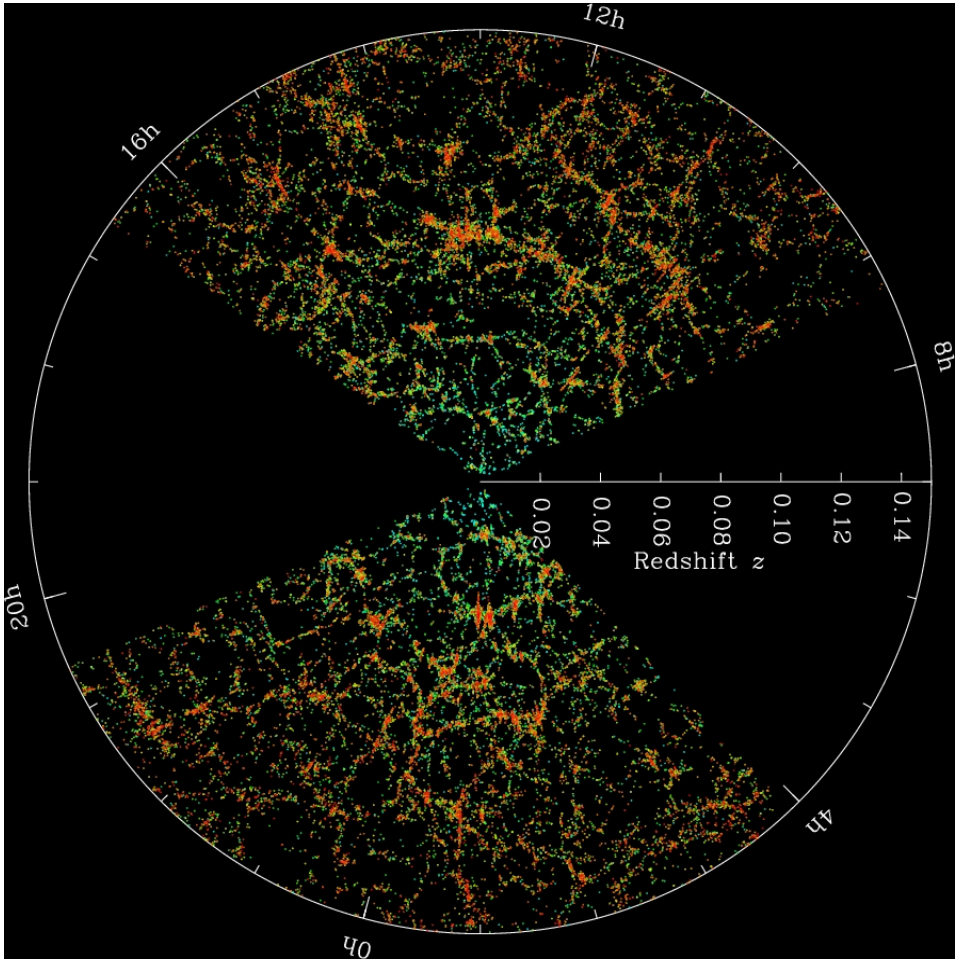
An Overview of the Dark Energy Spectroscopic Instrument (DESI) and the Collaboration Efforts at FNAL

Conett Huerta

DESI on the Kitt Peak 4-m telescope!

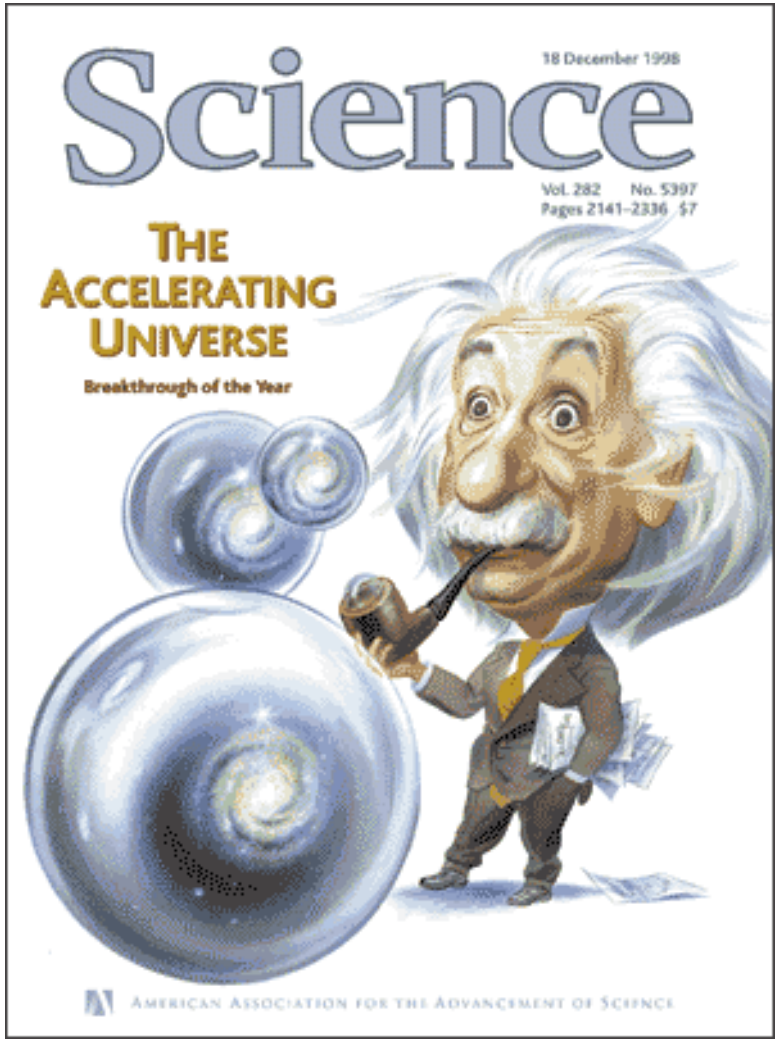
Mapping in Three Dimensions!



Measuring spectra allows us to measure velocity and infer distance.

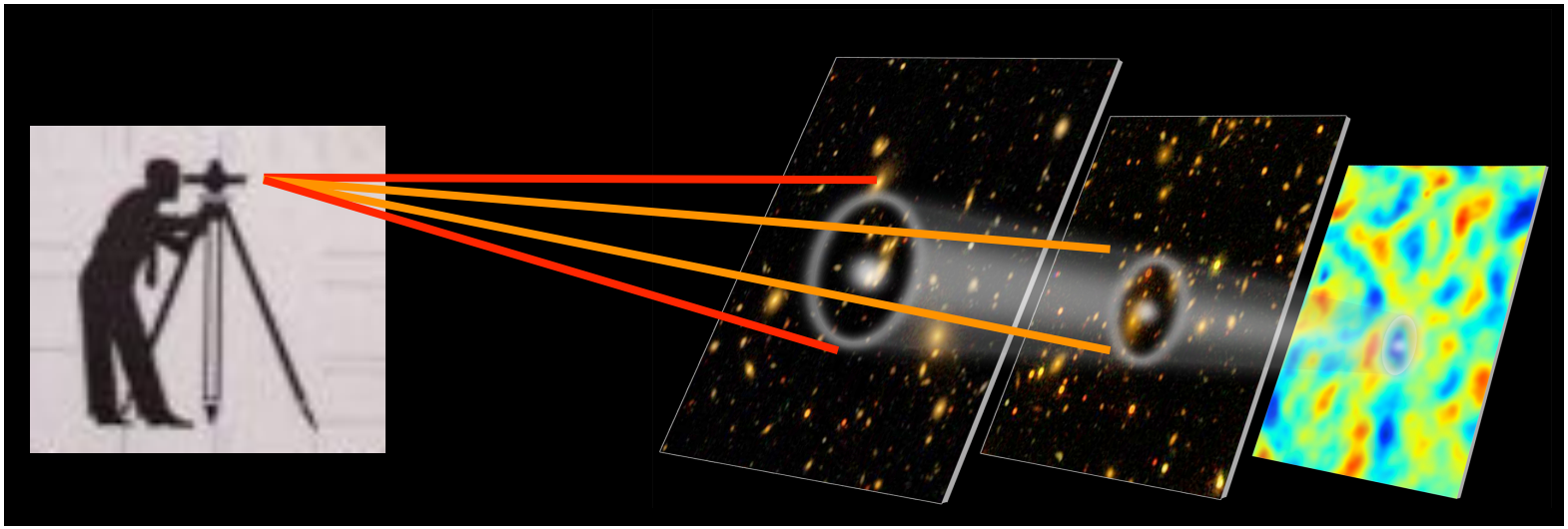
Dark Energy

- In 1998, two groups argued from supernova data that the expansion rate of the Universe is accelerating!
- Many possible explanations have been advanced.
  - Cosmological constant
  - New low-mass field(s)
  - Modification to gravity
  - Extra dimensions
  - Your favorite here
- All are exotic, and none is so aesthetically compelling as to be the obvious preference.
- What more can we do observationally?
  - Main path is very accurate distance measurements, 1% and better!



Baryon Acoustic Oscillations

- Sound waves propagating in the first 400,000 years after the Big Bang create a distinctive feature in galaxy clustering: pairs of galaxies are slightly more likely to be separated by 500 million light-years than by 400 or 600.
- When we see this pattern in the clustering data as an angular scale, we can infer the distance to the galaxies.



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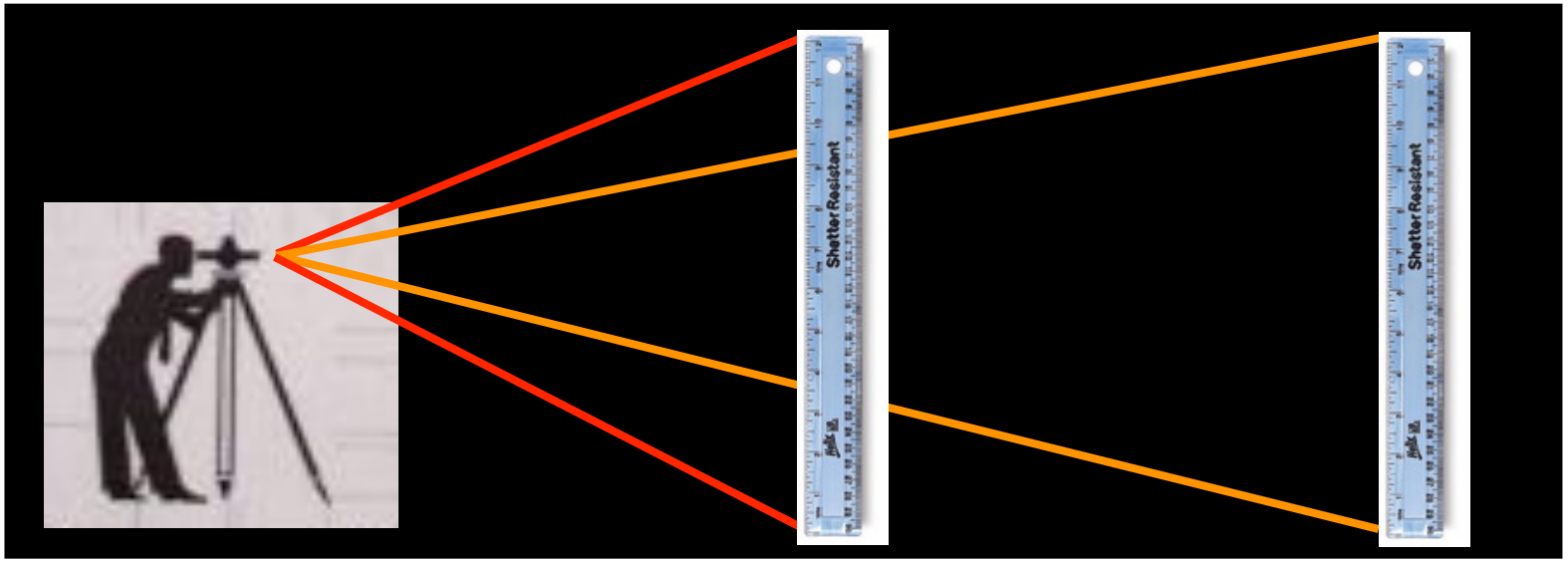
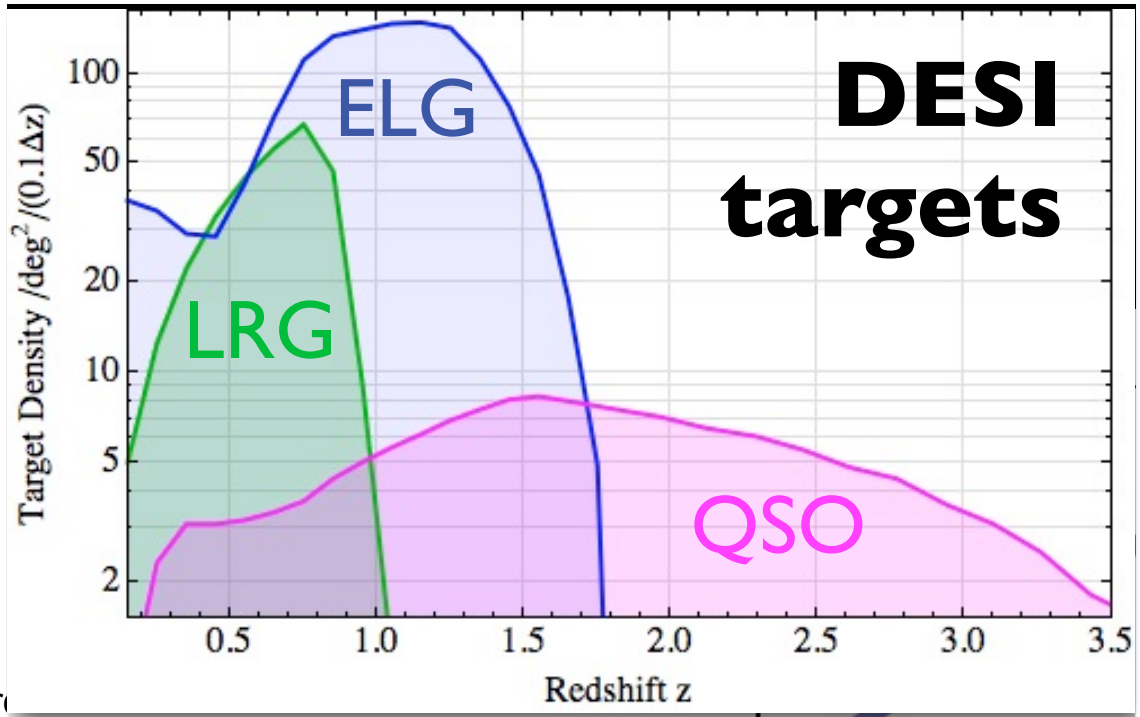


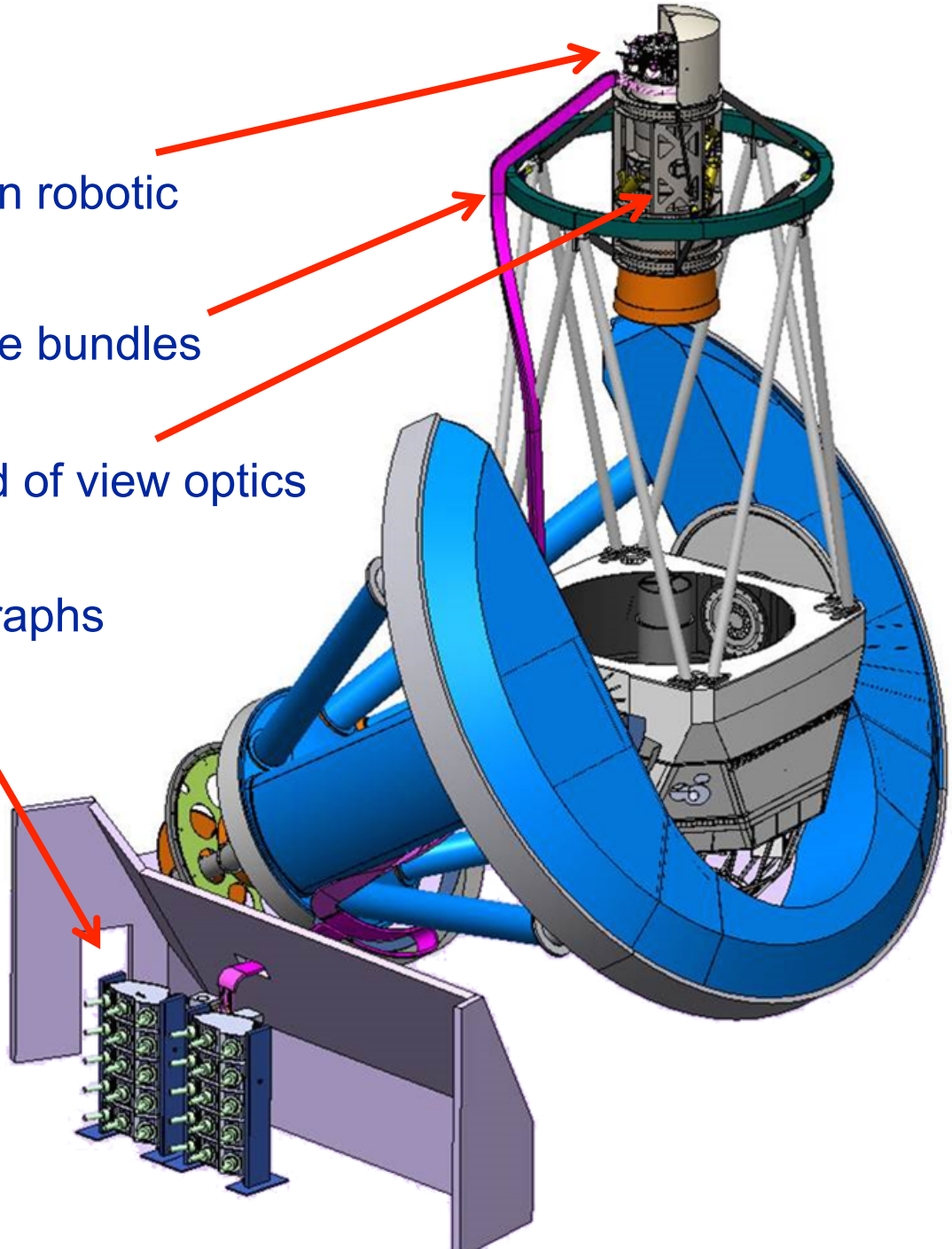
The DESI Survey

- Will produce the best measurement of BAO by performing a spectroscopic survey over 14,000 sq. degrees out to redshifts of 3.5
- 4 million Luminous Red Galaxies (LRGs)
- 18 million Emission Line Galaxies (ELGs)
- 2.4 million quasars (QSO), including 0.7 million quasars at z>2.2 for Lyman-alpha-forest
- Plus bright galaxies, r<19.5 z<0.4



DESI

- 5000 fibers in robotic actuators
- 10 fiber cable bundles
- 3.2 deg. field of view optics
- 10 spectrographs



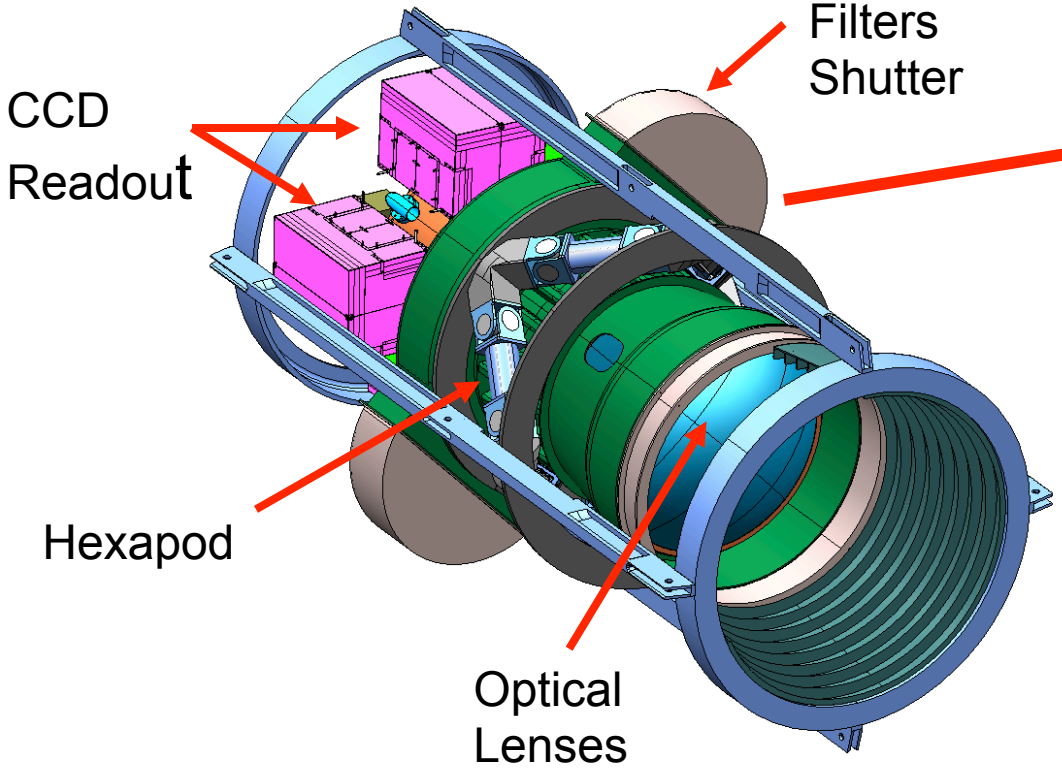
Mayall 4m Telescope Kitt Peak Tucson, AZ

Readout & Control

Context: DESI Project is very similar to the DECam Project

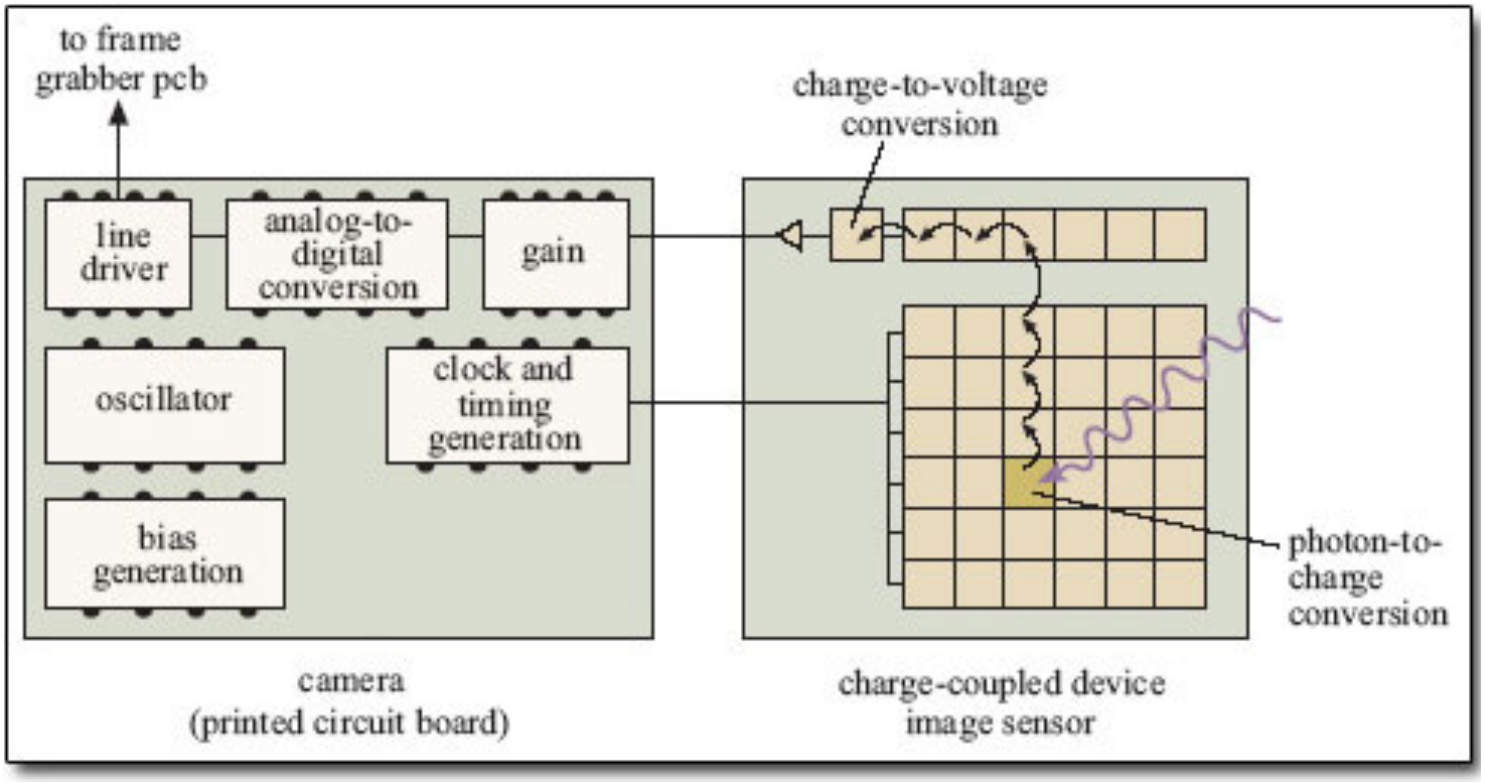
DECam Construction 2008-2012 :
570 Mpix, 3 sq. deg. CCD camera, 5 filters (griz,Y)

Dark Energy Survey (DES) just finished 2nd year of operations

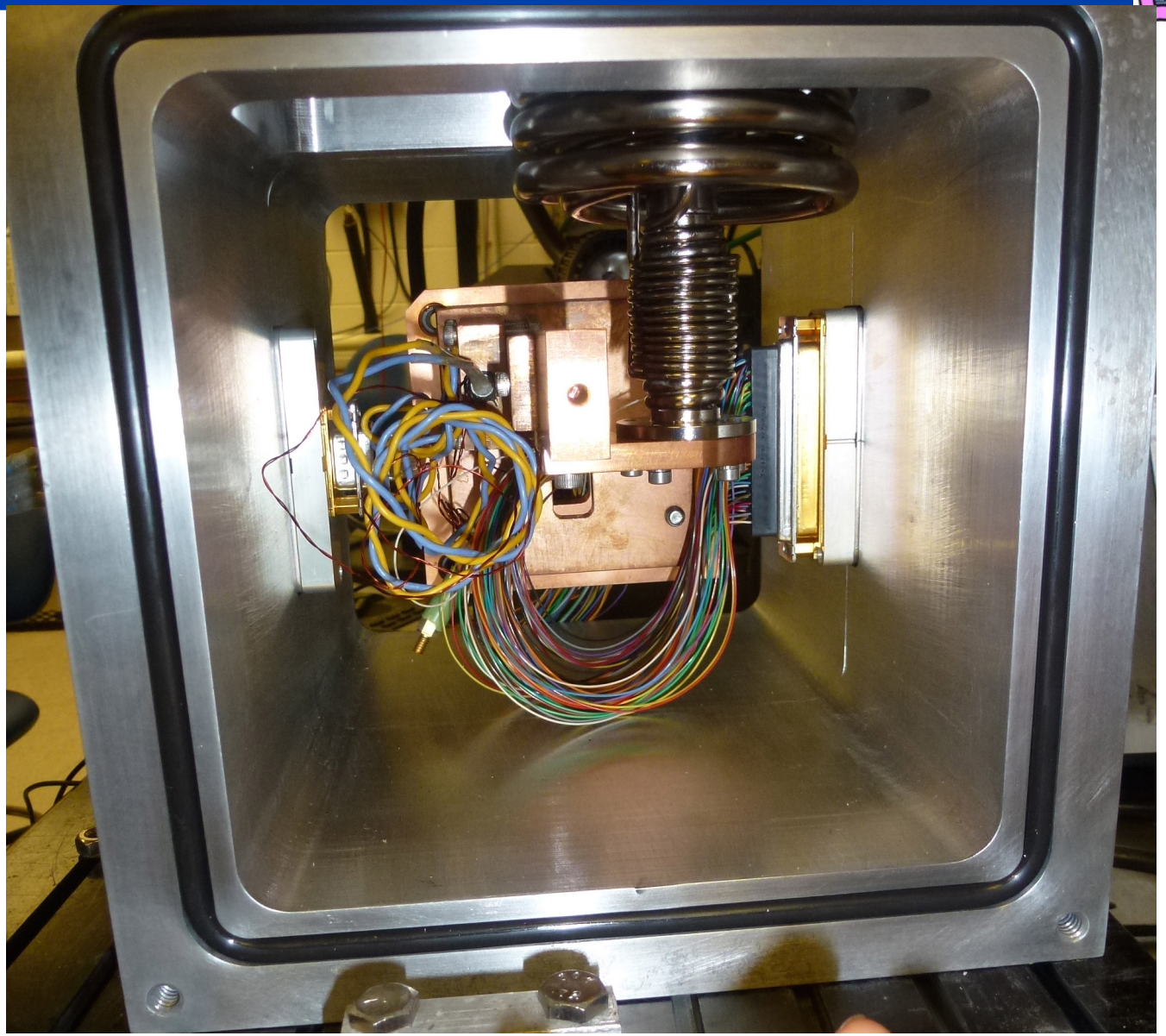


Blanco Telescope @ CTIO

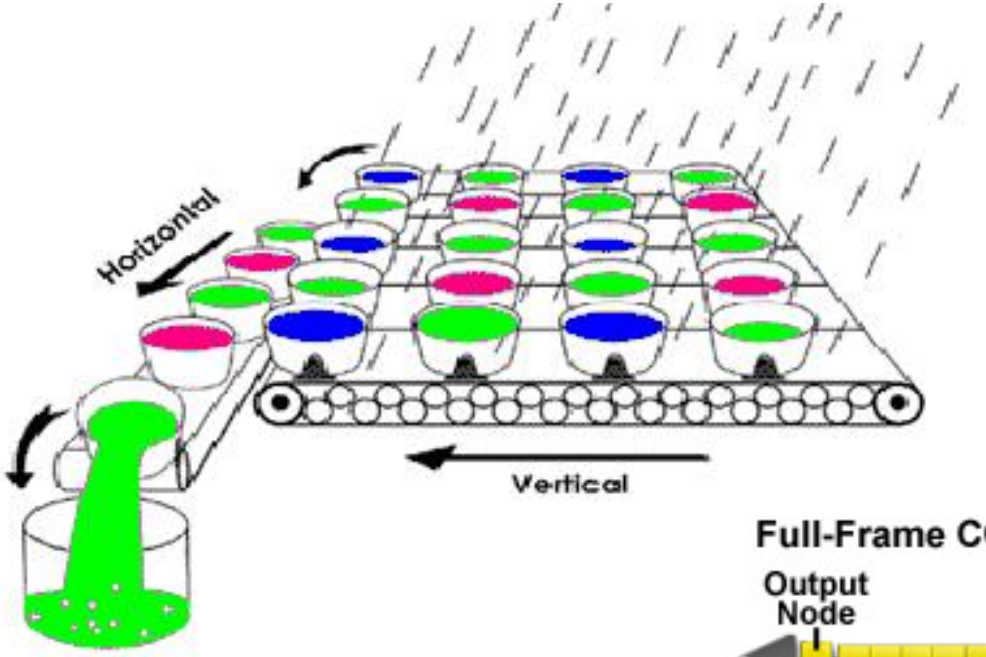
Science grade CCD schematic



Testing Dewar



Principle of CCD operation



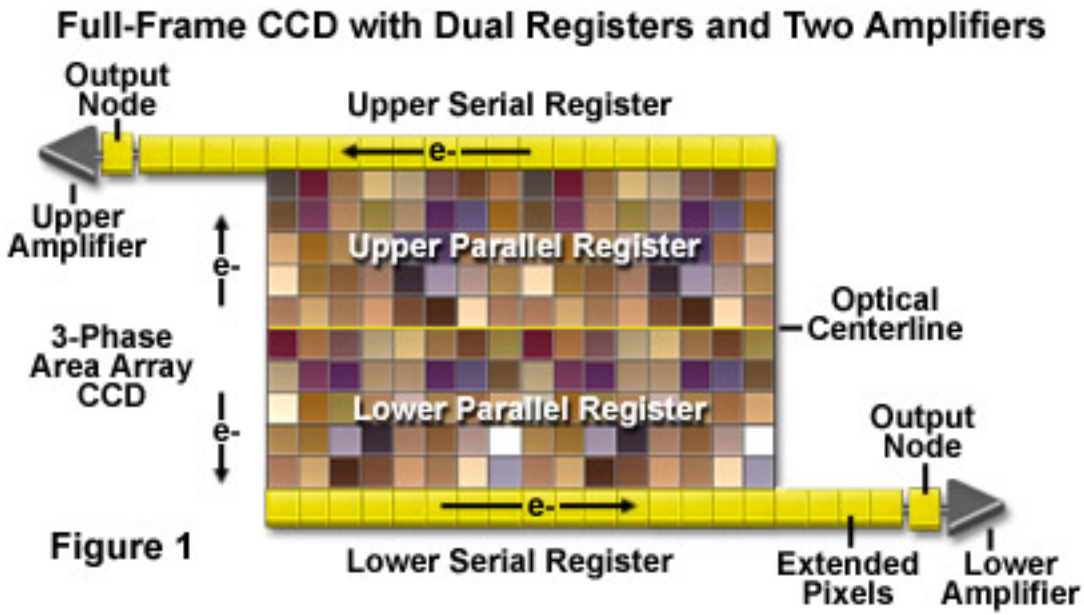
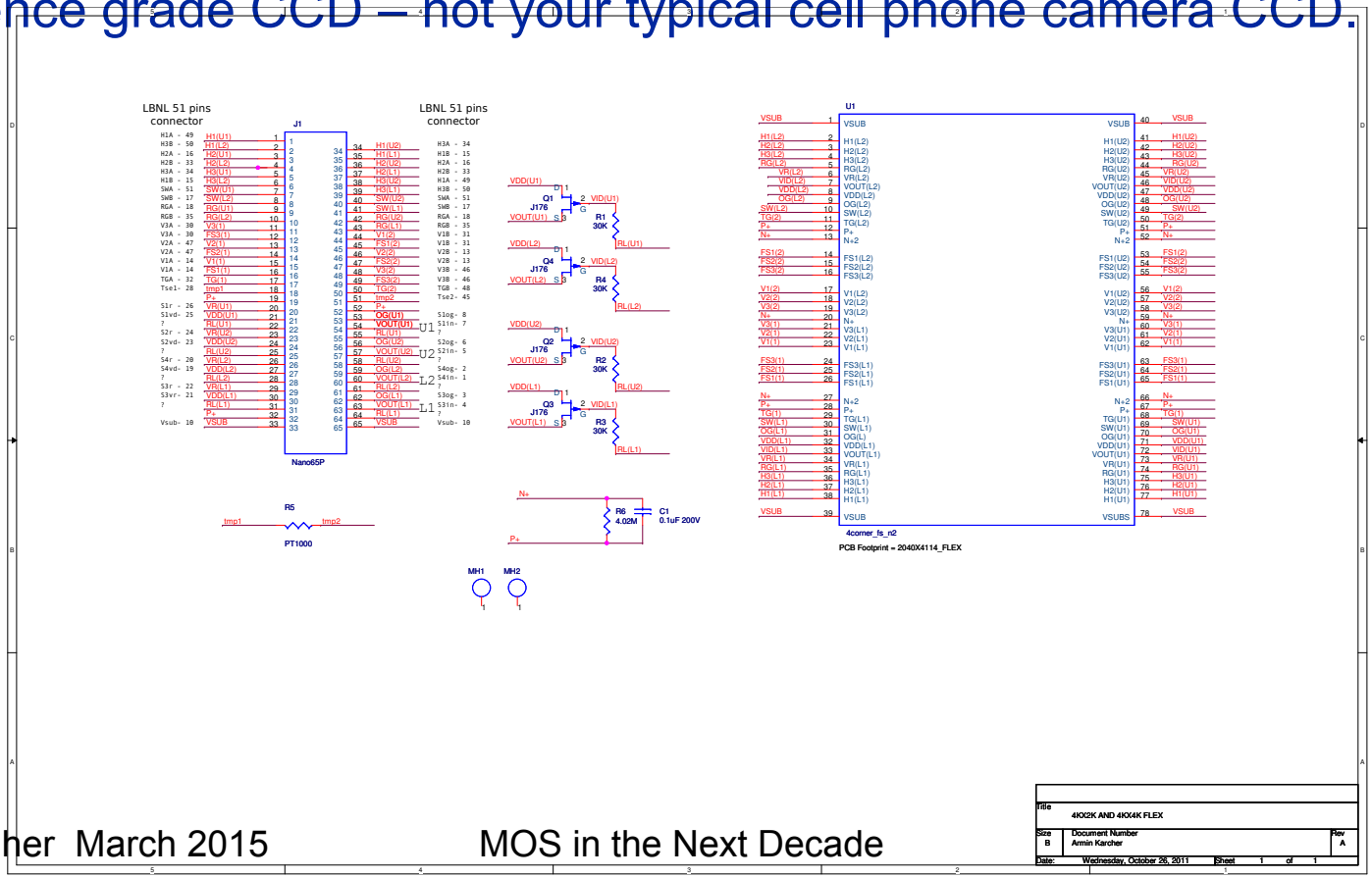


Figure 1

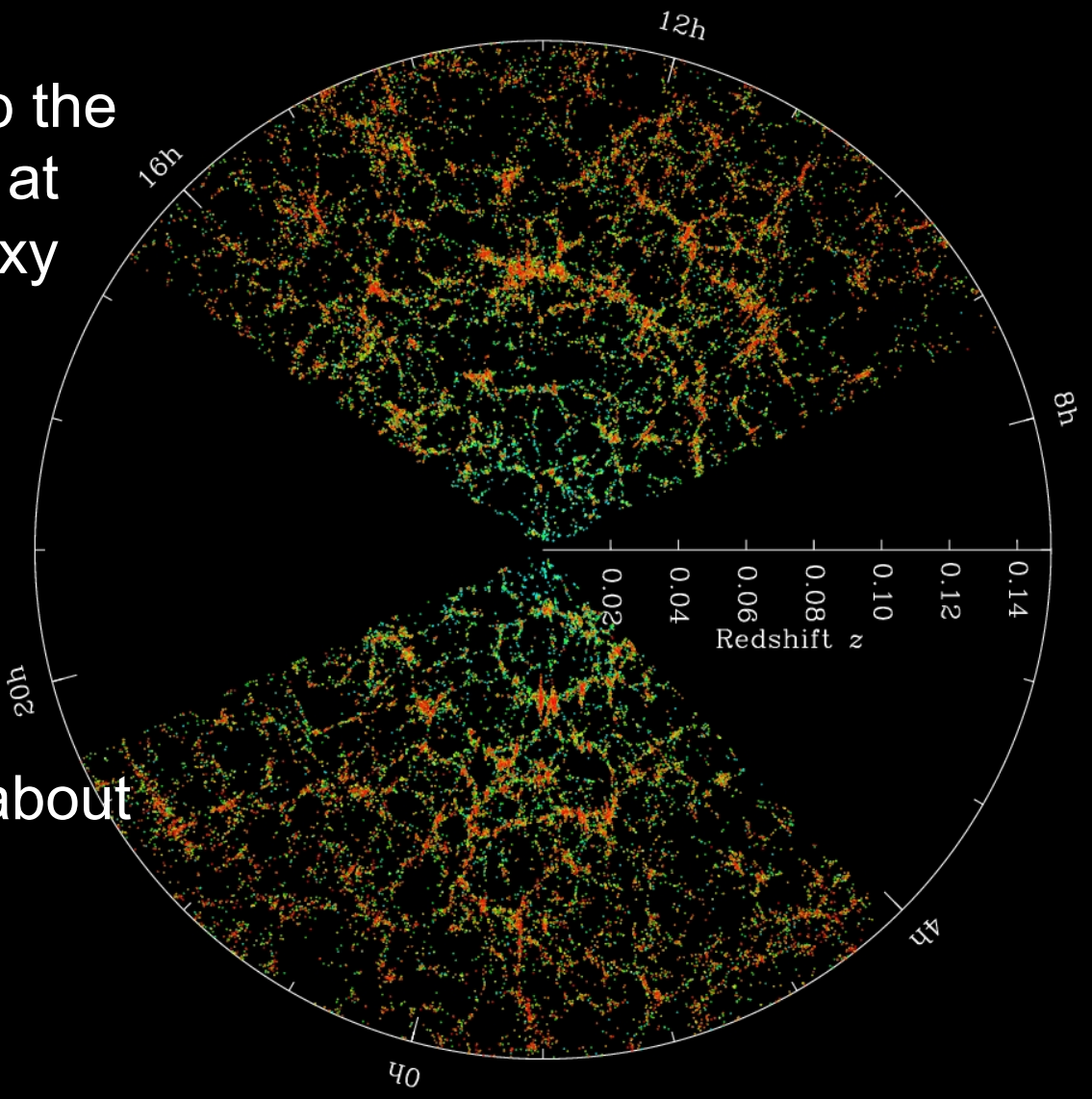
Science grade CCDs

- Low noise.
- No defects on the silicon.
- Large format.
- ~~Science grade CCD – not your typical cell phone camera CCD.~~

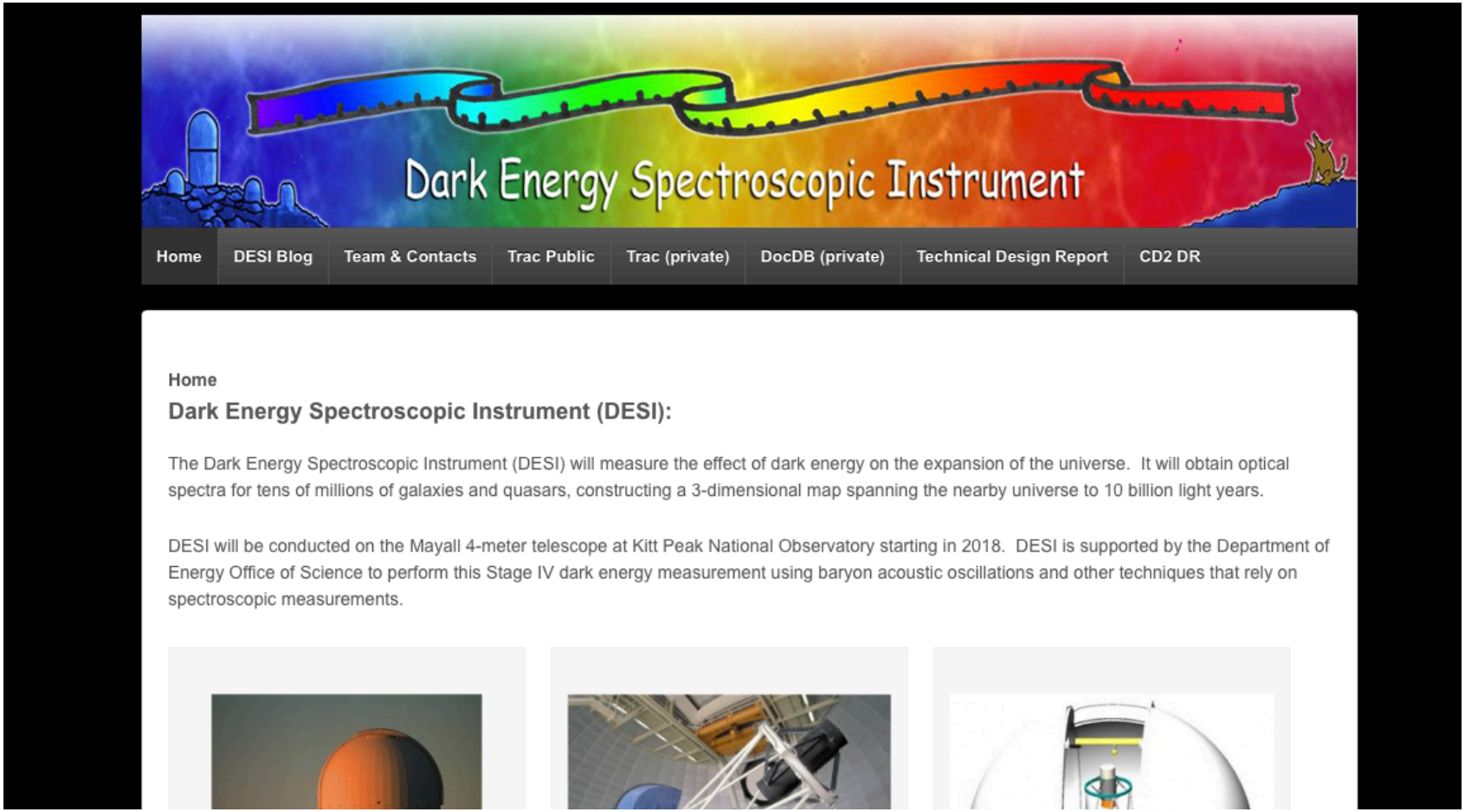


Mapping the Universe

- The easiest way to map the density of the Universe at low redshift is with galaxy surveys.
- We make two-dimen. maps with imaging and then add the third dimension with spectroscopy.
- Largest 3-d maps use about a million galaxies.



http://desi.lbl.gov

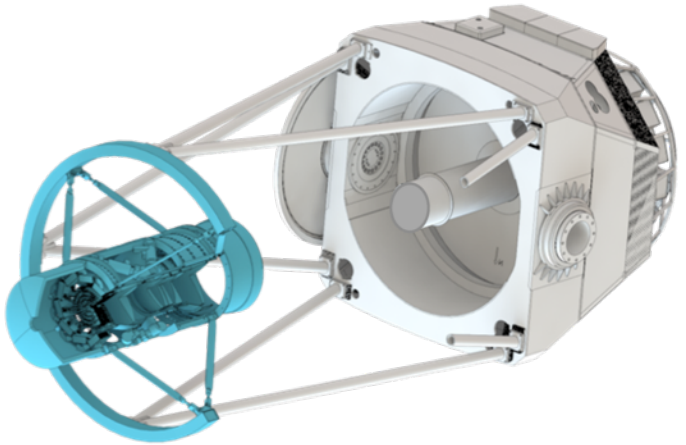


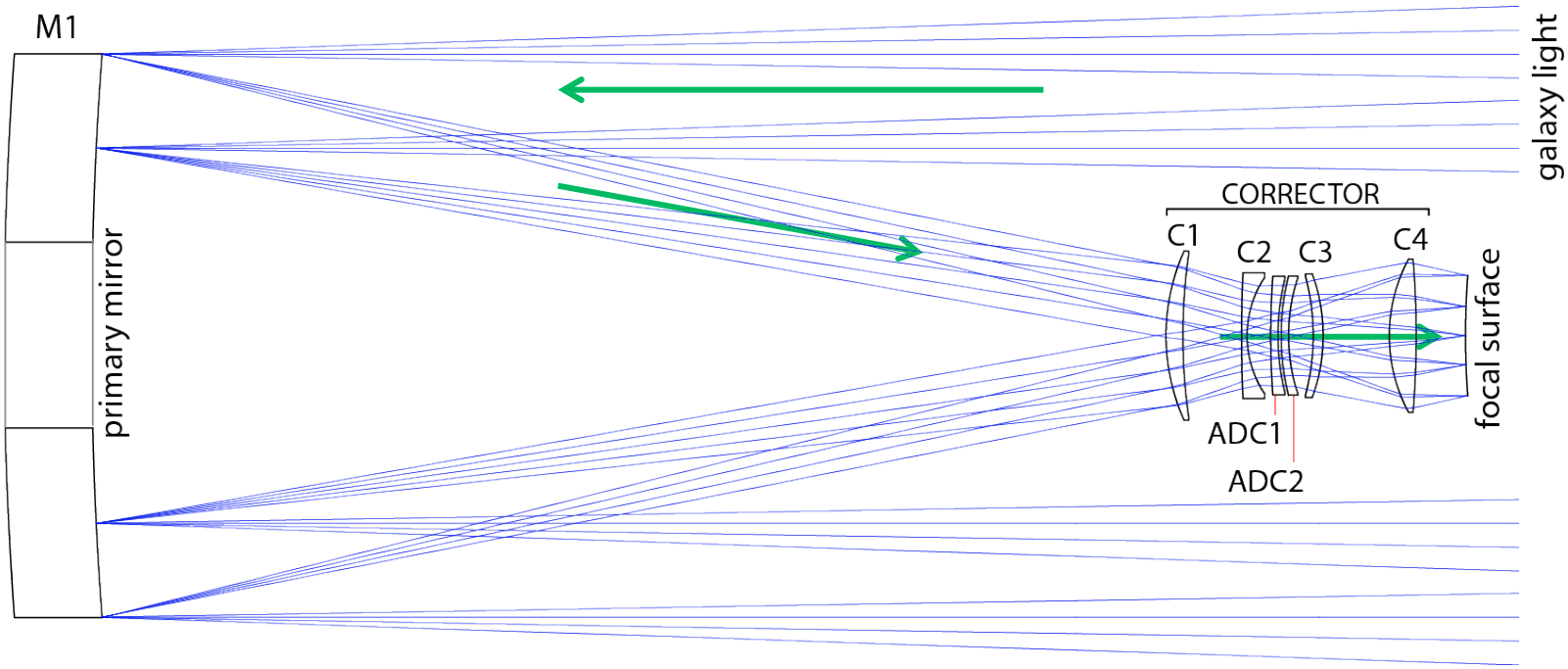
Thank you!

Back-up

DESI Prime Focus Corrector

- Requirements
  - Field of view >3˚ linear
  - *Wavelength bandpass 360 – 980 nm*



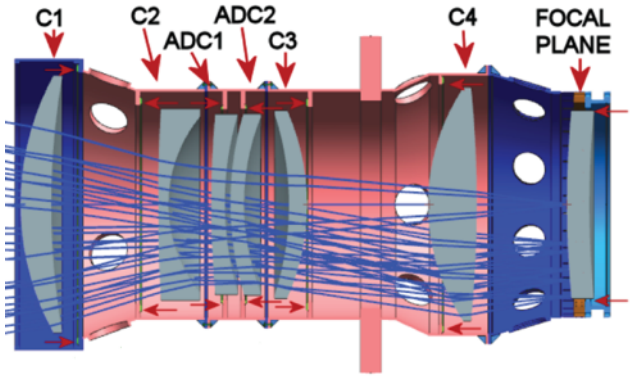


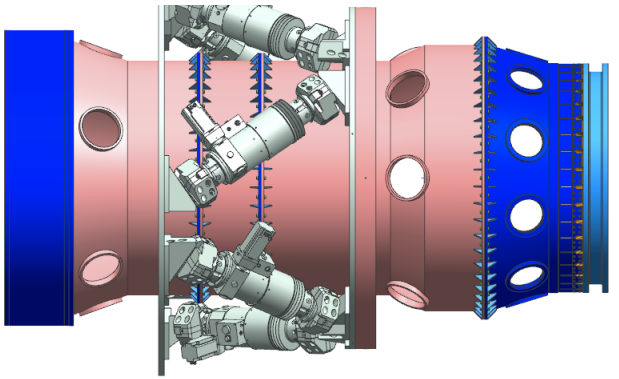
Corrector Mechanical

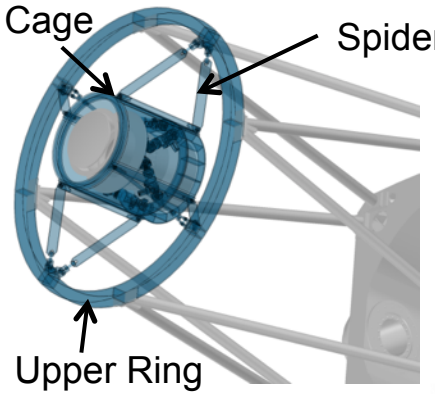
- Lenses are mounted in cells that are in turn mounted in the stiff barrel structure – DECam heritage

- Barrel is supported in cage on a hexapod to compensate for temperature, gravity, and misalignment – DECam heritage

- Cage is suspended from telescope trusses by a ring and spiders – Inner Flip ring is eliminated, spiders attach to new outer ring.

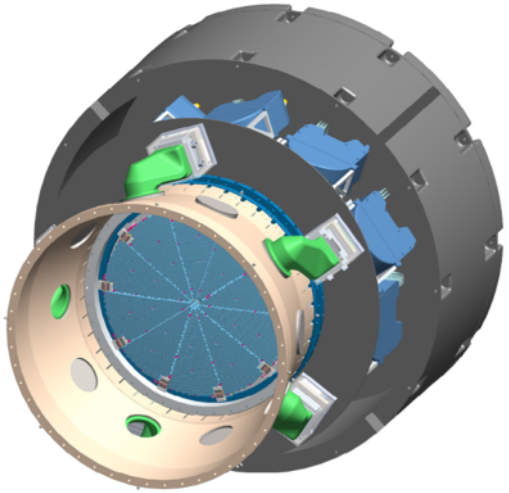




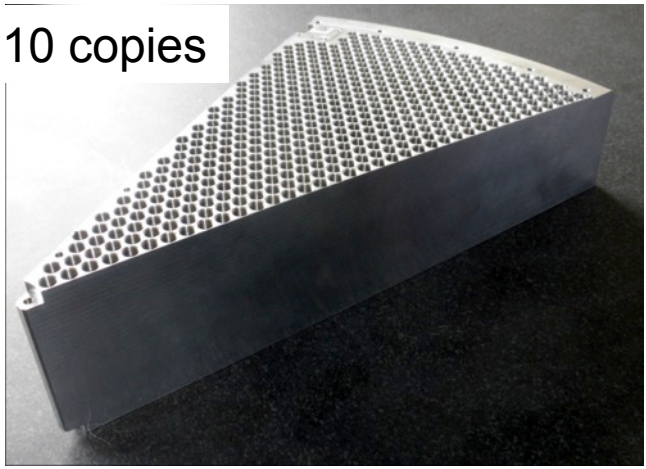


Focal Plane System

- Focal plane system
  - Attaches to the back of the corrector barrel
  - Carries the focal plane, fiber positioners and support systems
  - Will be assembled and installed as a unit (similar to the DECam CCD imager)

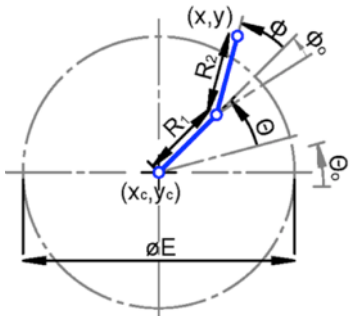


- Petals
  - 10 standalone wedge systems
  - Each holds 500 positioners
  - All electronics and fiber supports fit in shadow of each petal

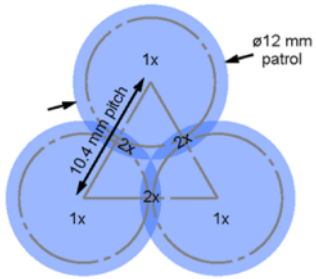


Fiber Positioners

- Position a fiber tip on a galaxy
  - 5 μm RMS accuracy in <45sec
- 500 per petal 10.4 mm center-to-center, 12 mm patrol disk
- 10 petals (5000 positioners) in the focal plane
- Finished part, final design, with prototype electronics, based on high-speed miniature DC motors.



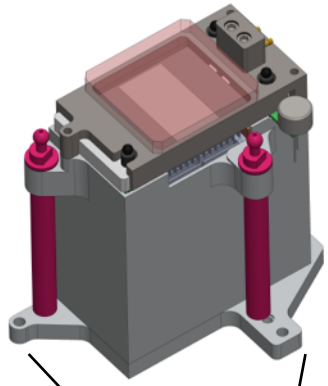
KINEMATICS / COORDINATES

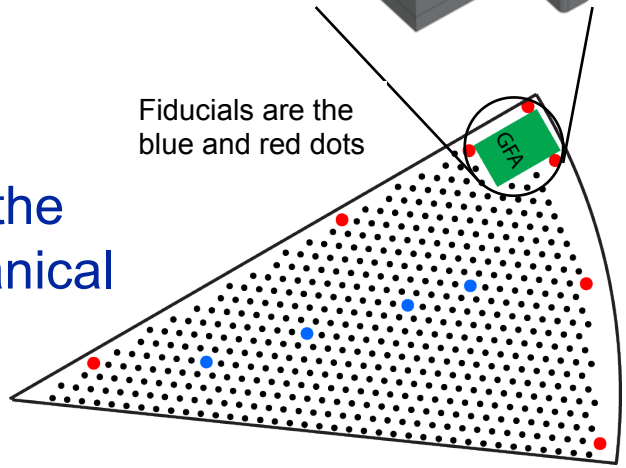


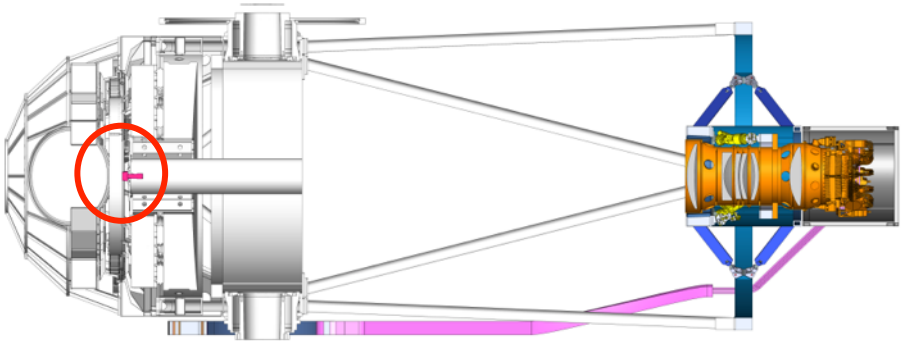
EXACT COVERAGE
R1 = R2 = 3 mm

Focal Plane System

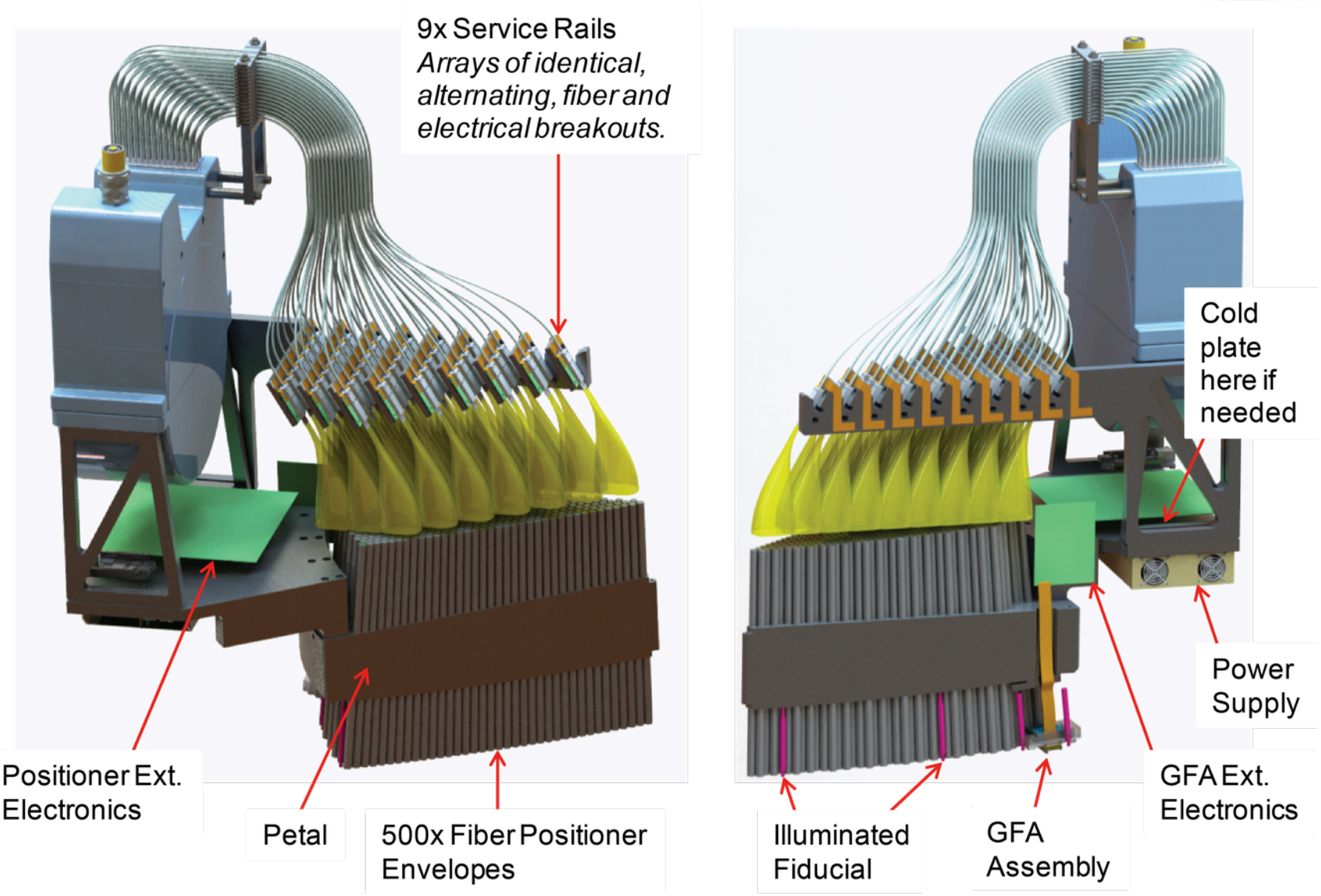
- Guide / Focus / Alignment sensors – 1 per petal
  - Guide star tracking feedback to telescope – 6 units
    - Guide star catalog study to optimize guider area
  - Focus and alignment data for hexapod – 4 units
- Illuminated fiducials – 11 per petal
  - Precisely surveyed to GFA sensors
  - When viewed from near primary mirror through the corrector, provides optical distortion and mechanical deformations data
- Fiber view camera (FVC)
  - Observes illuminated fiducials …
  - … *and* backlit fiber positioners
  - Provides feedback to positioners to align fibers to guide stars





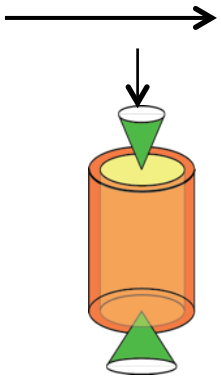


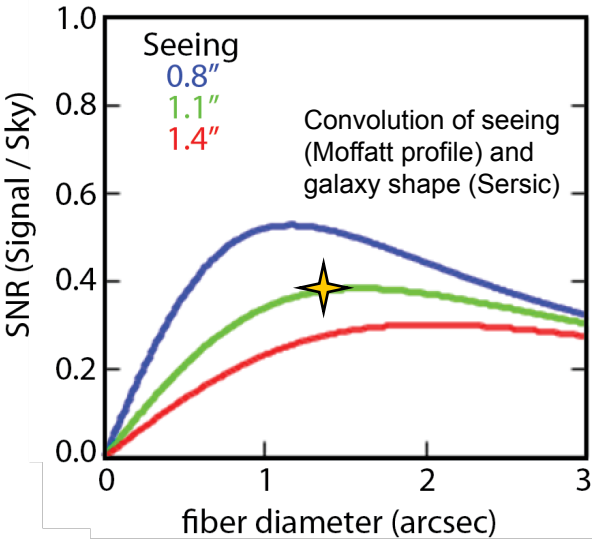
Focal Plane Petal System

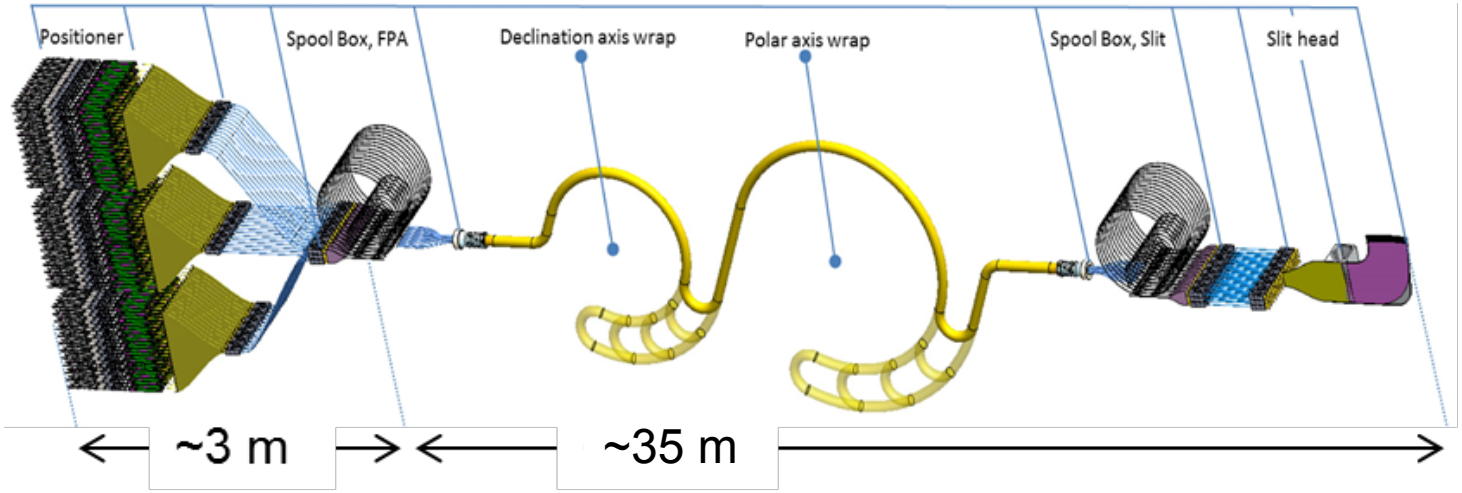


Fiber System

- Requirements
  - Maximize *throughput*
    - Fiber core size –Φ107 μm (1.47 arcsec)
    - Optimize fiber transmission and FRD
  - 90% of the output light within f/# > 3.57

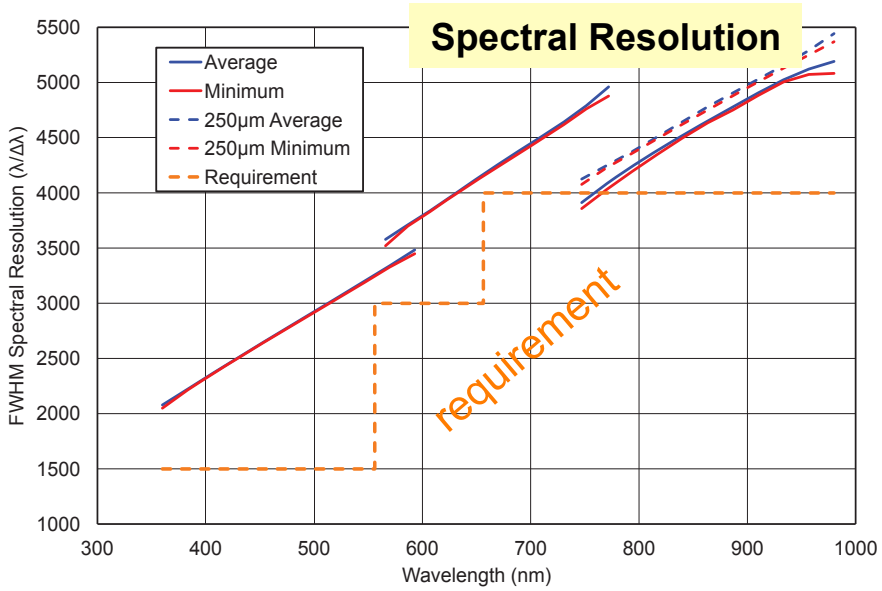






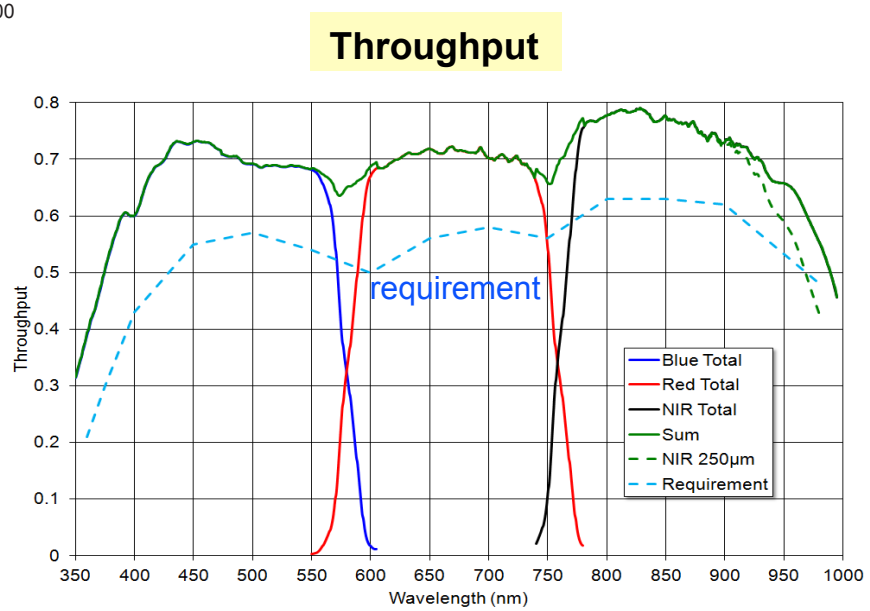
5000 Positioners, 20 Spool Boxes, 10 Cables, 2 Wraps, 10 Slits

Spectrograph Requirements and Design

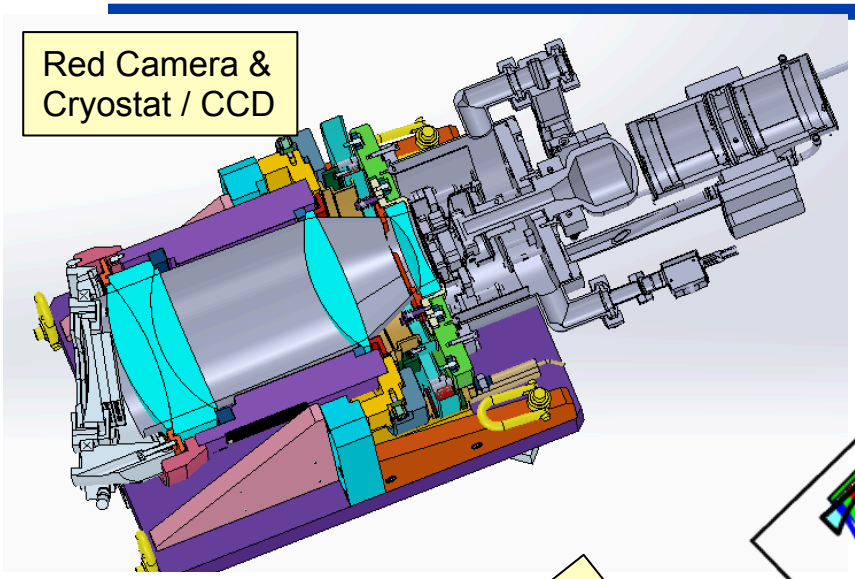


Analysis includes:

- geometric blur
- fiber size
- diffraction
- CCD effects



Spectrographs

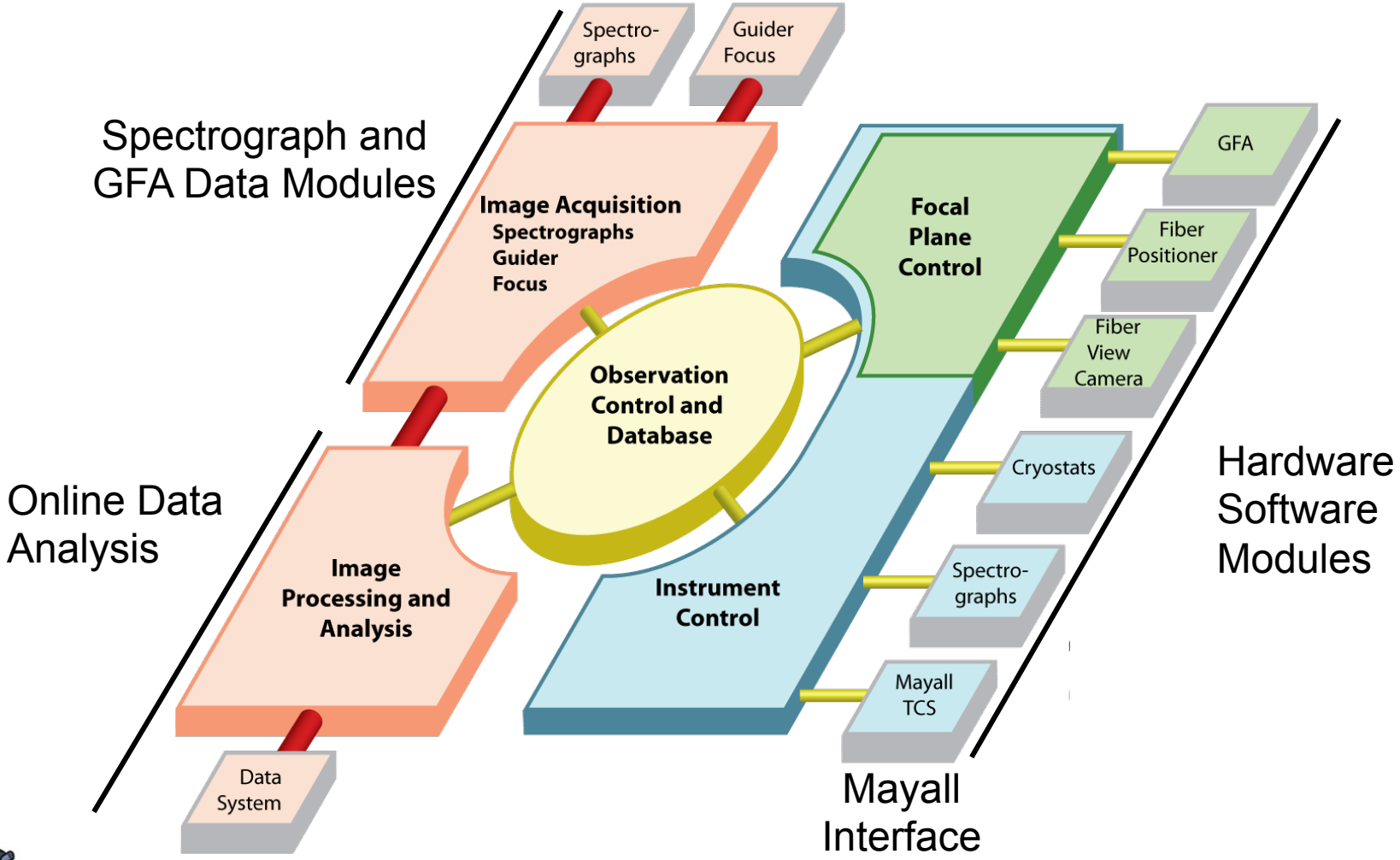


Prototype spectrograph currently under construction, evaluation this summer

CCDs: 4096 x 4096, 15 μm pixel, 500 spectra

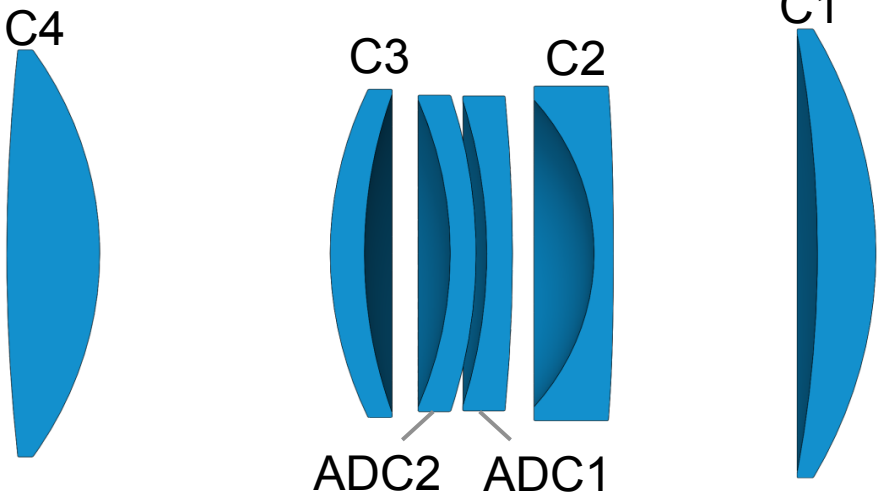
Instrument Readout and Control

- Instrument and observation control, and telescope interface
- Builds on DECam – same people, same components



Project Status

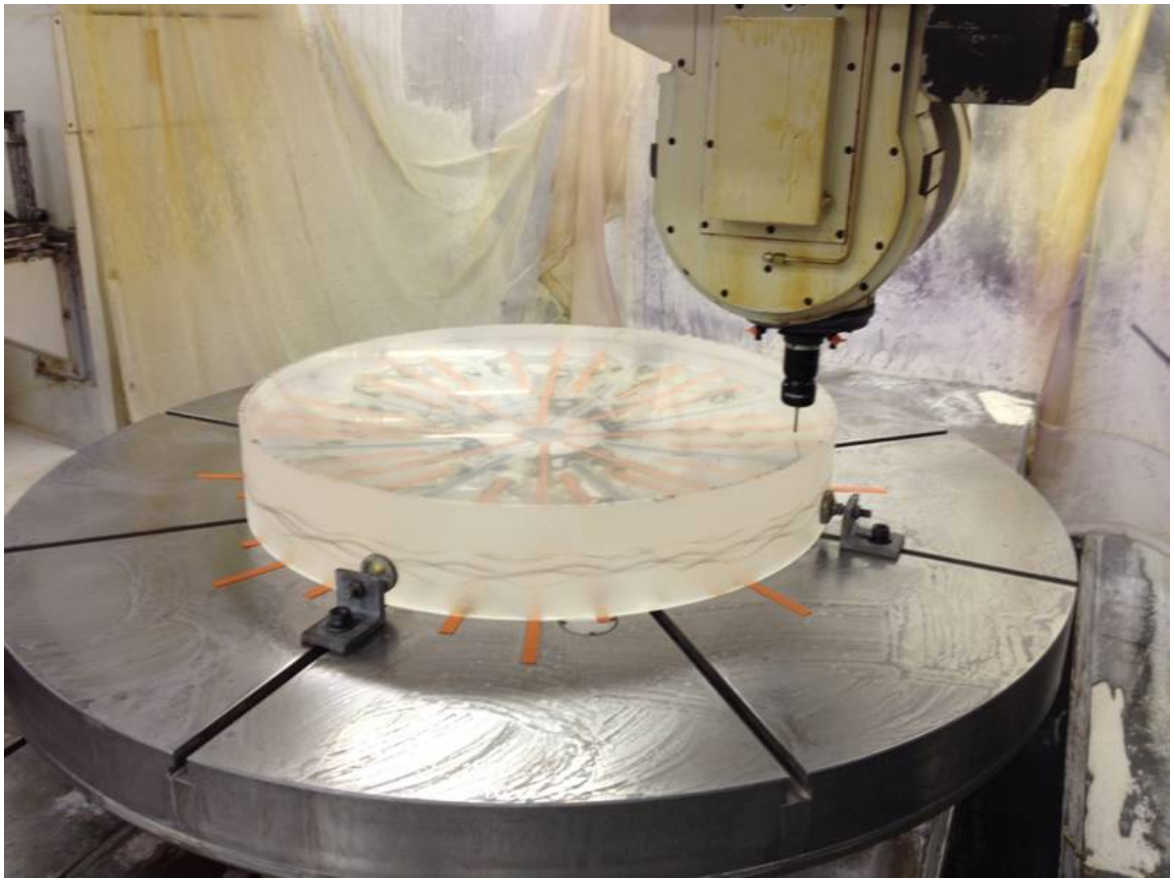
- The project is making great progress. Main focus – keep the optics off the critical path with foundation grants (non-DOE funding)
- Procurement of C1-C4 blanks is complete. Grinding and polishing is in progress (AOS and L3-Brashear).
- Procurement of ADC blanks is in progress (Schott and Ohara) Polishing contract is being placed.
- Expect all lenses to be complete by end of 2016.



Element	Diameter (mm)	Mass (kg)	Material	Aspheric surfaces
C1	1140	201	Silica	0
C2	850	151	Silica	1
ADC1	800	102	N-BK7	0
ADC2	804	89	N-BK7	0
C3	834	84	Silica	1
C4	1034	237	Silica	0

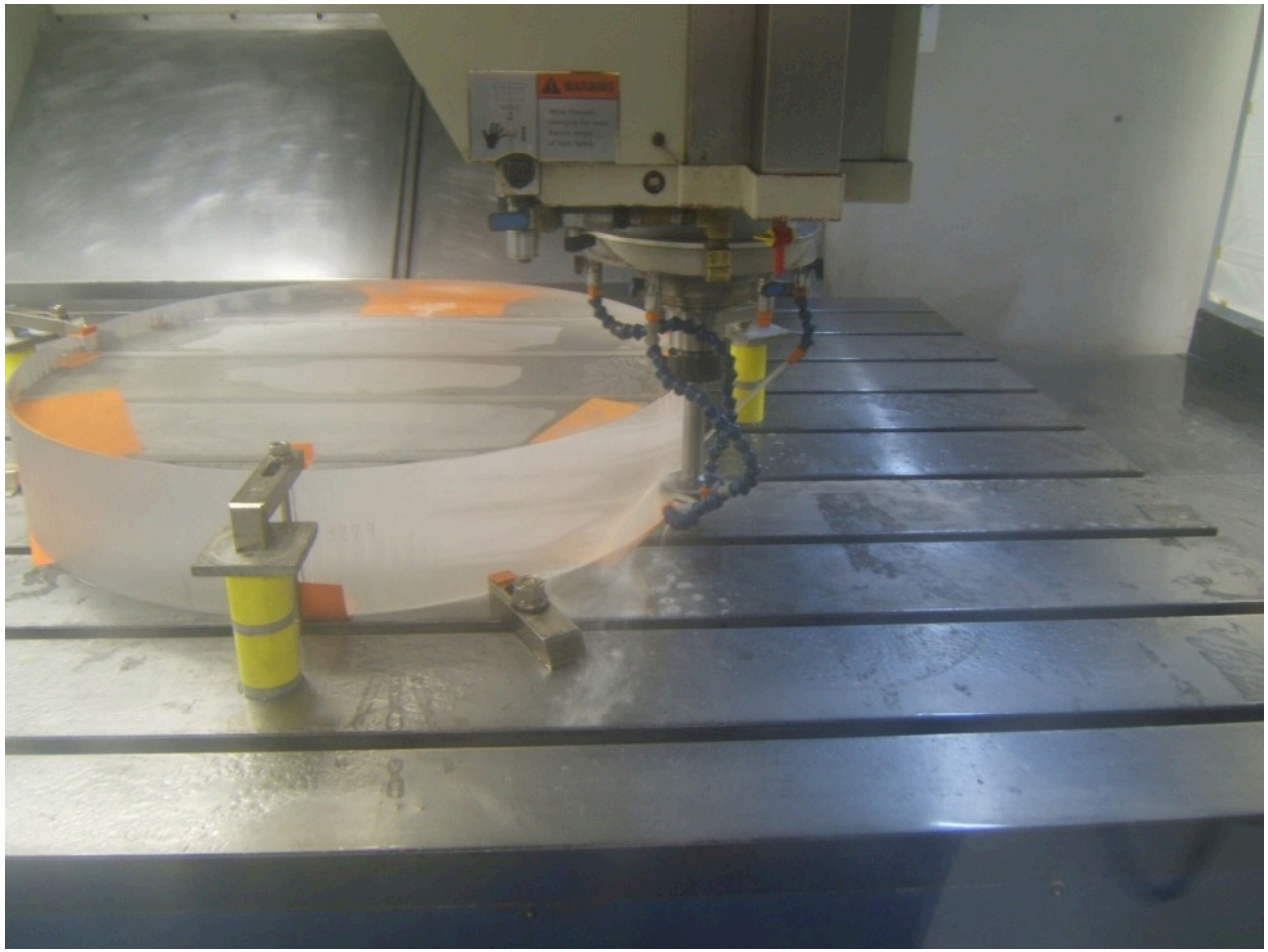
C1 Lens

- C1 (1.15 m diameter) on the coordinate measuring machine at L3-Brashear immediately after completion of the concave surface machining.
- C1 is well ahead of schedule



C3 Lens

- C3 is in process on edging machine at Inventex. Is being ground to near net shape.



Spectrograph Oil Filled Lens

- Blue Camera triplet lens test. Test structure with lenses to test oil seal. The oil interface between lenses provides exceptionally high throughput:

Project Status

- Sept. 2014: Successful CD-1 review. DOE Funding profile negotiations nearly settled. Expect “advanced procurement authority” in Mid March 2015.
- DOE CD-2/3a review scheduled for July 28-30, 2015 – this is the big one (~ Critical Design Review) - nails down the design, cost and schedule.
- Spectrographs are the critical path (funding limited). Fabrication of a prototype will be complete and tested this summer.
- DESI installation begins Jan. 2018. Start moving the telescope with DESI installed in Oct. 2018
- On-sky commissioning will start in Jan. 2019 with 6 spectrographs, the rest arriving by July. DESI is the only instrument on the telescope
- 5 year DESI survey will start in Jan. 2020 (after a 6m science verification period)

Conclusion

- DESI builds on the long and successful experience of multiple collaborations in defining, building and executing wide area surveys to study the formation of our universe and the mystery of Dark Energy
  - SDSS, BOSS, DES
- DESI will essentially complete BAO measurements in the northern sky out to redshift of 1.5, plus RSD and limits on neutrino masses
- Technical design of DESI is mature, Private/non-DOE funding being used for lenses and prototype spectrograph
- Strong support from DOE: CD-2/3a baseline review scheduled for July 2015.
- On track for on-sky commissioning <4 years from now in 2019!

Design Concept Validation

- Event generation – creates emission line galaxies
- Corrector PSF across the focal plane
  - Measured Mayall seeing, PSF, and Moffat profiles
  - Zemax transport galaxies to fiber input
- Spectrograph – pixel level simulation
  - Zemax transport from fiber output to CCD
  - Detector response – incident angle, depth of conversion, diffusion
- 1D spectrum fitter – feature S/N extraction
- Uses for instrument design
  - CCD read noise
  - Exposure time
  - [OII] resolution
  - ELG SNR >7 on [OII] for 8,9,10x10^{-17} erg/….