DESI and Future Spectroscopic Technologies

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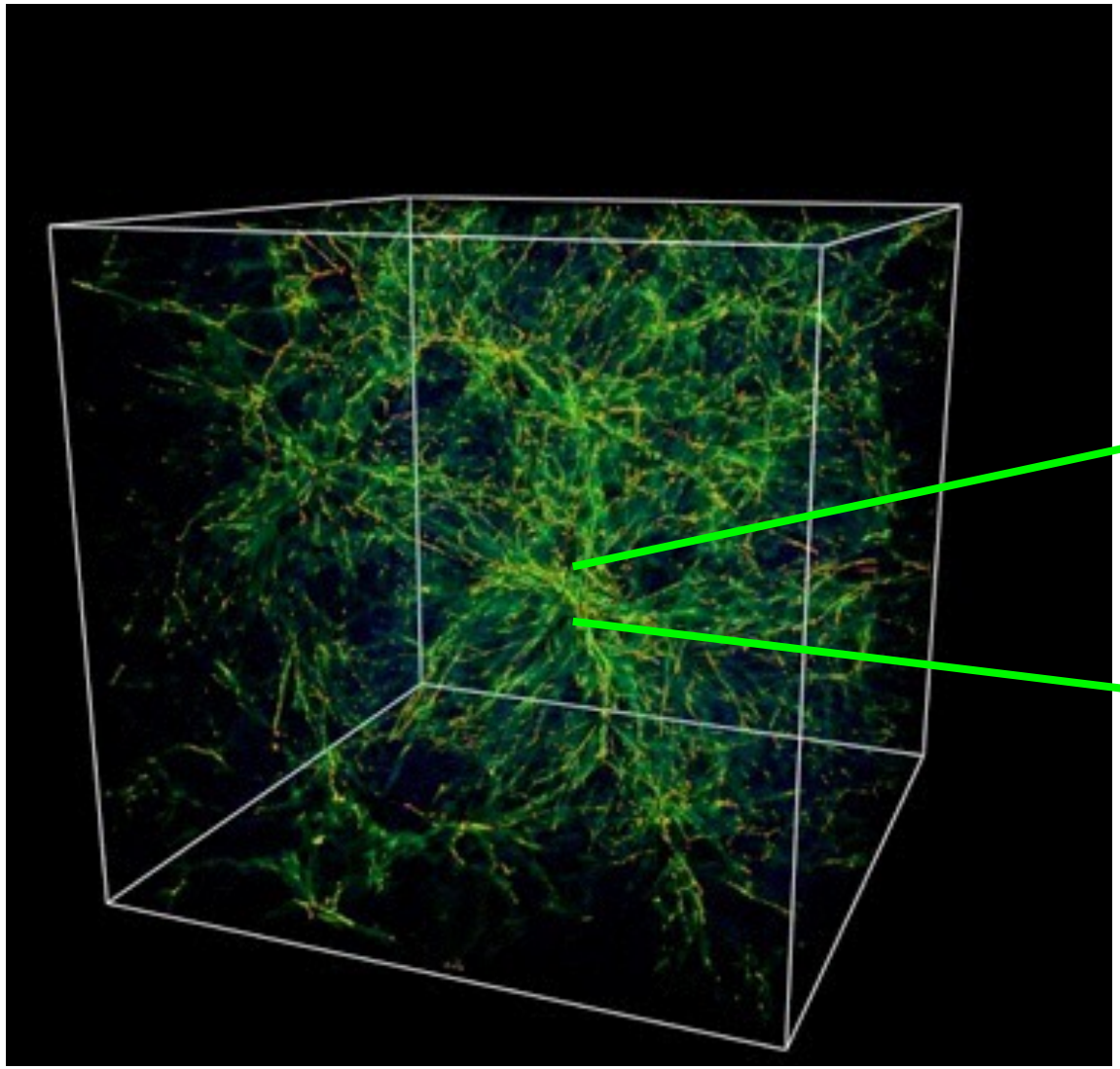
Outline

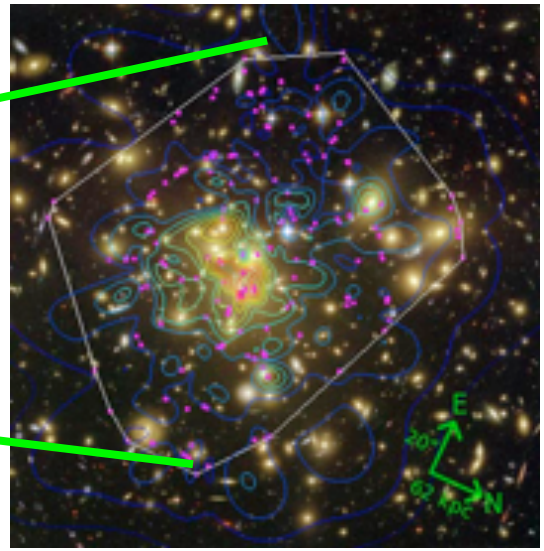
- Redshift survey objectives: mapping linear modes
- DESI goals + technologies
- Redshift surveys are easy! DESI cost models
- Future investments to keep us “on the curve”

Optical redshift survey objectives: Map all the linear modes

Easily-interpreted information content is in the linear regime



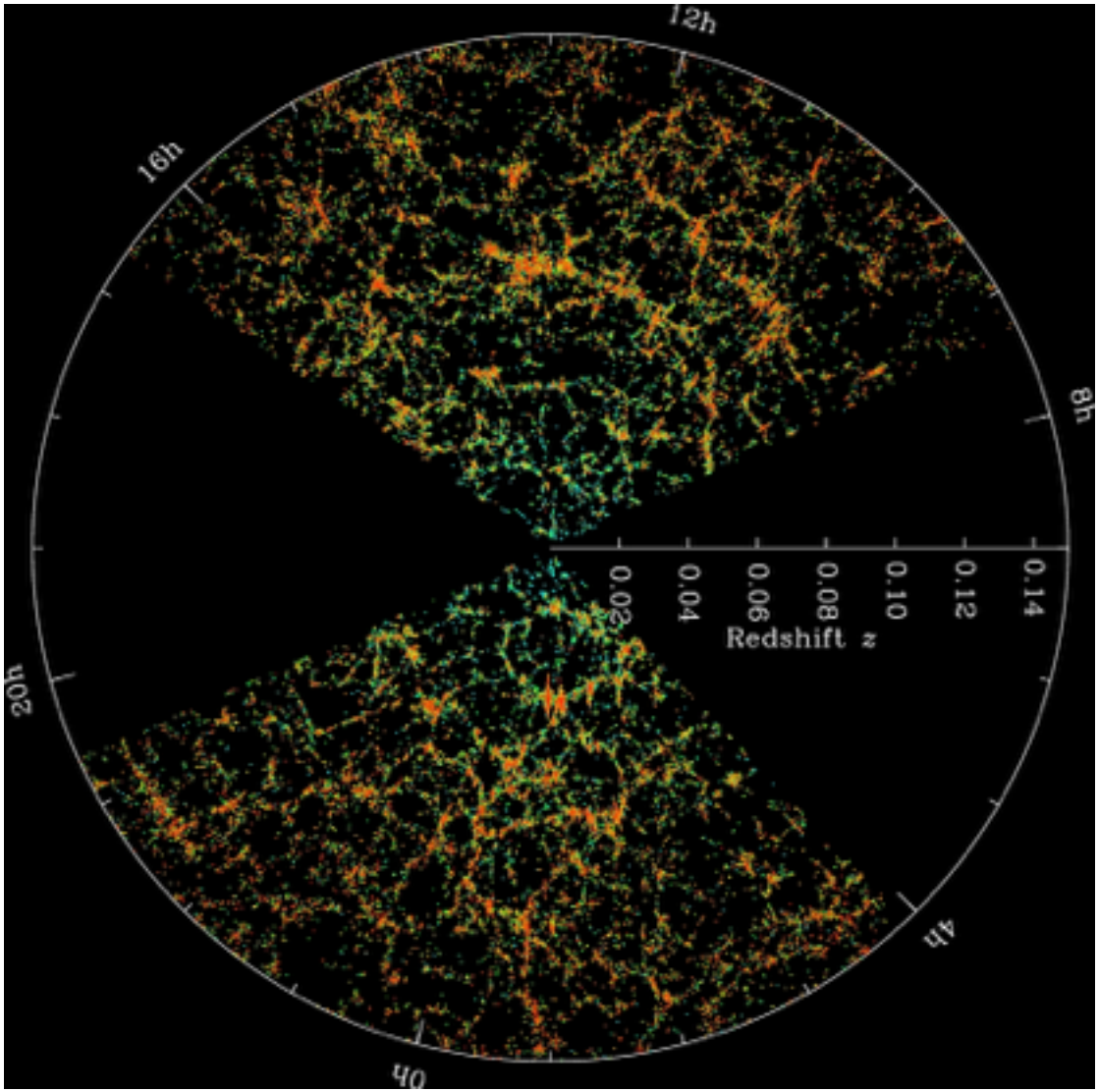
99% volume
~linear perturbations
on scales > 10 Mpc



<1% volume
non-linear clusters

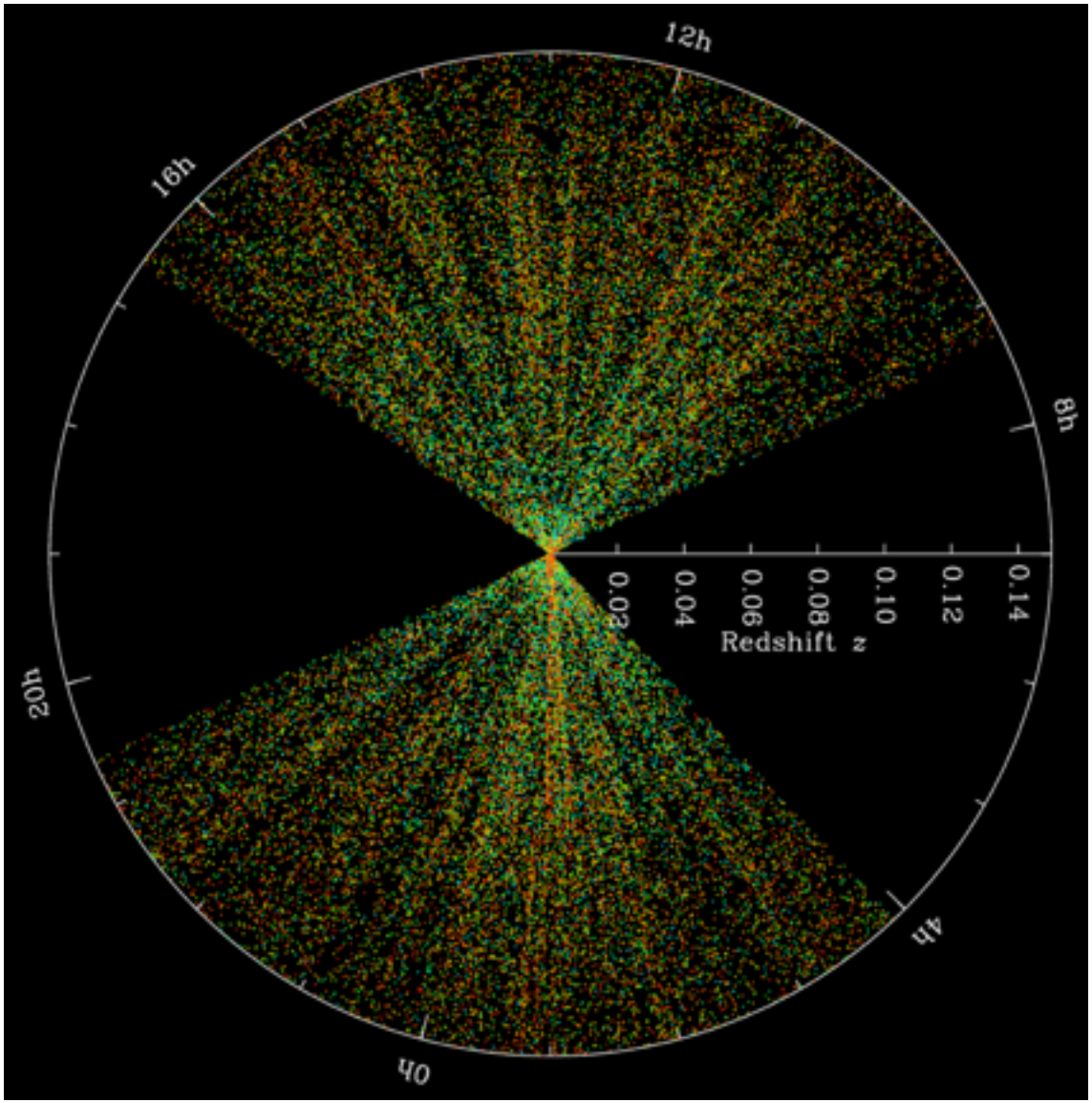
Redshift surveys necessary to map all modes

Redshift surveys Δcz ~ 300 km/s at z=0,
preserves information down to non-linear regime (e.g., small scales)



Redshift surveys necessary to map all modes

Photometric surveys Δcz ~ 10,000 km/s at z=0,
washes out many of the linear modes; not recoverable even w/numbers



Redshift surveys are necessary to map all modes

SDSS-III/BOSS mapped ~1 million linear modes

DESI (spectroscopy) will map ~15 million modes

LSST (photo-z) will map ~100 million modes

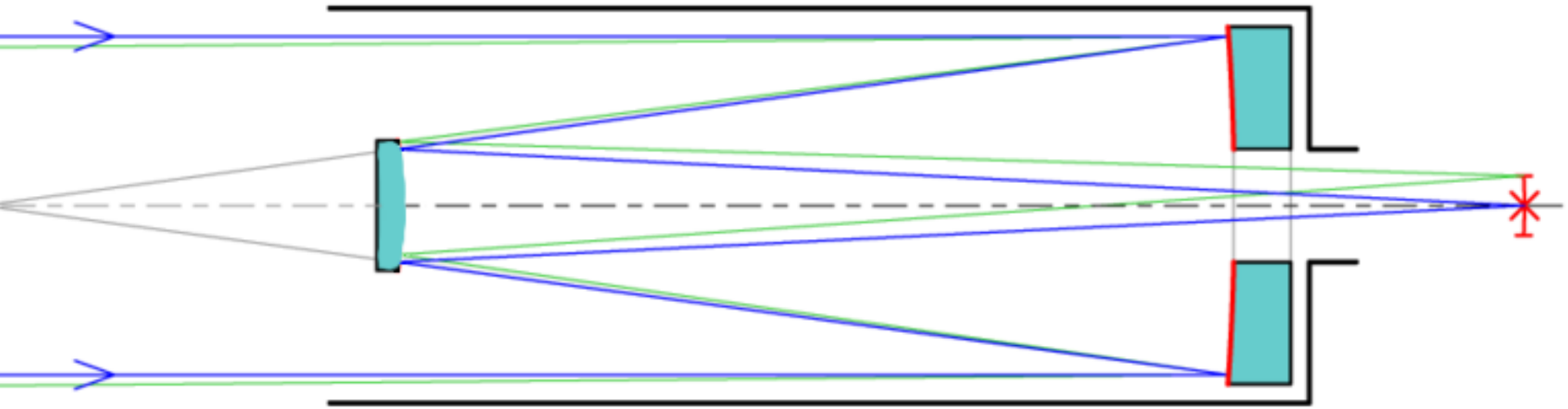
- Samples to the non-linear scale in angular directions
- In the z direction, only samples to $\Delta z \sim 0.03$

How many linear modes are there?

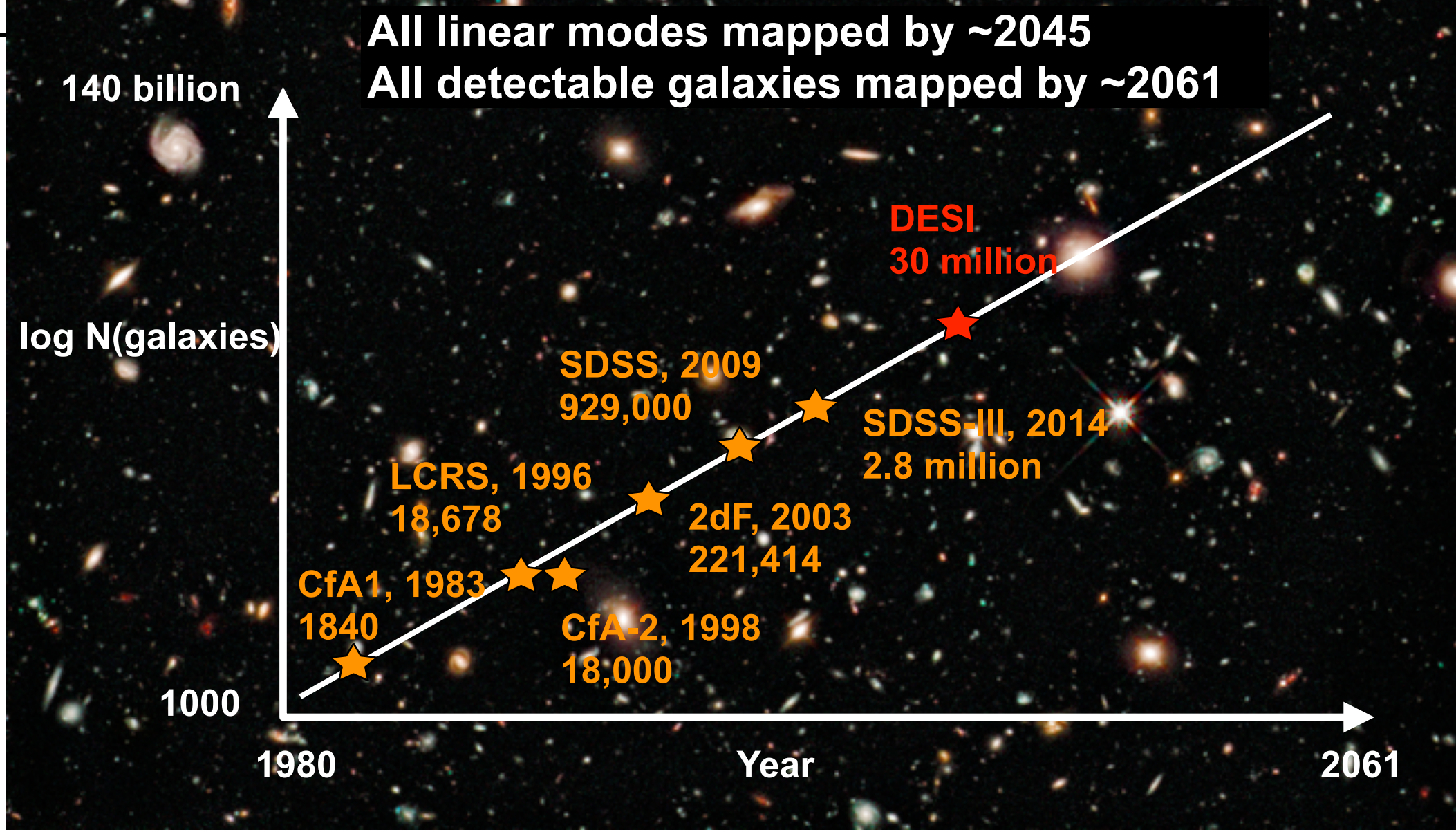
- ~5 billion from z=0-4

Redshift surveys are necessary to map all modes

There are more objects of interest on a spectroscopic focal plane
than on an imaging focal plane
6,000 / deg^2 for imaging → information has saturated
300,000 / deg^2 for spectroscopy

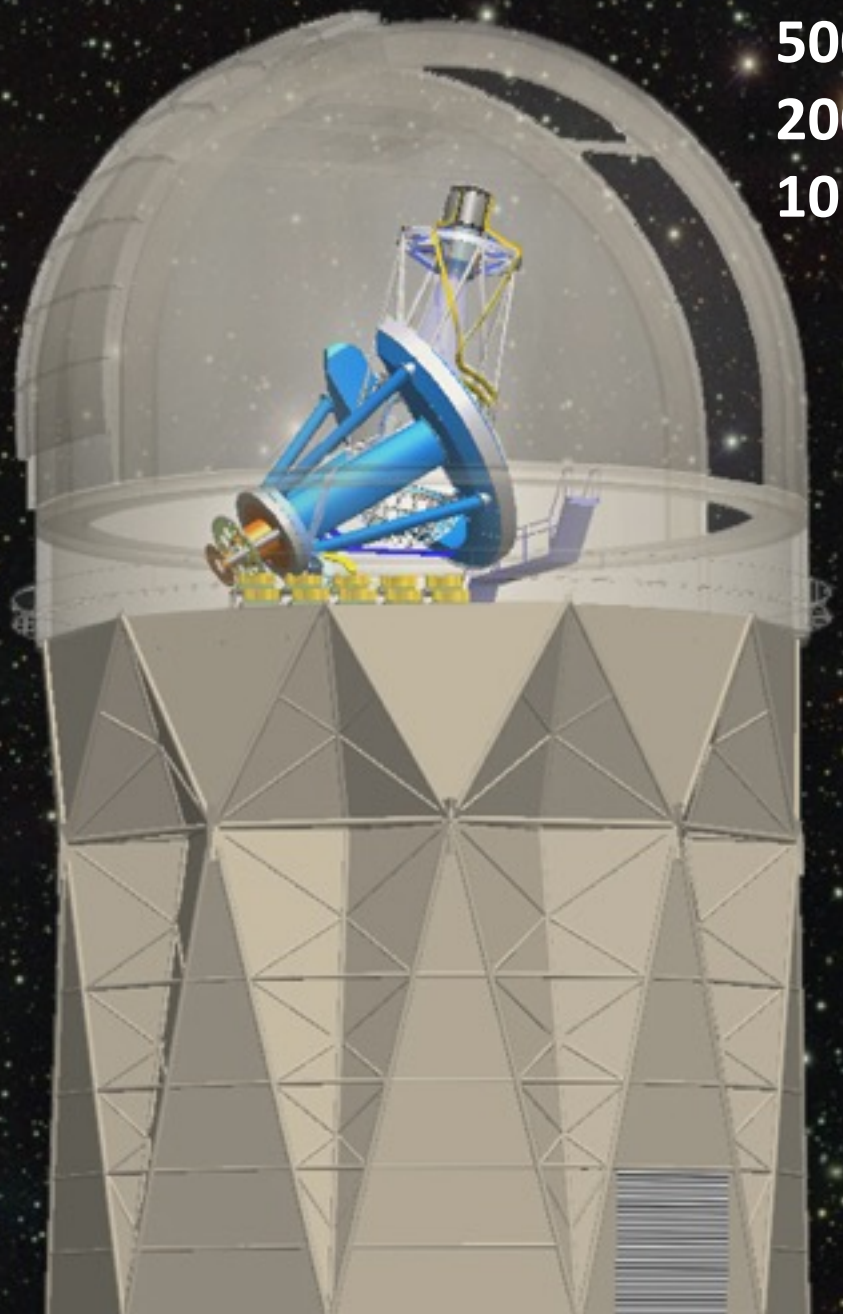


Redshift surveys increasing 10X every 10 years



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

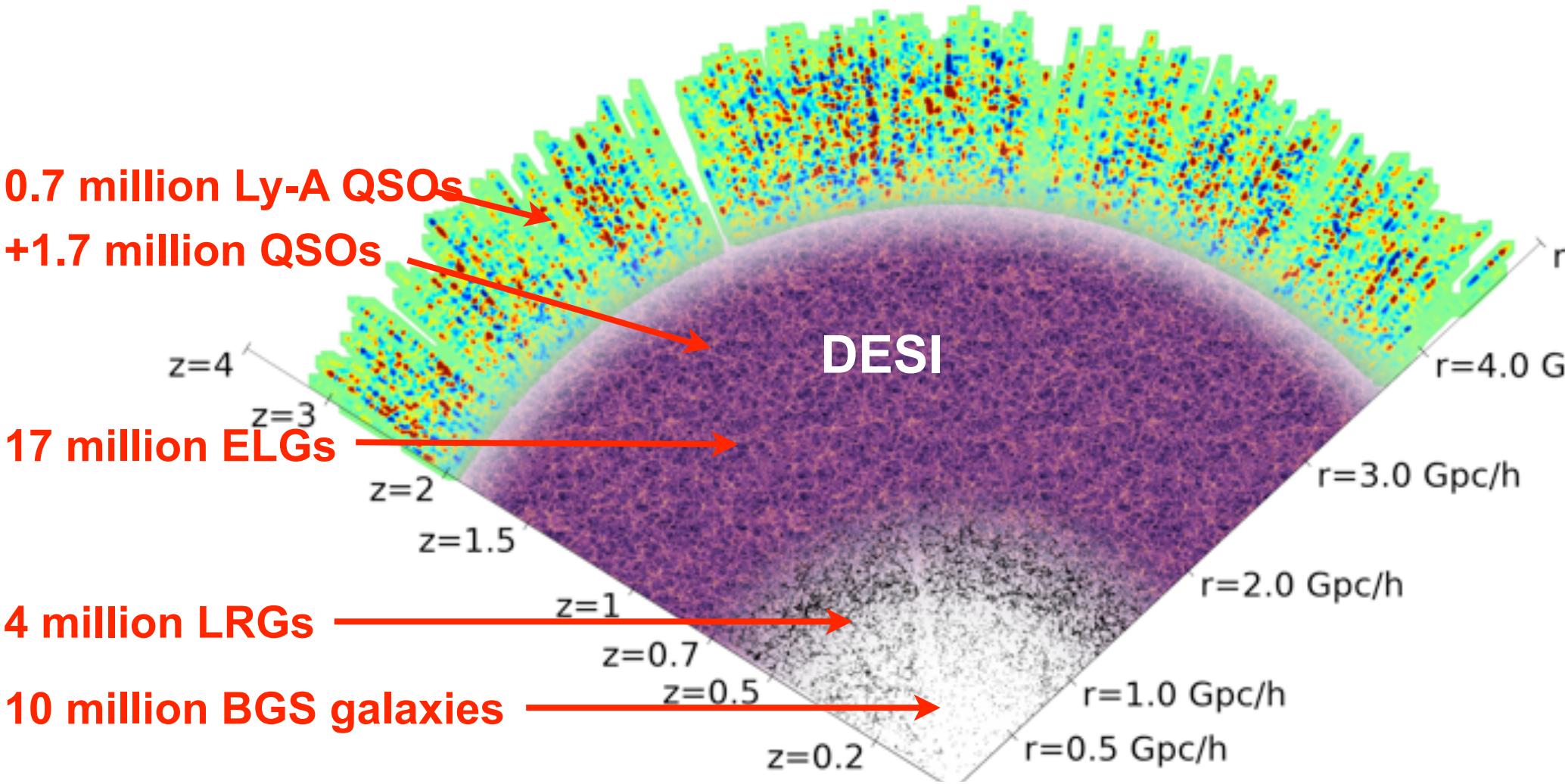
DESI Goals + Technologies



1 meter diameter corrector
5000 fiber-robot army
200,000 meters fiber optics
10 spectrographs x 3 cameras

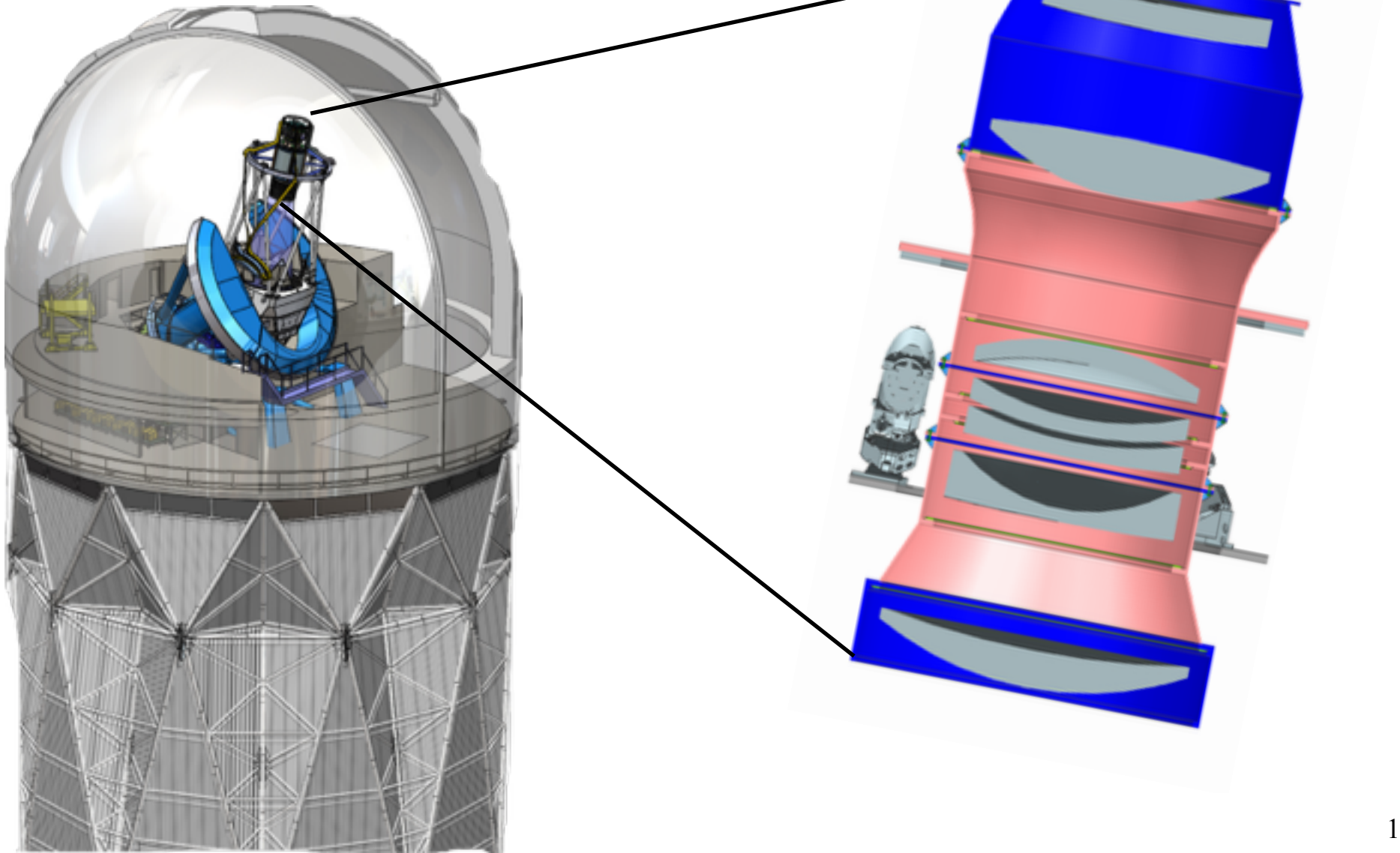
DESI Goals

35 million galaxy + QSO redshift survey



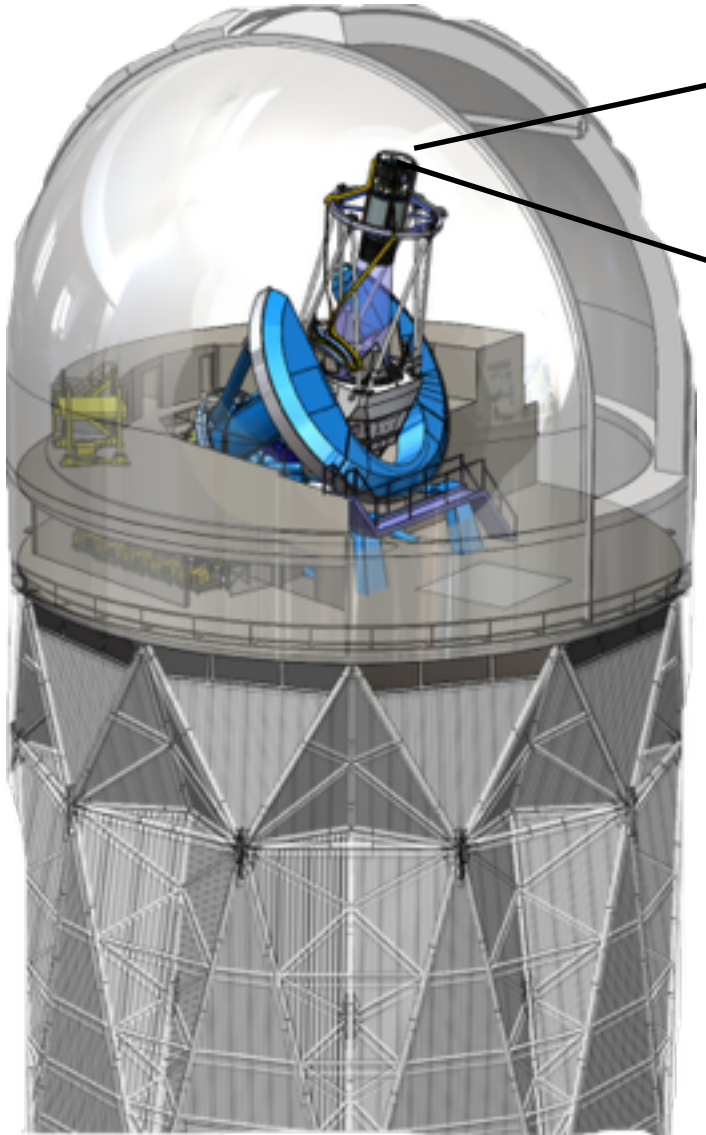
DESI Technologies

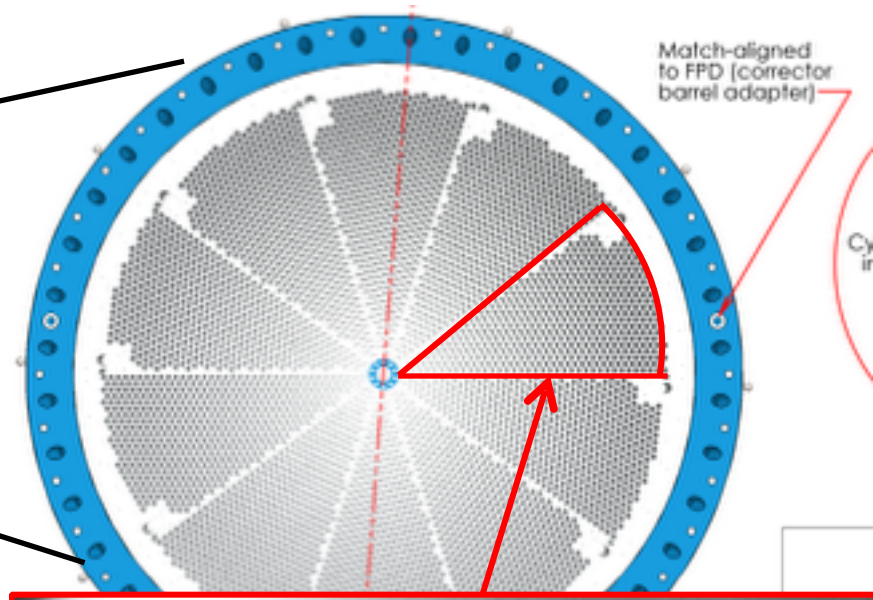
6-lens optical corrector, 1-m diameter, includes ADC

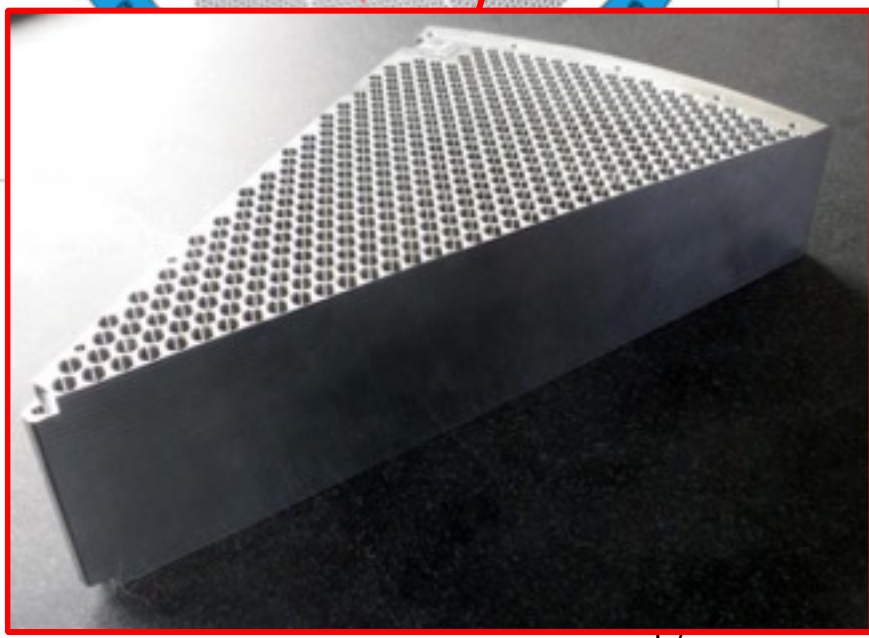


DESI Technologies

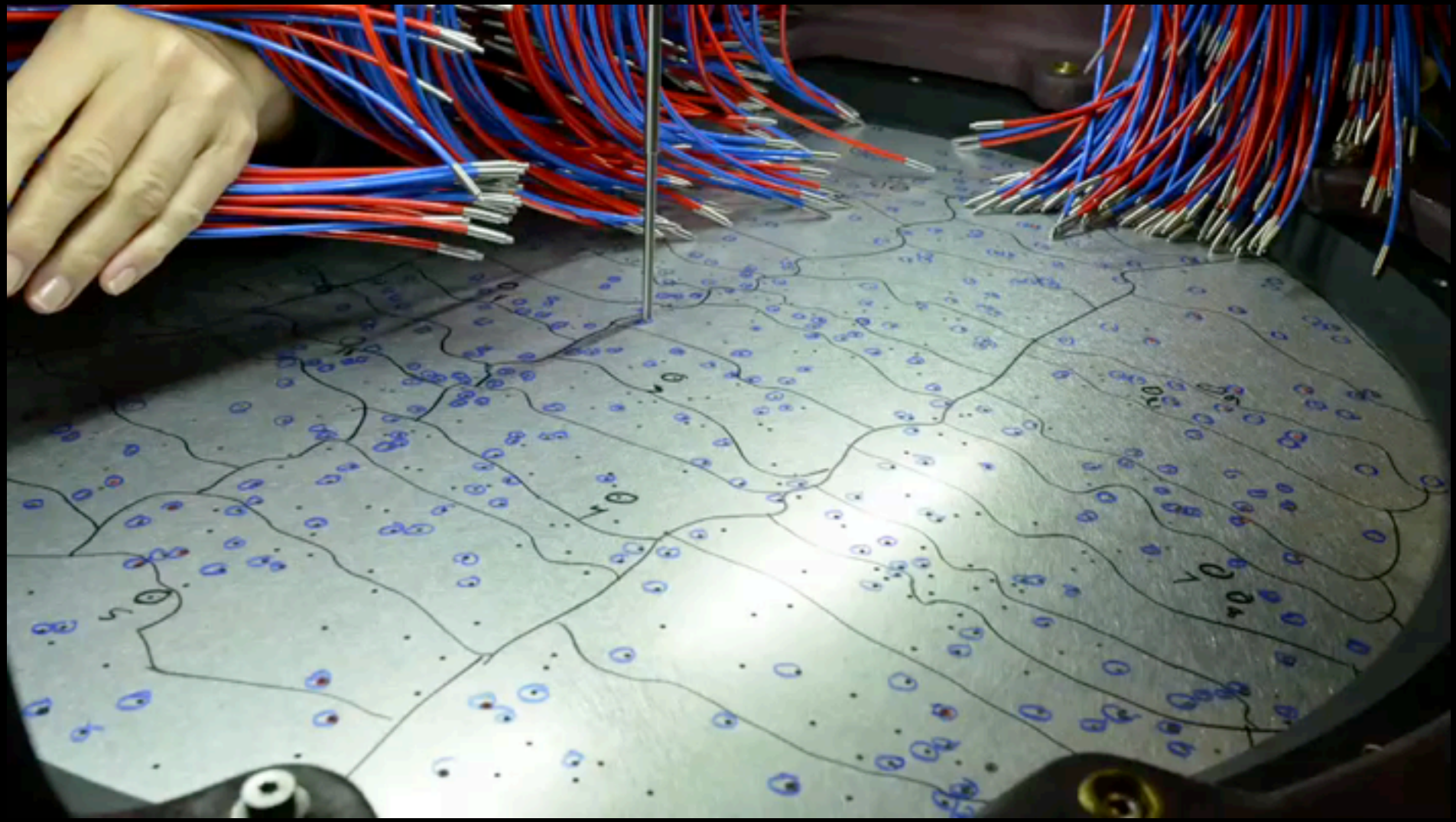
Focal plate mounting 5000 fiber robots



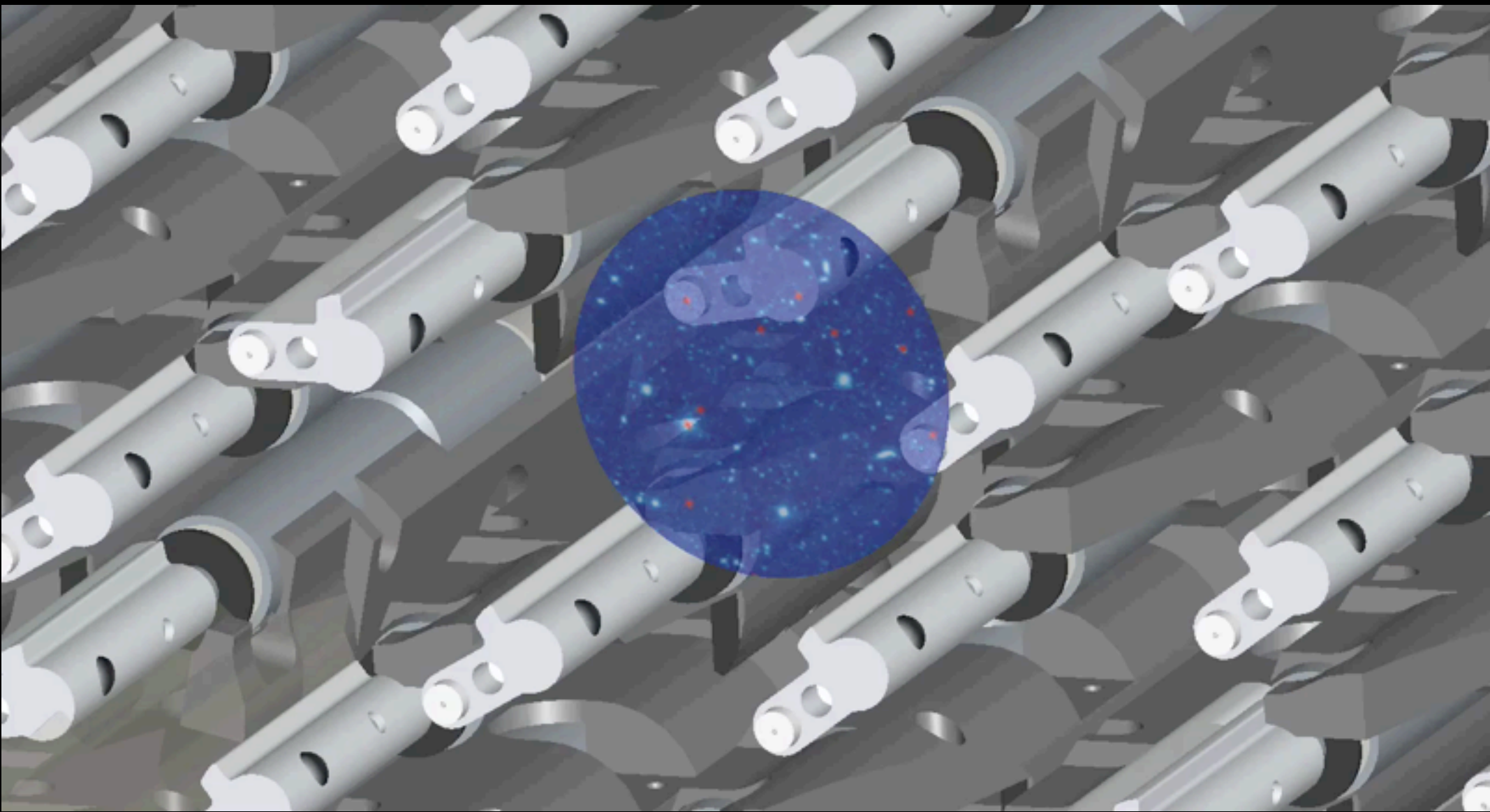




The Sloan project is a manually-intensive operation

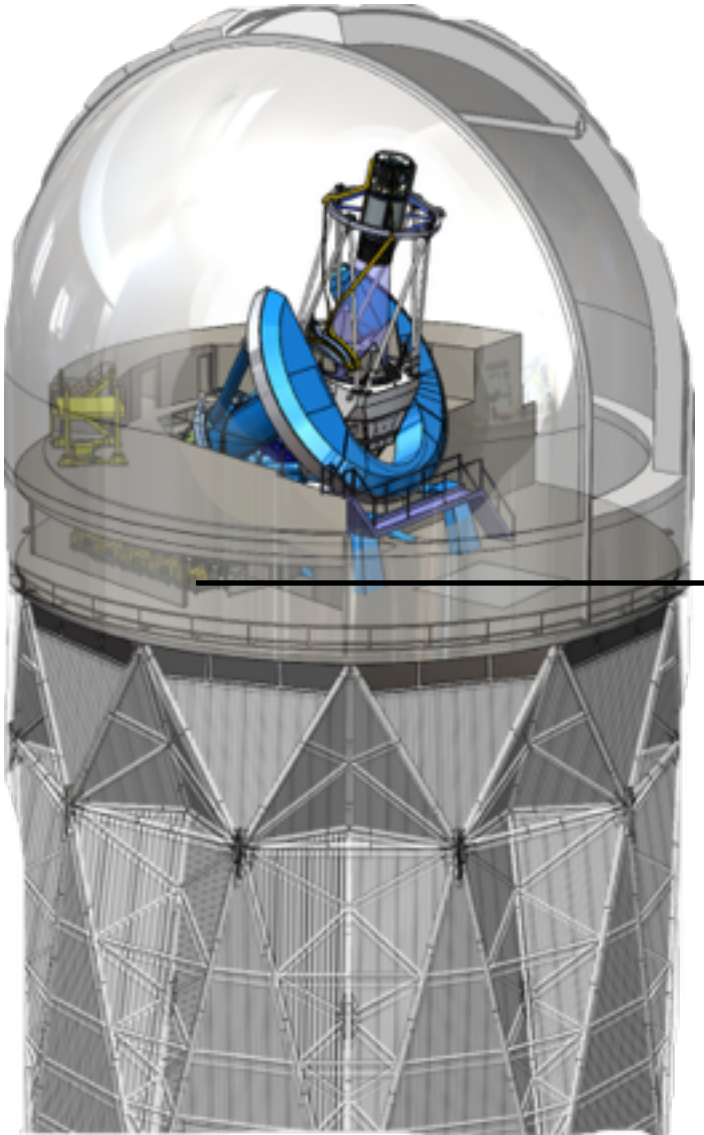


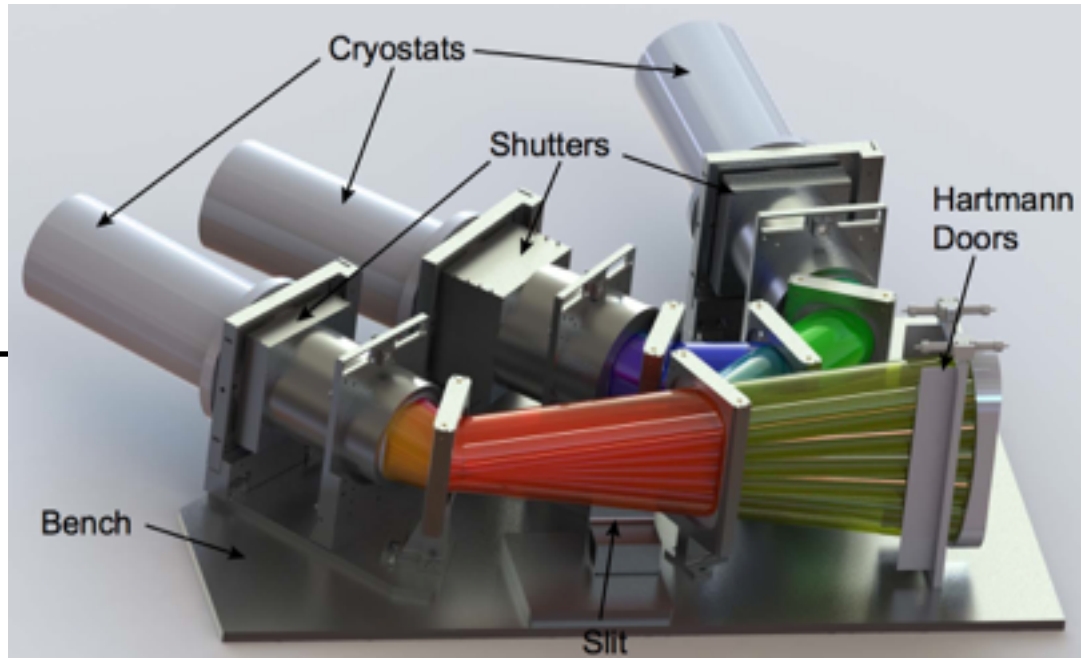
The robot army of DESI replaces hand-plugging of fibers



DESI Technologies

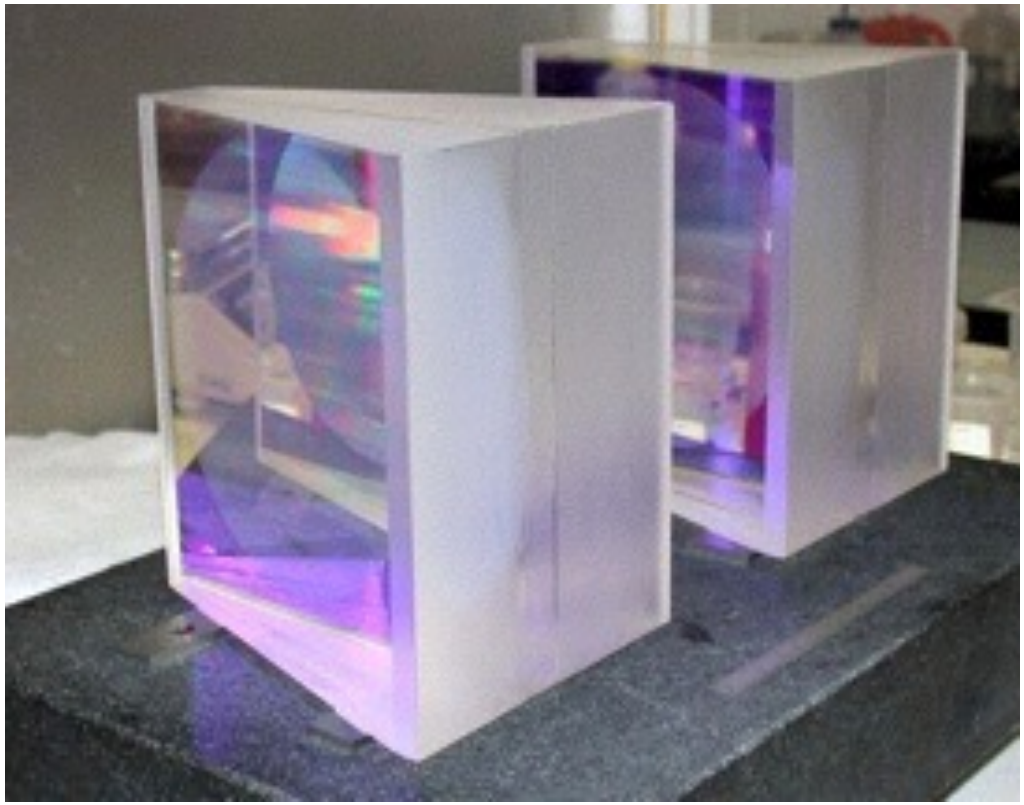
10 spectrographs X 3 cameras/spectrograph



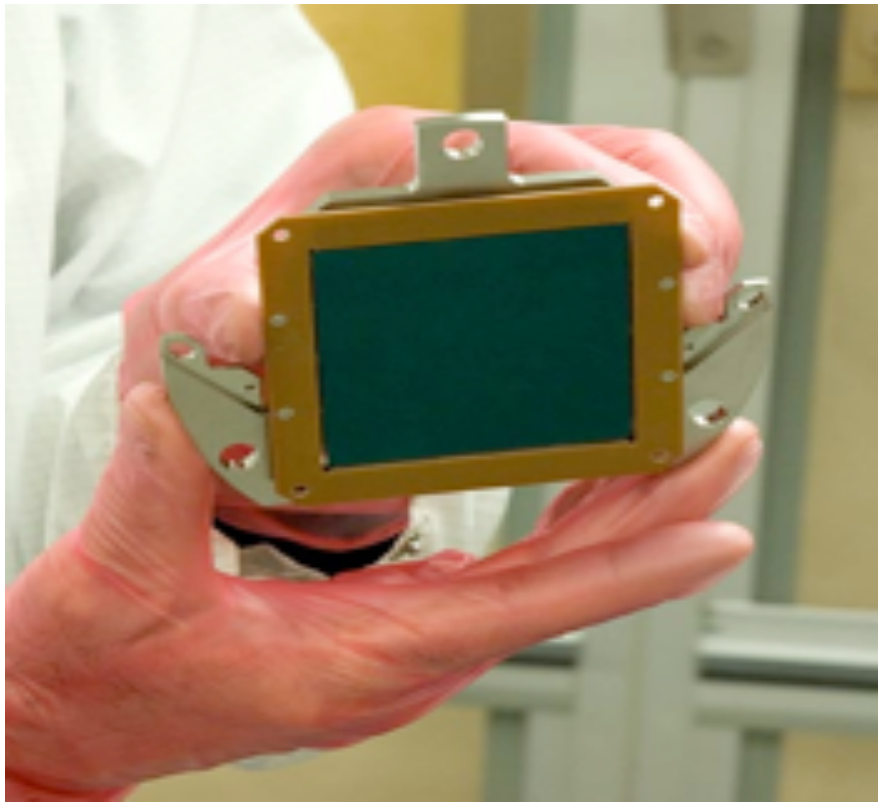


DESI Technologies

Spectrograph components have shown slow but steady progress



Large-format VPH gratings



Large-format, deep-depletion CCDs

Redshift surveys are not “hard”

Almost any galaxy can have it’s redshift measured

For ex, the first SDSS survey had 5 of 10^6 unknown spectra

- Weird 1
- Weird 2
- …
- Weird 5

All eventually measured with higher S/N data

“Published” in the Weekly World News

Modest improvements in capability from SDSS-I → SDSS-III/BOSS → DESI

How has capability improved?

- **CCDs → improved, esp. in the red/infrared**
- **CCD electronics → lower noise**
- **Stability of calibration systems**
  - **allowing better sky-subtraction, fainter objects**

Bigger gains have been in multiplexing

- **Optical designs for wider fields on telescope & in spectrographs**
- **More fibers, hand-plugged → massively-parallel robots**

Technical challenges are cost effectiveness

Pre-SDSS → SDSS revolution

Multiplexing from 1-30 objects → 640 objects
using fiber-fed spectrographs

In 2015, SDSS has collected more galaxy redshifts (2.7M)
than all other telescopes on earth combined

Cost models for multi-objects spectrographs scaling from DESI

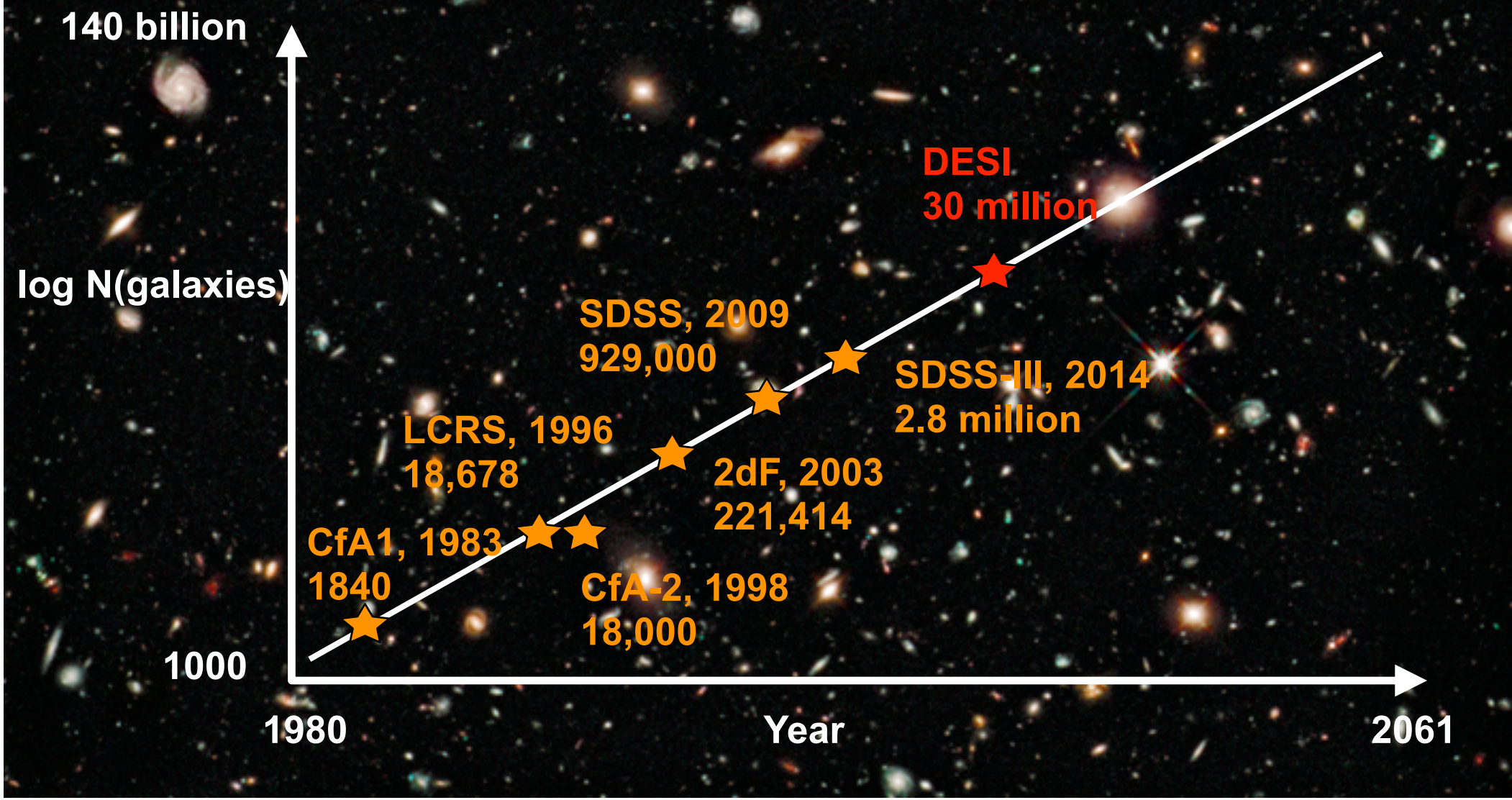
	Cost for 1% improvement
Telescope + corrector ($40M + $10M) * (Mirror area / 4-m)^2	+$200k + $50k
Focal plane + spectrographs $1000 X N_{fiber} + $1M X ($N_{fiber}$/500)	+$150k
Operations $6M/year X 5 years	+$300k

DESI cost model is reasonably well-balanced

Most improvement would come from more fibers,

but not possible on DESI given other design constraints

Future investments to keep us “on the curve”?



Future investments to keep us “on the curve”?

Telescope aperture has been a fixed cost

→ DESI is 3X SDSS aperture, but 3X operations cost

→ HETDEX is a novel design, but not obviously cost-effective

→ Possible solutions that break this cost model?

Fixed aperture, spectroscopy drift scan

Fibers track objects on focal plan

Promising, but never been done

Future investments?

→ Non-traditional telescope designs

→ Detector systems that would support this mode

Future investments to keep us “on the curve”?

Fiber robot costs

→ Pick-and-play fiber positioners (2dF, MMT, …) do not scale

→ Fiber robots w/ 1 robot per fiber scales

~$10,000 / fiber for Subaru/FMOS in ~2006

~$2000 / fiber for Subaru/PFS in ~2013

~$700 / fiber for DESI in ~2015

Future investments?

→ DOE started R&D in 2006 with LBNL LDRD support, followed by extensive R&D

→ Continued R&D would further reduce per-robot costs

Future investments to keep us "on the curve"?

Detector development

→ Past R&D has increased red sensitivity for galaxy redshifts

→ New mode of spectroscopic drift scans could break cost mode

→ Selective detector readout on a per-object basis could allow tuning of exposure time per object

(This harks back to the earliest redshift surveys in the 1980s)

Future investments?

→ Improved CCD blue response would improve z>2 mapping from Lyman-alpha forest

→ Low-noise, many-amp readouts (for ex, low-noise HiViSi)

→ Significant investment by DOE in the past has paid off, but little investment currently

Summary

- **Mapping the linear modes requires redshift surveys**
  - **At least 5 billion modes available**
- **DESI has balanced cost model**
  - **Telescope aperture, # of fibers, operations**
- **Tech investments are required to stay "on the curve":**
  - **Non-traditional telescope designs**
  - **Cheaper fiber robots**
  - **New survey modes could be enabled with future detector development**