainter (harder) galaxies



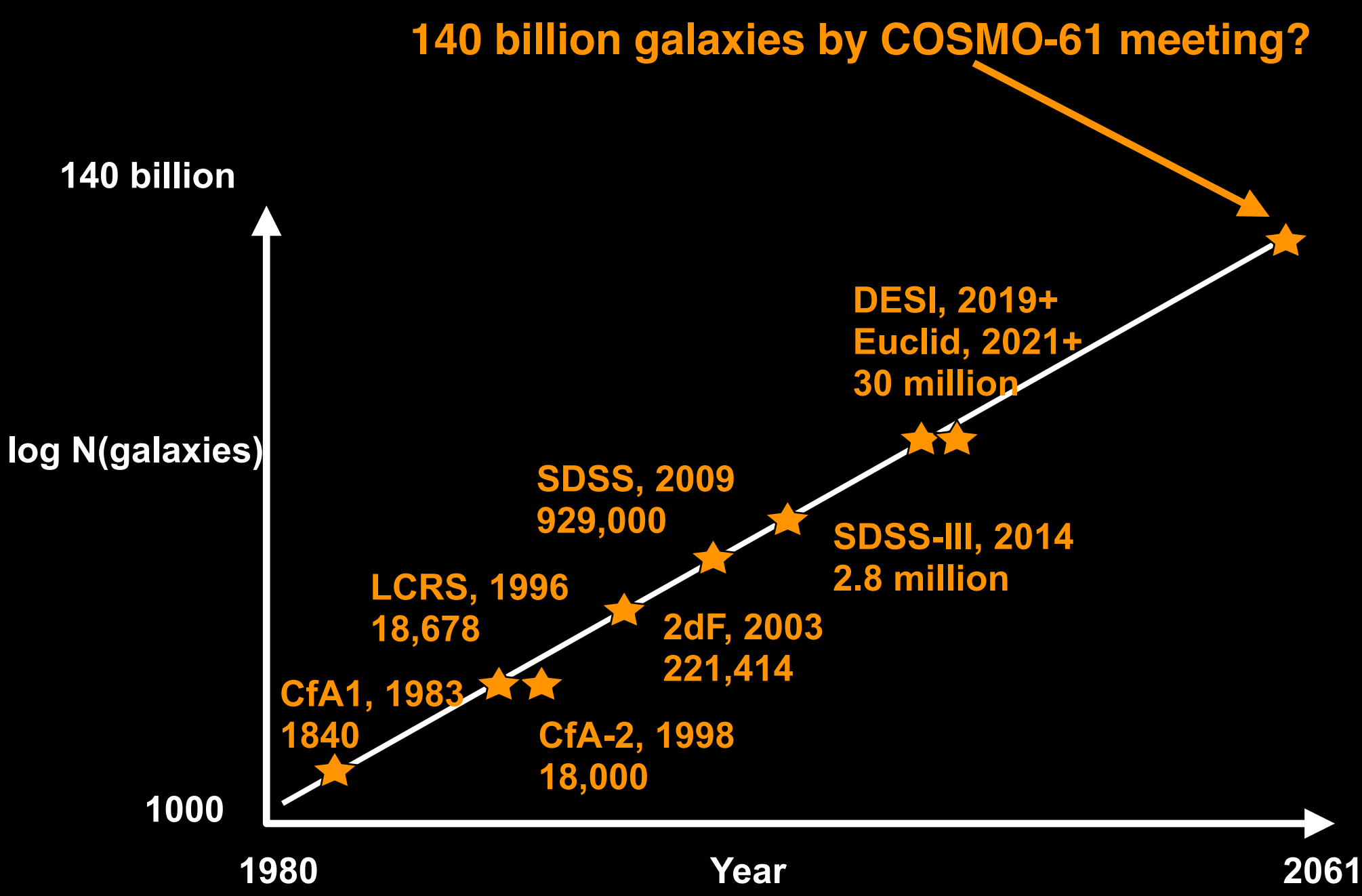
Redshift surveys larger by ~10X every 10 years

- Improvements are due to wit + luck + money, and some covariance…

$$\begin{pmatrix} \text{wit}^2 & - & - \\ \text{wit-luck} & \text{luck}^2 & - \\ \text{wit-money} & \text{luck-money} & \text{money}^2 \end{pmatrix}$$

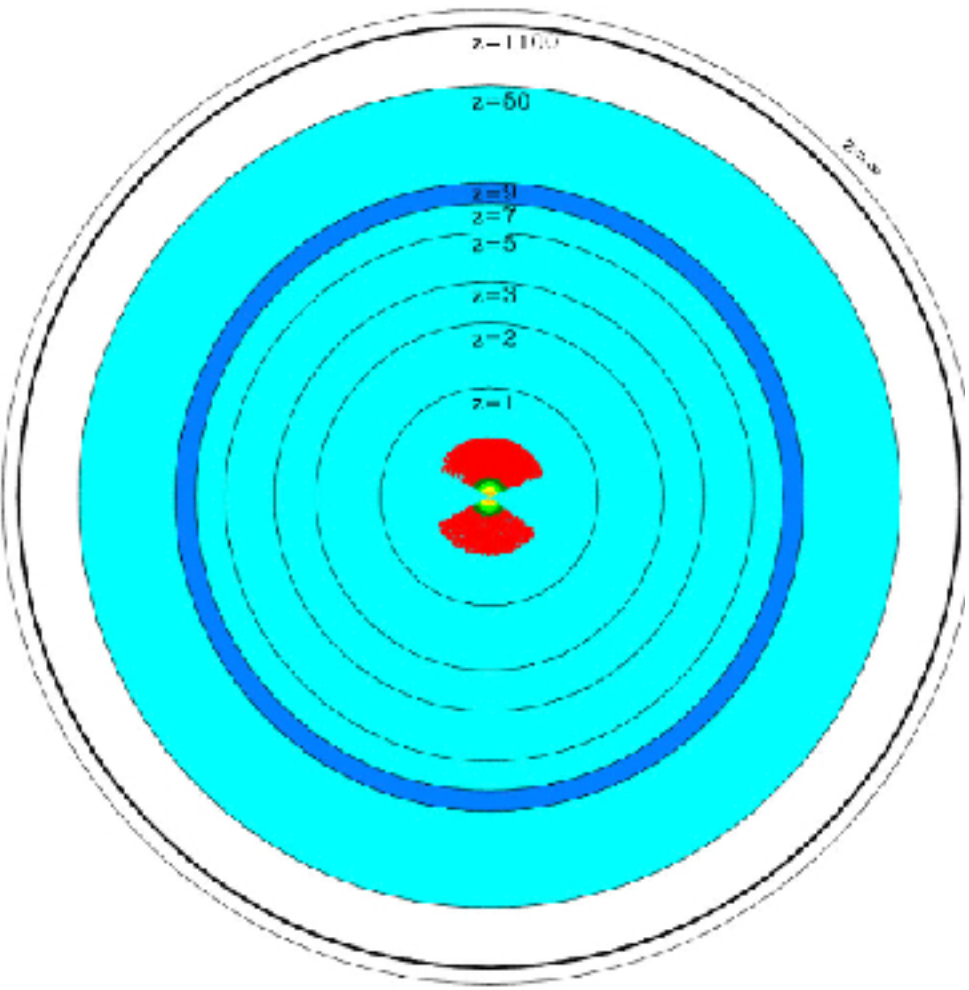


Redshift surveys larger by ~10X every 10 years

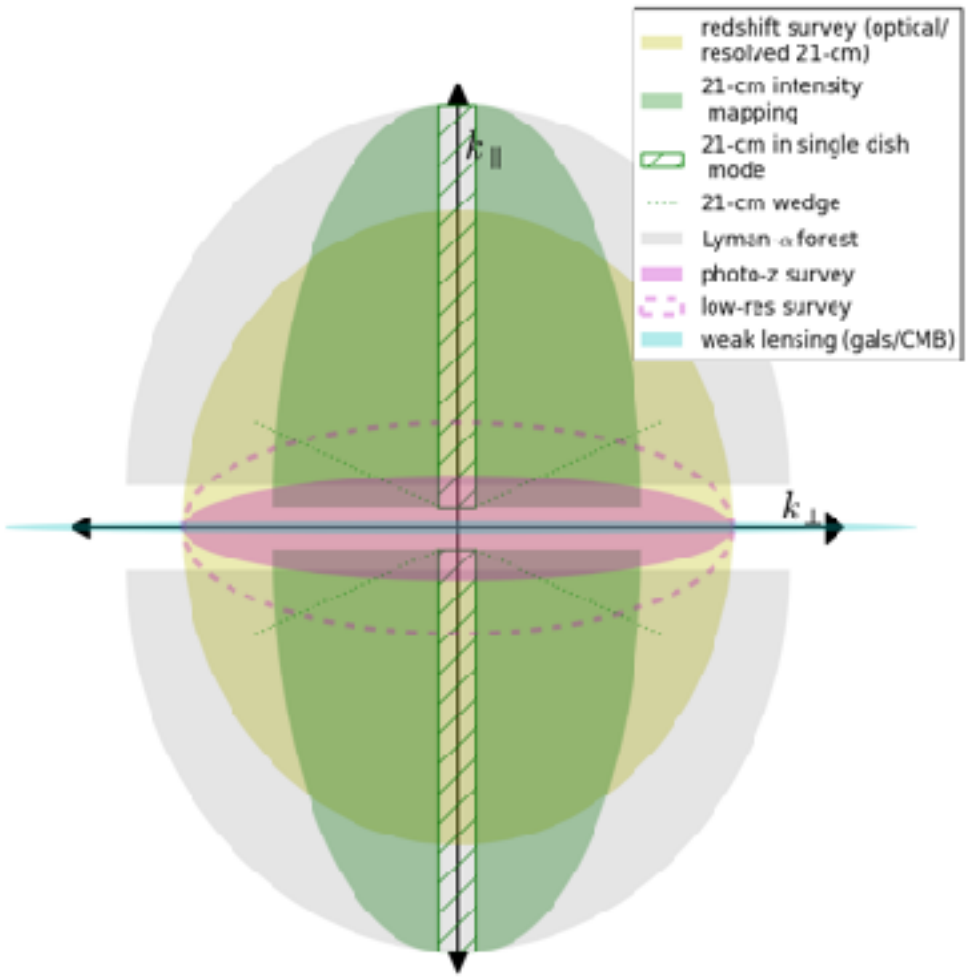


Larger maps improve all cosmological parameters

Volume



Number of modes



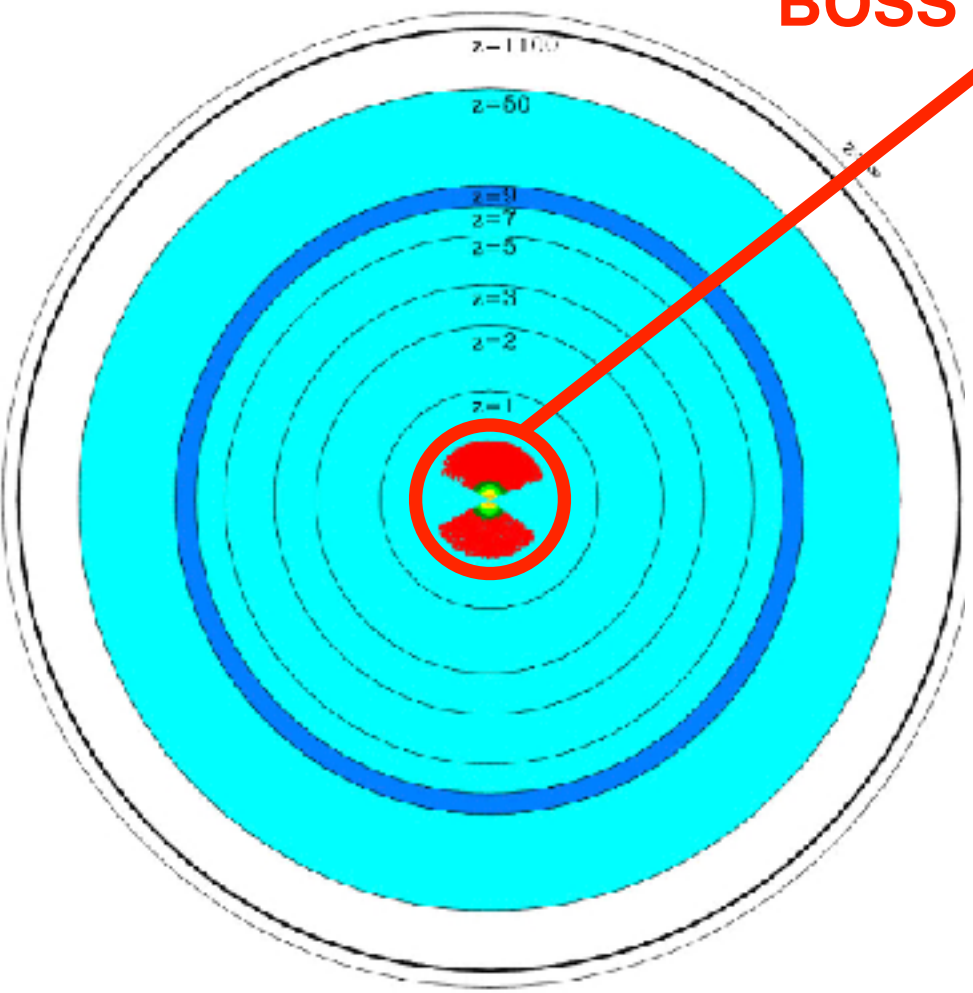
A. Slosar

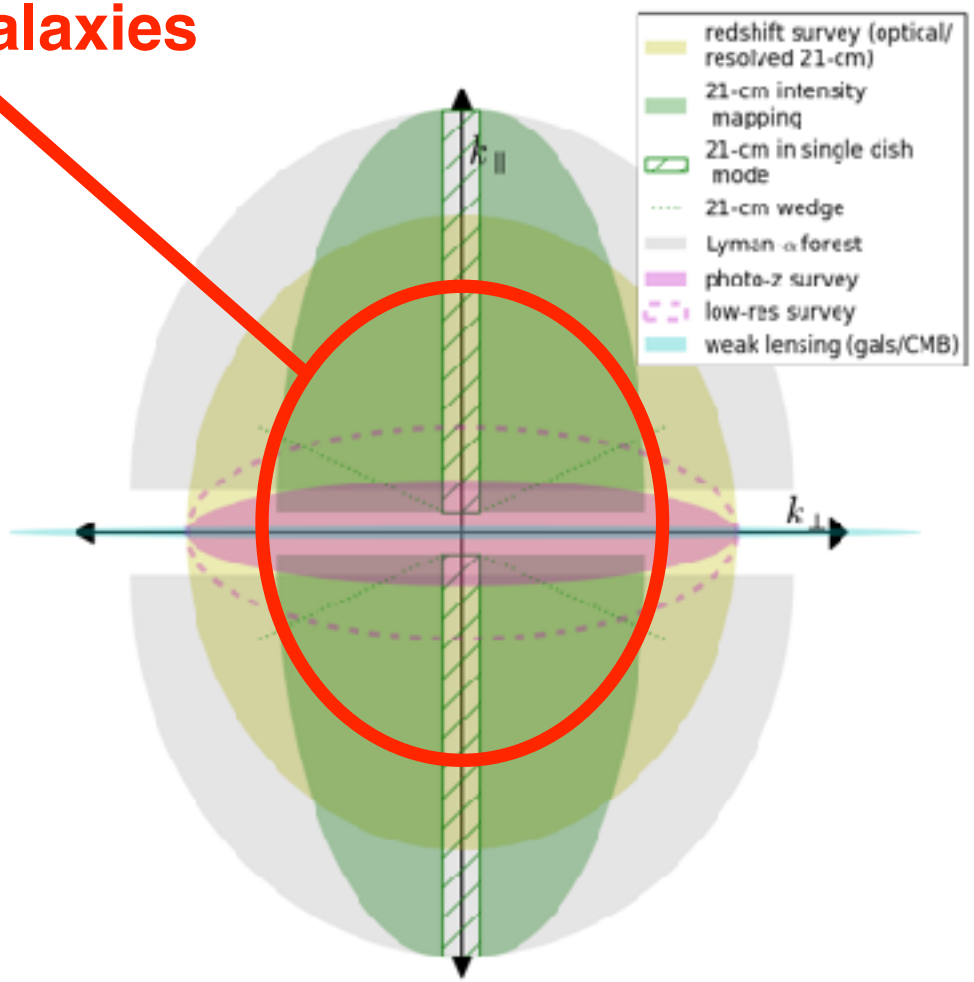
Larger maps improve all cosmological parameters

Volume

Number of modes

BOSS galaxies





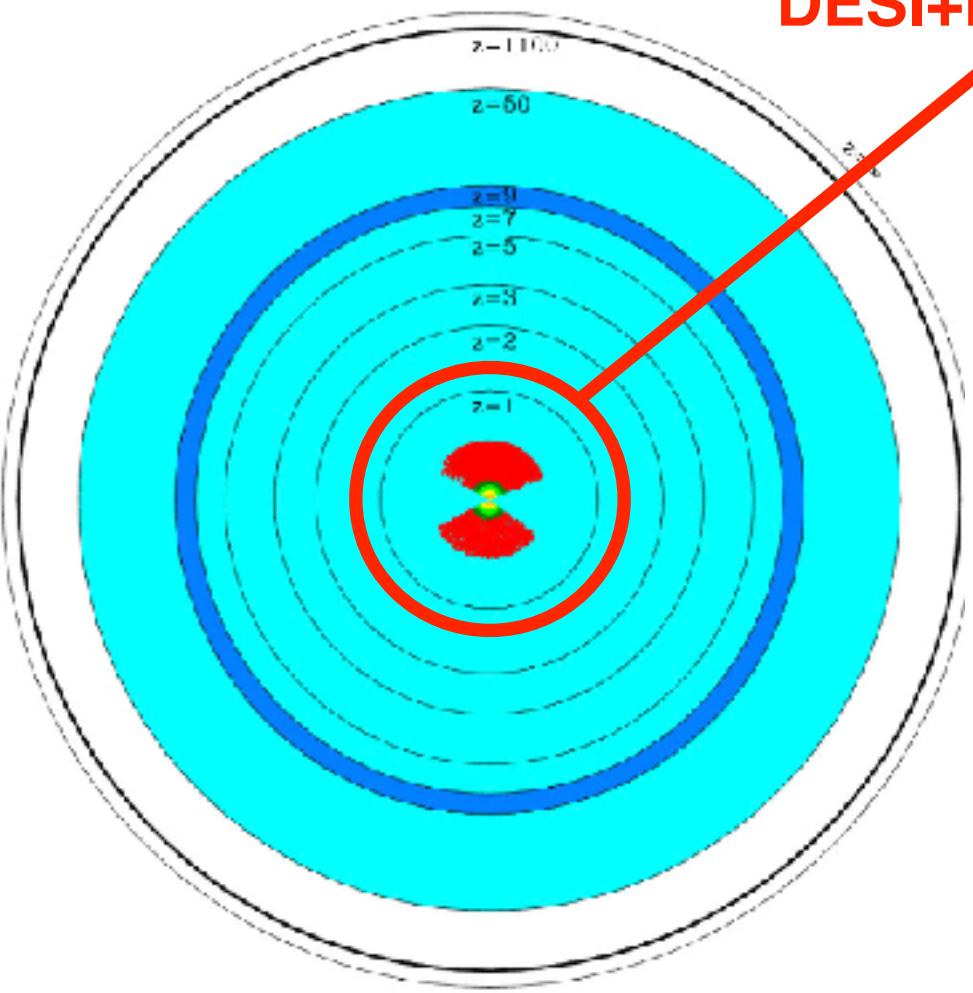
A. Slosar

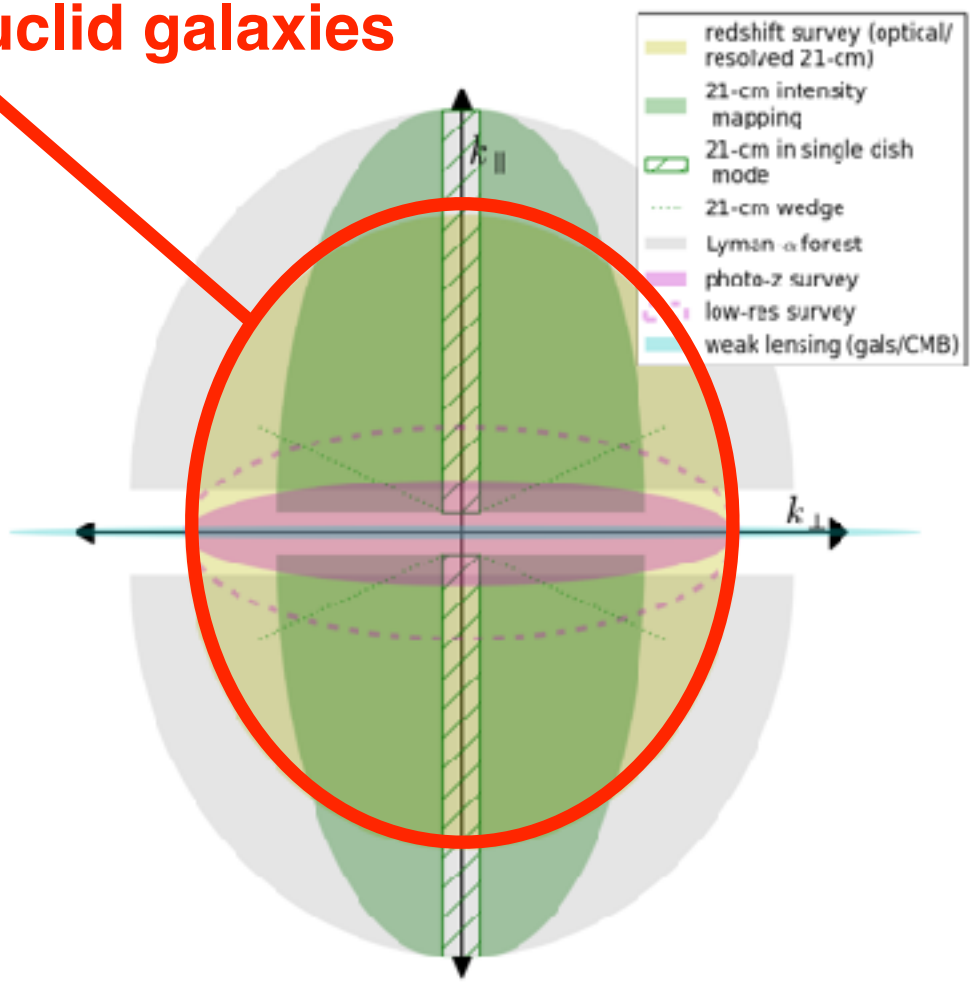
Larger maps improve all cosmological parameters

Volume

Number of modes

DESI+Euclid galaxies





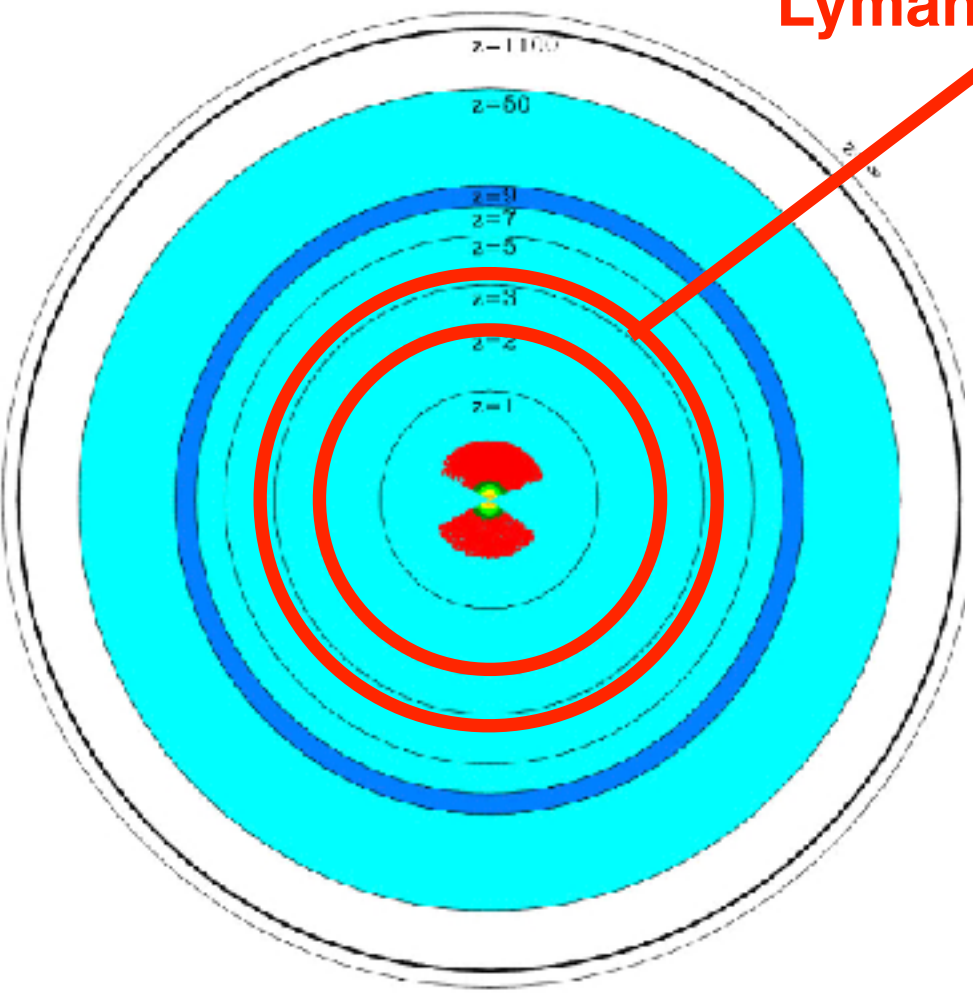
A. Slosar

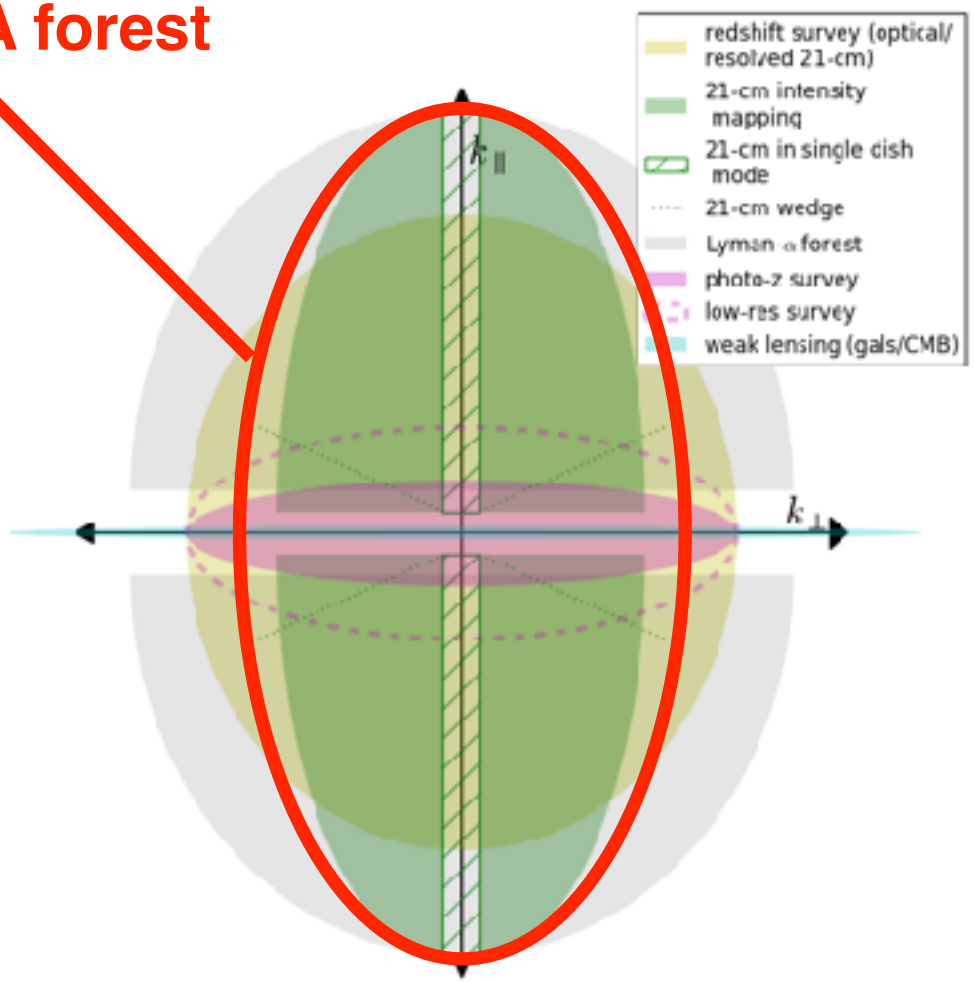
Larger maps improve all cosmological parameters

Volume

Number of modes

Lyman-A forest

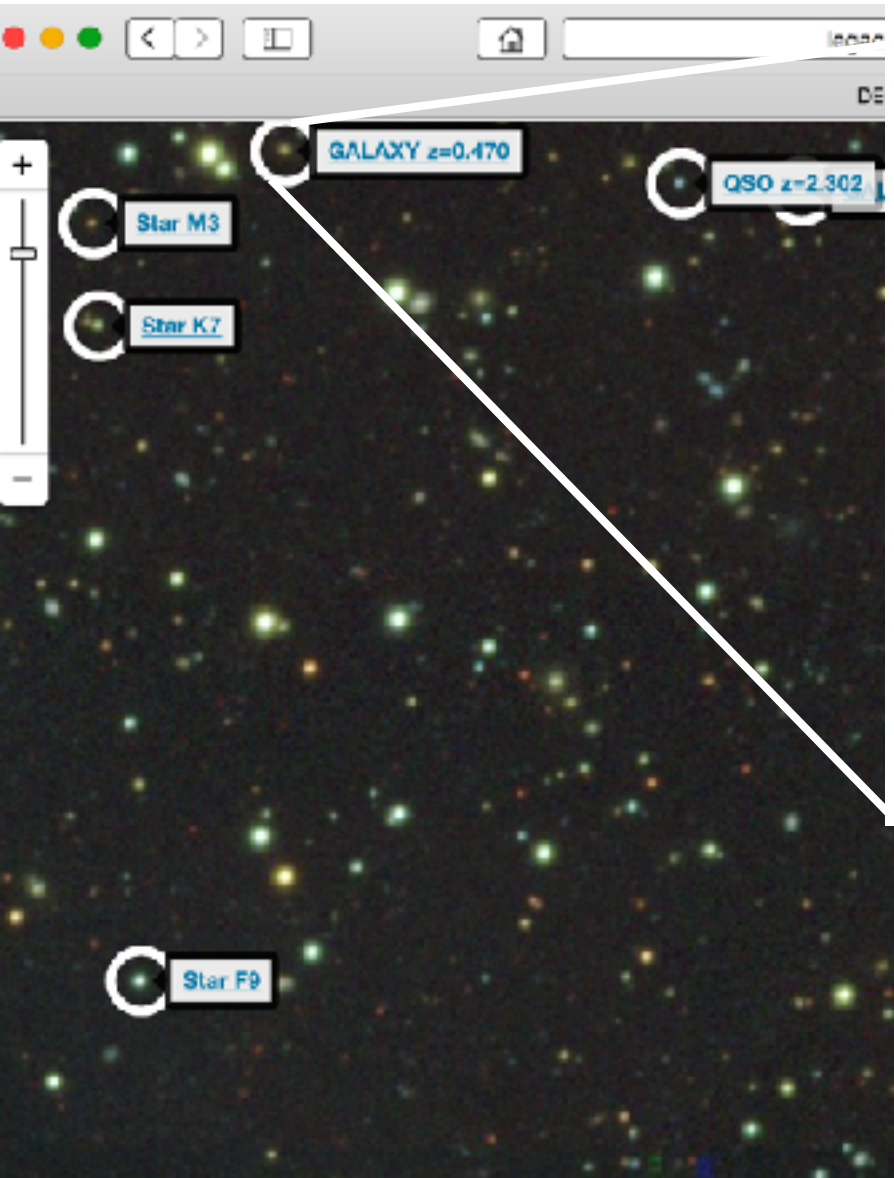


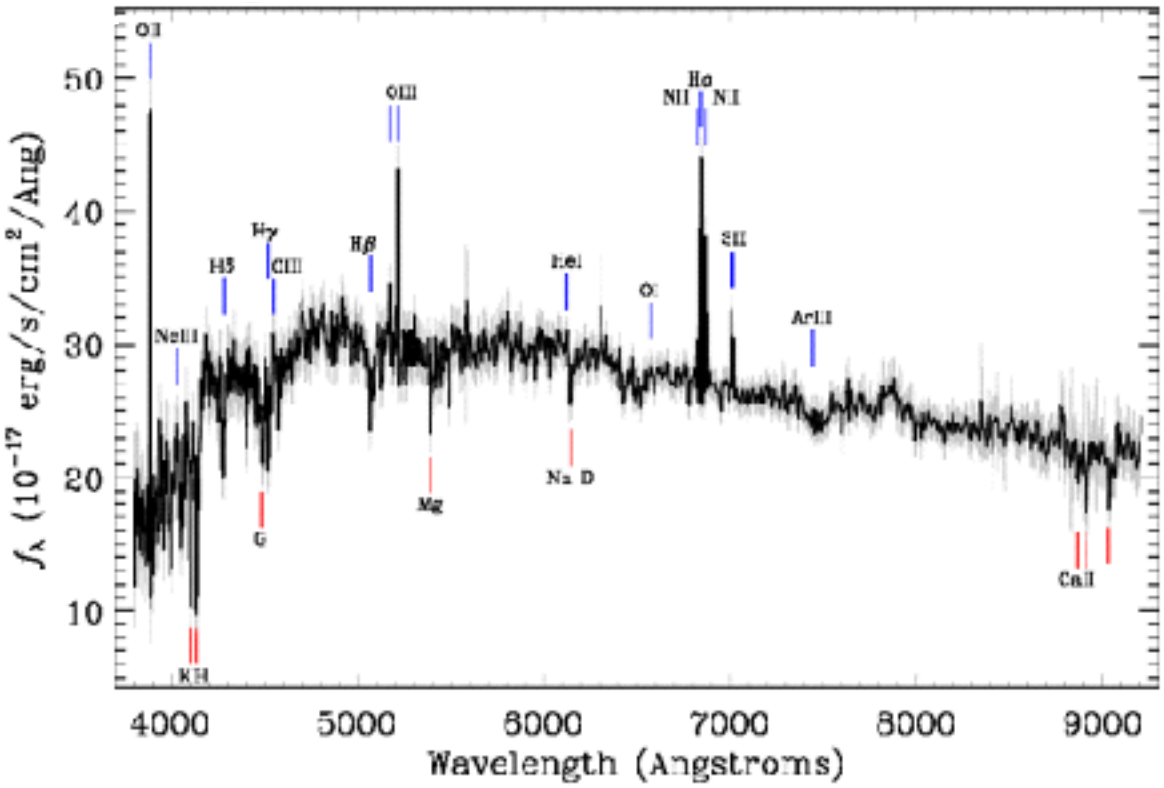


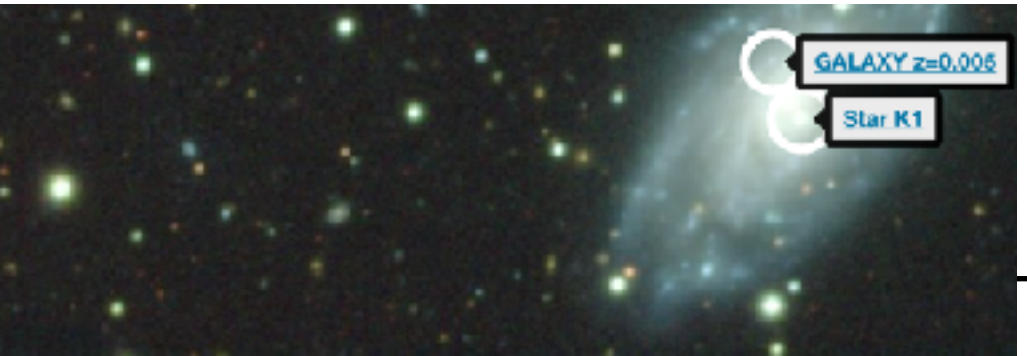
A. Slosar

Redshift surveys of “easy” objects or “hard” ones

“Easiest” are nearby bright galaxies, not buried in sky noise
As of 2017, most redshifts fall in this category:
SDSS, 2dF, GAMA, SDSS-III/BOSS





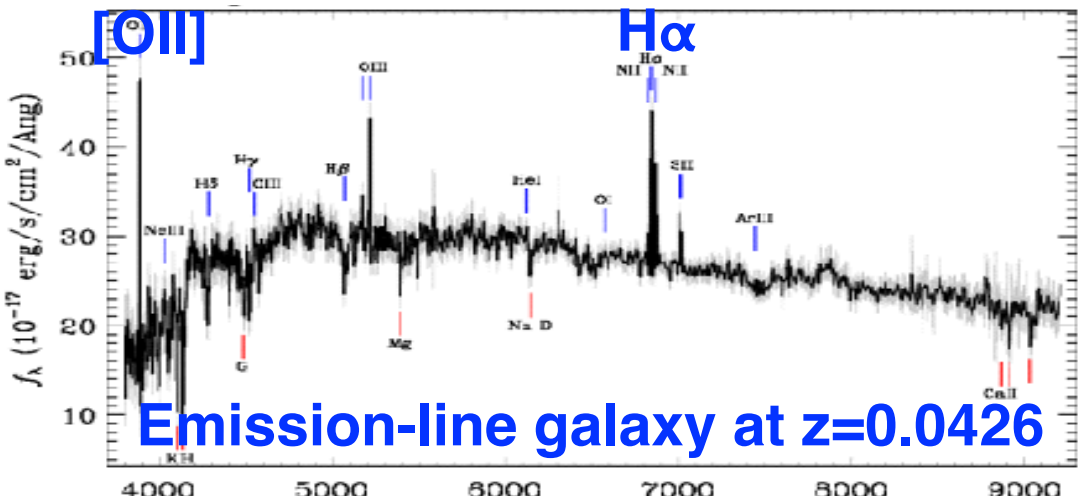


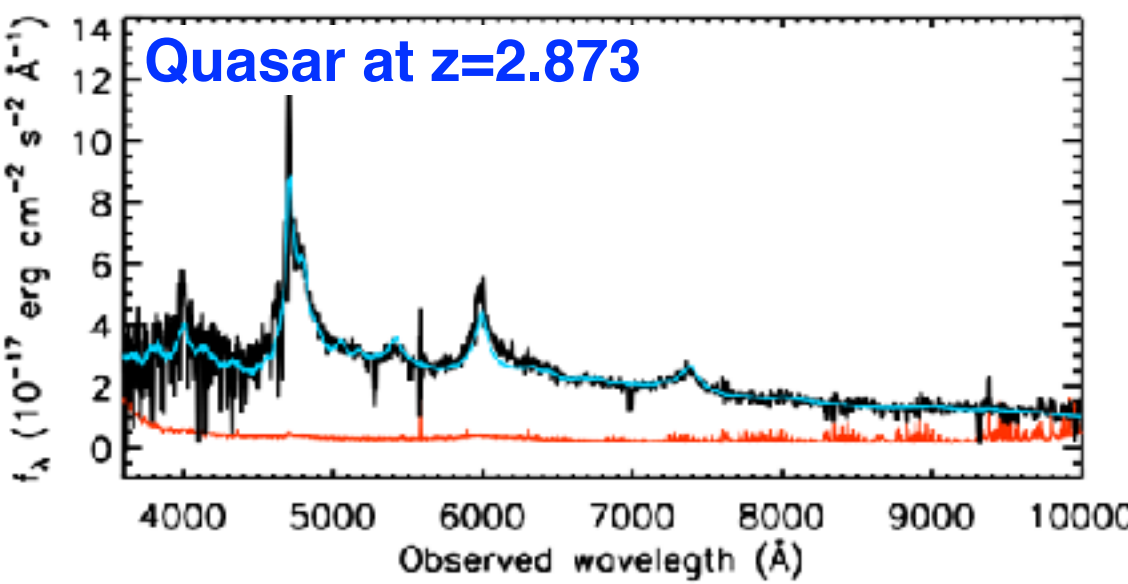
Redshift surveys of "easy" objects or "hard" ones

"Easy" are galaxies with good spectroscopic features
Current + near-future redshifts fall in this category:
SDSS-IV/eBOSS, DESI, Euclid, HETDEX

Some luck here:
Star-formation at z~1
turns lots of energy into
emission lines

Dust is wonderful !!

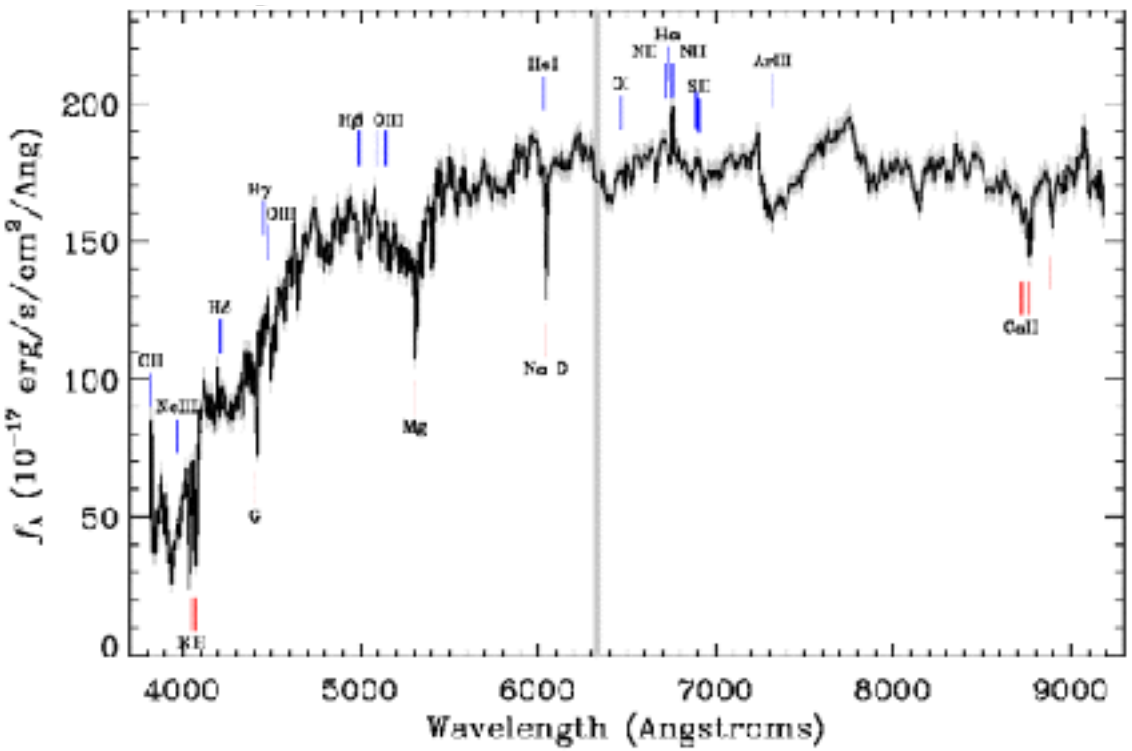




Redshift surveys of “easy” objects or “hard” ones

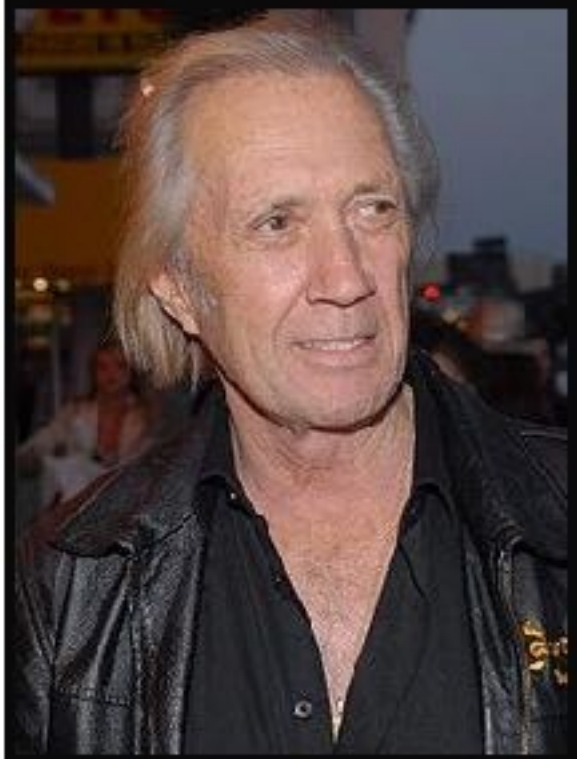
“Hard” are galaxies with faint spectroscopic features
Smaller-area surveys: VVDS, DEEP2, PFS

No extra luck here:
But with enough photons,
we still get redshifts



Redshift surveys of “easy” objects or “hard” ones

There’s also a “third way”… the Lyman-alpha way



There's an alternative. There's always a third way,
and it's not a combination of the other two ways.
It's a different way.

(David Carradine)

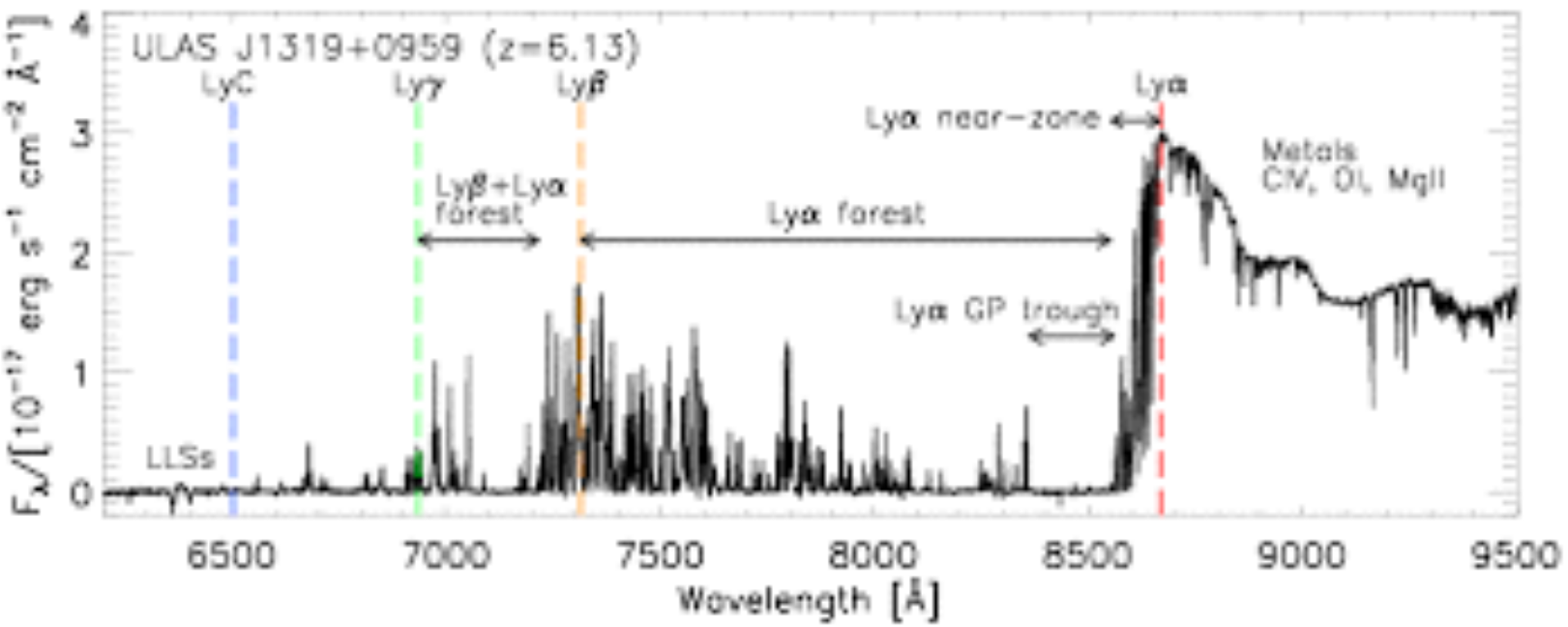
izquotes.com

Redshift surveys of “easy” objects or “hard” ones

There’s also a “third way”… the Lyman-alpha way

Maps hydrogen gas to line-of-sight of each quasar

- **BOSS, eBOSS, DESI, PFS(?)**
- **(Not practical with space missions)**



$$P_{\rm raw}(\mathbf{k}) = \left[P_F(\mathbf{k}) + n^{-1} P_F^{\rm 1D}(k_\parallel)\right] W^2\left(k_\parallel R\right) + P_N^{\rm eff}$$

Ideal 3D power (perfectly sampled)

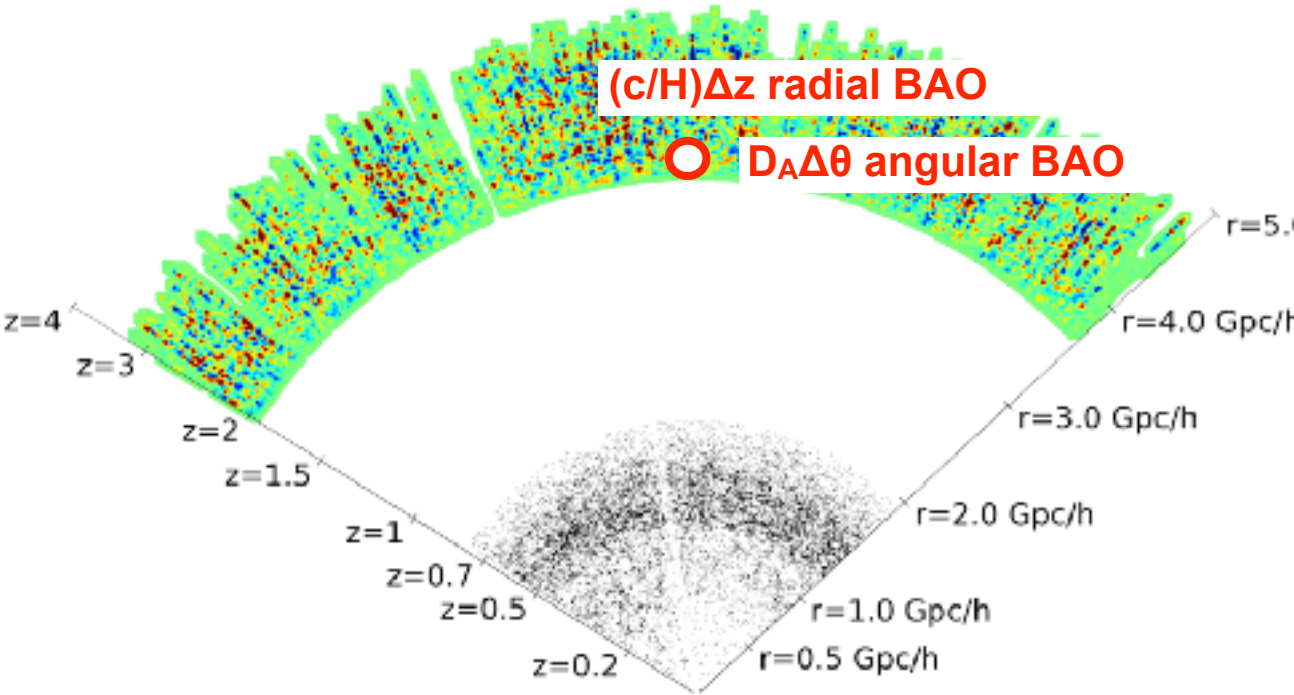
Sampling noise
n=surface density of lines of sight
(analogous to galaxy shot noise)

Resolution

Detector noise

DESI will start the next leap in redshift surveys

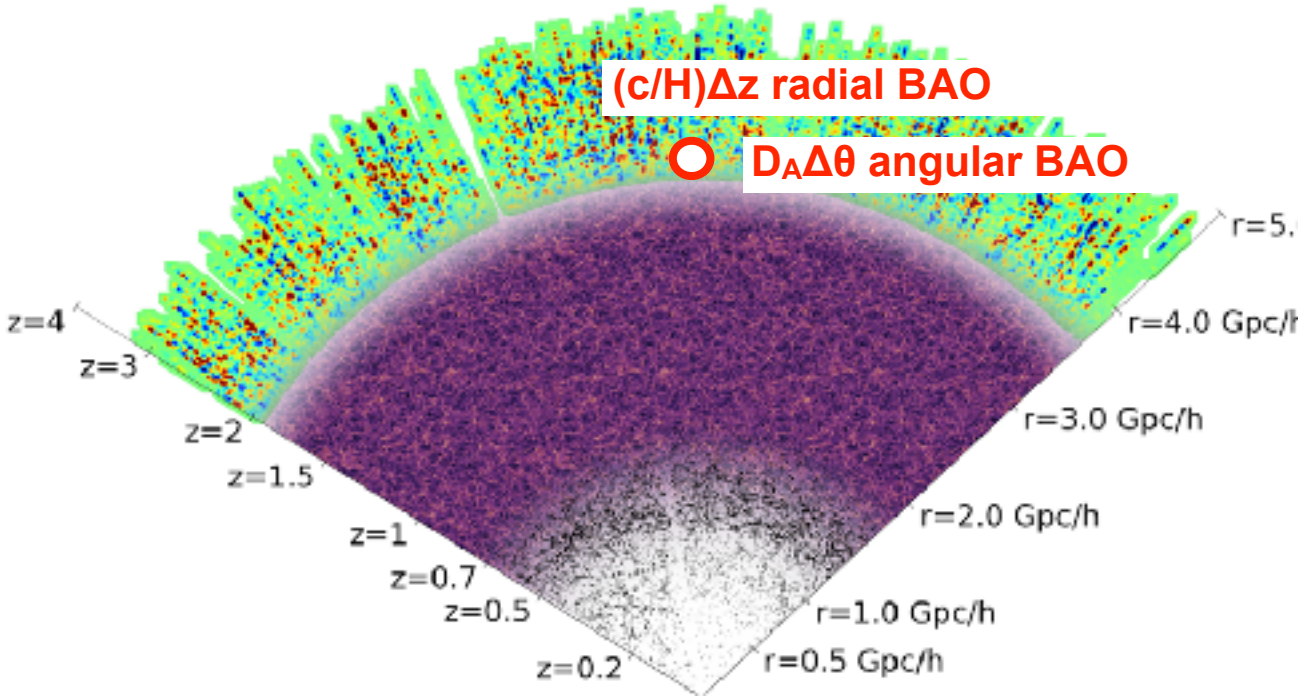
Installation 2018, First Light January 2019



3-D map of 1.5M galaxies (BOSS)

DESI will start the next leap in redshift surveys

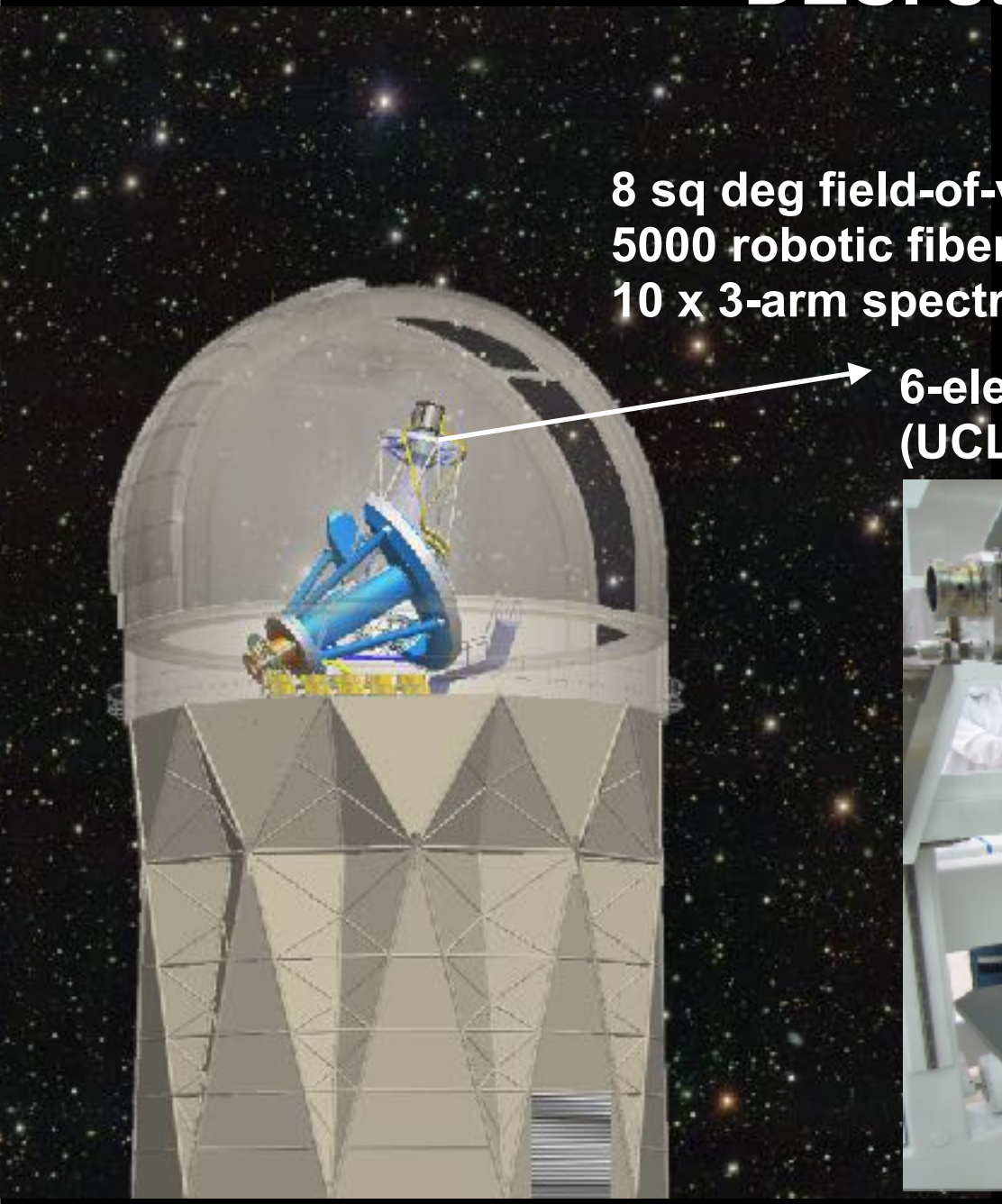
Using "easy" redshifts, with peak of distribution at z~1



3-D map of 35M galaxies (DESI)
including a sample of 10M nearby galaxies

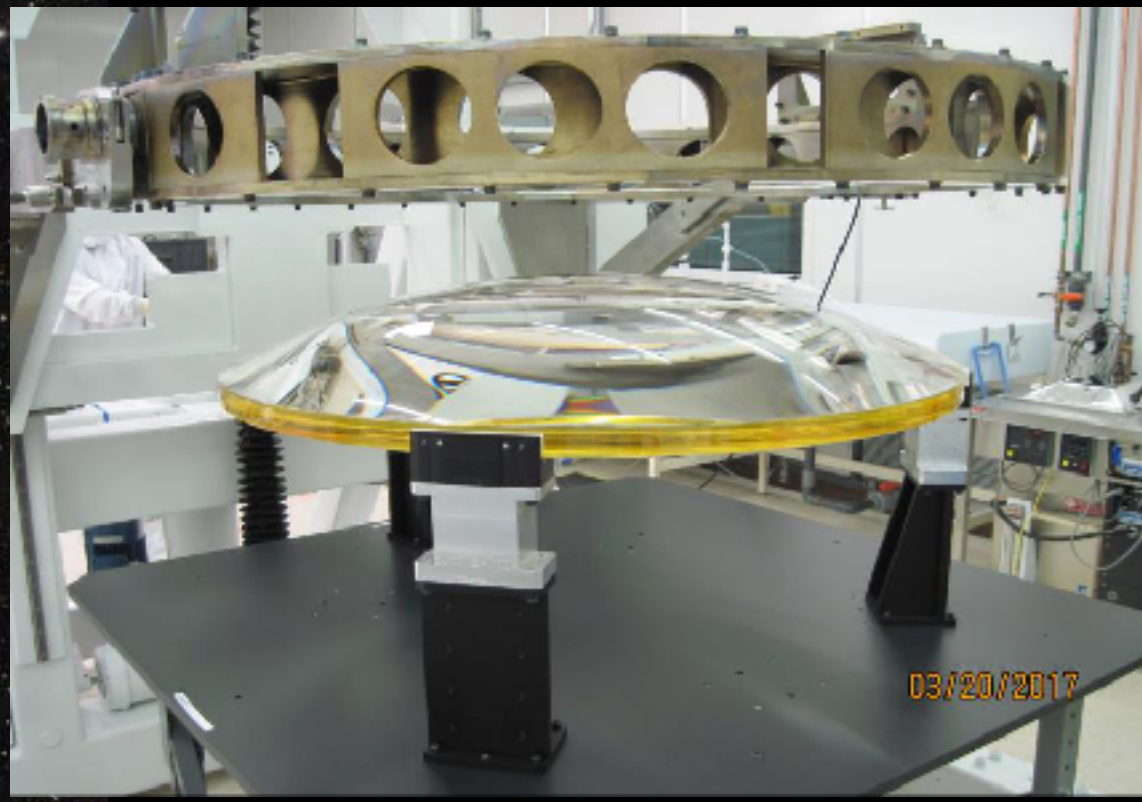
DESI @ Mayall 4-meter Telescope
Kitt Peak, AZ

DESI status

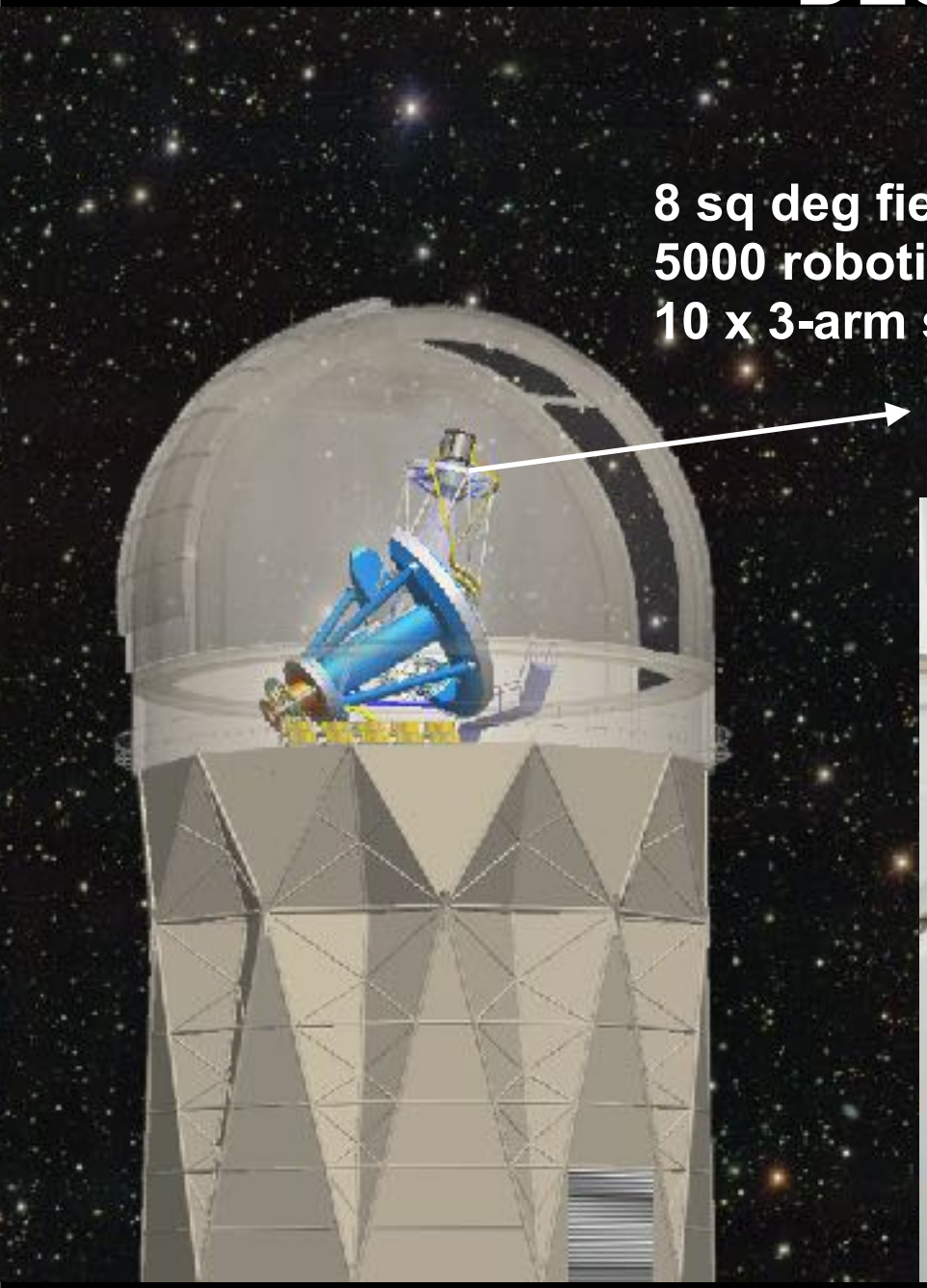


8 sq deg field-of-view
5000 robotic fiber positioners
10 x 3-arm spectrographs spanning 3600-9800 Ang

6-element optical corrector (5 completed)
(UCLondon, LBNL)

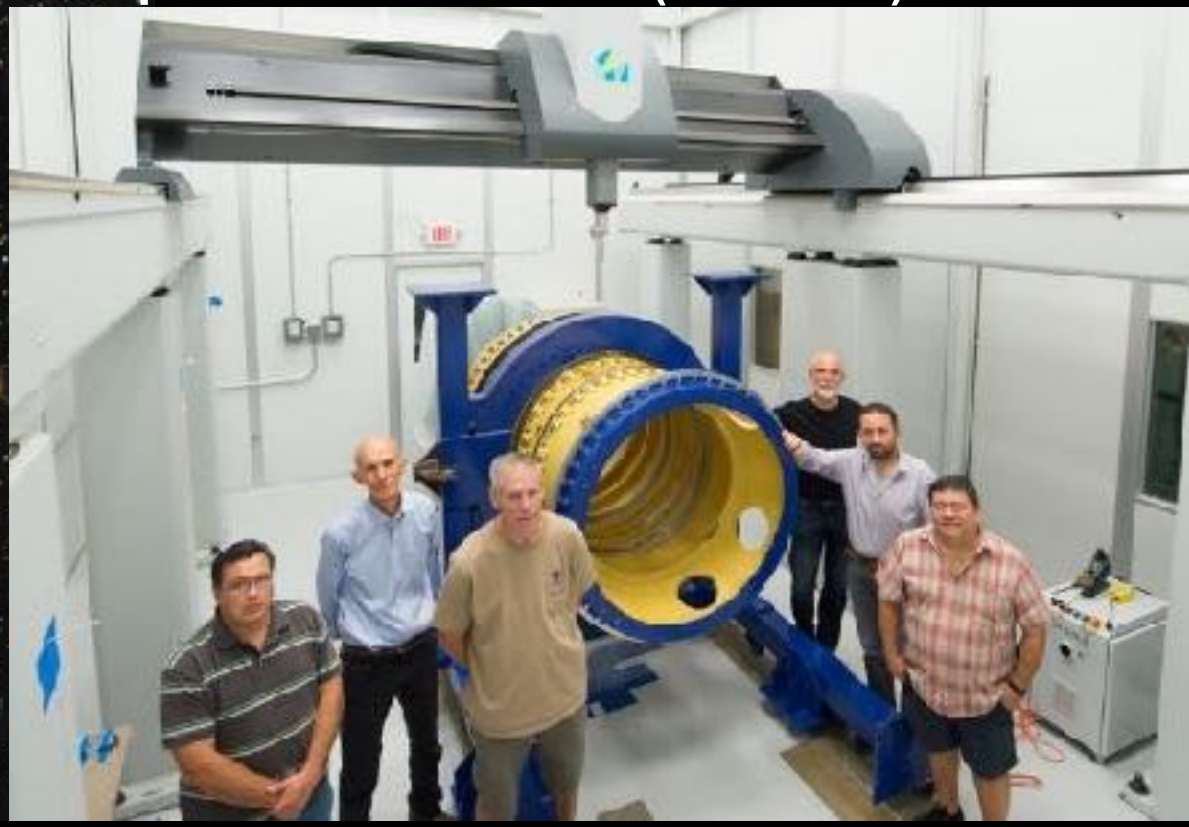


DESI status



8 sq deg field-of-view
5000 robotic fiber positioners
10 x 3-arm spectrographs spanning 3600-9800 Ang

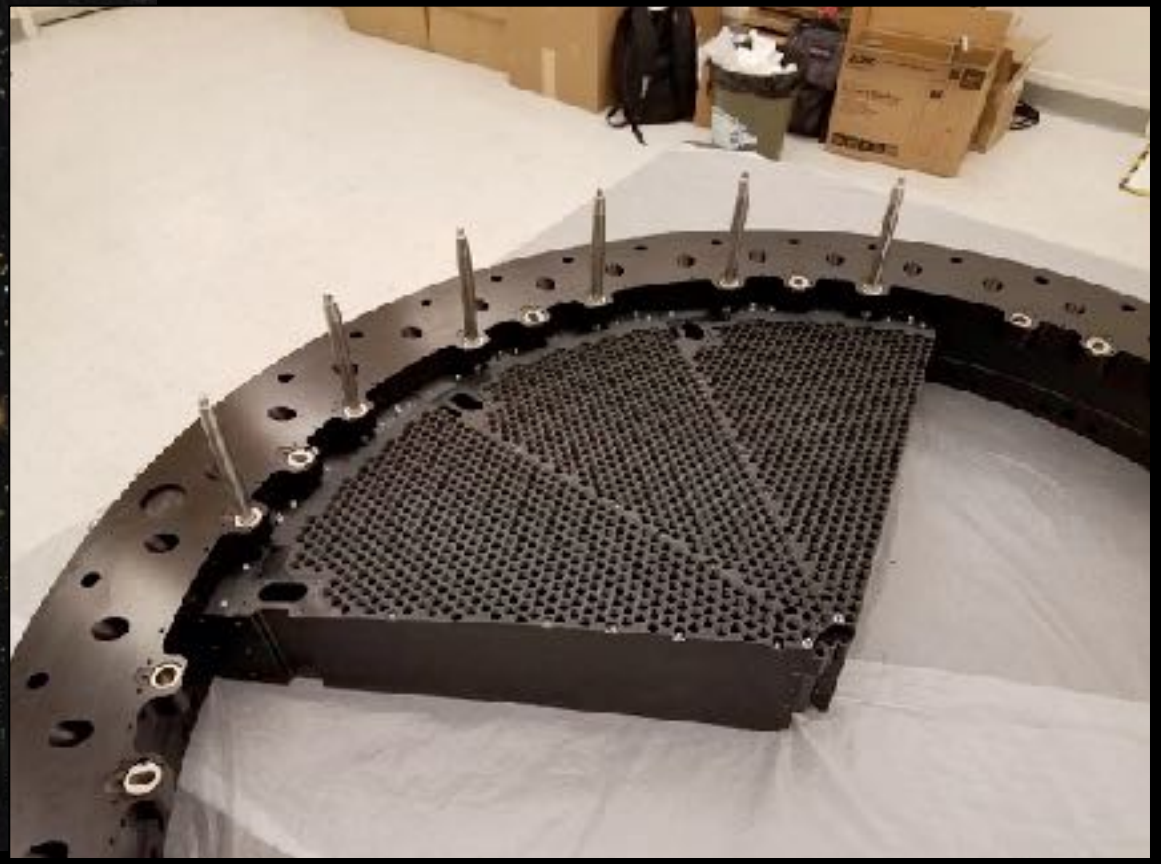
Barrel assembly complete for corrector lenses
hexapod in construction (Fermilab)



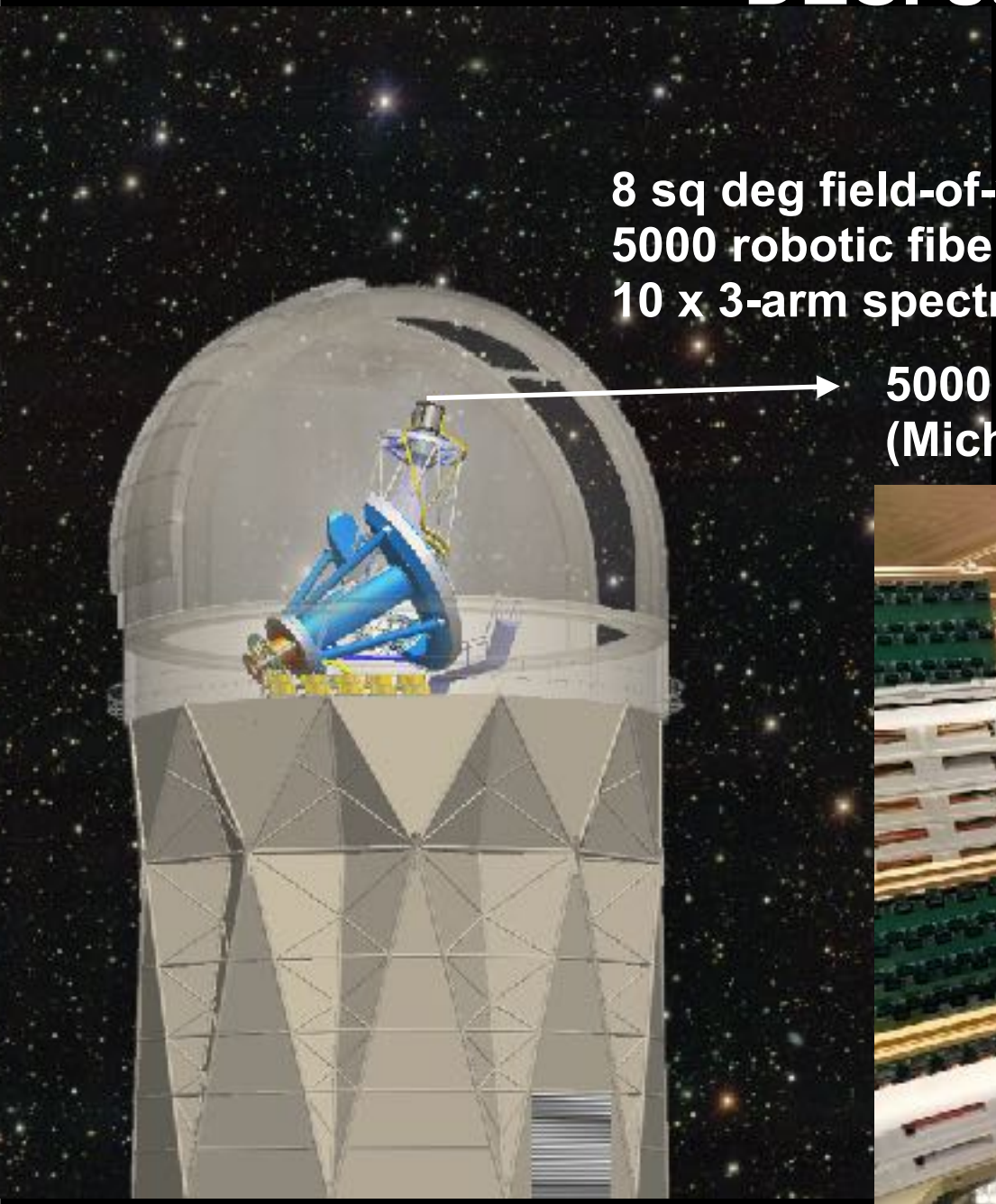
DESI status

8 sq deg field-of-view
5000 robotic fiber positioners
10 x 3-arm spectrographs spanning 3600-9800 Ang

6 of 10 focal plane petals complete (Boston U.)

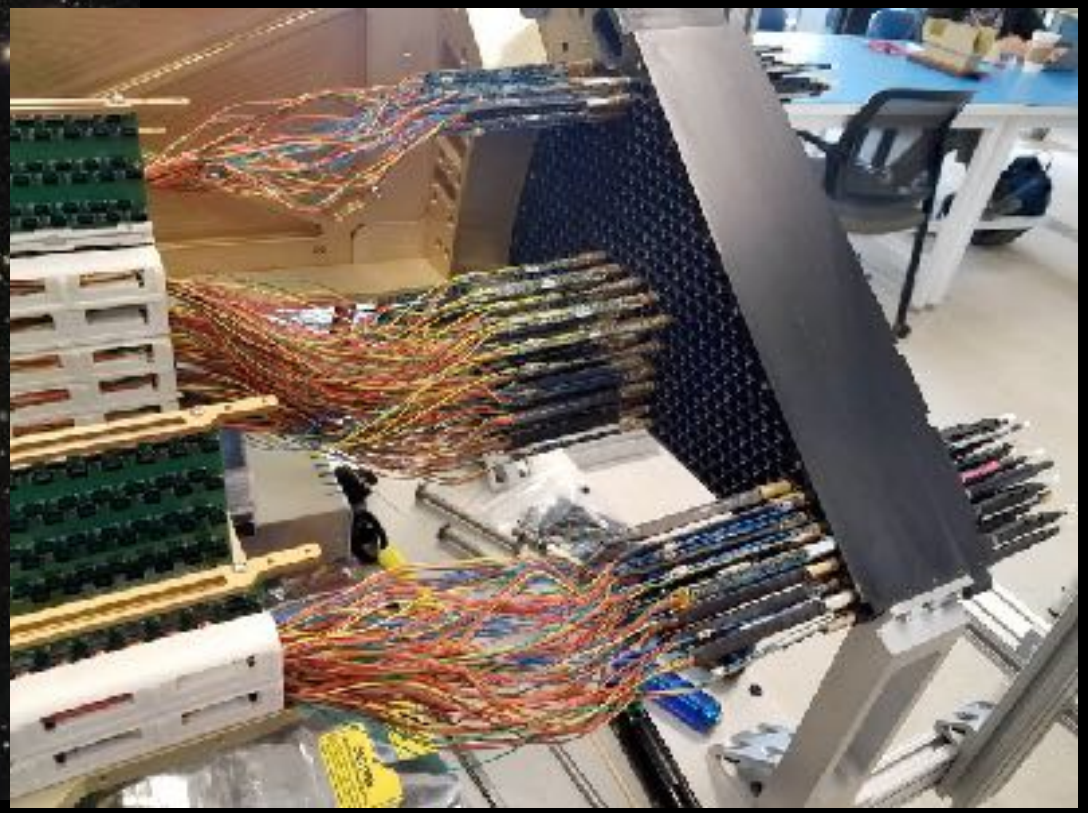


DESI status

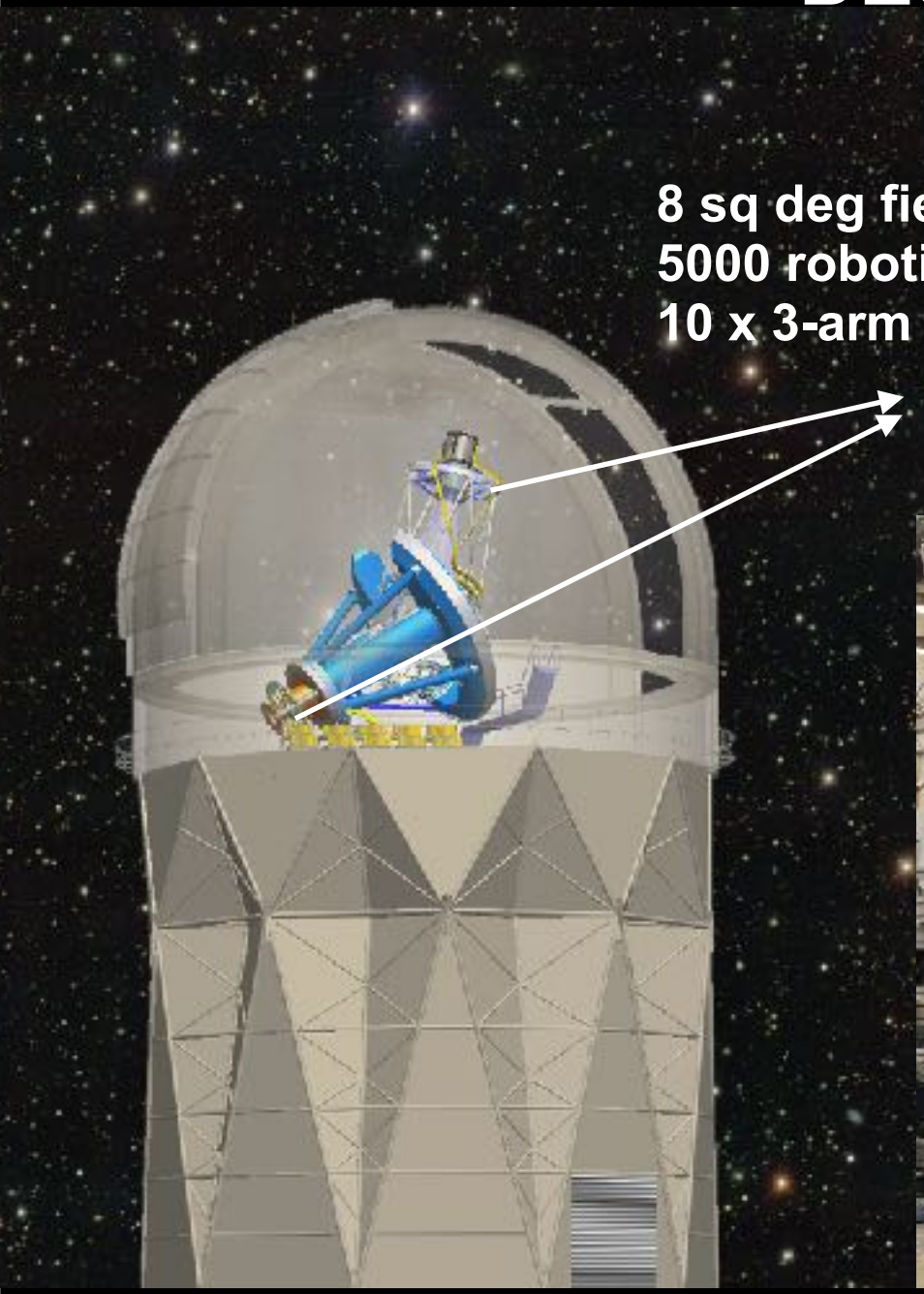


8 sq deg field-of-view
5000 robotic fiber positioners
10 x 3-arm spectrographs spanning 3600-9800 Ang

5000 robotic positioners in assembly
(Michigan, EPFL, LBNL)



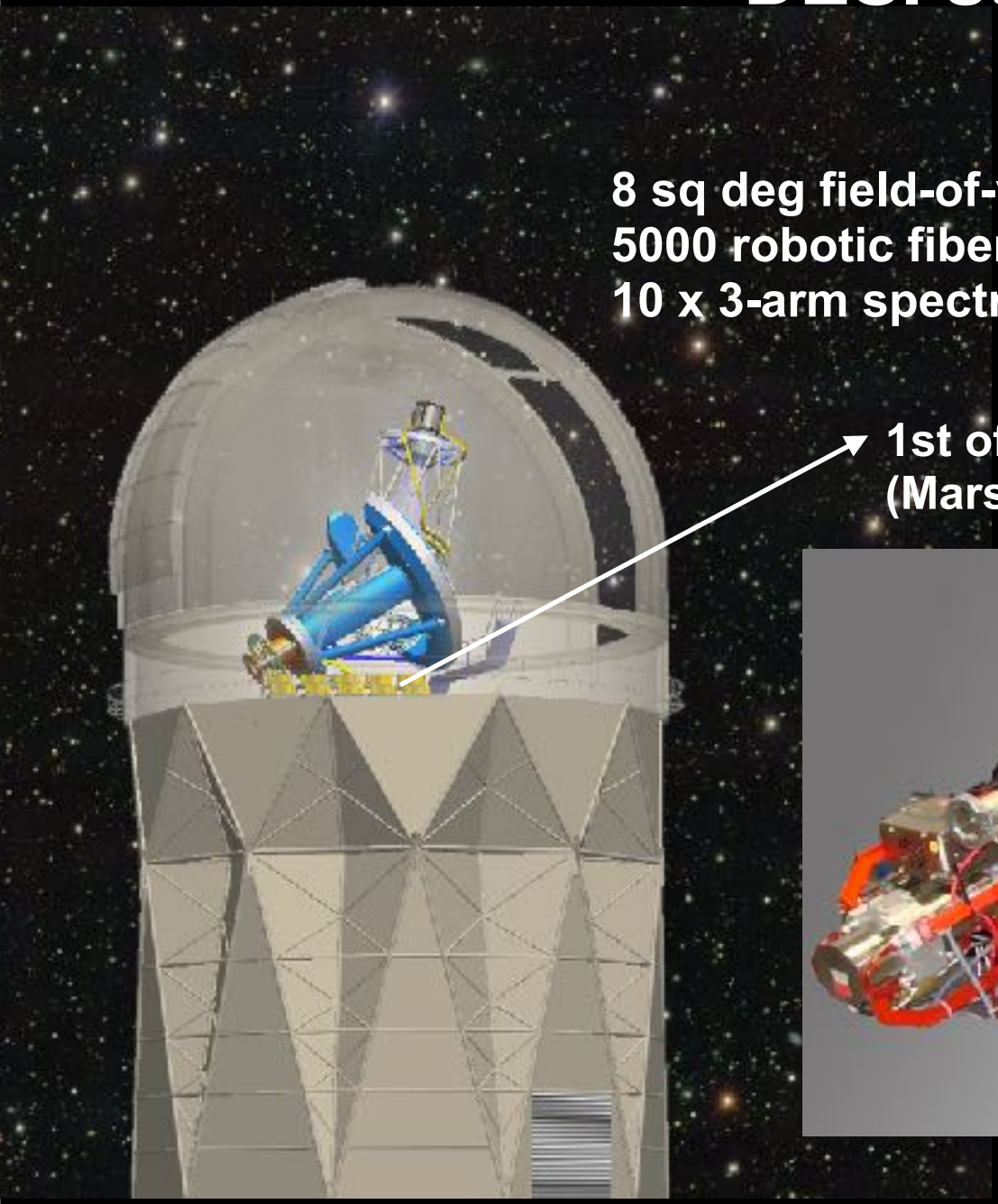
DESI status



8 sq deg field-of-view
5000 robotic fiber positioners
10 x 3-arm spectrographs spanning 3600-9800 Ang

250 km of optical fiber packaged in steel-core cables (Durham & LBNL)

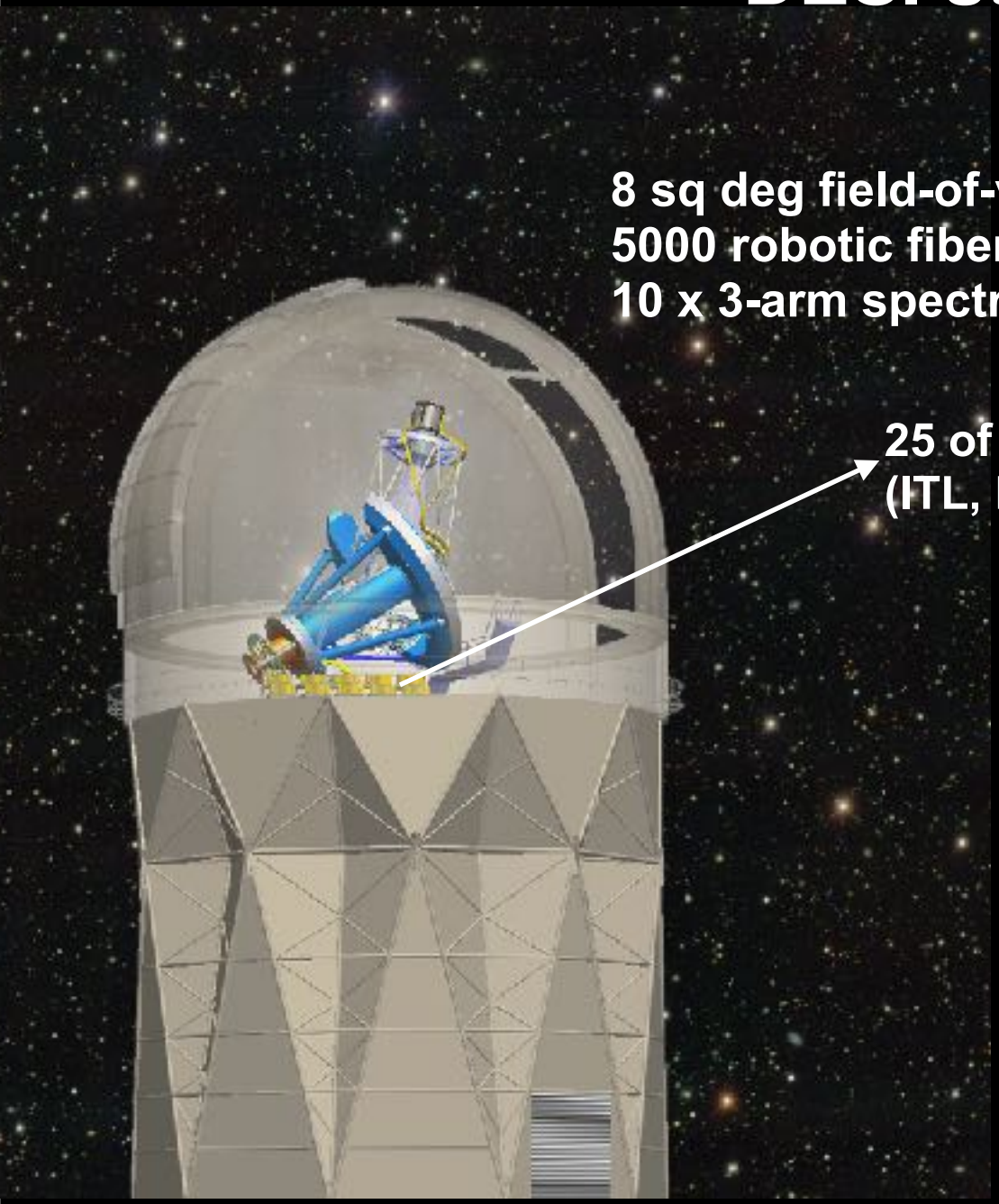
DESI status



8 sq deg field-of-view
5000 robotic fiber positioners
10 x 3-arm spectrographs spanning 3600-9800 Ang

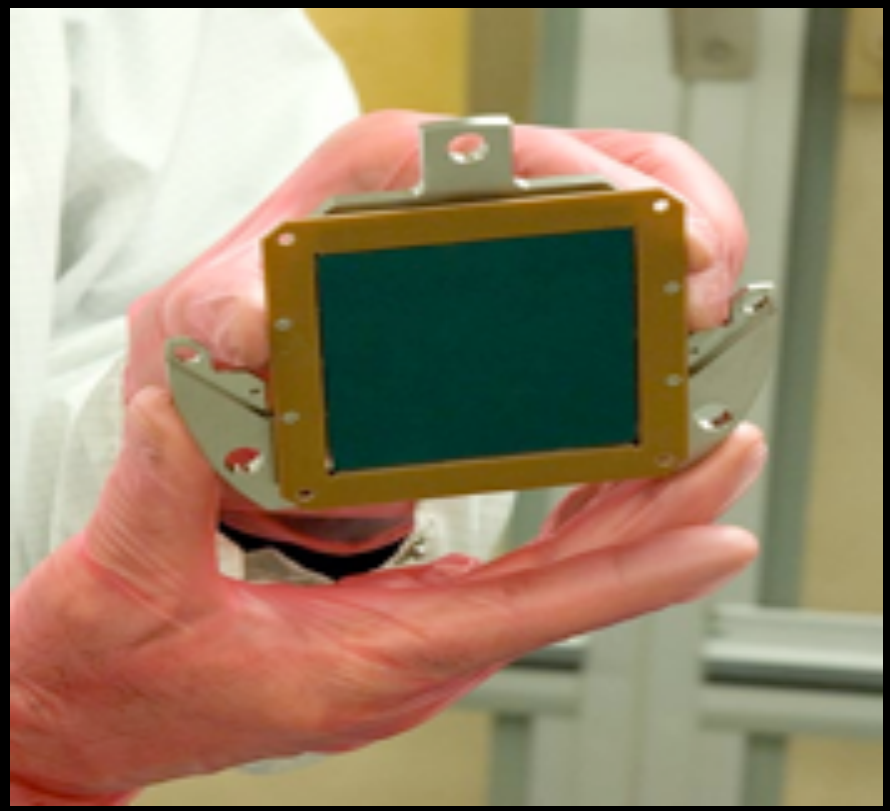
1st of 10 spectrogaphs ready to ship
(Marseille, OHP, CEA Saclay, Ohio State, LBNL)

DESI status

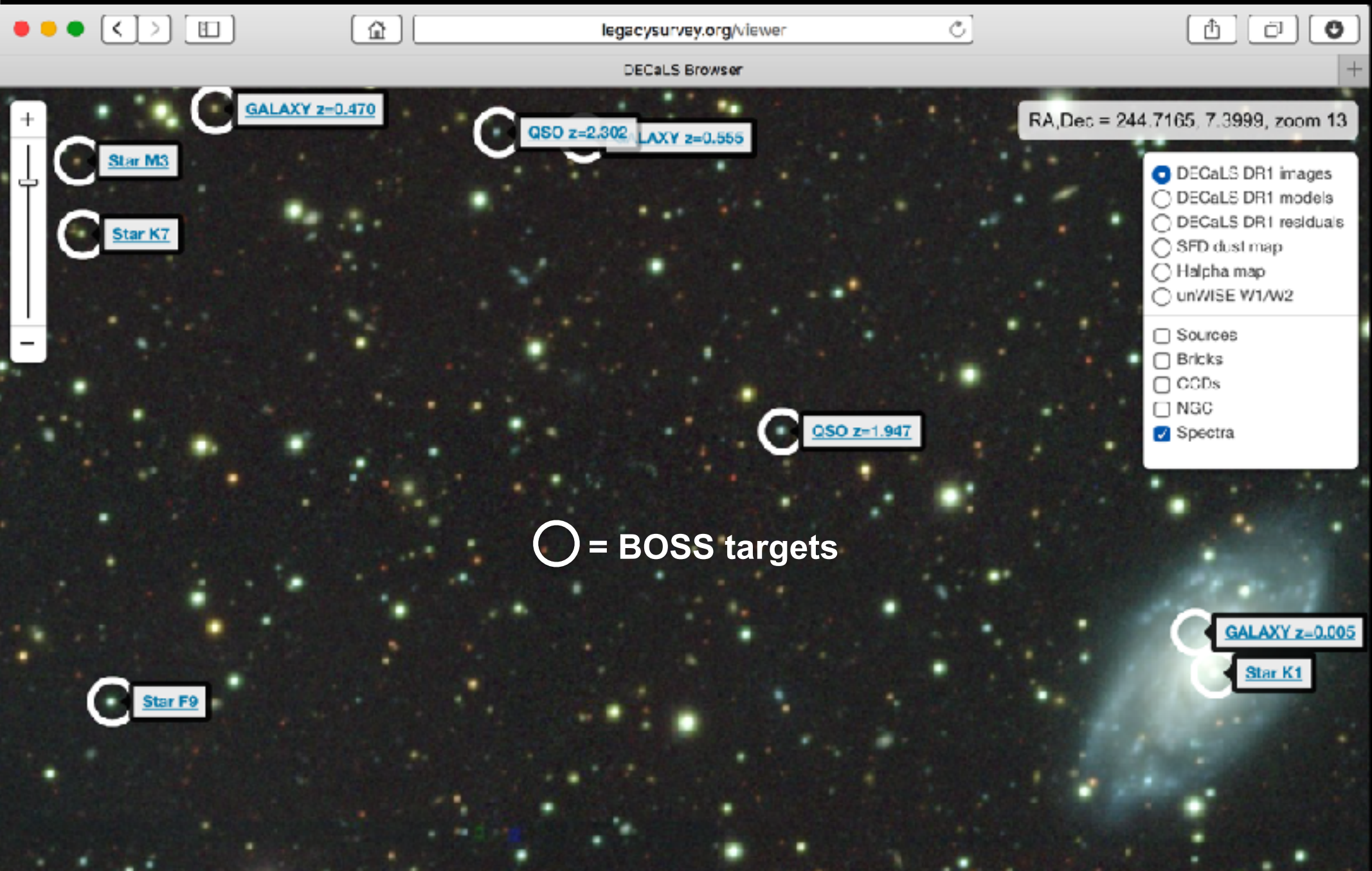


8 sq deg field-of-view
5000 robotic fiber positioners
10 x 3-arm spectrographs spanning 3600-9800 Ang

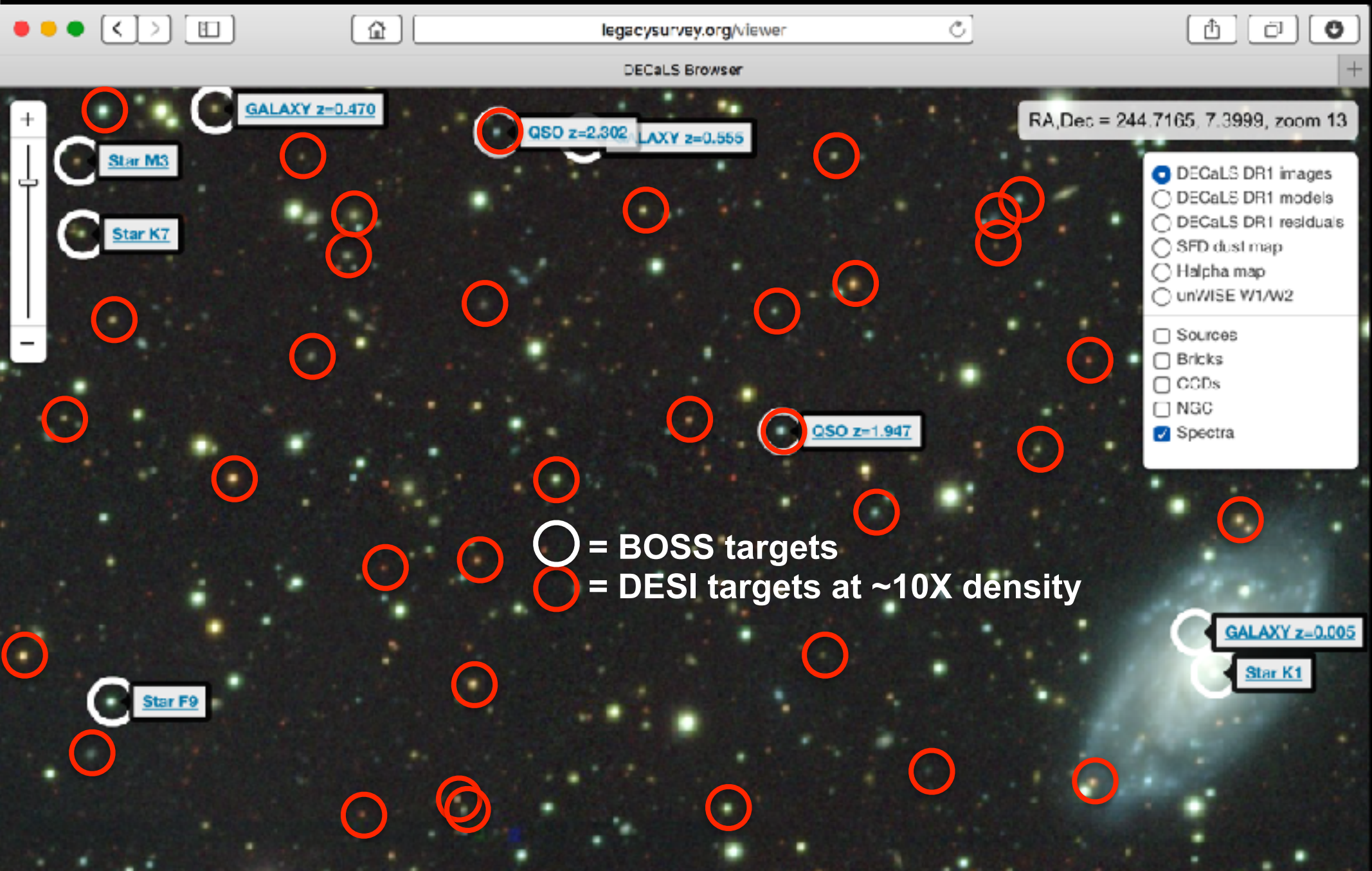
25 of 30 science-grade detectors packaged (ITL, LBNL)



Redshift-space maps today

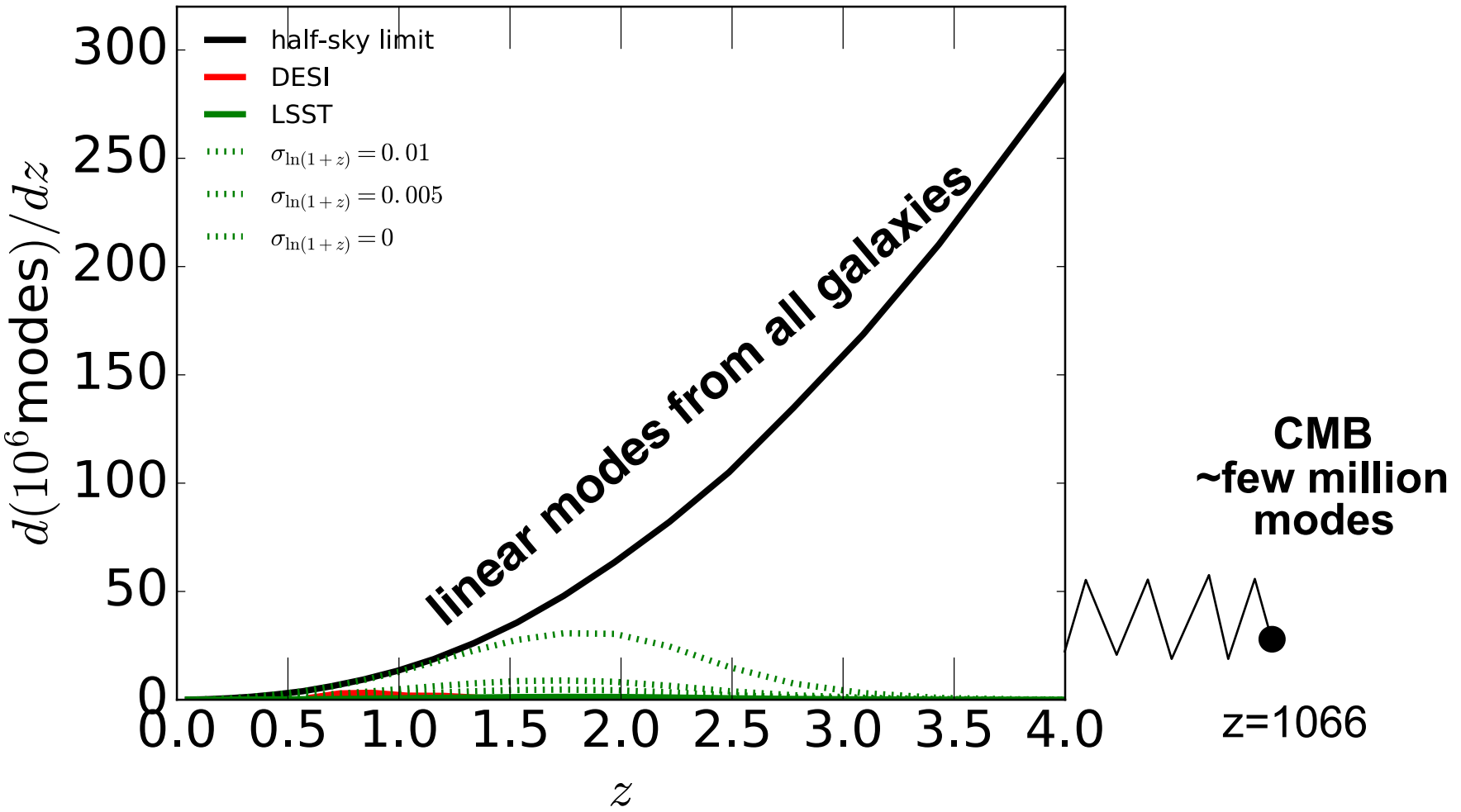


Redshift-space maps in 2019+ from DESI



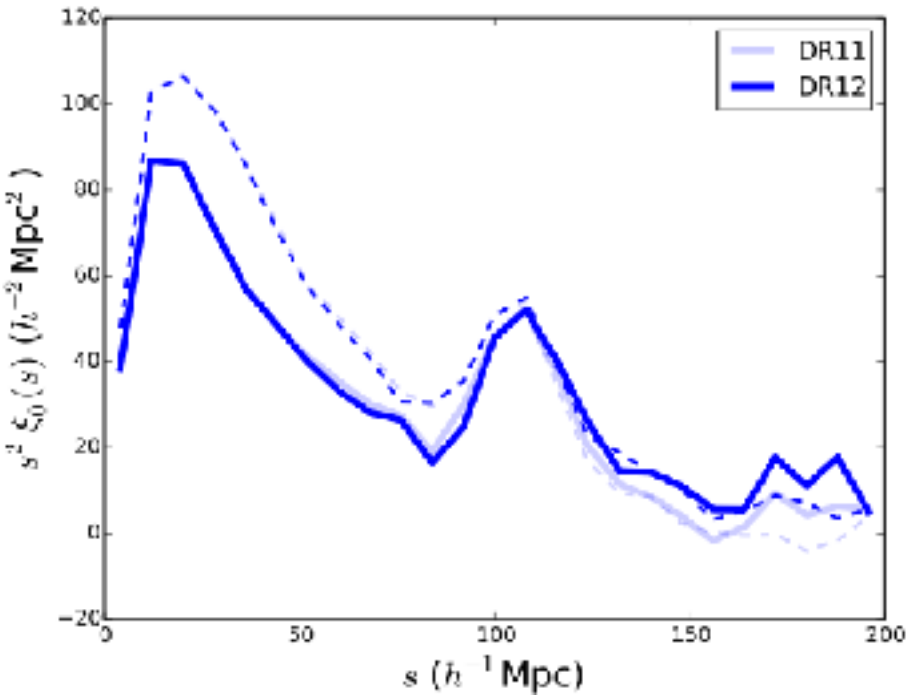
Beyond DESI & Euclid

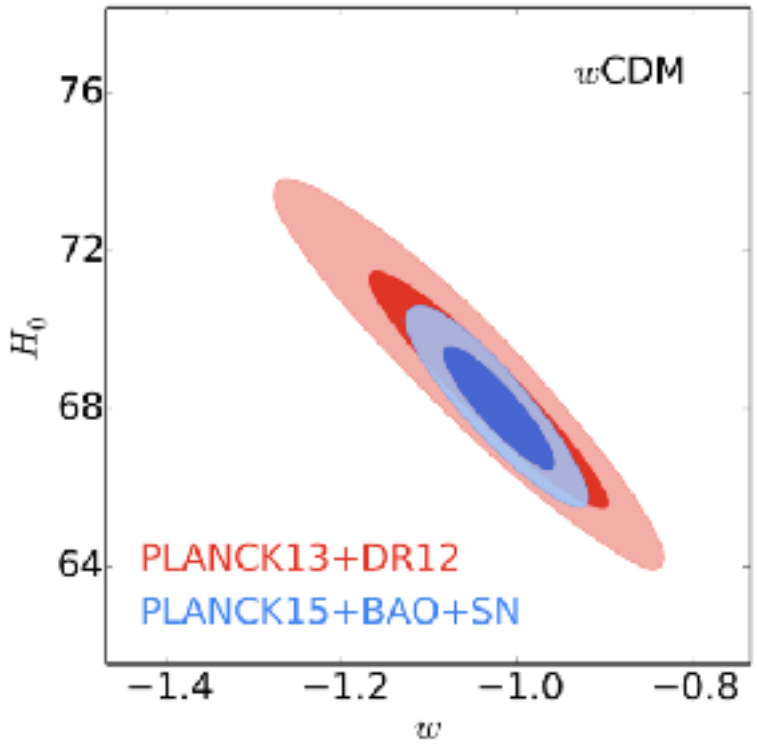
10 million galaxies 0 < z < 0.4 → **DESI will map ~100% of these**
120 million galaxies 0 < z < 1.5 → **DESI will map ~20%**
2 billion galaxies 0 < z < 4 → **DESI will map 0.1%**



Beyond DESI & Euclid

To date, we have designed around Dark Energy parameters (w,w')





Cuesta et al. 2016

Beyond DESI & Euclid

In the future, should we design around inflation parameters?

Non-gaussianity

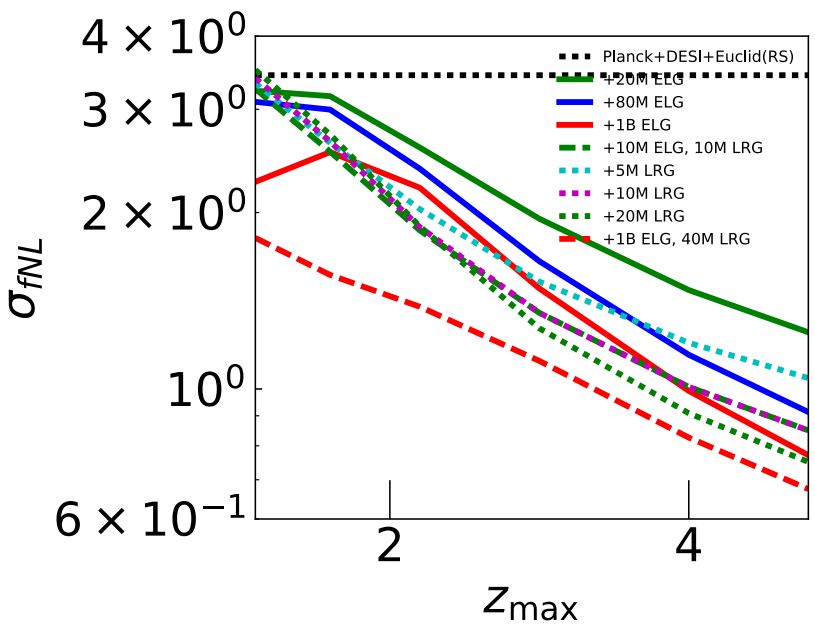


FIG. 26. Local non-Gaussianity constraints, for 14000 sq. deg. with numbers added to approach uniform comoving density out to $z_{\rm max}$, for different numbers of "ELGs" (objects with bias $0.84D(0)/D(z)$) and "LRGs" (objects with bias $1.7D(0)/D(z)$). Bias is always capped to be no greater than the bias expected if the objects lived in the most massive halos with this number density (this is why increasing the density of LRGs can actually give worse results).

Inflation spectrum

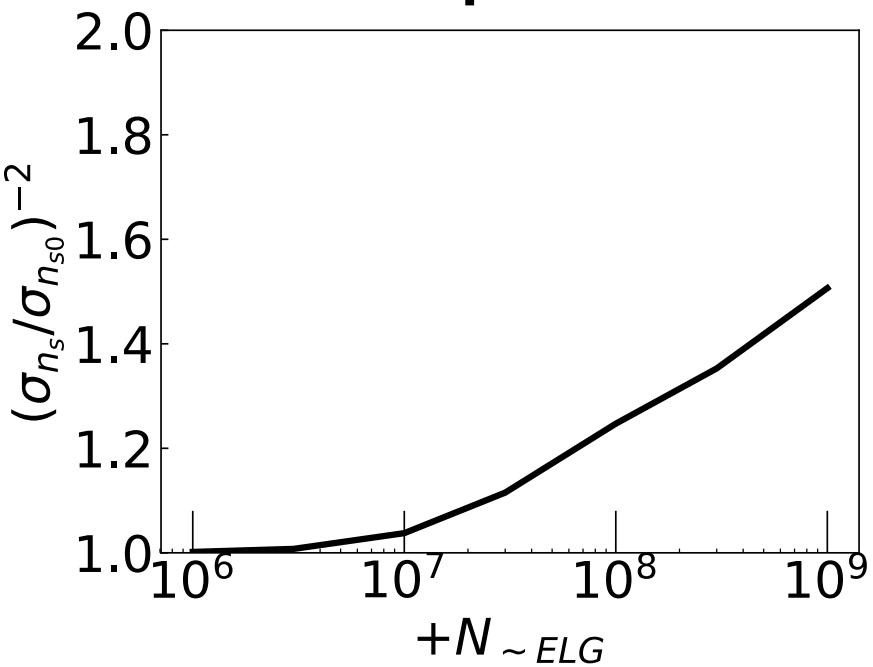


FIG. 16. n_s constraint improvements (inverse variance relative to baseline), for 14000 sq. deg. with uniform como added over the range $2 < z < 3.5$. Baseline is DESI plus CMB-S4 plus Euclid redshift survey only.

P. McDonald, in prep.

Beyond DESI & Euclid

Improvements also possible in dark energy, curvature, …

Dark energy w-w'

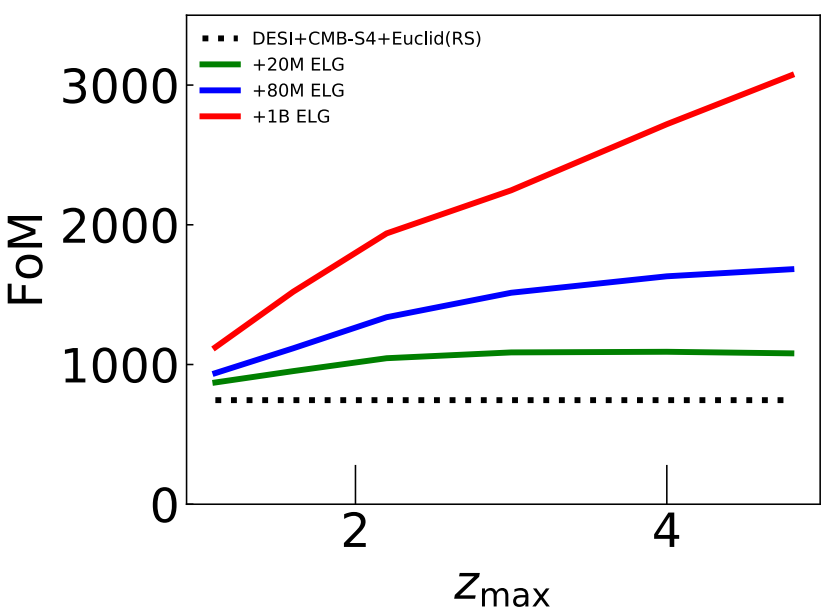


FIG. 7. DETF FoM (marginalized over neutrino mass) for 14000 sq. deg. with uniform comoving density out to z_{max}. Baseline is DESI plus CMB-S4 plus Euclid redshift survey only. Improvement factors 1.5, 2.3, 4.1.

Curvature

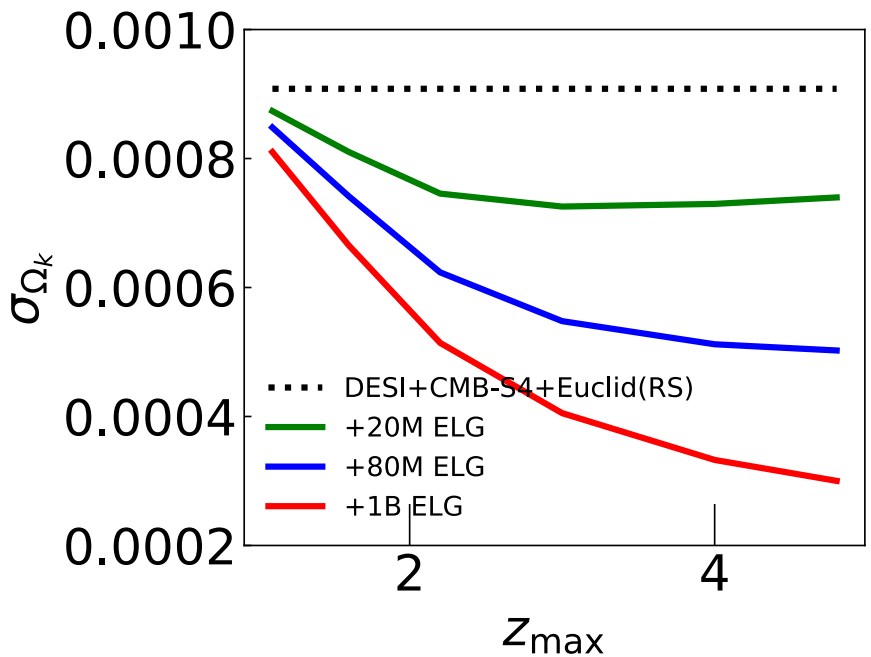
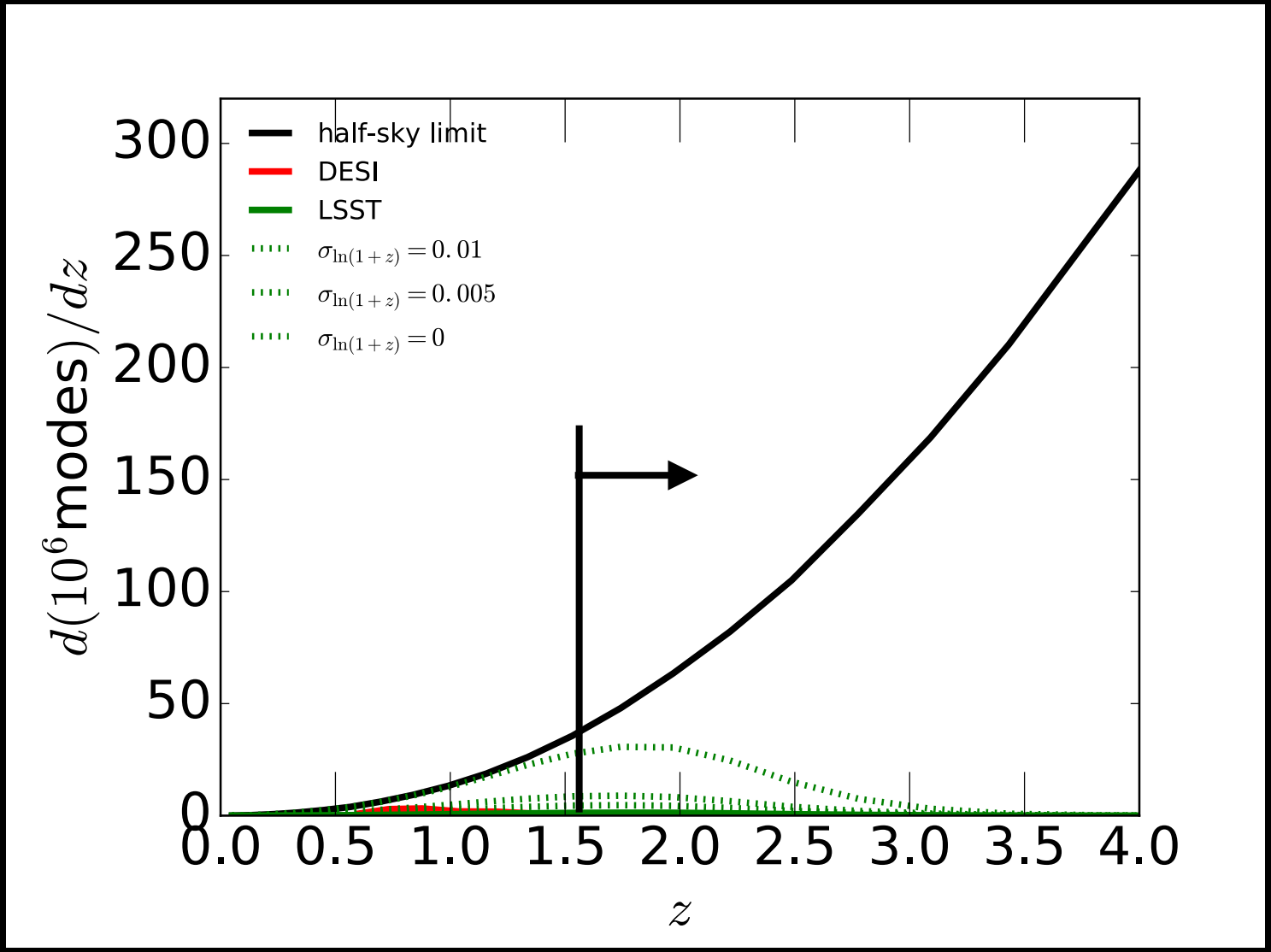


FIG. 20. Curvature, i.e., Ω_K, constraints for 14000 sq. deg. with uniform comoving density out to z_{max}. Baseline is DESI CMB-S4 plus Euclid redshift survey only. Improvement factors 1.6, 3.3, 9.2.

P. McDonald, in prep.

Beyond DESI & Euclid

How do we efficiently map beyond z=1.5?

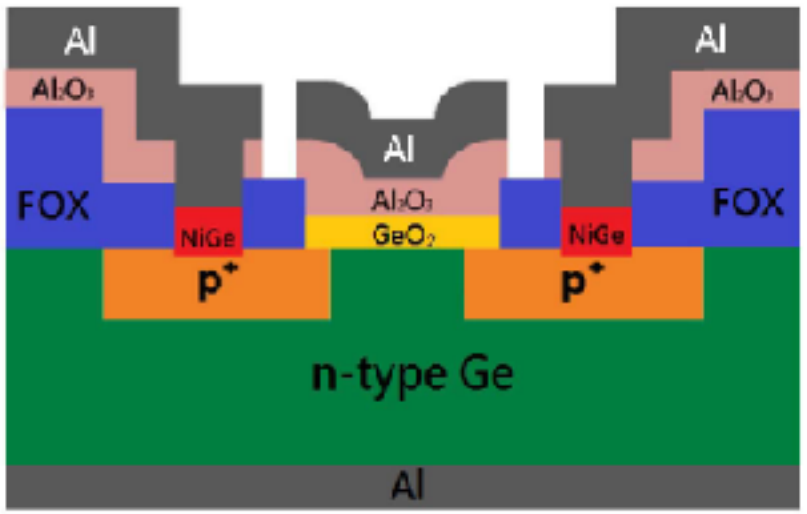


Technical developments for future redshift surveys

More multiplexing from 640 → 5000 →???
- **cheaper/smaller fiber positioners**
- **cheaper spectrographs**

Better detectors
- **low-noise CCDs (skipper)**
- **Germanium CCDs**
- **MKIDs**

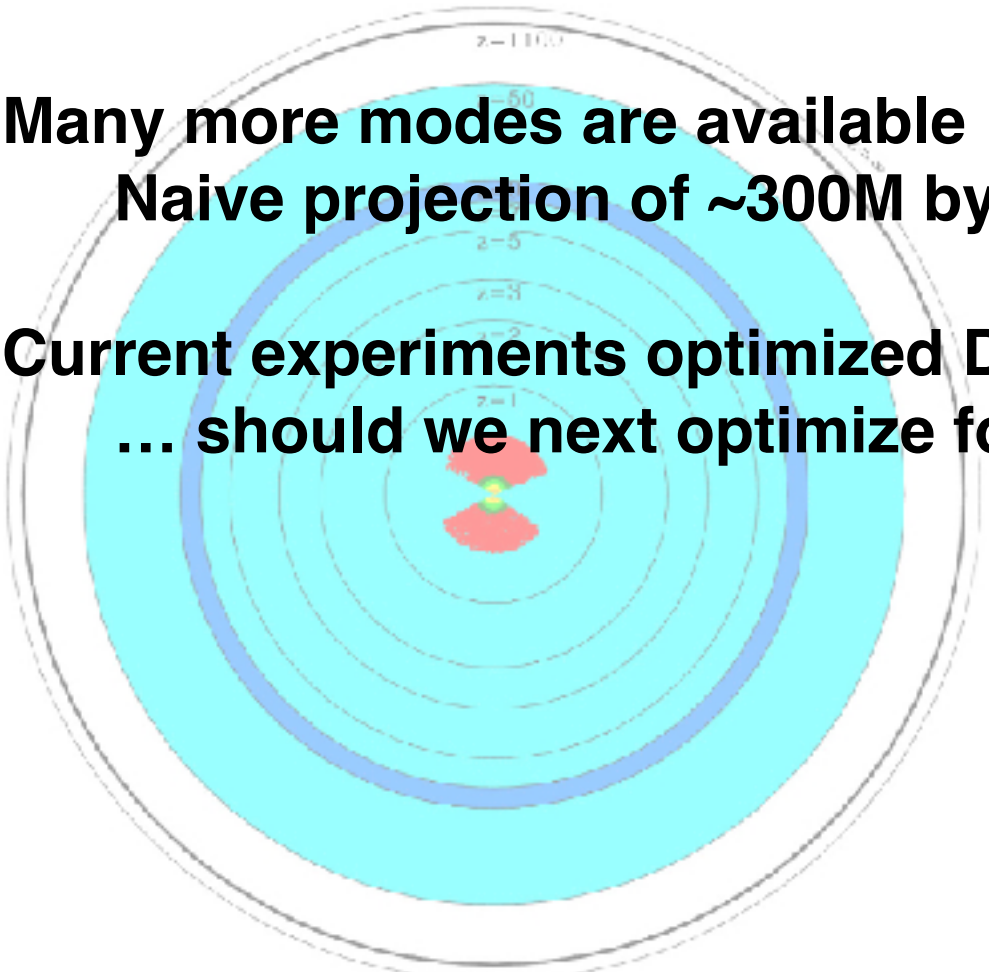
More clever
- **redshifts at S/N < 10**
- **unconventional optical designs**



Conclusions

Redshift surveys + CMB define the current cosmology

Get prepared for 30M redshifts soon!
DESI, Euclid, PFS



Many more modes are available
Naive projection of ~300M by 2030s

Current experiments optimized Dark Energy parameters
… should we next optimize for inflation parameters?