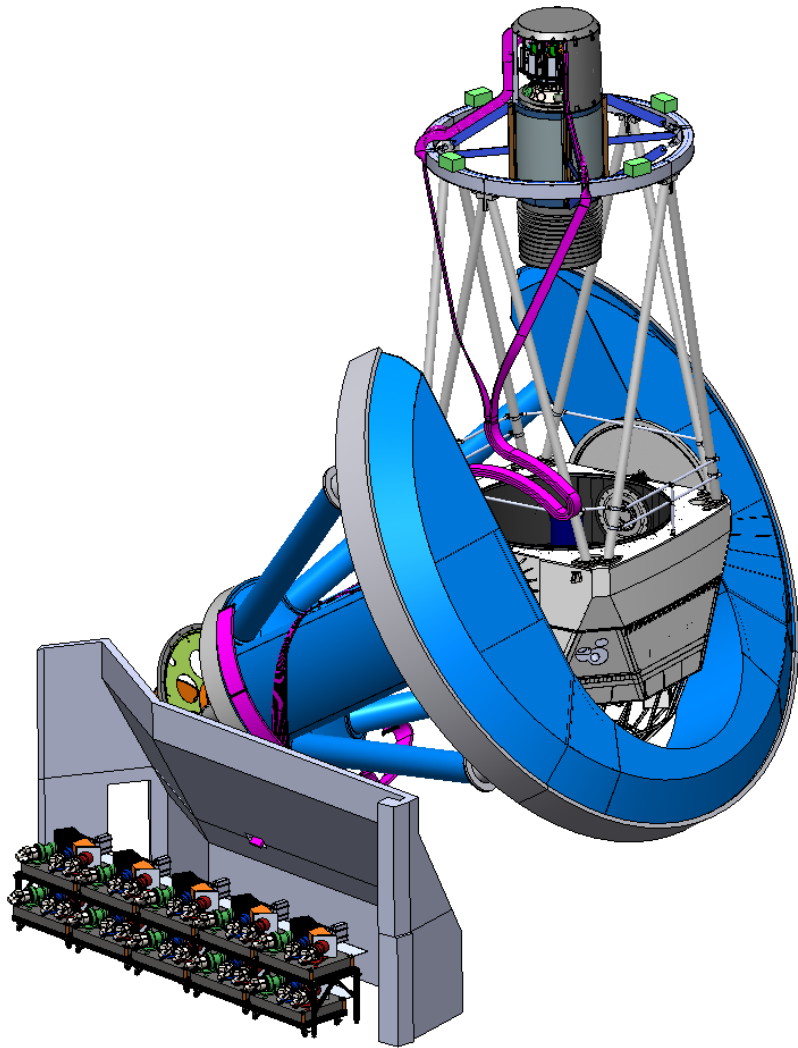


# The Dark Energy Spectroscopic Instrument (DESI)

Michael Schubnell  
(University of Michigan / LBNL)  
for the DESI Collaboration

15<sup>th</sup> Rencontres du Vietnam  
ICISE Quy Nhon, August 2019



**Dark Energy Spectroscopic Instrument**

U.S. Department of Energy Office of Science  
Lawrence Berkeley National Laboratory



# DESI Science Goals

The **Dark Energy Spectroscopic Instrument** will

- make a **precision measurement of dark energy**, while making important contributions to the **physics of inflation and neutrinos**
- observe 14,000 deg<sup>2</sup> of the night sky
- study the distribution of  $\sim 35\text{M}$  distant galaxies (correlations between them)

DESI will use **Baryon Acoustic Oscillation (BAO)** & **Redshift Space Distortion (RSD)** techniques

- BAO gives us a ruler in the sky and enables us to measure the expansion of the Universe
- RSD allows us to measure the pull of gravity and check General Relativity





DESI will be the largest spectroscopic survey for dark energy.  
Each spectrum measures a galaxy redshift.

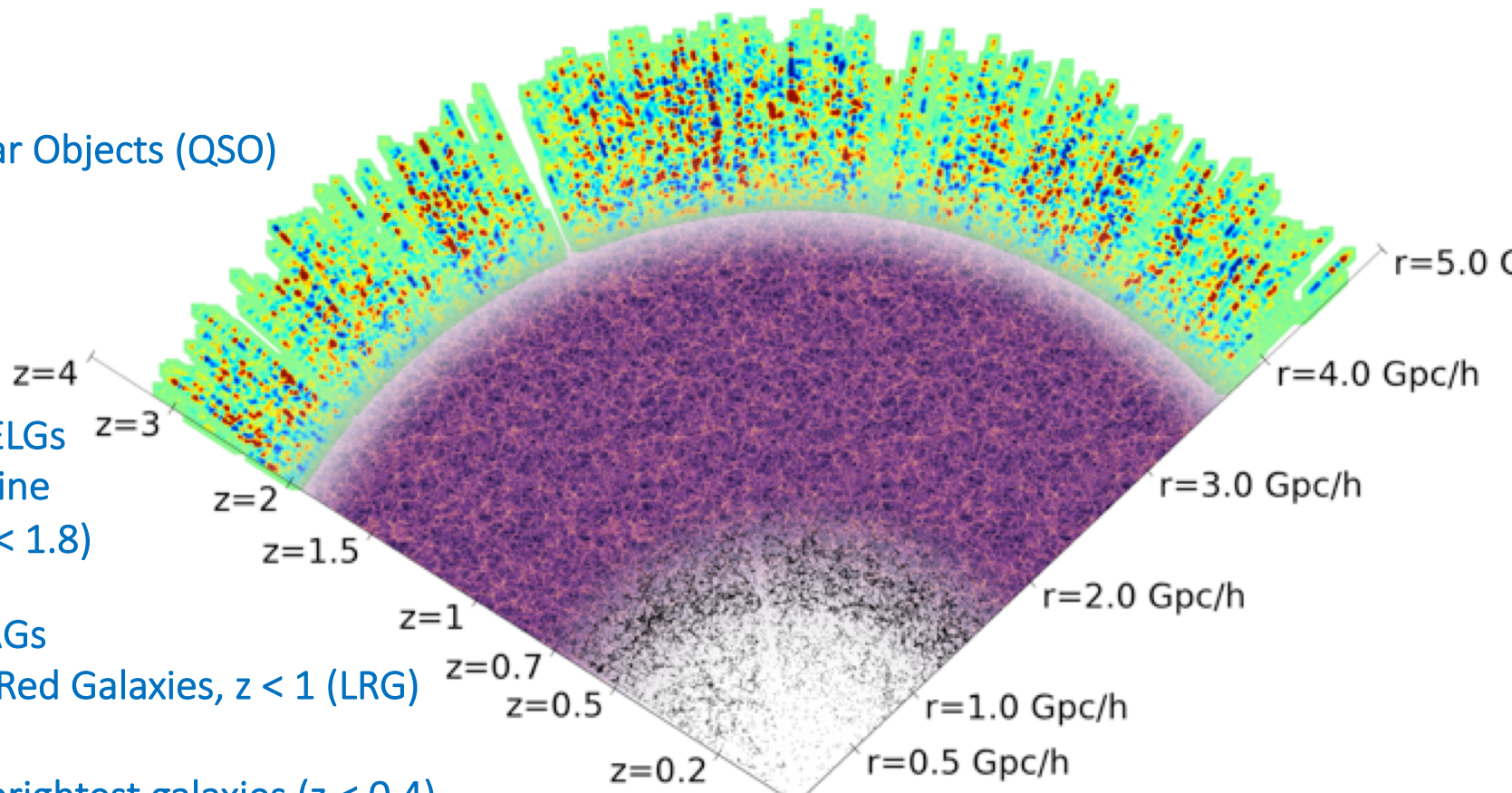
DESI will explore a x30 larger map over a x10 larger volume than SDSS

2.4 million  
Quasi Stellar Objects (QSO)

17 million ELGs  
(Emission Line  
Galaxies,  $z < 1.8$ )

4 million LRGs  
(Luminous Red Galaxies,  $z < 1$  (LRG))

10 million brightest galaxies ( $z < 0.4$ )

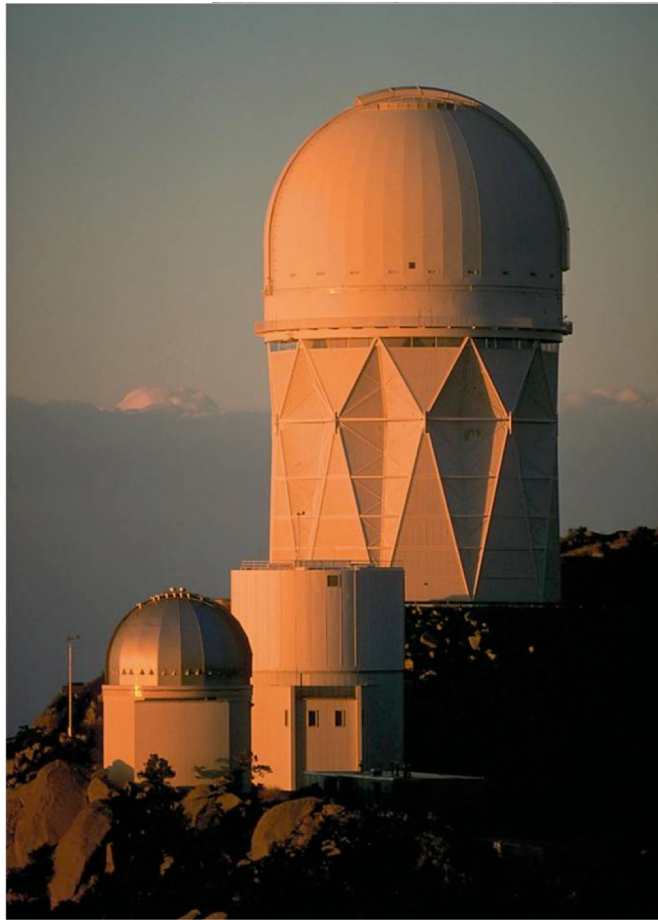


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# DESI is installed at the Mayall 4 meter Telescope at Kitt Peak National Observatory (KPNO), Arizona (US)



## Dark Energy Spectroscopic Instrument

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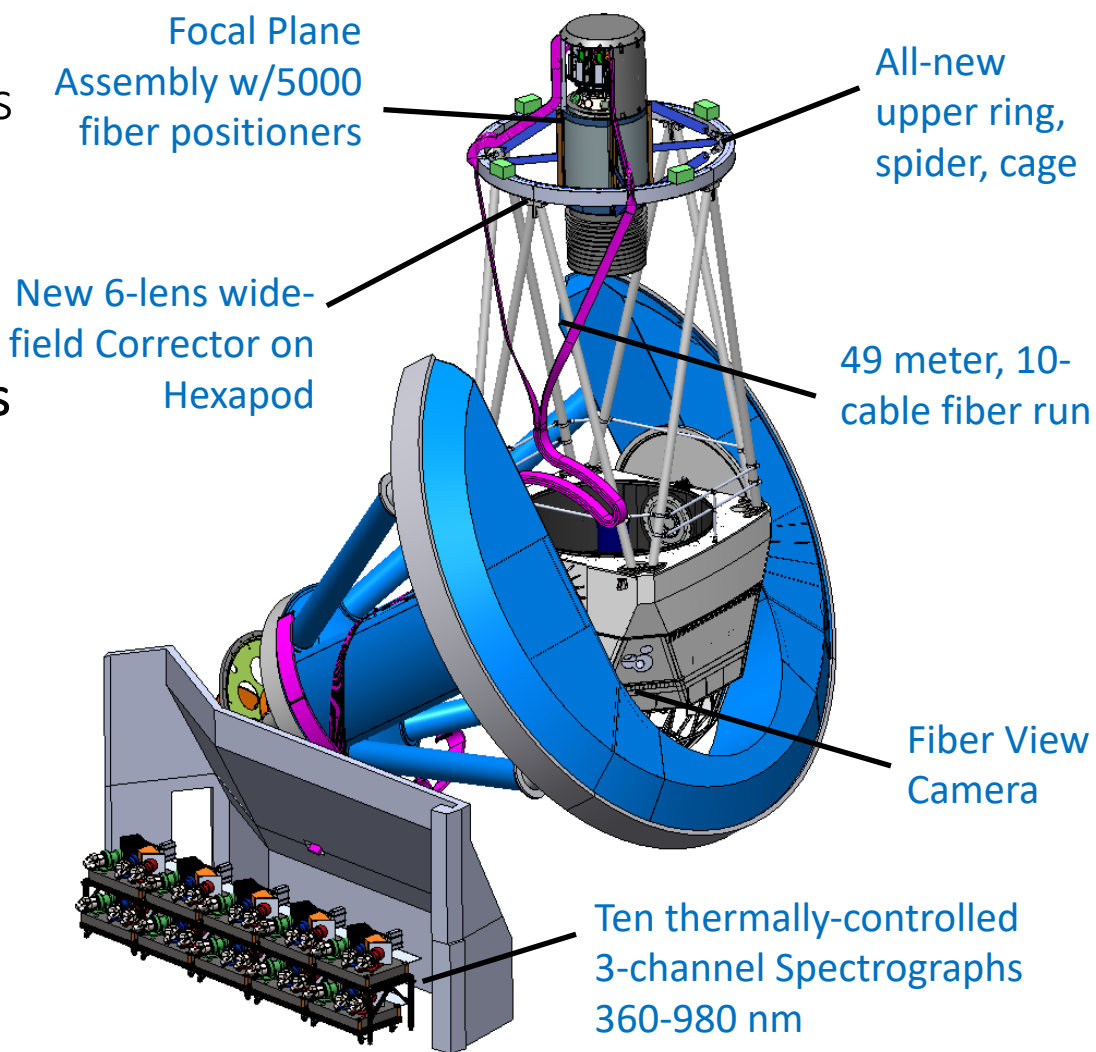
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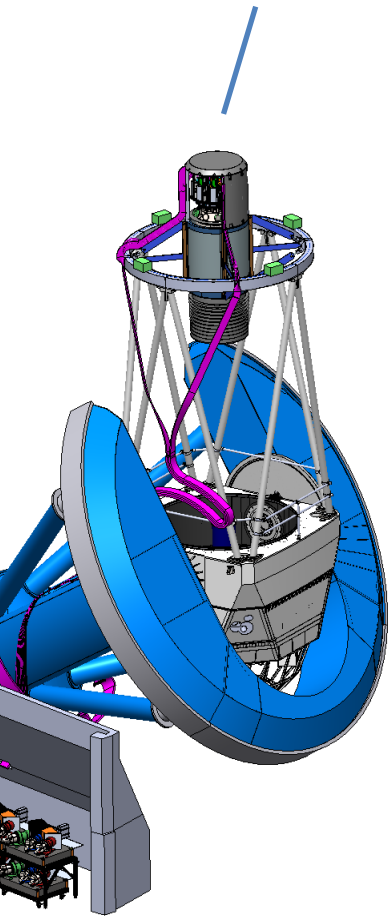
# DESI by the Numbers

- DESI is a Fiber-fed multi-object spectrograph. It uses robotic control to position optical fibers onto the location of a known galaxy
- **5000 fiber positioner robots** on the focal plane
- **8 sq. deg. FOV**
- **Ten 3-channel spectrographs**
- Spectra of **35 million galaxies and quasars** over **14,000 deg<sup>2</sup>** in five years



# DESI Subsystems – Wide-field Corrector

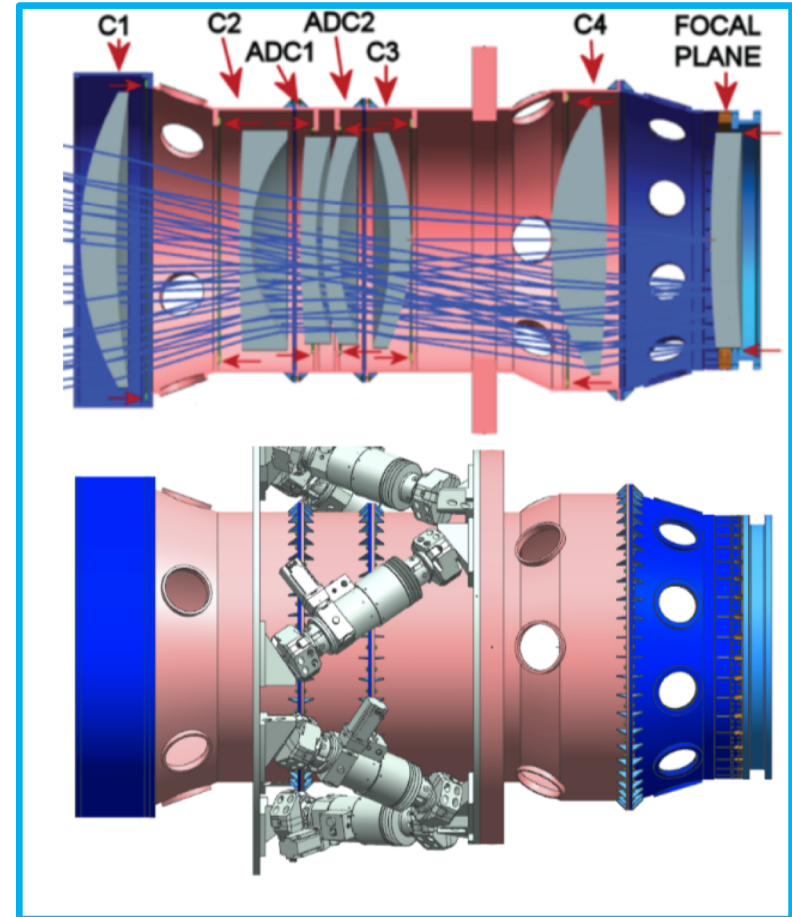
## New 6-lens wide-field Corrector on Hexapod



Lenses mounted in cells that are in turn mounted in the stiff barrel structure

Barrel is supported in cage on a hexapod to compensate for temperature, gravity, and misalignment.

Cage is suspended from telescope cage trusses by a ring and spiders.



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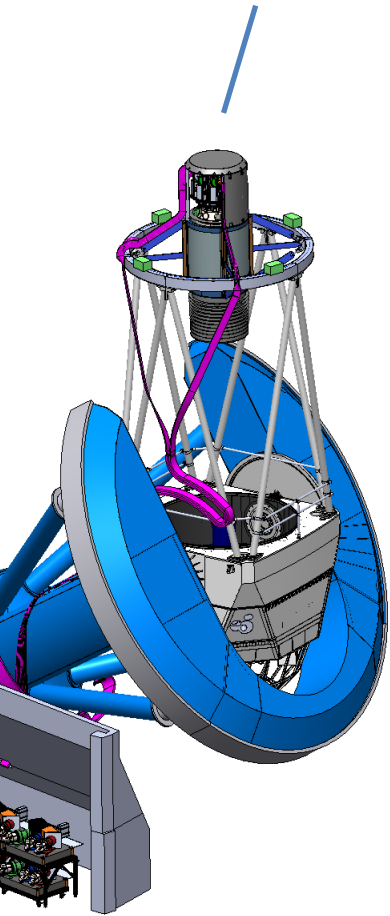
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# DESI Subsystems – Wide-field Corrector

## New 6-lens wide-field Corrector on Hexapod



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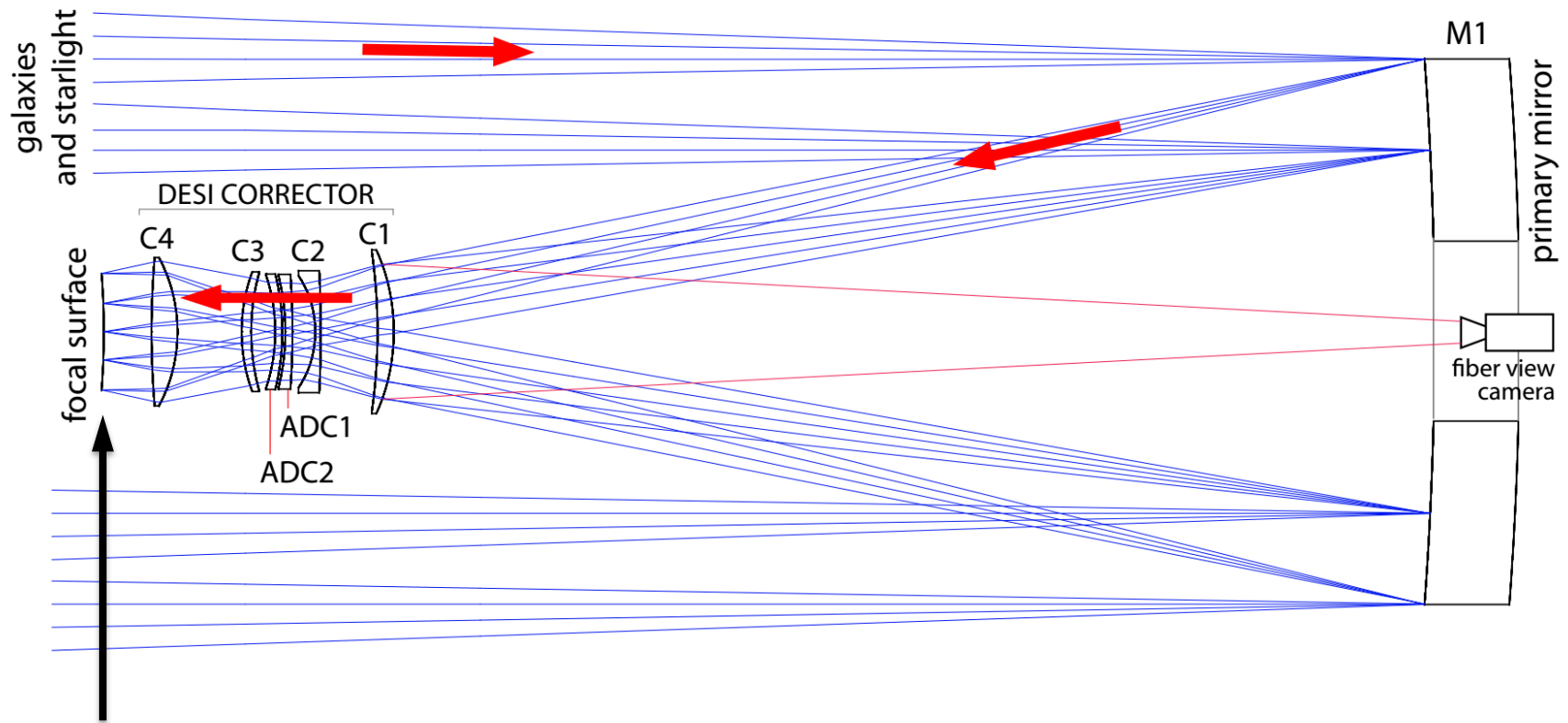
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Wendel Schnitzler



# This is the light path from the galaxies to the robots

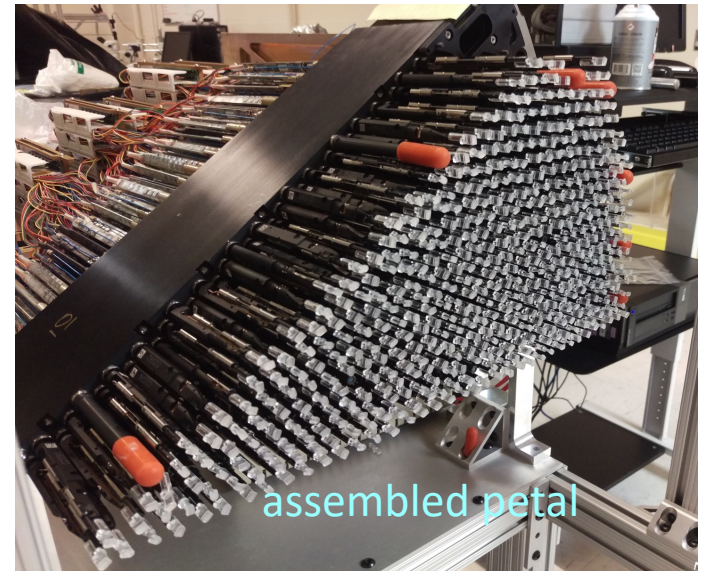
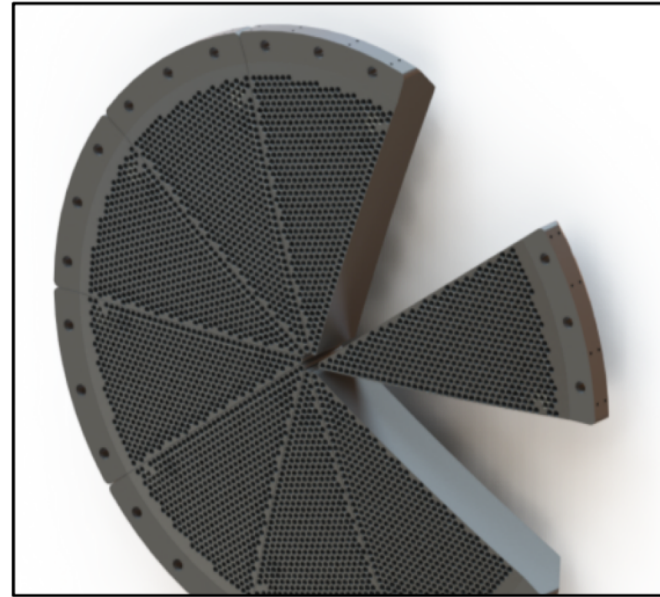
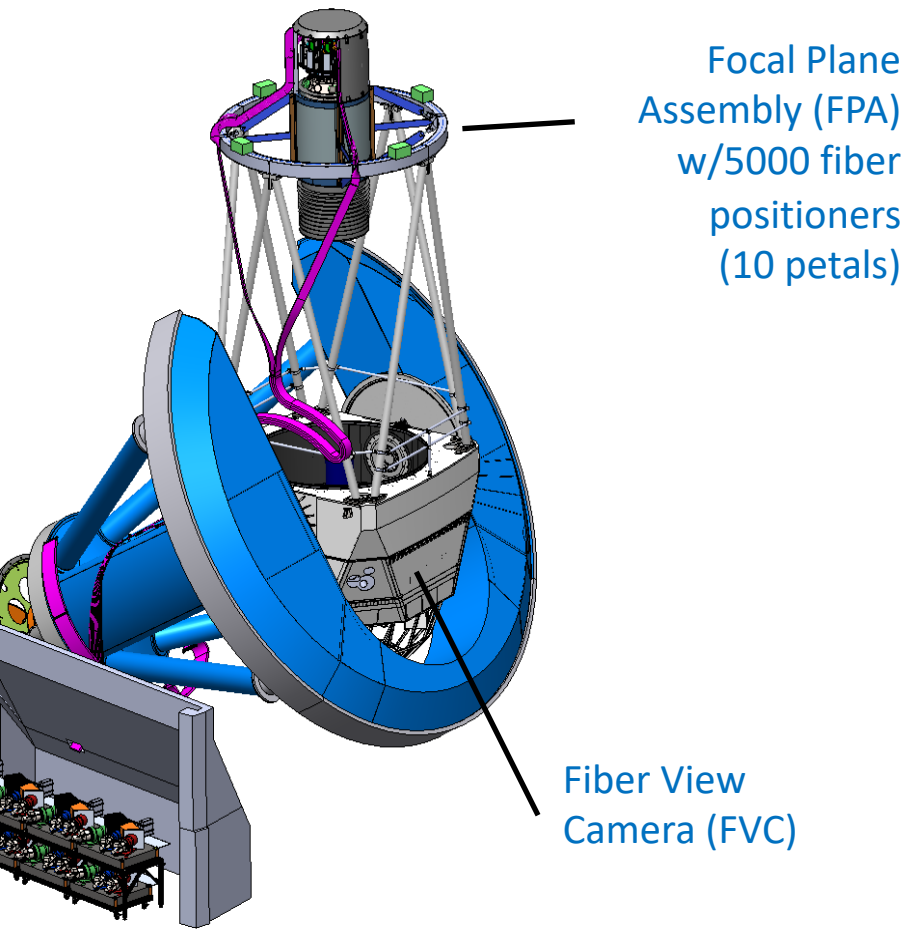


5000 fiber positioner robots here,  
in the **Focal Plane System**





# Focal Plane Assembly

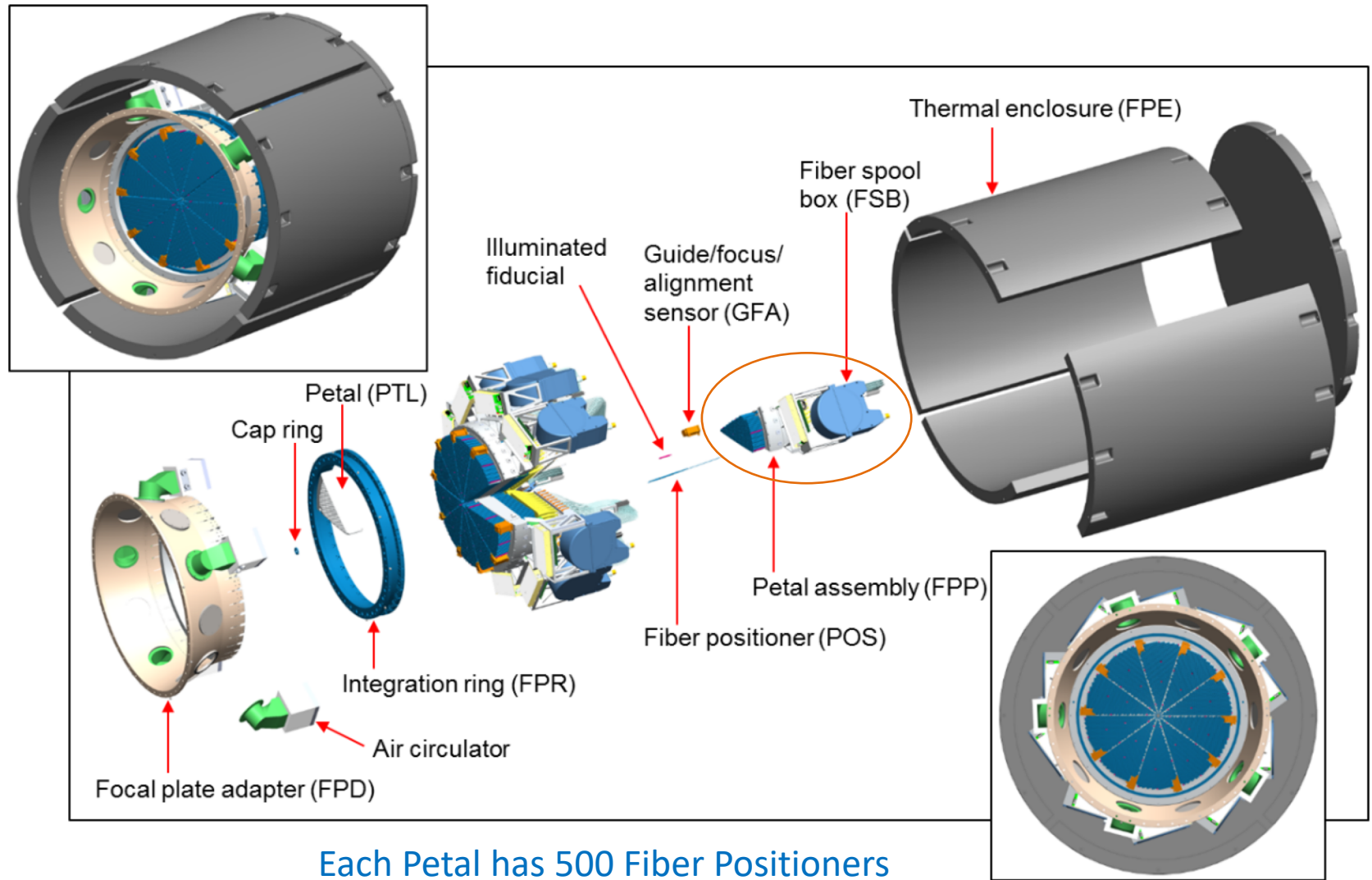


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# FPA: 10 Petals → 10 Fiber cables → 10 spectrographs



Each Petal has 500 Fiber Positioners

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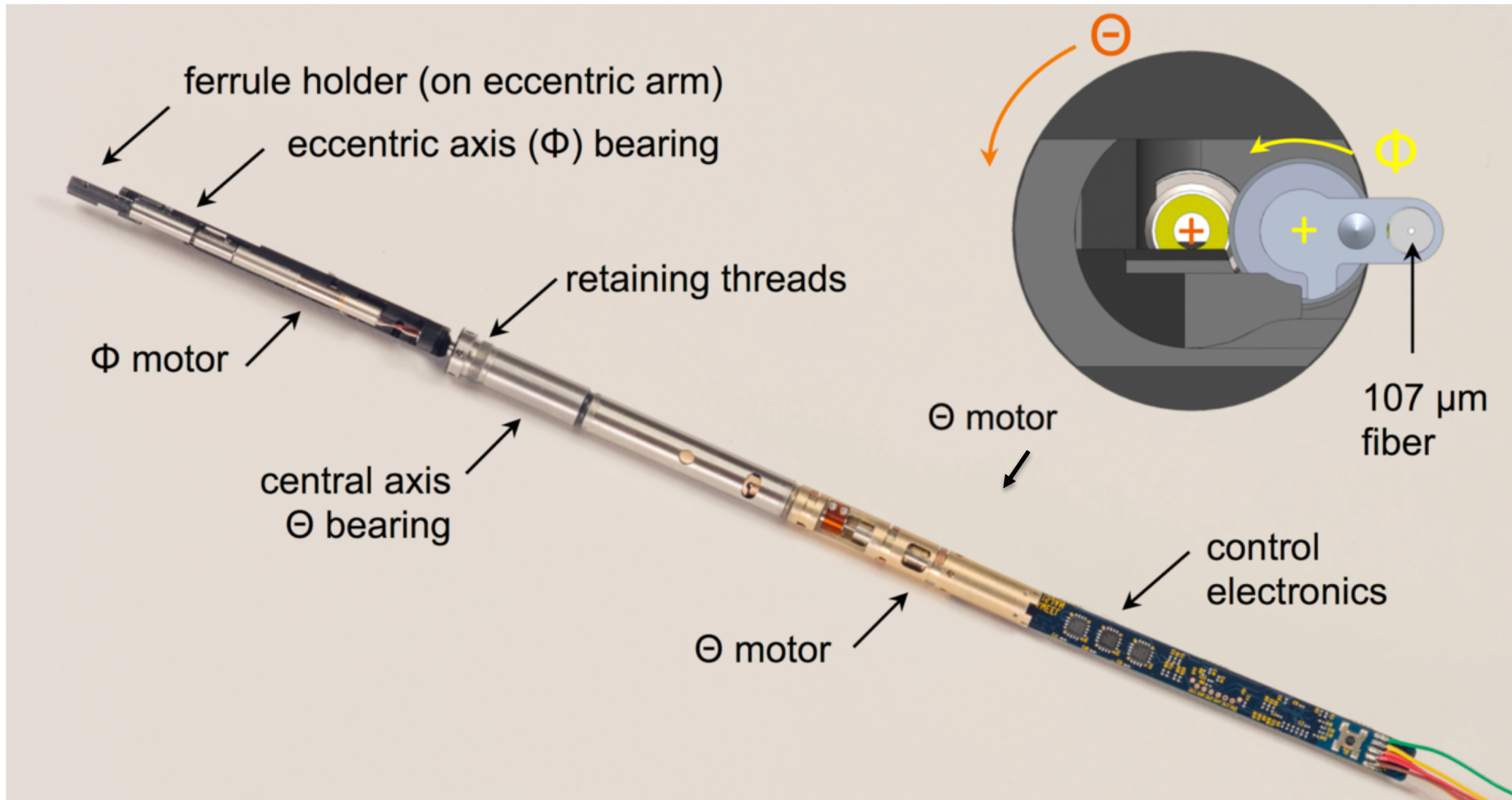
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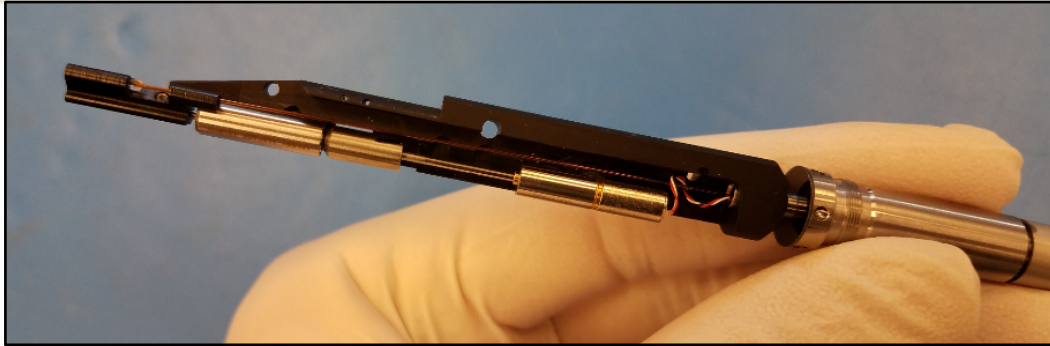




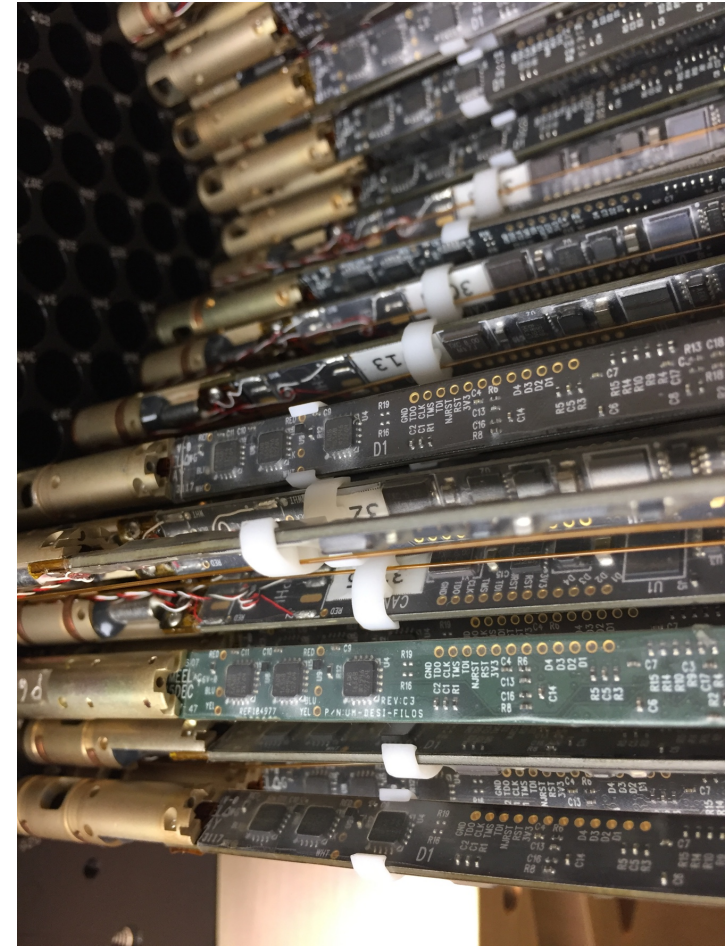
# DESI Fiber positioner robots have 2 DoF, driven by two independent, open-loop controlled gearmotors



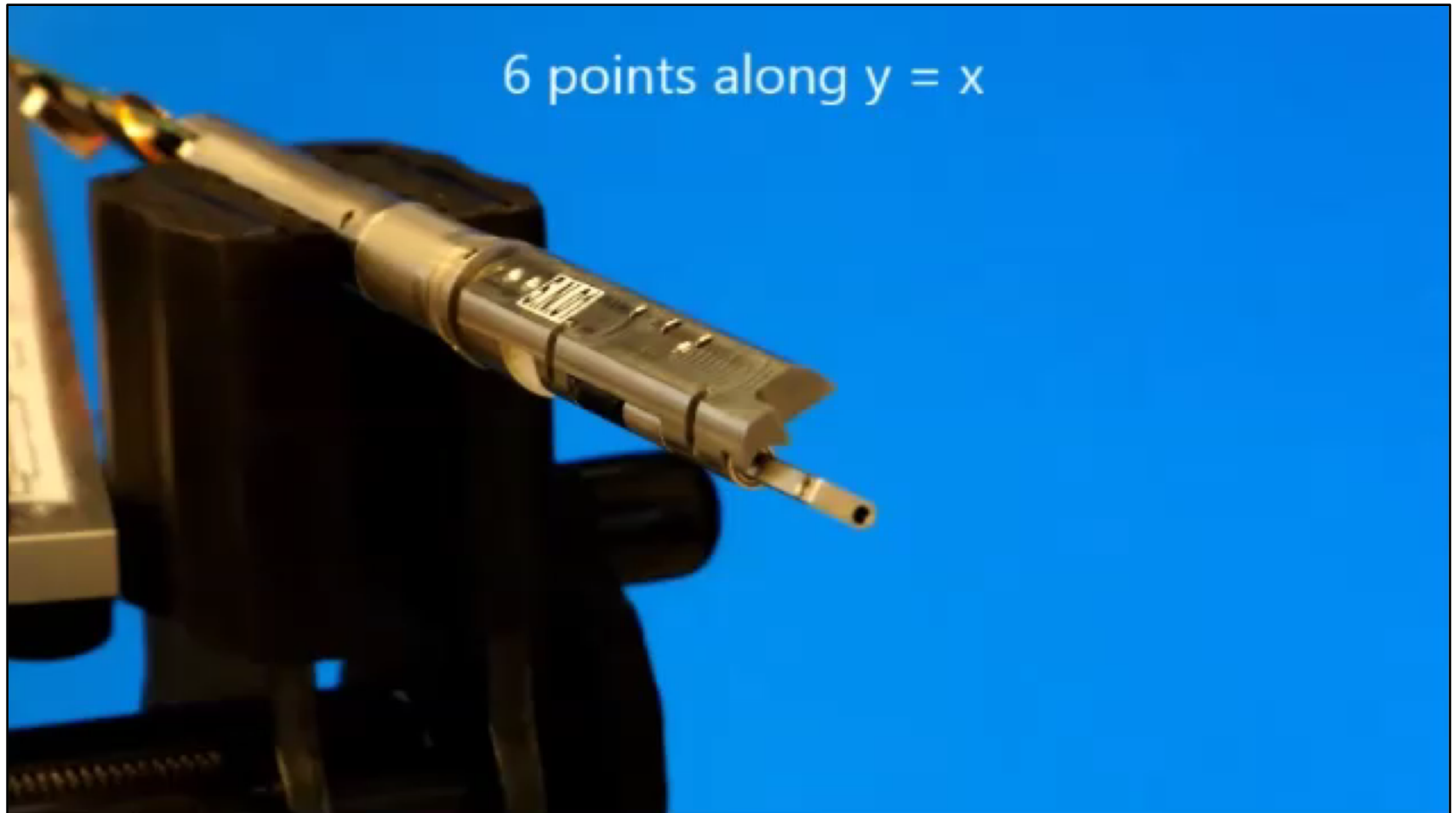
# 5000 Fiber Positioning Robots



- Position a 107 fiber  $\mu\text{m}$  tip on a galaxy  
< 5  $\mu\text{m}$  RMS accuracy in <45sec
- 500 per petal 10.4 mm center-to-center, 12 mm patrol disk
- Positioner powered and controlled through an attached driver board.
- Motors driven by PWM (motor current 0% - 100%)
- Open-loop control
- Each positioner uniquely addressed by ID on CAN bus



# 2013: First prototype fiber positioner



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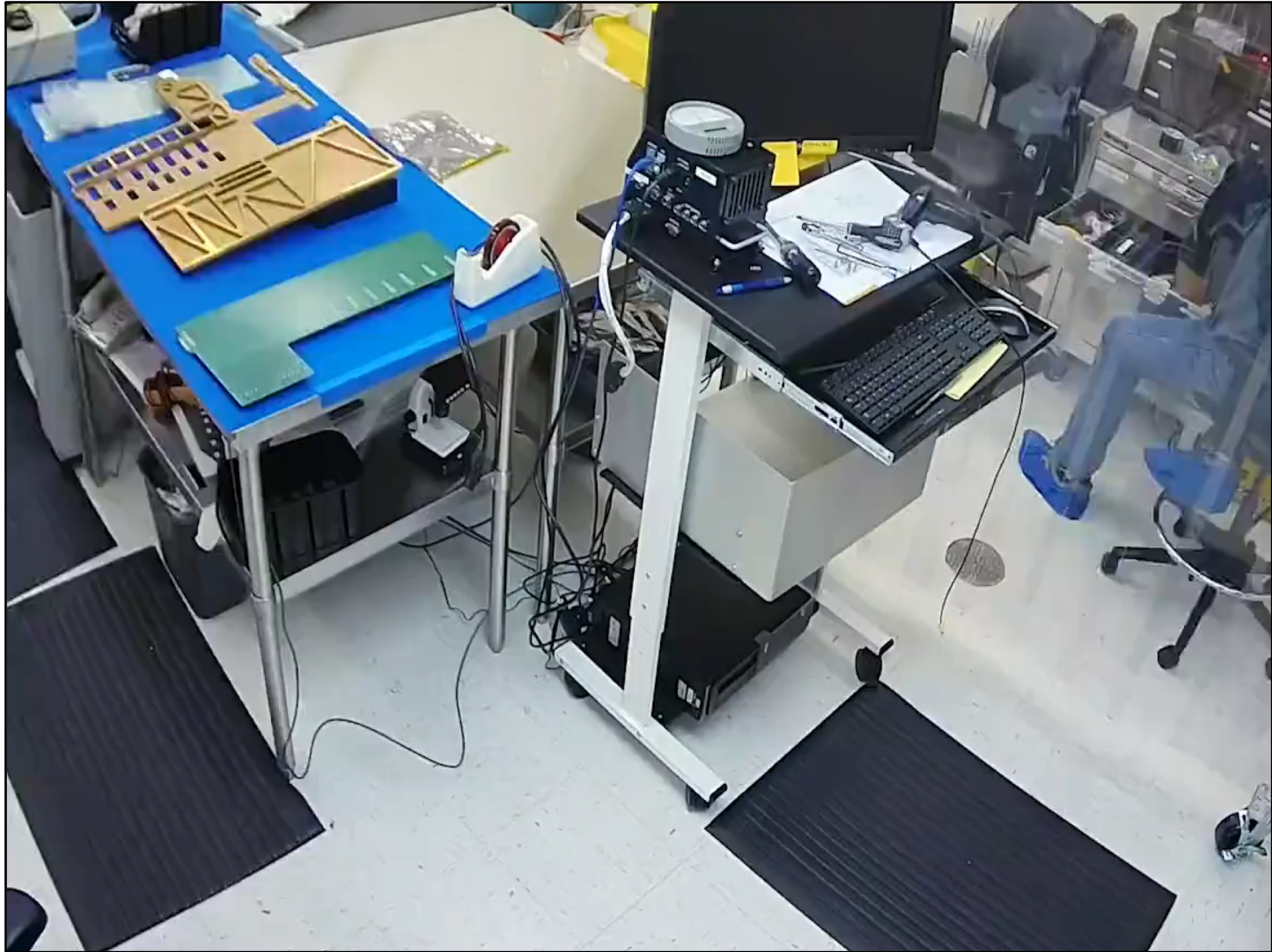
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# Assembly of DESI Petal (2018)



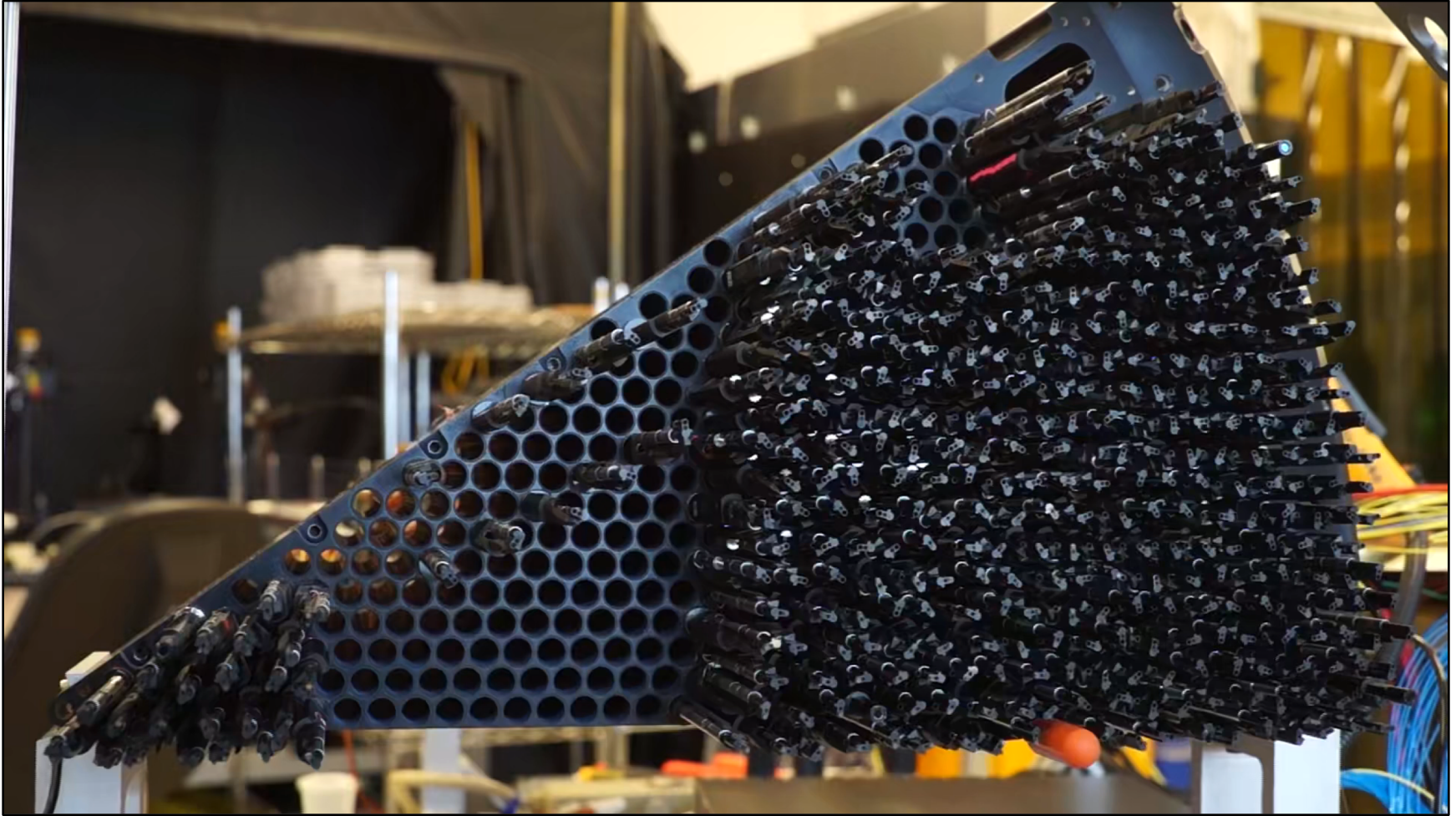
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# 2017: R&D petal with $\sim 300$ positioners



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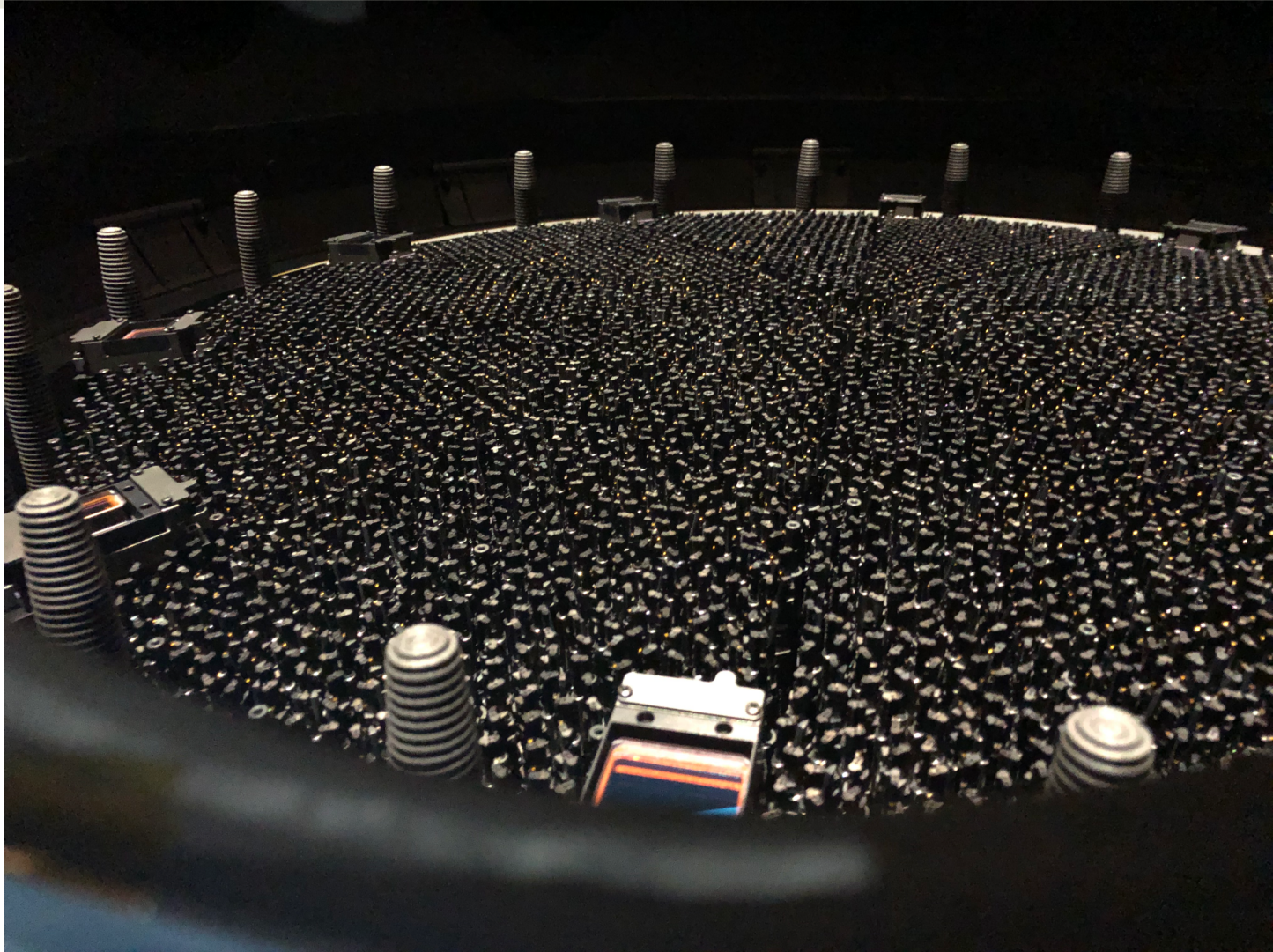
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# July 2019: 5000 positioners in the DESI focalplane



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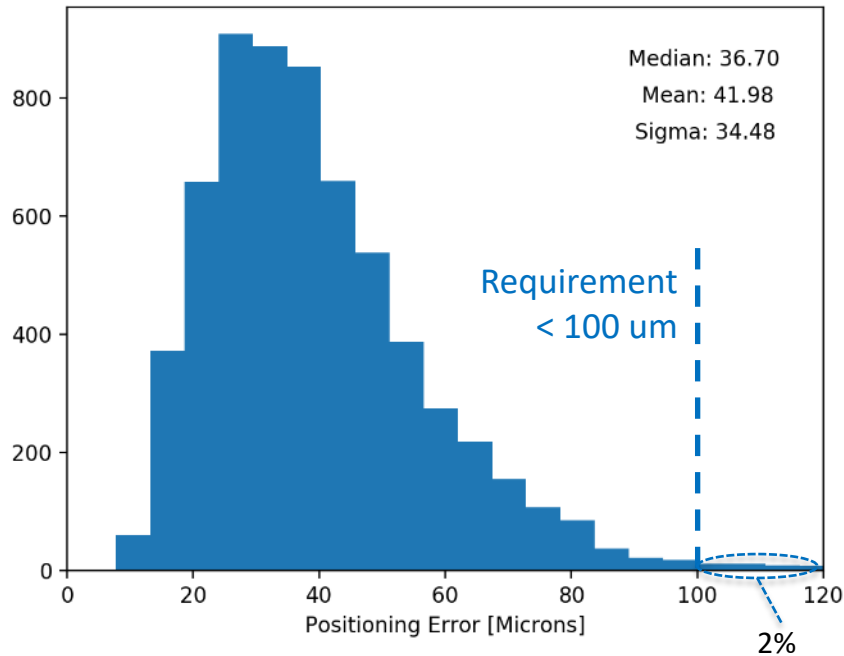
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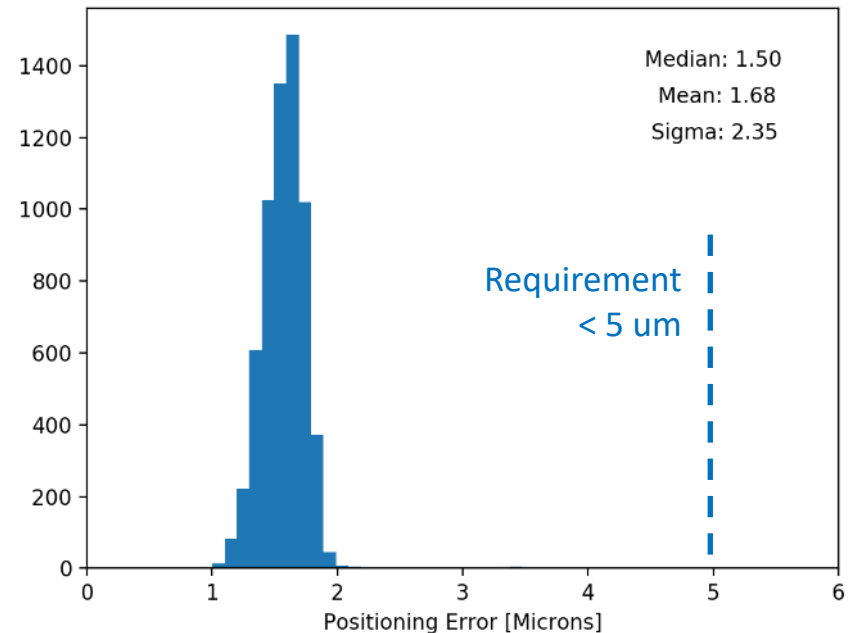


# Positioner performance is excellent

**First (blind) move**



**Correction move RMS**

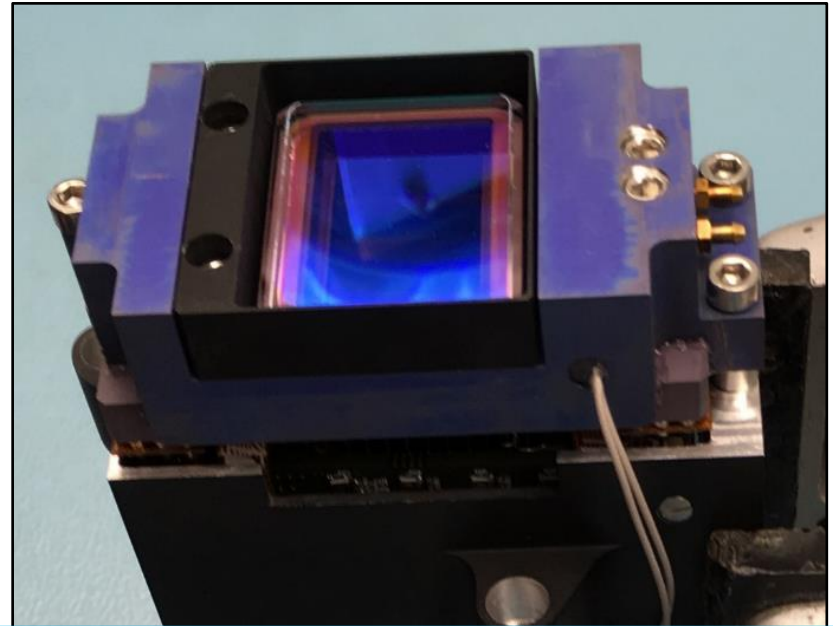
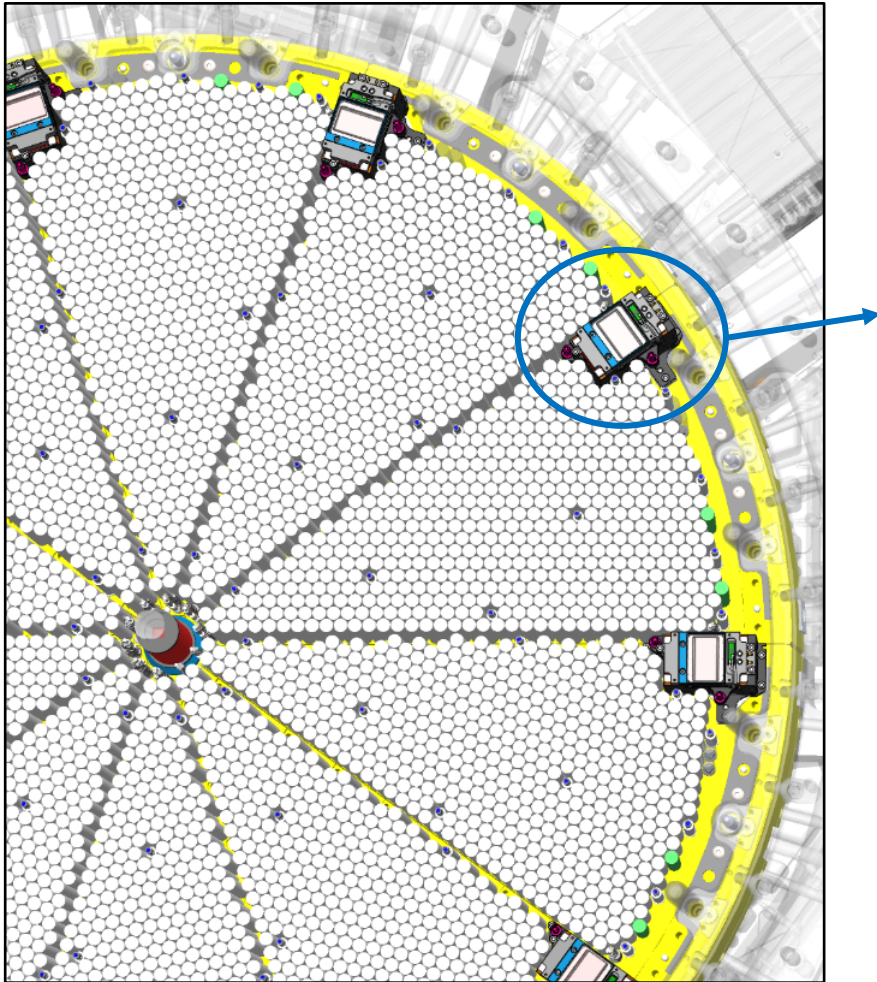


Performance of 6404 DESI positioners built and tested at the University of Michigan





# 10 Custom CCD cameras (one per petal) **guide** telescope and **focus/align** the corrector + focal plane on the 6 DOF hexapod



## GFA cameras

two types - identical except for optical filter:

- 6 x guide star tracking

  - feedback to telescope

- 4 x focus and alignment

  - data for hexapods



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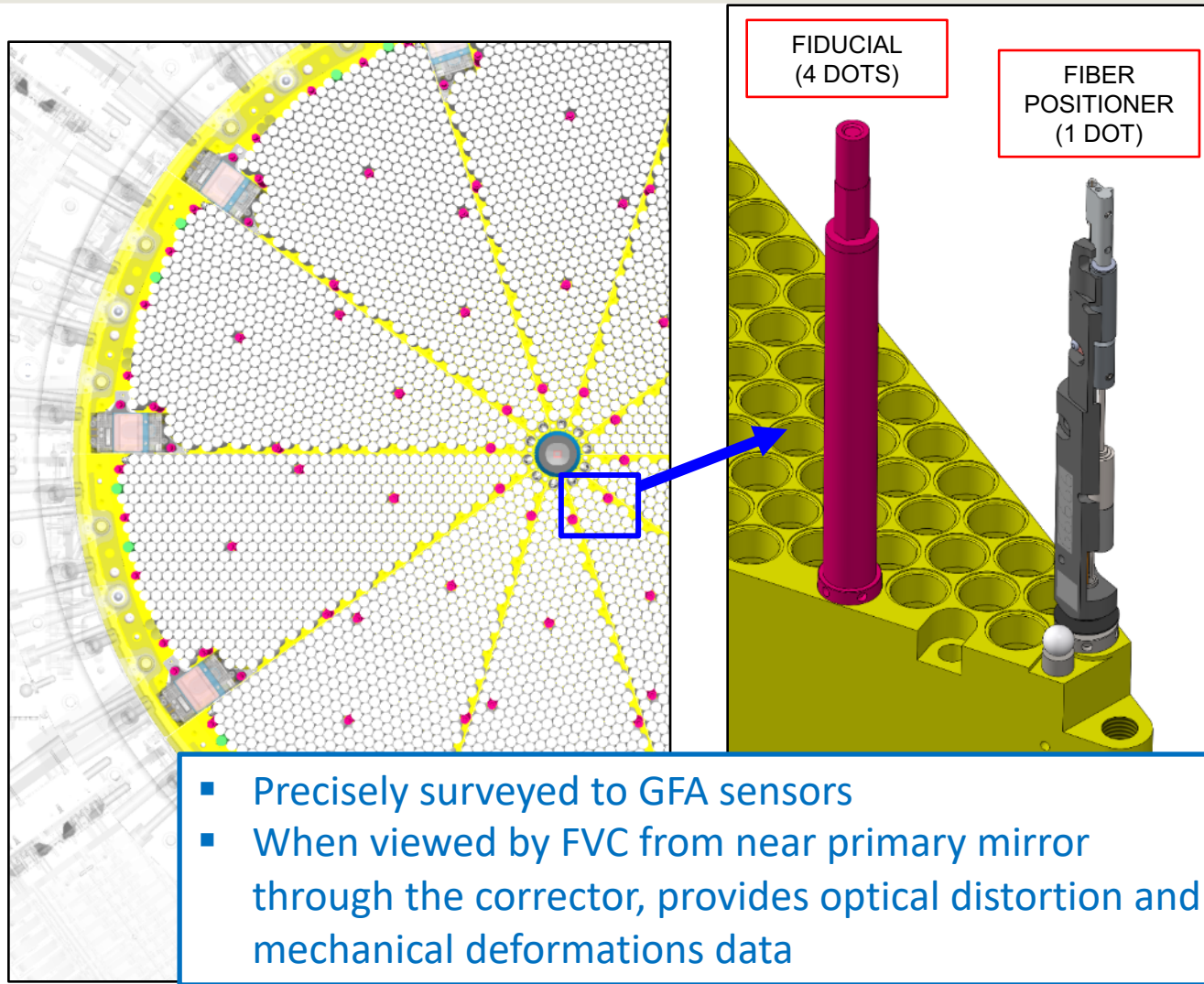
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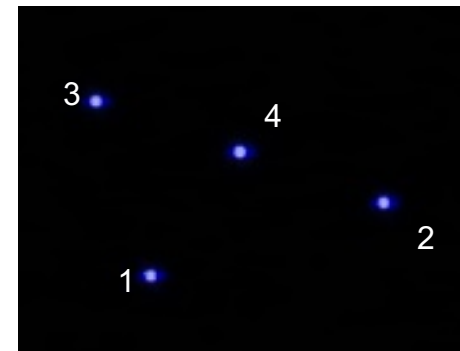
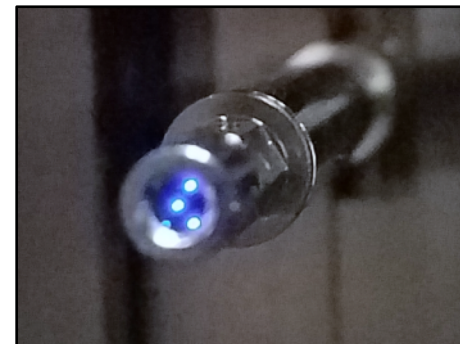
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# Fiducial point sources, embedded throughout the array constrain optical plate scale and distortion polynomials

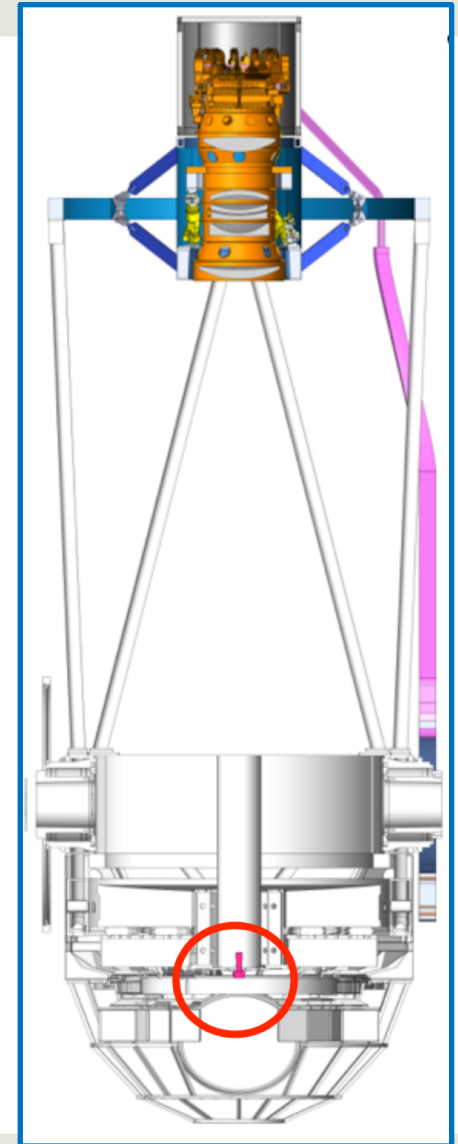
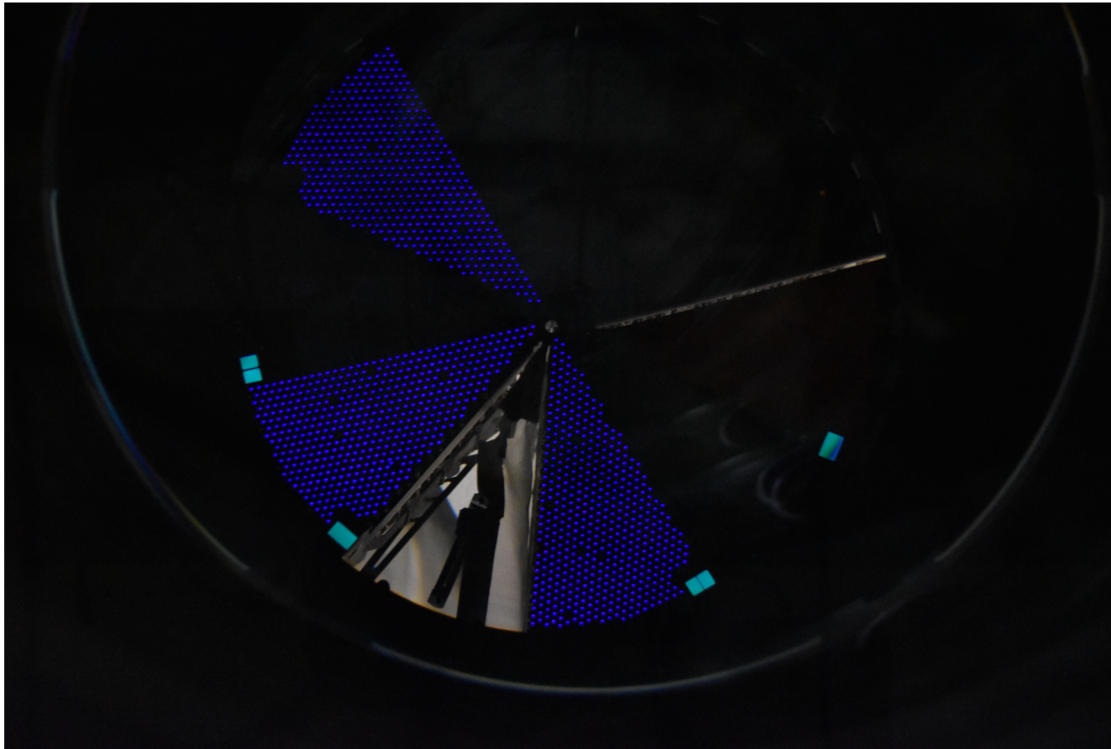


120 total fiducials  
x 4 dots each



# Fiber View Camera

- Observes illuminated fiducials ... *and* backlit fiber positioners
- Provides feedback to positioners to align fibers to guide stars



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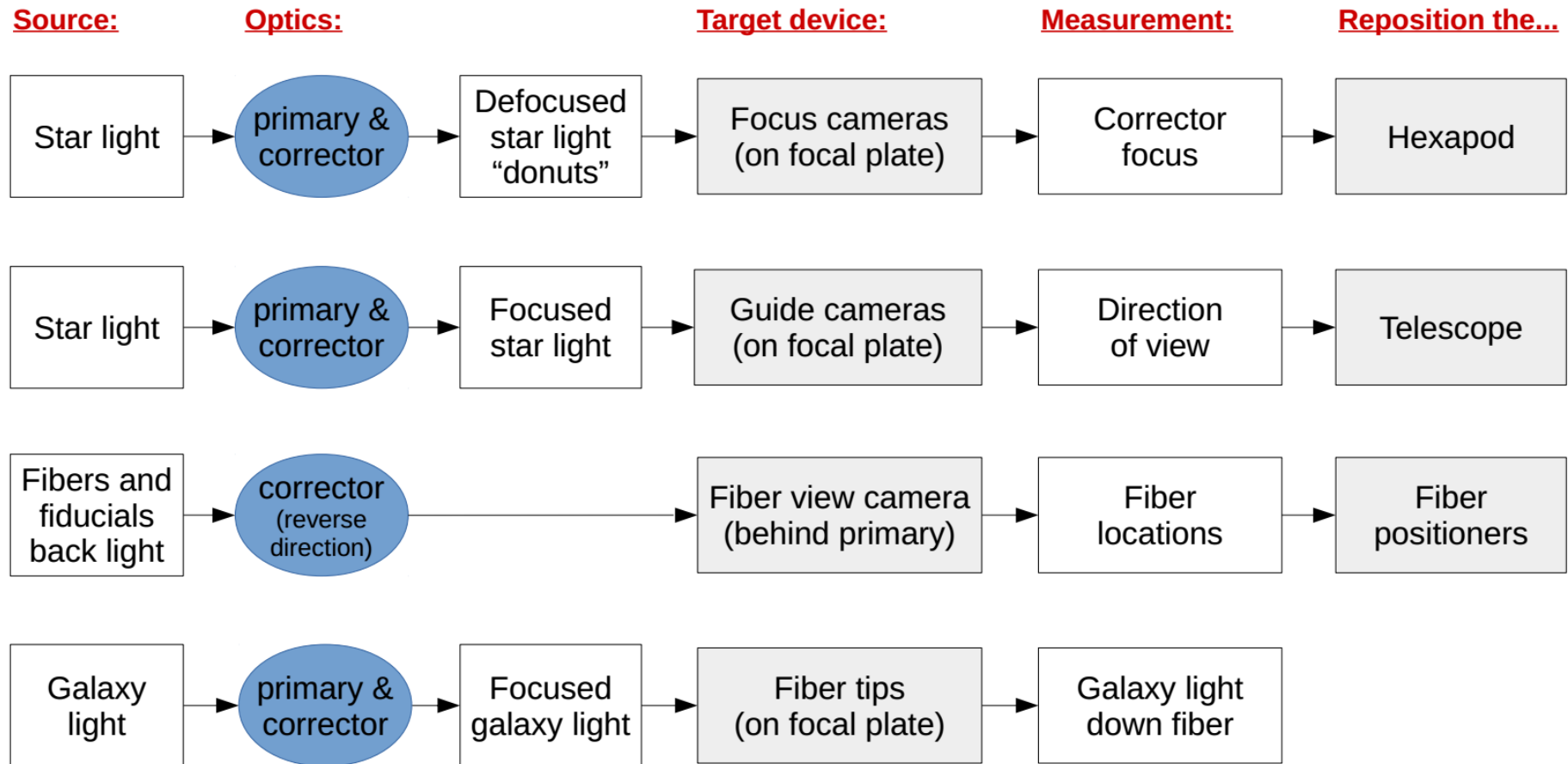
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# How we position the fibers on galaxy targets



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# Subsystem key performance requirements

Requirement Name	Requirement	Actual	Notes
Positioner Accuracy	100 um blind, 5 um final rms	42 um typical, < 2 um rms	All units burned in and tested after built and re-tested after install into petal
Lifetime moves	> 100,000k	tested to 1,600,000 (98% > 107,000)	Test program included lifetime testing at low/high temperature extremes.
Positioner Reconfiguration Time	45s rms blind 5s rms correction	16.4s rms blind 5.2s rms correction	Simple speedups exist for correction calculation time.
Power consumption	< 3W	3.23 W while moving	Idle: 180 mW Sleep mode: < 1mW
GFA Read Noise	25 e-/pixel max	17.5 e-/px rms 20.0 e-/px max	Measured on GFAs #1-#8, all 4 amps on each.
FVC Camera Accuracy	3 um	2 um	Successful ProtoDESI run, Au.g 2016.



# Petal Install



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# Installation of Petals



Installation sled



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# June 25, 2019: First petal installed

First petal is mounted to installation sled arm and slowly cranked into place



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# Inbound



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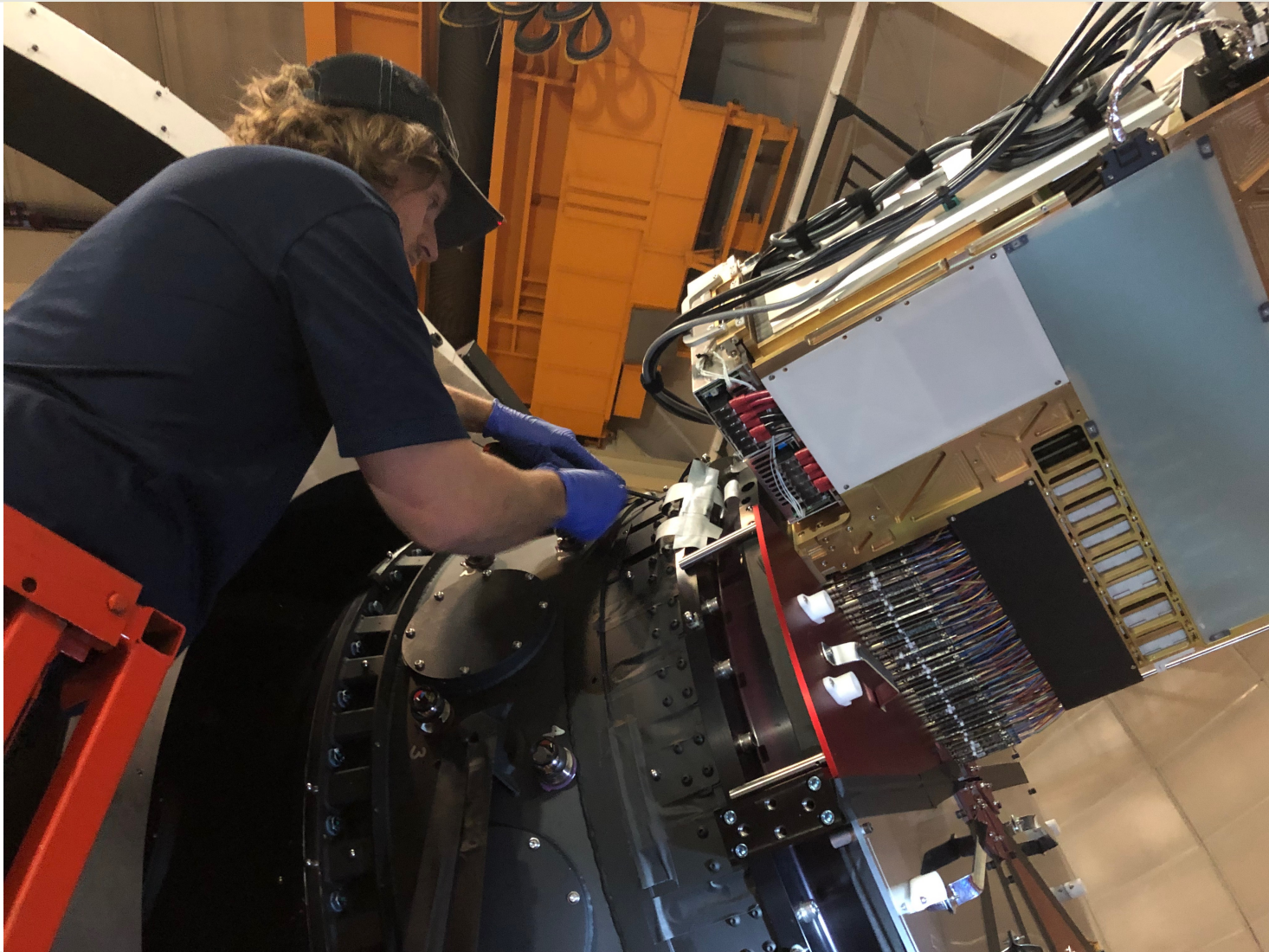
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# Done, nine to go.



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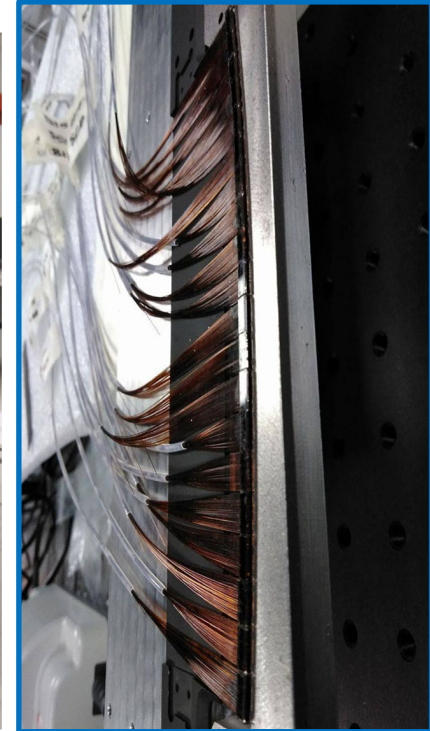
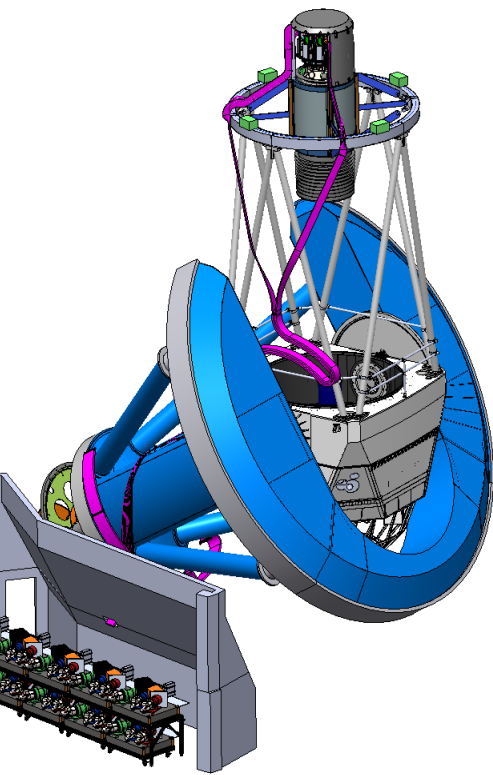
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# Fiber System: 10 X 49 meter fiber cable

No connectors to maximize throughput

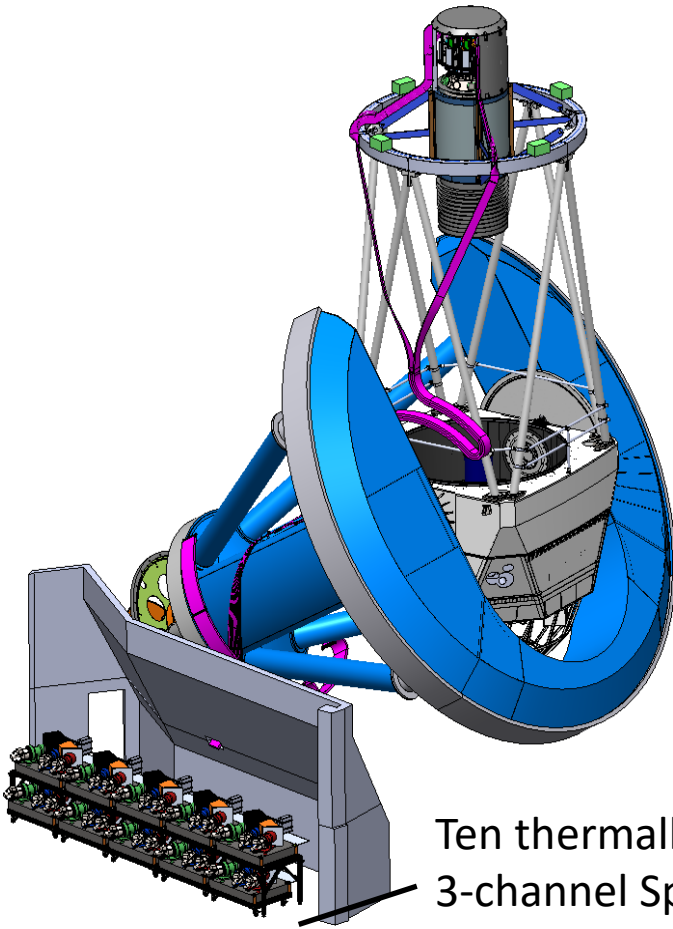


- Fiber core size  $\text{--}\phi 107\text{ }\mu\text{m}$  (1.47 arcsec)
- optimize fiber transmission and FRD
- 90% of the output light within  $f/\# > 3.57$

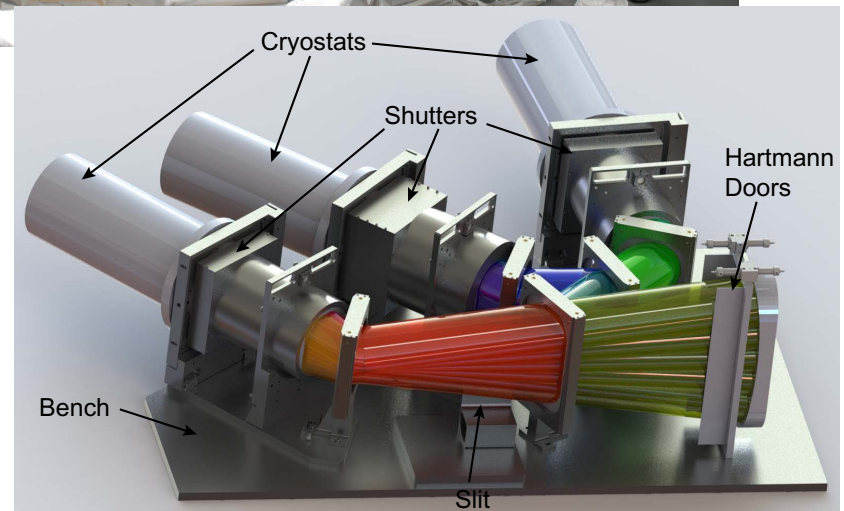




# DESI Subsystems - Spectrographs



Ten thermally-controlled  
3-channel Spectrographs  
360-980 nm



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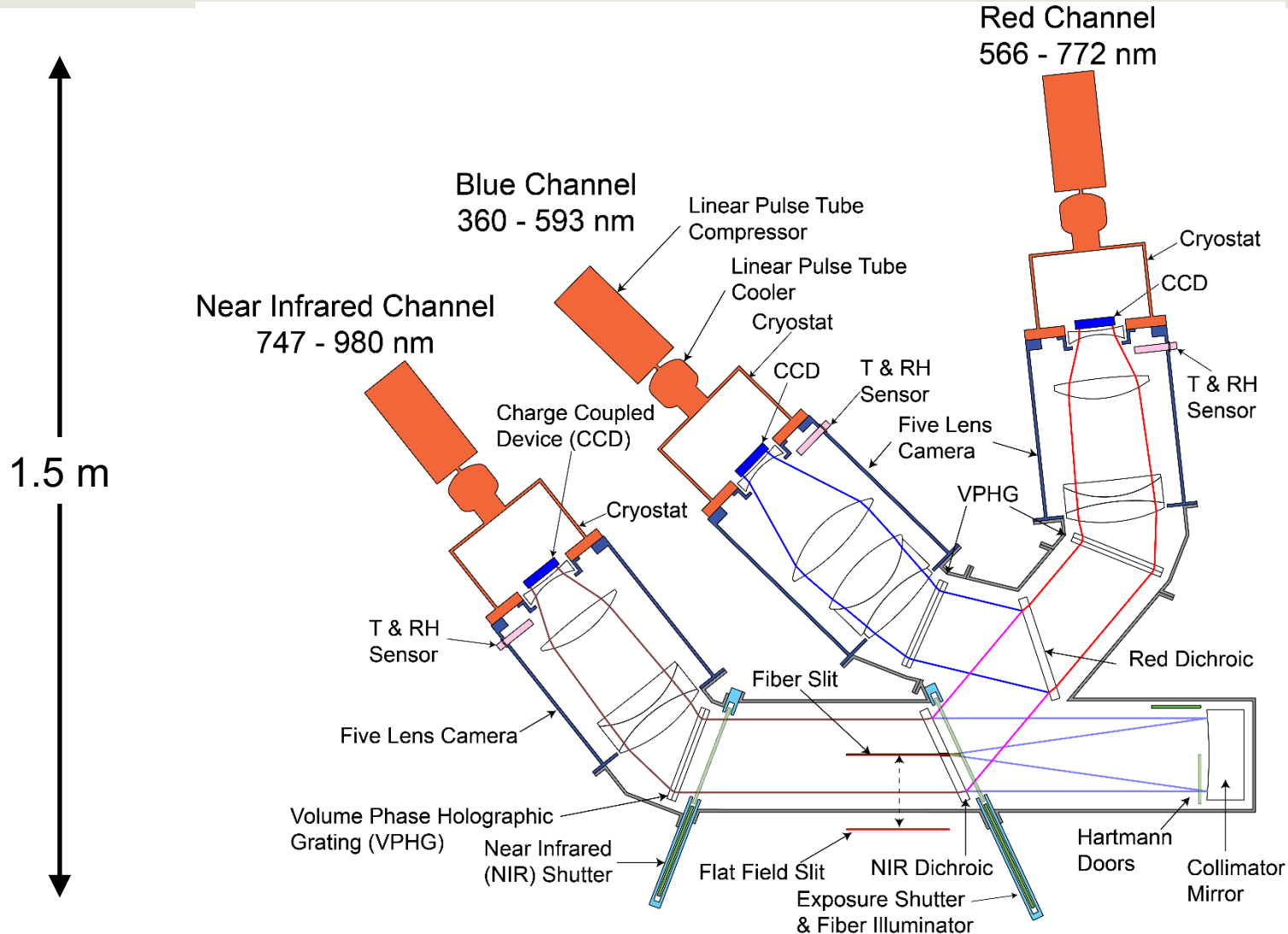
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# 3 channel spectrograph design follows BOSS heritage



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# Key Requirements and Performance

Requirement Name	Requirement	Actual or Expected Performance	Notes
Spectrograph Bandpass	360-980nm	352-983 nm	
Spectrograph throughput	see next slide	3 spectrographs below near 550 nm	Little impact to science
Number of Fibers	5,000	5,000	10 spectrographs, each with 500 fibers
CCD Total noise (per Pixel in 20 min)	<3.51 e- Avg. < 4.0 e- Max	2.6e- (LBL), 3.45e-(ITL) 2.9e- (LBL), 3.8e- (ITL)	LBL: 21 Grade A and 4 Grade B ITL: 13 Grade A and 2 Grade B



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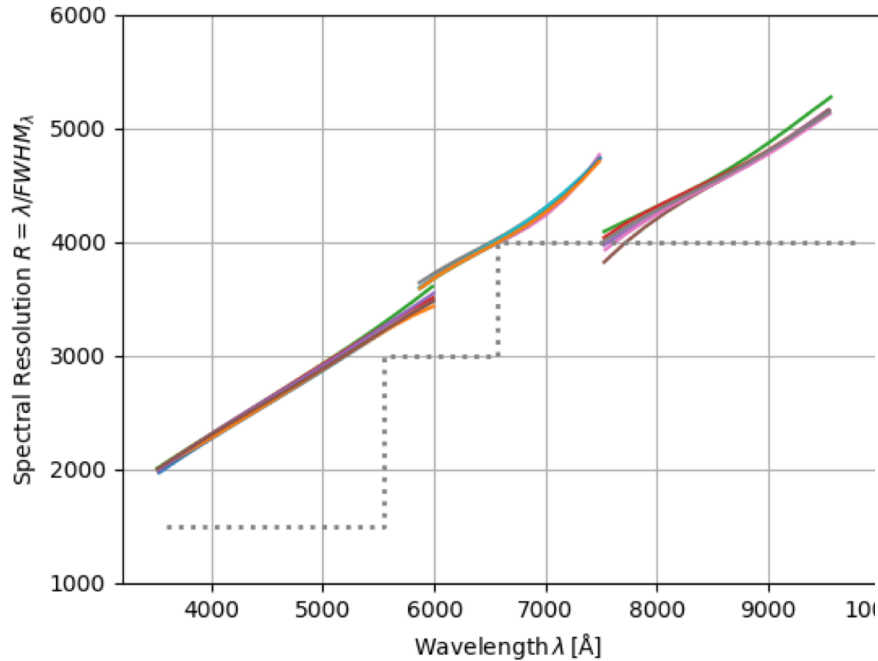
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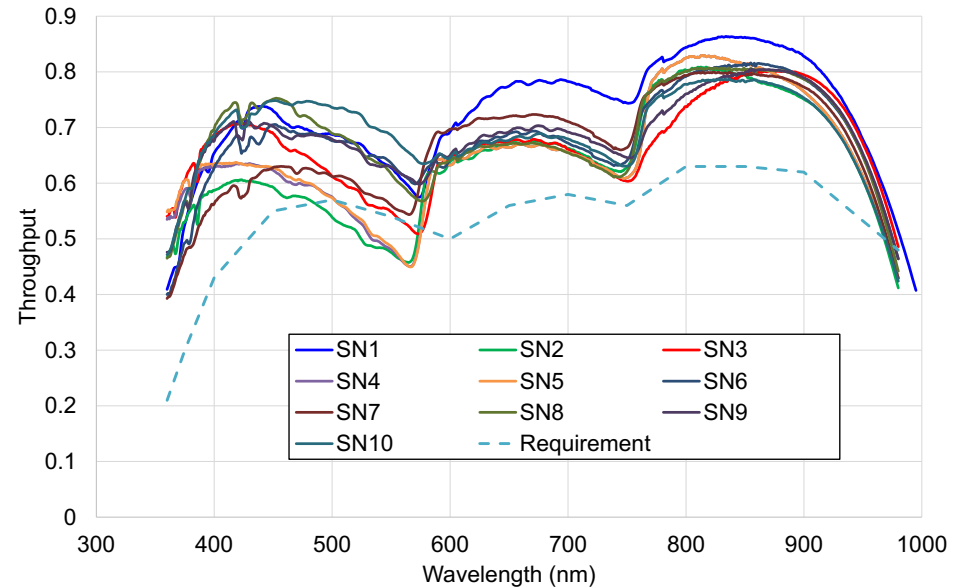
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# Summary of Testing Results

Spectral Resolution  
(6 spectrographs @ Kitt Peak)



Estimated Throughput





# First of ten spectrographs delivered to Kitt Peak



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# 6 spectrographs tested at Mayall



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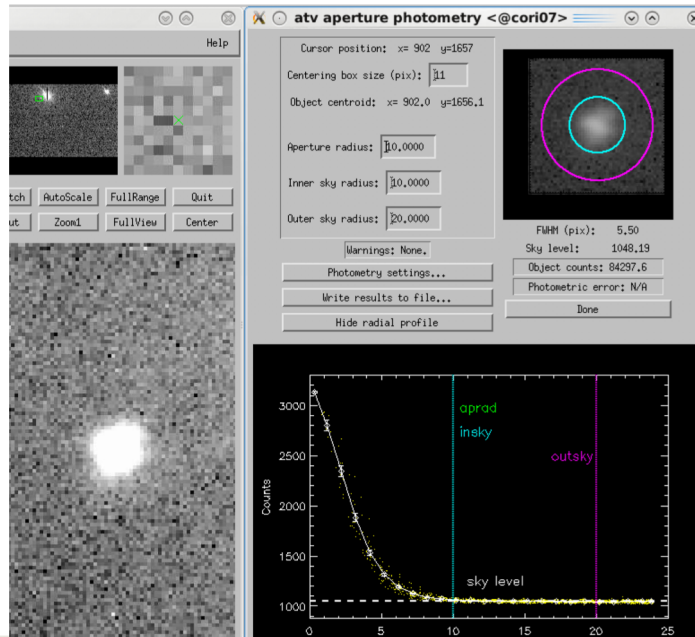




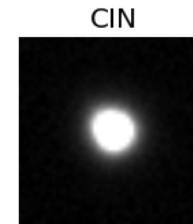
# 2019: Commissioning Instrument – Success!

- Commissioning Instrument run started April 1, ended June 3
- Hugely successful! Important checkout of software & hardware
- Sub-arcsecond images obtained on all 5 cameras within 2 hours of opening the dome on April 1.
- Corrector, hexapod, ADC, works perfectly
- Image quality excellent and as modeled:

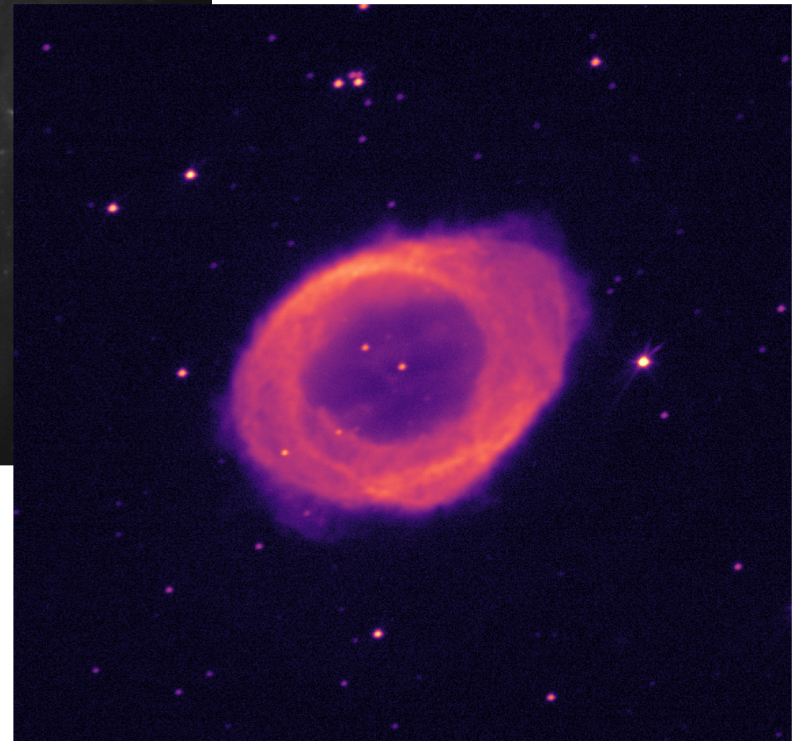
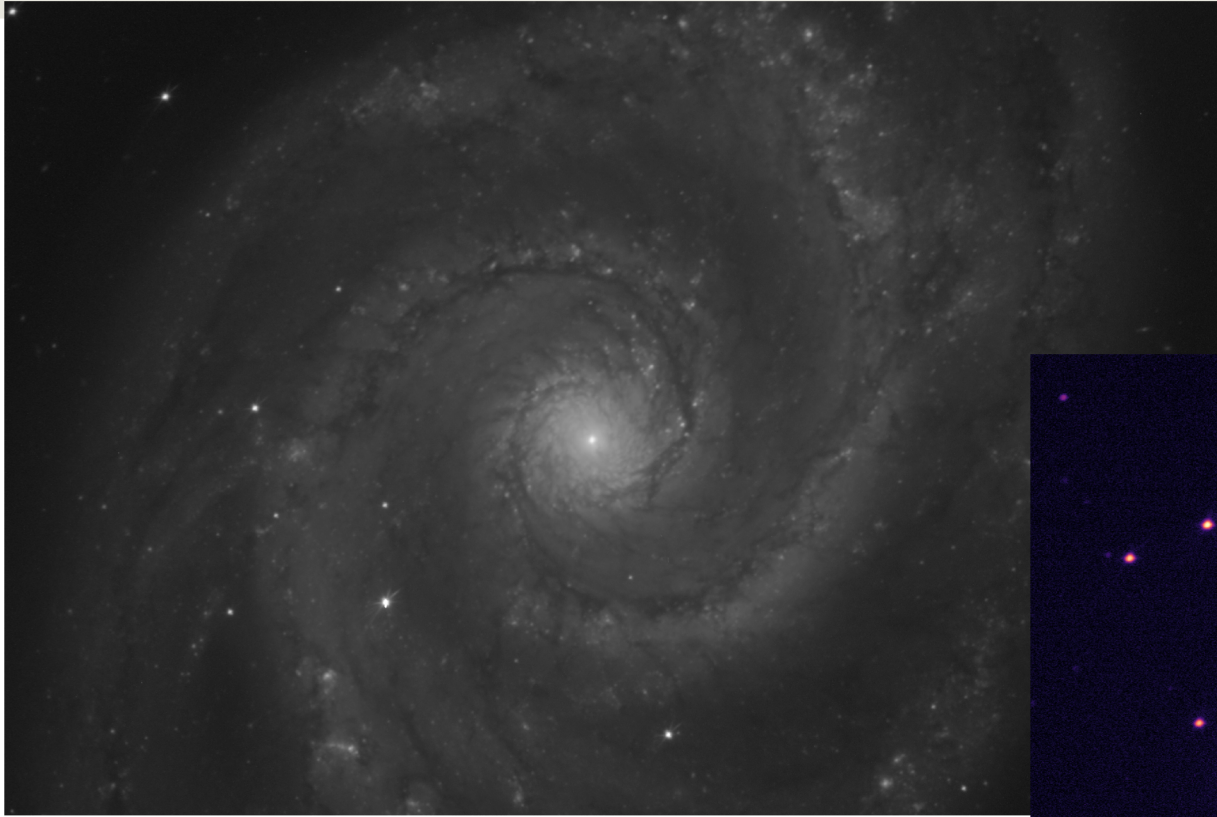
April 1, 2019  
FWHM = 0.73"



EXPID: 14374  
PROGRAM:  
Self Mode test with CIC  
EXPTIME: 20.0  
SKYRA: 185.6  
SKYDEC: 32.0  
NIGHT: 20190529



# Took images on the first night of CI run



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# DESI Operations Schedule

Milestone	Date	Data Products
Start of Commissioning	October 2019	
	December 2019	Final Imaging Data Assembly
Start of Survey Validation	February 2019	
Start of Science Survey	June 2020	
	November 2020	SV Data Assembly
	April 2021	Data Assembly 1
	April 2022, '23, '24, '25	Data Assembly 2,3,4,5
Science Survey End	June 2025	
	March 2026	Final Survey Data Assembly



## Dark Energy Spectroscopic Instrument

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# DESI is a large Project with many Institutions involved

Argonne National Laboratory + Barcelona – Madrid RPG + Boston University Brookhaven + National Laboratory + Carnegie Mellon University + Cornell University + École Polytechnique Fédérale de Lausanne (EPFL) + Eidgenössische Technische Hochschule Zürich (ETHZ) + Fermi National Accelerator Laboratory + GMT RPG + Harvard University + Korea Astronomy and Space Science Institute (KASI) + Korea Institute for Advanced Study (KIAS) + Laboratoire de Physique Nucléaire et de Hautes Énergies (LPNHE) + Lawrence Berkeley National Laboratory + LinEA-Brazil + Max Planck Institut für Extraterrestrische Physik + Mexico RPG + National Astronomical Observatories of the Chinese Academy of Sciences (NAOC) – Shude Mao + National Optical Astronomy Observatory + New York University + Ohio State University + Ohio University + Peking University + Sao Paulo Laboratorio Interinstitutional de e-Astronomia + Shanghai Jiao Tong University + Siena College + SLAC National Accelerator Laboratory + Southern Methodist University + Swinburne University of Technology + UK RPG + Universidad de los Andes + Universitat de Barcelona + Université Aix-Marseille (AMU) + University College London + University of Arizona + University of California, Berkeley + University of California, Irvine + University of California, Santa Cruz + University of Durham + University of Florida + University of Michigan + University of Paris Saclay + University of Pittsburgh + University of Portsmouth + University of Queensland + University of Rochester + University of Toronto + University of Utah + University of Waterloo + University of Wyoming + Yale University



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Visit DESI at: [desi.lbl.gov](http://desi.lbl.gov)

Follow our progress on Twitter: [@desisurvey](https://twitter.com/desisurvey)



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