Spec-S5

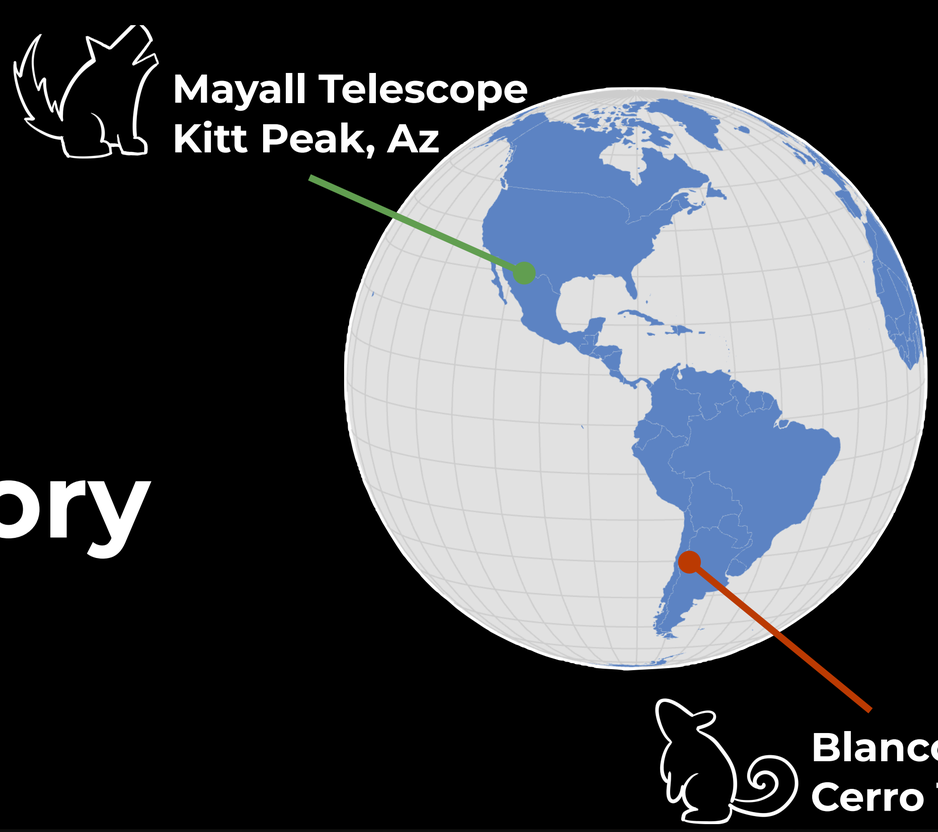
A Next Generation Spectroscopic Observatory

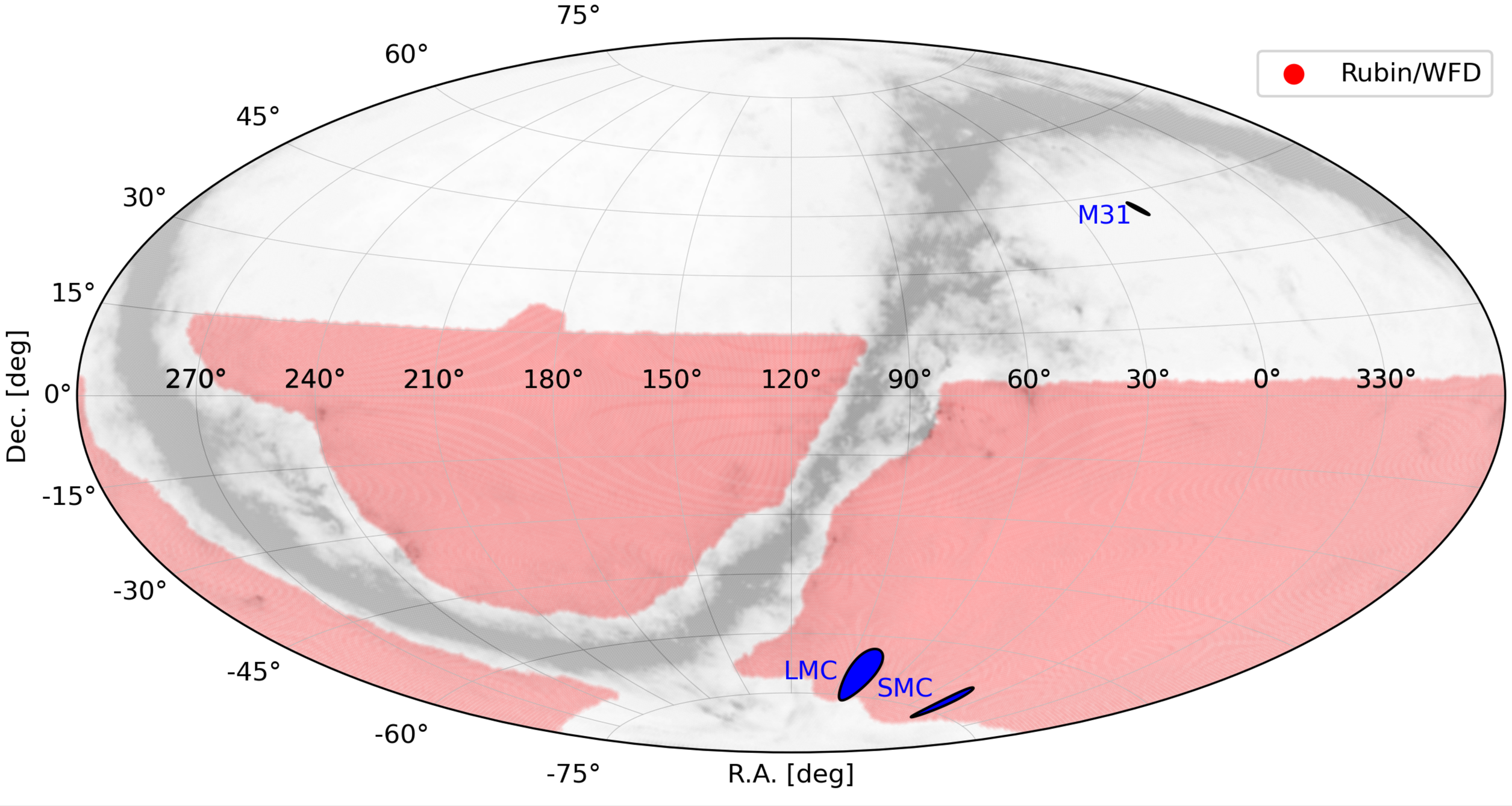
Claire Poppett, UC Berkeley, Space Sciences Lab

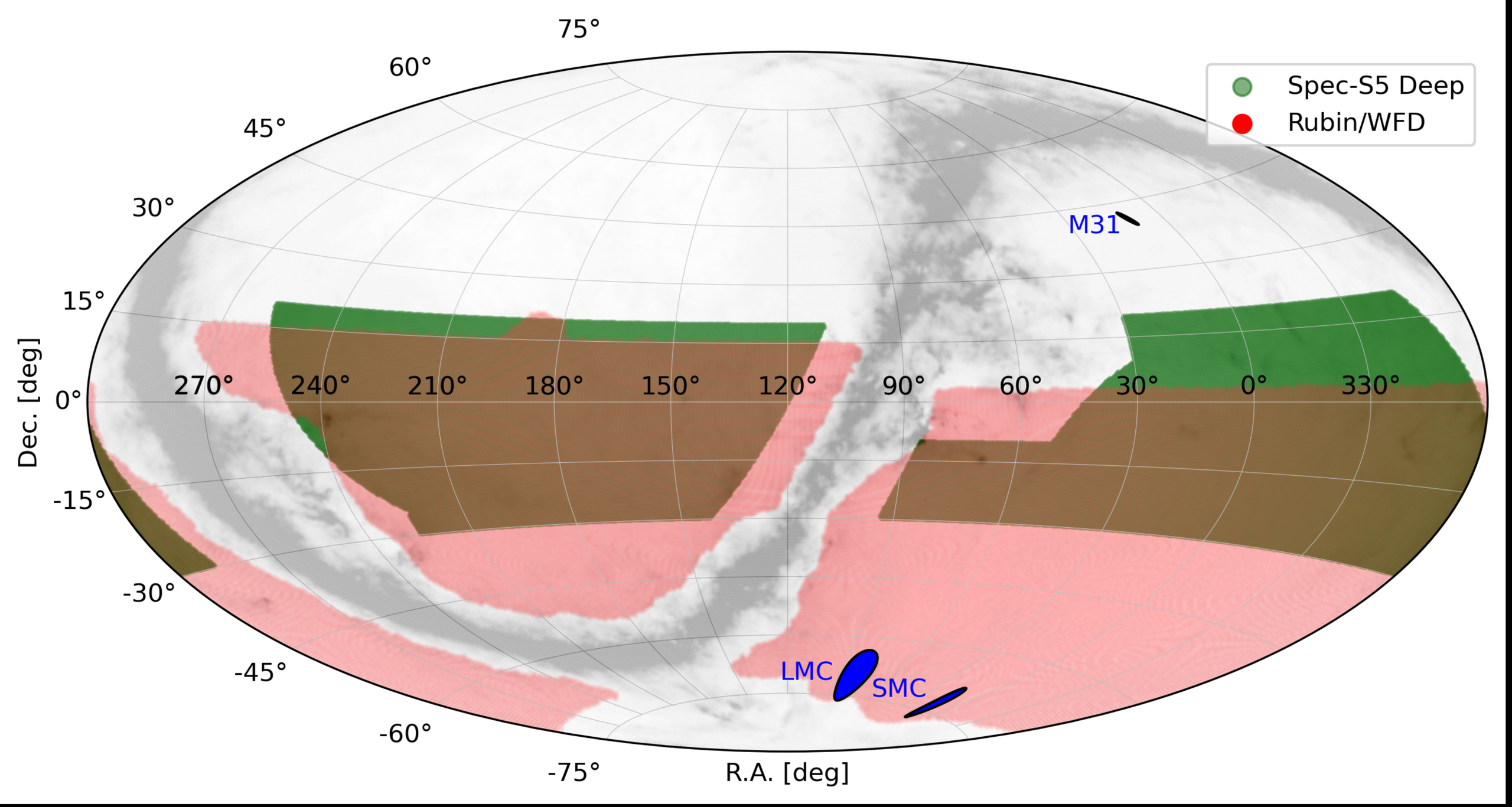
Rubin Workshop, August 2026

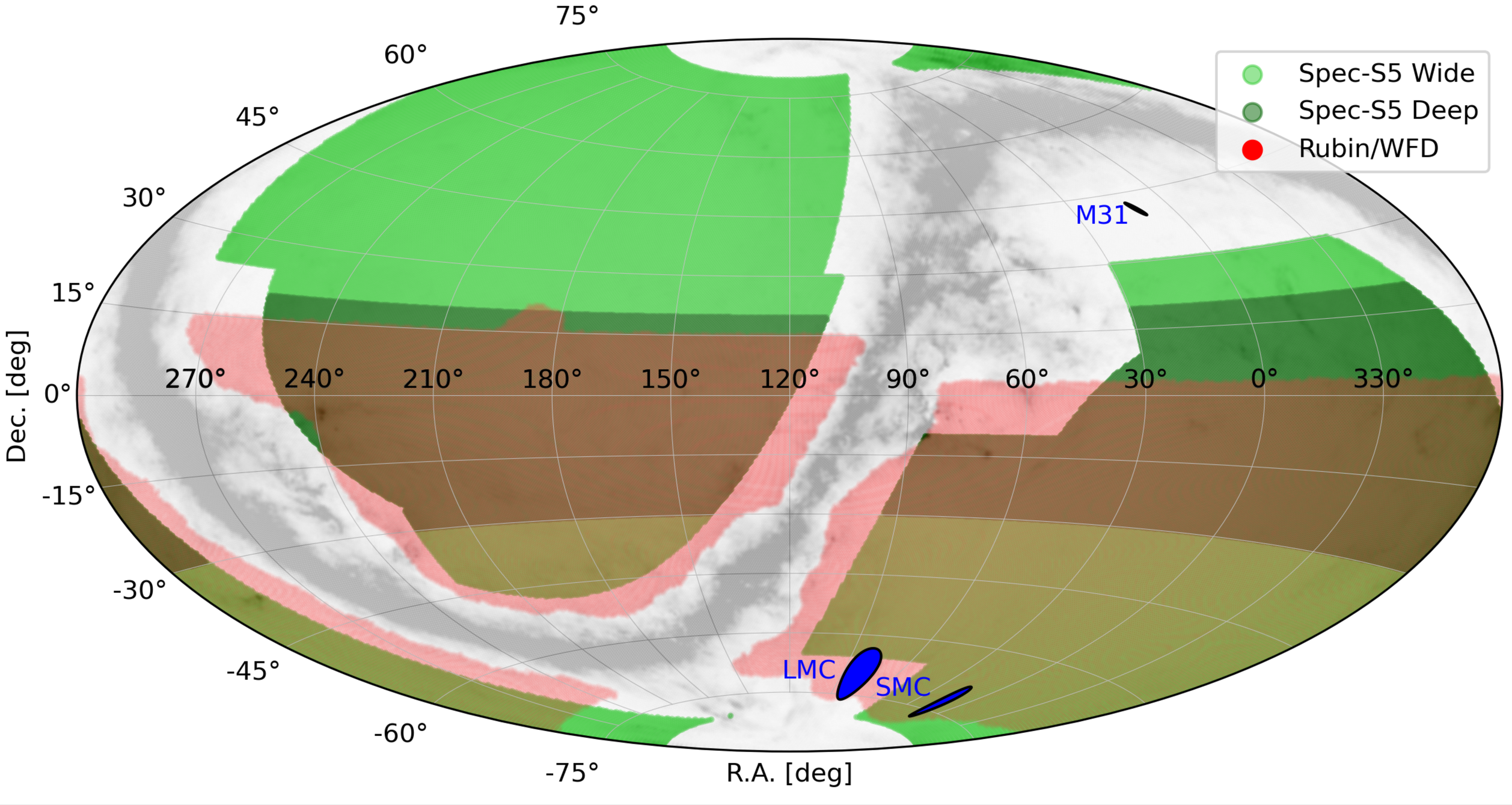






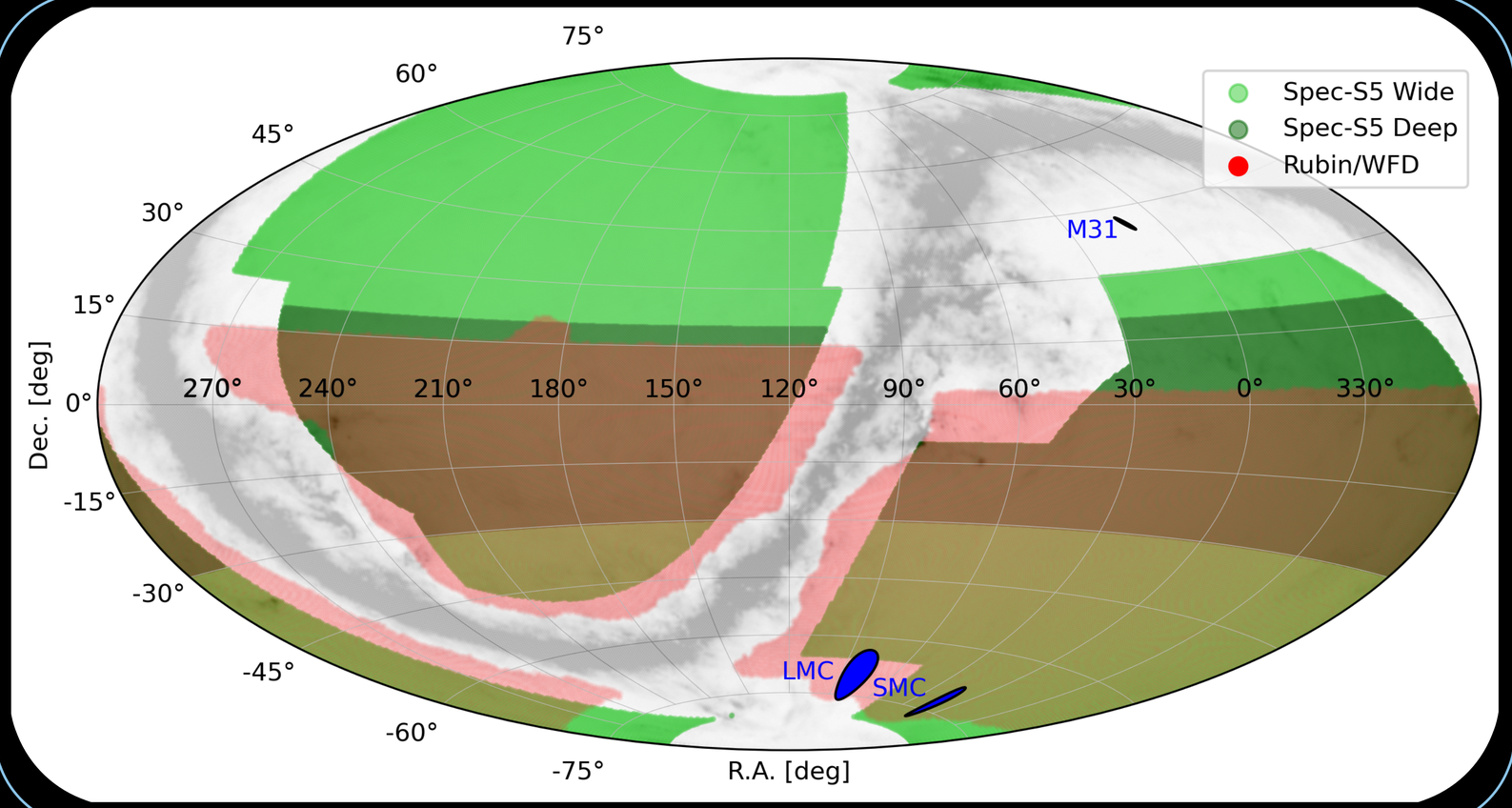

Rubin/WFD
M31
LMC
SMC
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
270°
240°
210°
180°
150°
120°
90°
60°
30°
0°
330°
Dec. [deg]
R.A. [deg]


Spec-S5 Deep
Rubin/WFD
M31
LMC
SMC
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
270°
240°
210°
180°
150°
120°
90°
60°
30°
0°
330°
Dec. [deg]
R.A. [deg]


75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
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Dec. [deg]
270°
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180°
150°
120°
90°
60°
30°
0°
330°
R.A. [deg]
Spec-S5 Wide
Spec-S5 Deep
Rubin/WFD
M31
LMC
SMC

The Spec-S5 reference survey

A dual-hemisphere survey optimized for precision cosmology and dark matter science.



Spec-S5 white paper: https://arxiv.org/abs/2503.07923

WIDE AREA COSMOLOGY SURVEY

- 25,000 deg2 extragalactic footprint
- 110 million galaxies and quasars
- Dark and bright time observations
- Uniform target selection enabled by improved galactic extinction maps
- Dual hemisphere operation from Mayall and Blanco

DEEP SURVEY (z>2)

- 11,000 degrees equatorial footprint (-30->+20)
- Probes the high-redshift universe
- Optimised for overlap with Rubin
- Observable from either hemisphere for flexibility

BEYOND COSMOLOGY

- 100 million stars - galactic extinction mapping (1 arcmin resolution)
- 50 million stars - dark matter dynamics in the Milky Way
- Time domain spectroscopy - Rubin follow-up, AGN variability, TDEs, reverberation mapping, and more

Rubin Imaging Depth Sets the Lyman Alpha Emitter (LAE) Target Density

Imaging depth required to achieve ~3,000 LAEs per square degree with 7 medium bands

13,000 FIBERS
Available per exposure

4 deg2 FOV
(each telescope)

~3,000 LAEs per deg2
Req to fully utilize the fibers

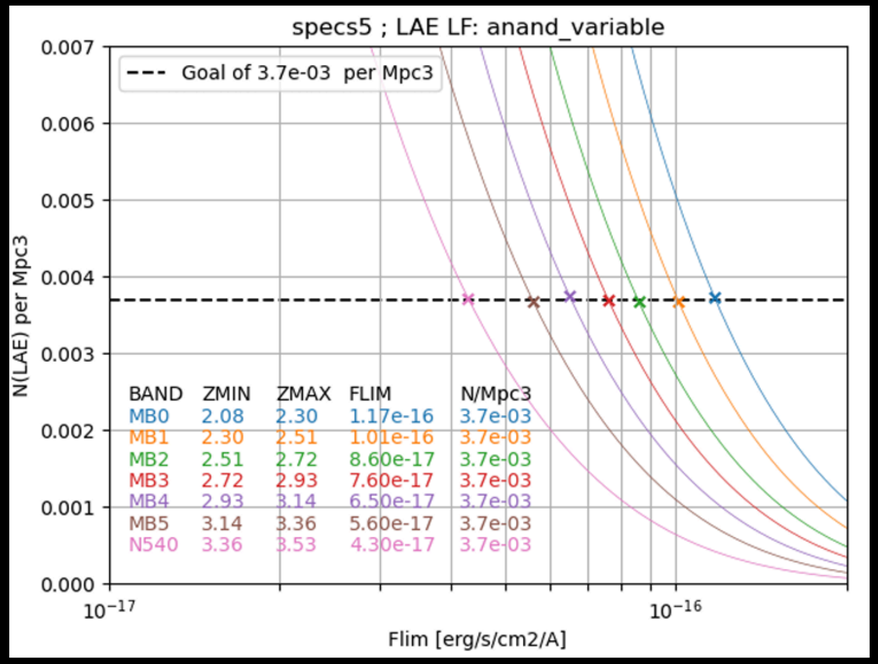
7 RUBIN MEDIUM BANDS
Evenly split across redshift

3,000/7~430 LAEs per deg2
Needed in each band

REQUIRED IMAGING DEPTH
AB~25.5-25.7
In every medium band

Spec-S5: Goal of 3,000 LAEs per deg2 - projections from Anand

Central wavelngth (nm)	Bandpass (A)	z_min	z_max	Mag Limit	N_PER_MPC3	N_PER_DEG2
387.8	256	2.08	2.3	25.5	3.7E-03	430
413.55	259	2.3	2.51	25.53	3.7E-03	431
439.2	254	2.51	2.72	25.55	3.7E-03	439
464.9	260	2.72	2.93	25.59	3.7E-03	430
490.75	257	2.93	3.14	25.63	3.7E-03	426
516.65	261	3.14	3.36	25.7	3.7E-03	418
540.2	210	3.36	3.53	25.65	3.7E-03	410



The predicted LAE density per filter is ~410-440 deg2 when imaging reaches AB~25.5-25.7 in each medium band

Total across 7 bands ~2,900-31,000 LAEs per deg2

Rubin mediumcband imaging at AB~25.6 enables the full multiplex of Spec-S5 across the endire 4 deg2 field

Spec-S5: The Most Efficient Route to Stage-V

Leverage Proven Facilities, Hardware, Software, and Expertise

Spec-S5 maximises science return and minimises technical risk by building on the success of DESI and leveraging existing facilities, infrastructure, and teams.

UPGRADE, DON'T BUILD

Spec-S5 upgrades two existing 4-m class telescopes to 6-m wide field observatories



Existing 4-m Facilities

Proven Infrastructure & Site Assets



Upgraded 6-m Wide-Field Observatories



Shortest path to Stage-V science at the lowest risk and cost.

This continuity delivers reliability, efficiency, and rapid execution - maximizing the probability of delivering Stage-V science in the 2030s

BUILT ON DESI HERITAGE

→Upgraded positioners

Evolve the DESI fiber positioners for higher multiplex and improved performance

→Fiber expertise

Leverage deep in-house expertise with fiber systems and integration

→Same Spectrographs

Replicate and refine the DESI spectrographs - a proven, high-throughput, stable design

→Same Data reduction pipeline

Reuse and extend the proven DESI data reduction pipeline

→Same Core Team

Retain the end-trend expertise that delivered DESI & DES on time and on budget

Proven facilities. Proven technologies. Proven team
Spec-S5 delivers a step-change in capability with the highest confidence of success

Telescope Upgrade: Prime Focus → Cassegrain

A simpler architecture for more efficient integration and higher performance

BASELINE FACILITY

2 × 6-m
UPGRADED TELESCOPES

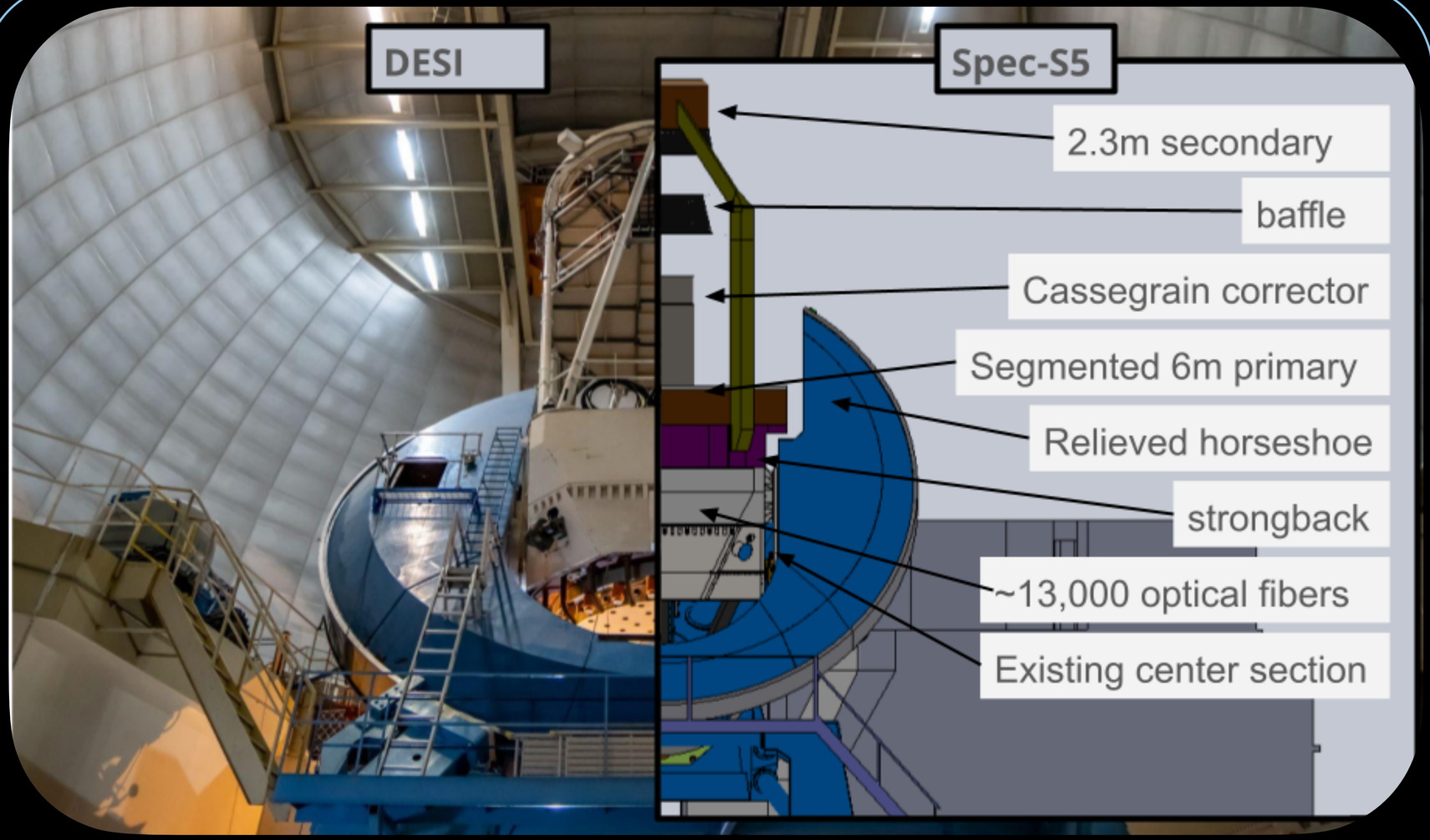
~13,000
SPECTRA / EXPOSURE

2.2°
CORRECTED FIELD

f/3.6
AT FOCAL SURFACE

- Segmented 6-m primary
- Six-element fused-silica corrector
- Dense modular fiber-positioner focal plane
- DESI-derived spectrographs and pipeline

Upgrade, don't build

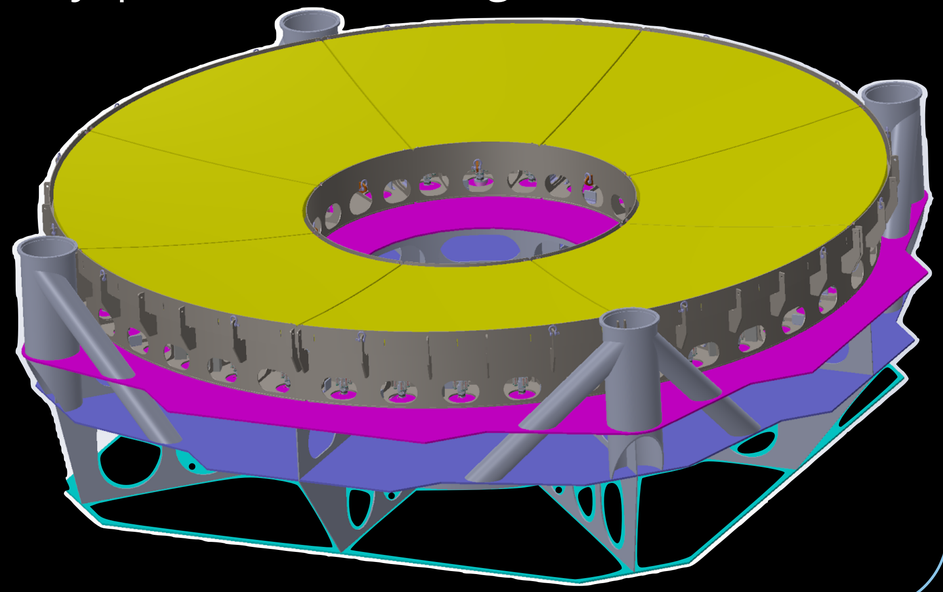


Prime focus → Cassegrain

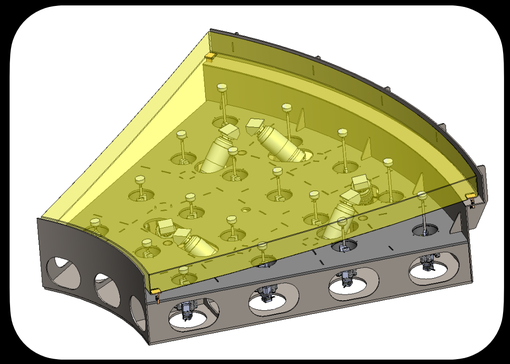
Enabling a 6-m Aperture: Segmented Primary & Horseshoe Relief

Optical and structural studies validate a low risk path to a 6-m upgrade

University of Arizona optical trade study selected the 8-segment architecture after evaluating cost, risk, manufacturability, performance, integration risk



HEISING-SIMONS FOUNDATION



SELECTED MIRROR DESIGN

- 8-segment meniscus primary
- 120 mm thick segments
- 17-point active axial support
- Bipod lateral supports

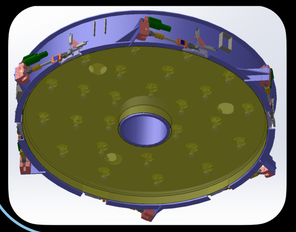
Optimized balance of:

- Cost
- Manufacturability
- Actuator count
- Structural performance

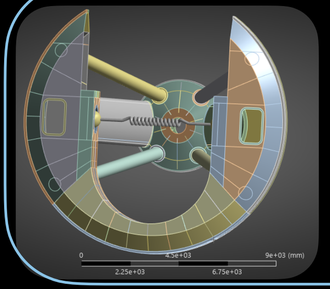
PREDICTED PERFORMANCE (FROM HIGH-FIDELITY (FEA)

METRIC	RESULTS	STATUS
Support print-through and polishing	15.6 nm RMS	✓
Gravity distortion (horizon)	~10 nm RMS	✓
Thermal distortion	2.1 nm RMS/°C	✓
Meets system allocations	YES	✓

SECONDARY MIRROR (M2) PROGRESS



Preferred design: 100 mm thick meniscus
27 axial supports + 6 lateral supports
Meets <30 nm RMS surface-figure requirement
Structural analysis confirm acceptable gravity-induced alignment behavior



HORSESHOE RELIEF UPGRADE

Relief of the telescope horseshoe accommodates the larger 6-m primary
FEA confirms structural integrity is maintained
No fundamental redesign of telescope mount required


Existing Telescope


Horseshoe Relief


6m Aperture

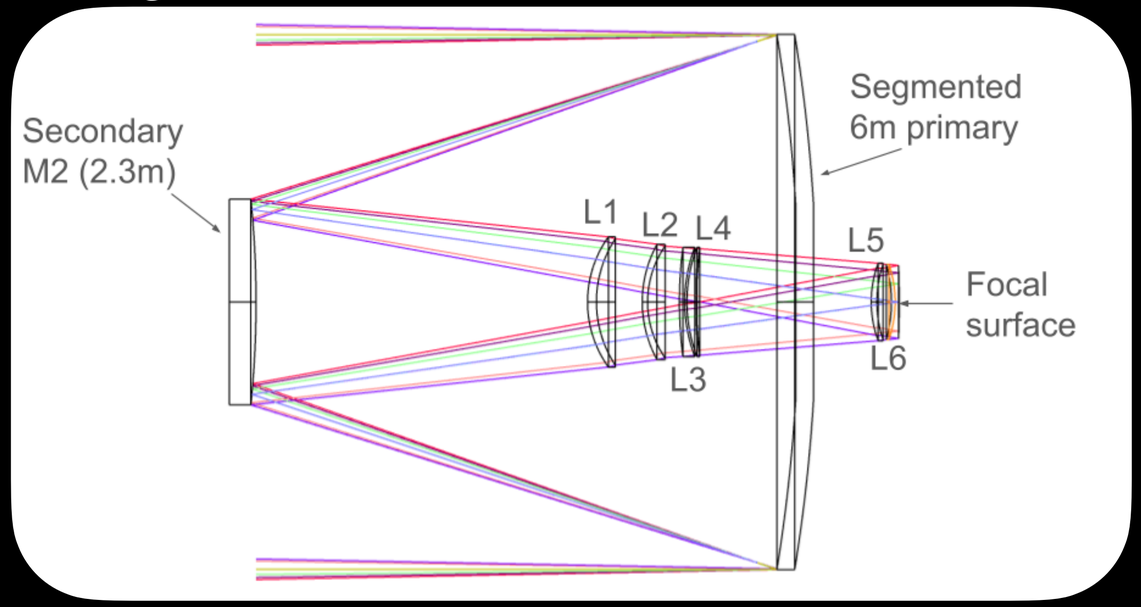
Optical design, mirror support system, and telescope structure have all been analytically validated.

Wide Field Corrector: DESI Heritage at a 6-m Scale

High throughput, large field of view, and manufacturable optics

BASELINE OPTICAL DESIGN

Wide-field Cassegrain with six-element all-silica corrector



CORRECTED FIELD
2.2°
diamater

FOCAL PLANE
0.82 m
diameter

BEAM
f/3.6
at focal surface

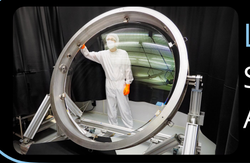
FOCAL RATIO VARIATION
<1%
across full field

CORRECTOR DESIGN

- Based on DESI corrector design
- Six-element all fused silica
- All spherical surfaces
- Low risk frabrication
- Delivers telecentric f/3.6 beam across 2.2° field

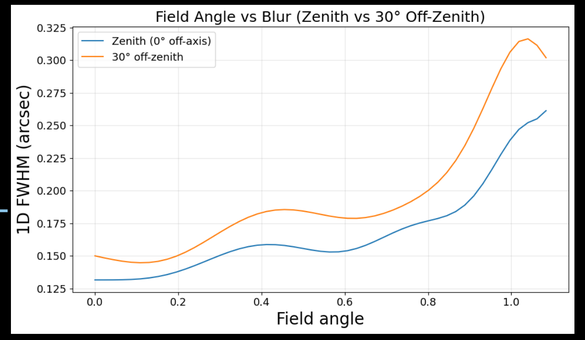
ATMOSPHERIC DISPERSION CORRECTION

Two counter-rotating lenses act as an ADC, enabling observations to zenith angles of 60°



Largest lens: 1.46 m diameter
Smaller than Rubin's largest lens
All fused silica construction

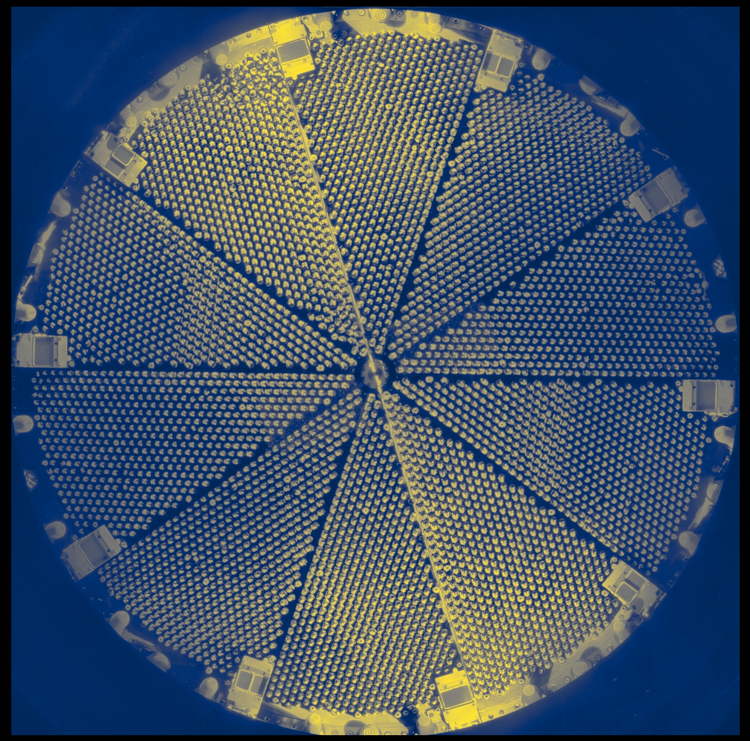
DESIGN MEETS OPTICAL REQS



The optical design achieves DESI-class simplicity at significantly larger aperture, delivering a 2.2 °field on a 6-m telescope without requiring challenging aspheric optics

Increasing Fiber Density Through Mechanical Redesign

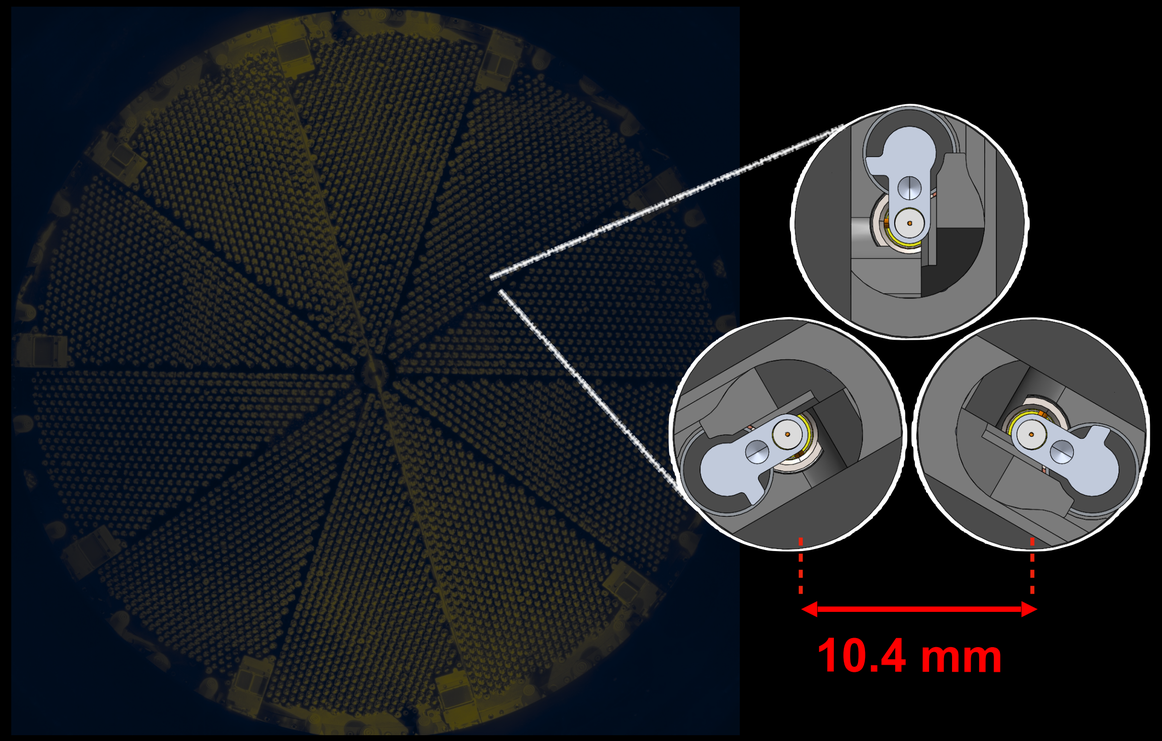
Leveraging proven DESI actuator technology with a new mechanical architecture



DESI
10 petals x 500 robots / petal = **5,000 robots**

Increasing Fiber Density Through Mechanical Redesign

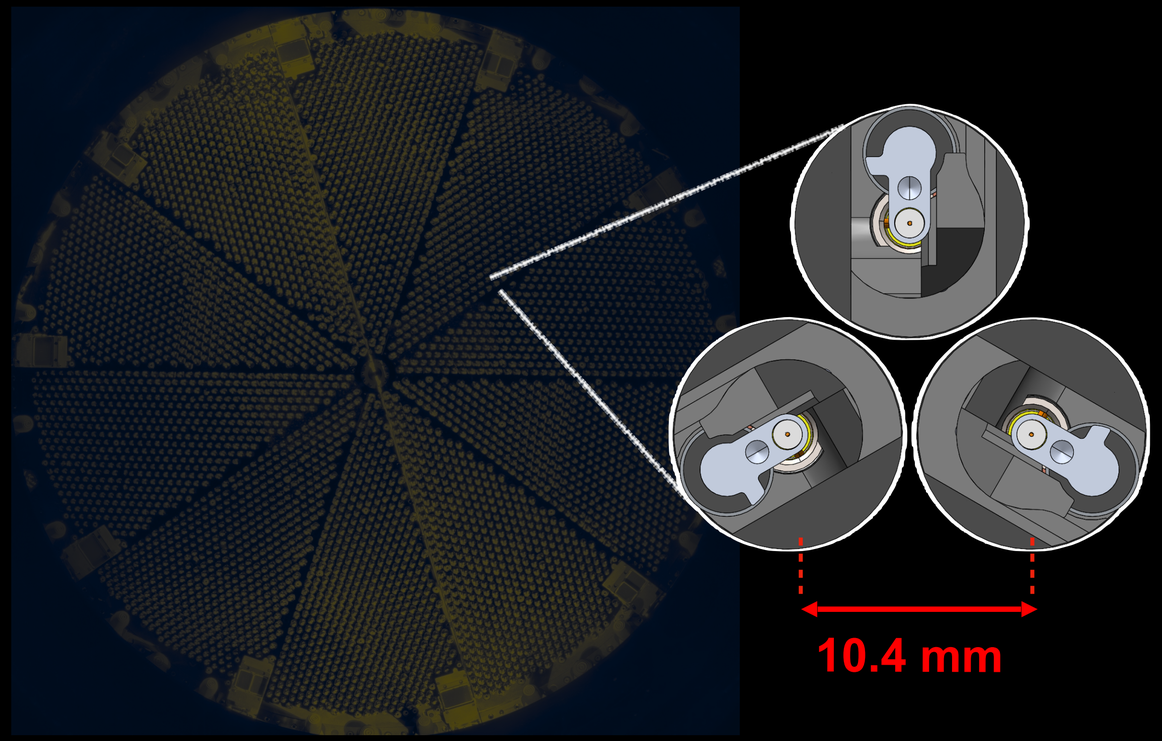
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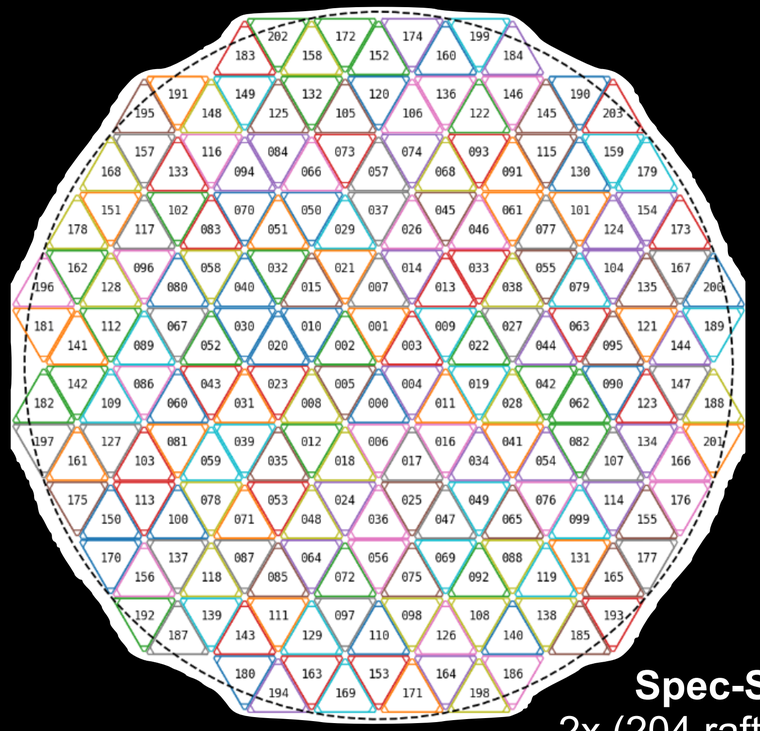
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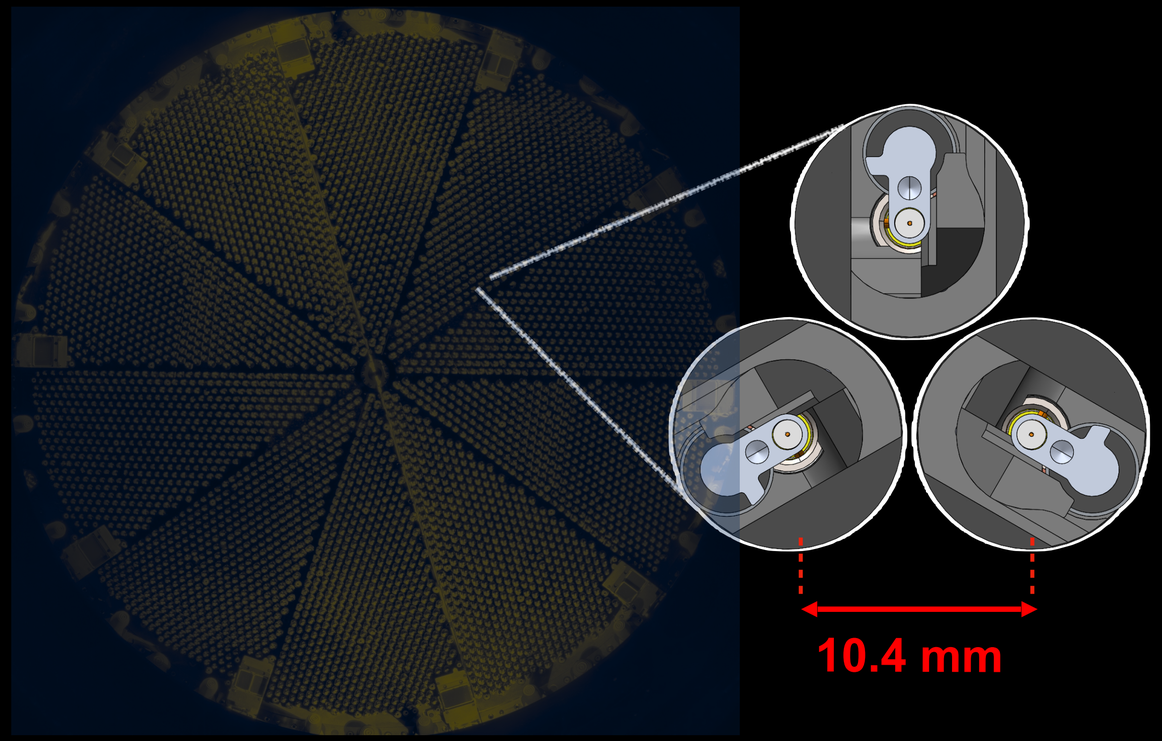
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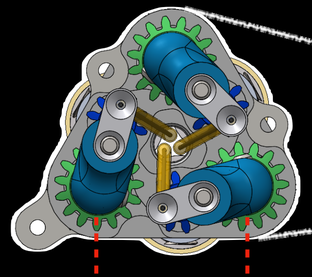
Spec-S5
2x (204 rafts x 63 robots / raft = 12,852 robots)
= **25,704 robots**

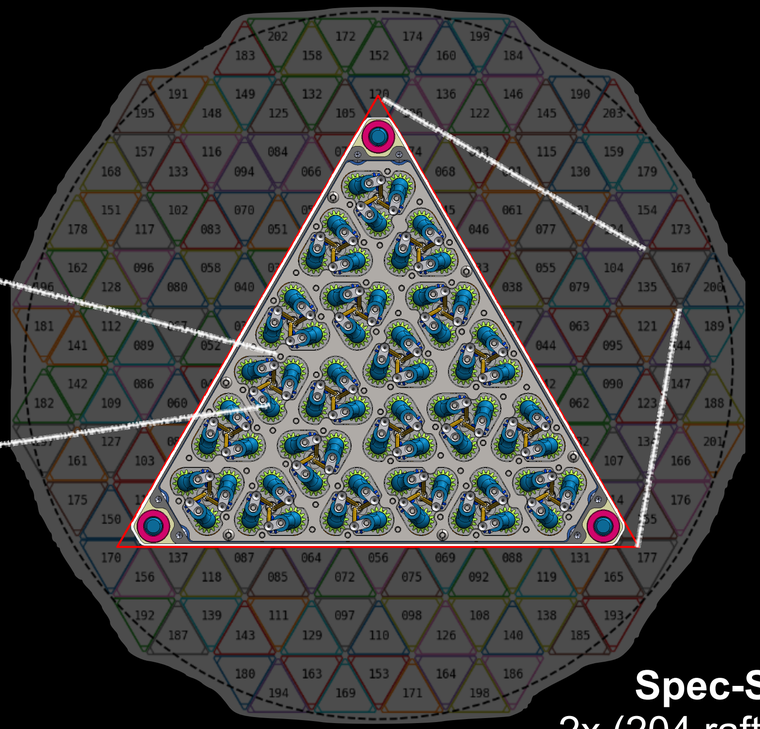
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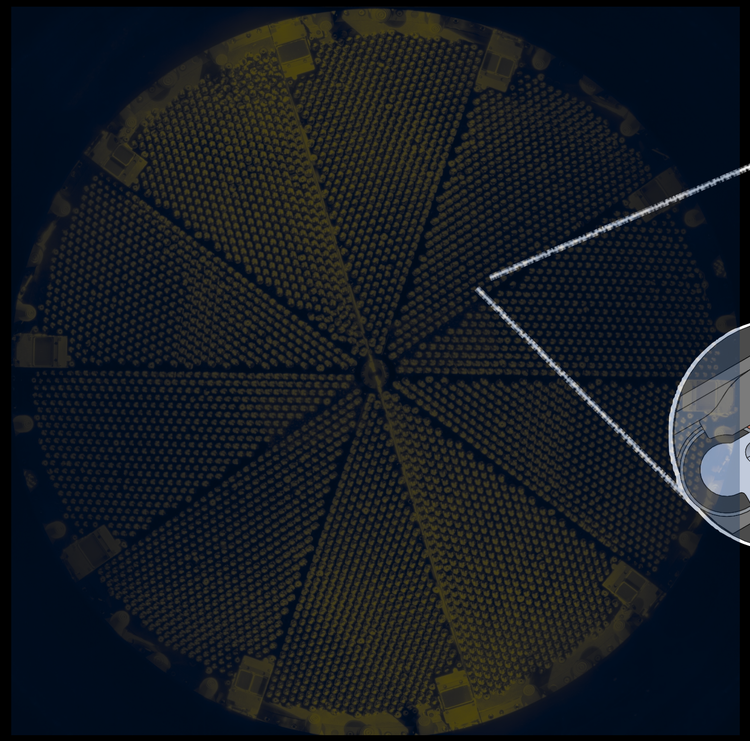


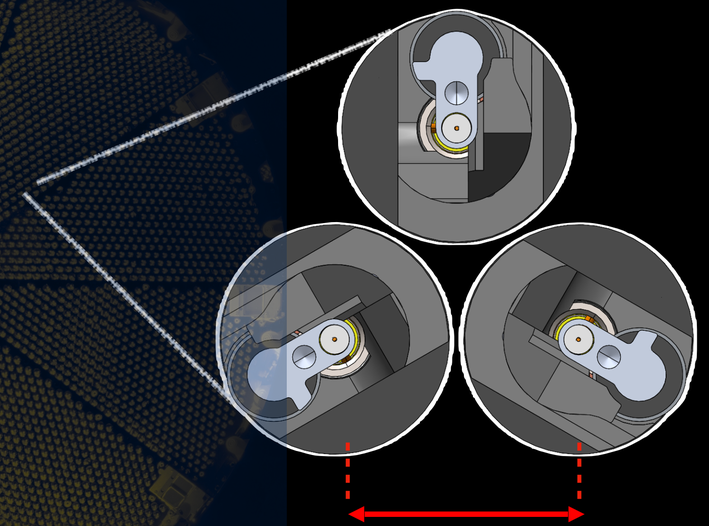


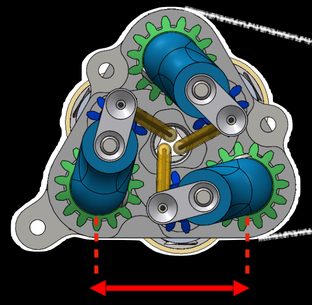
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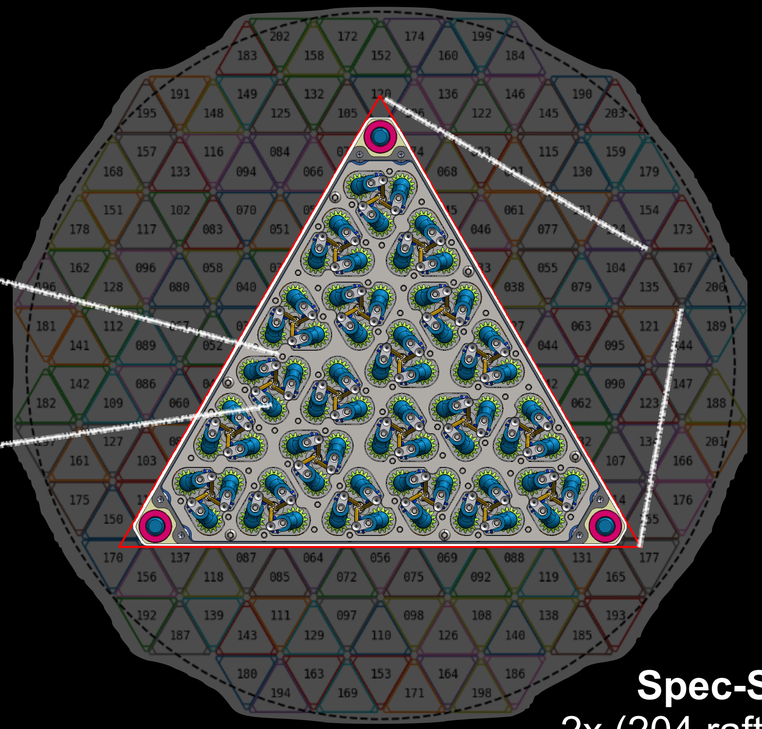
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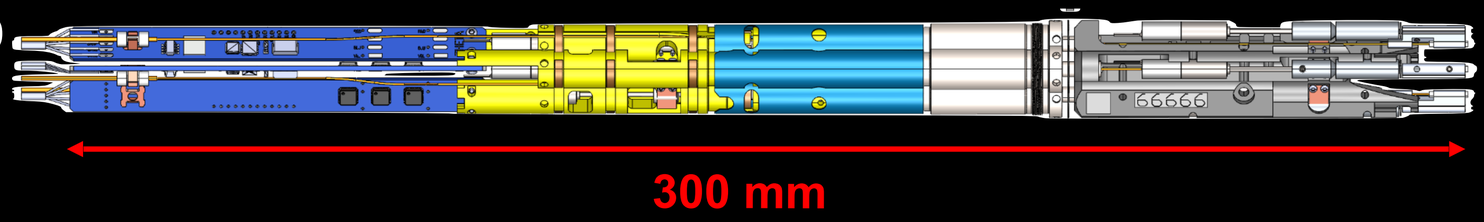






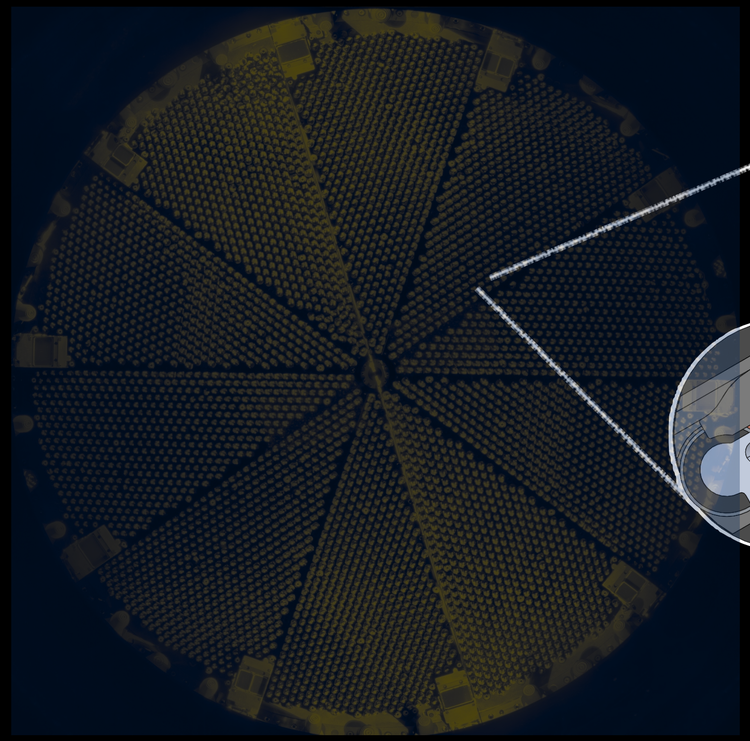
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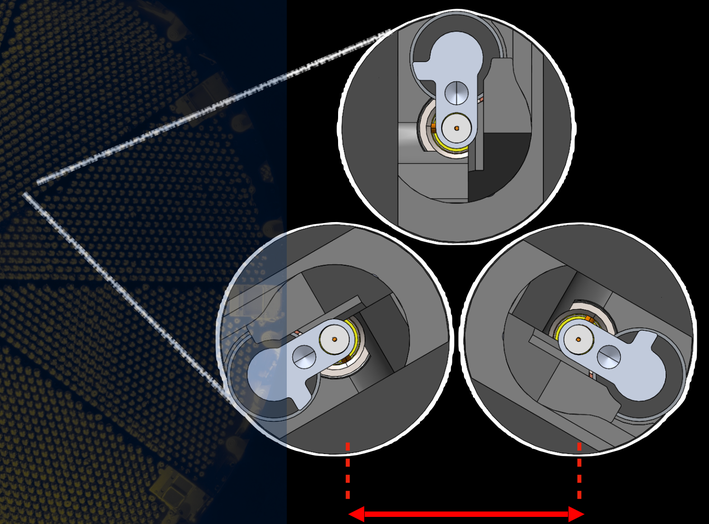
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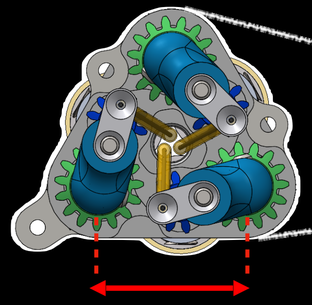


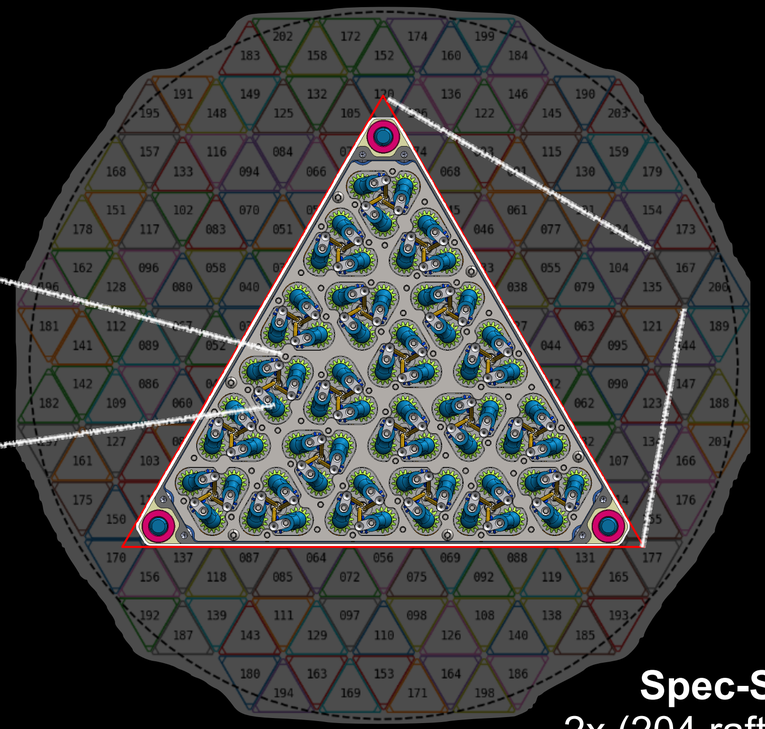
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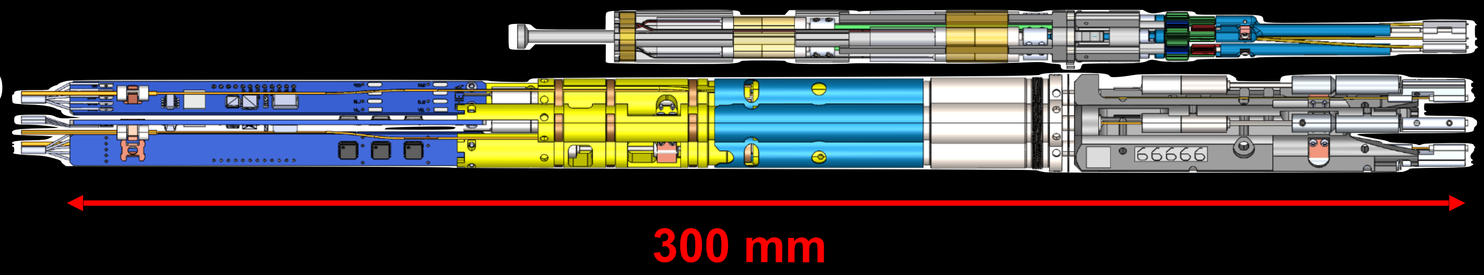








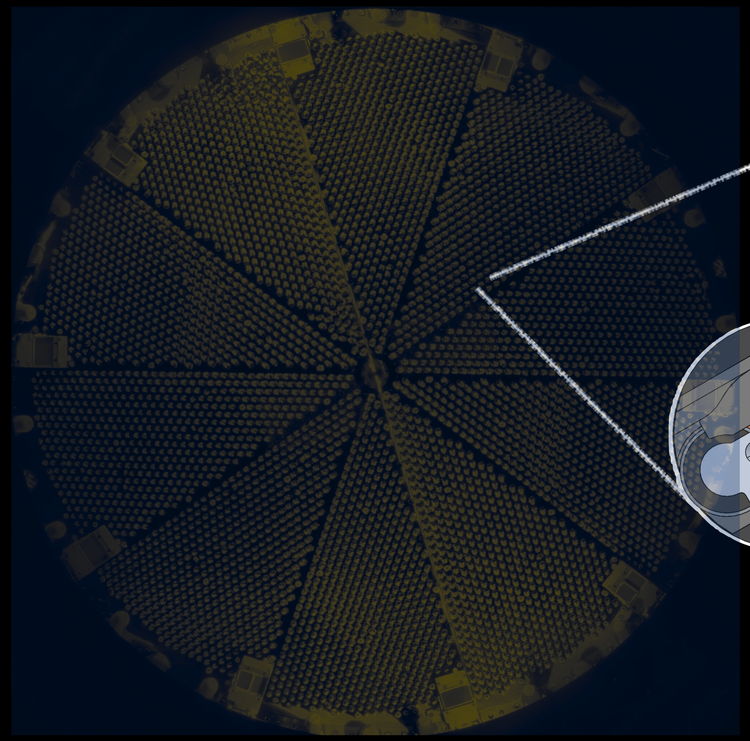
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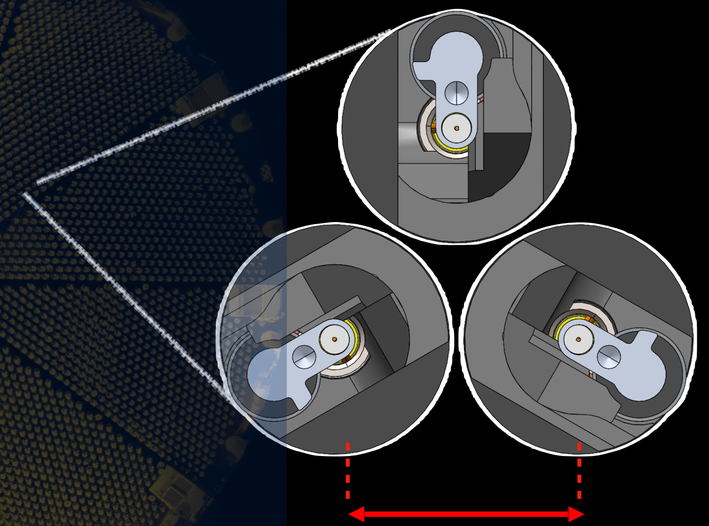


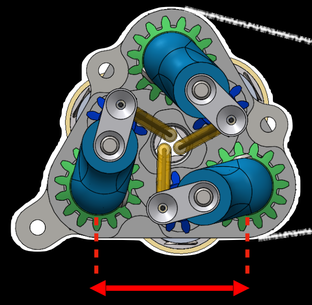
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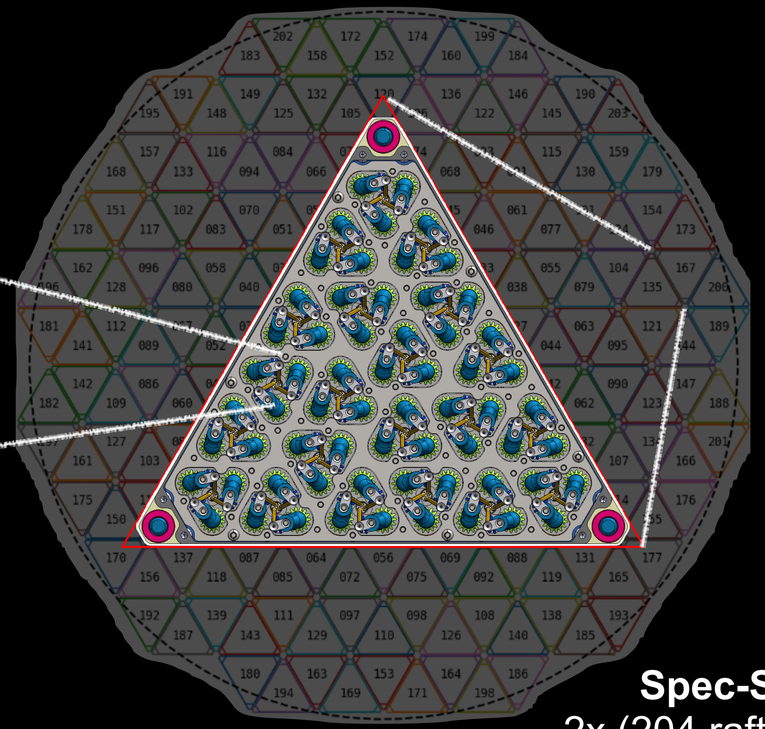
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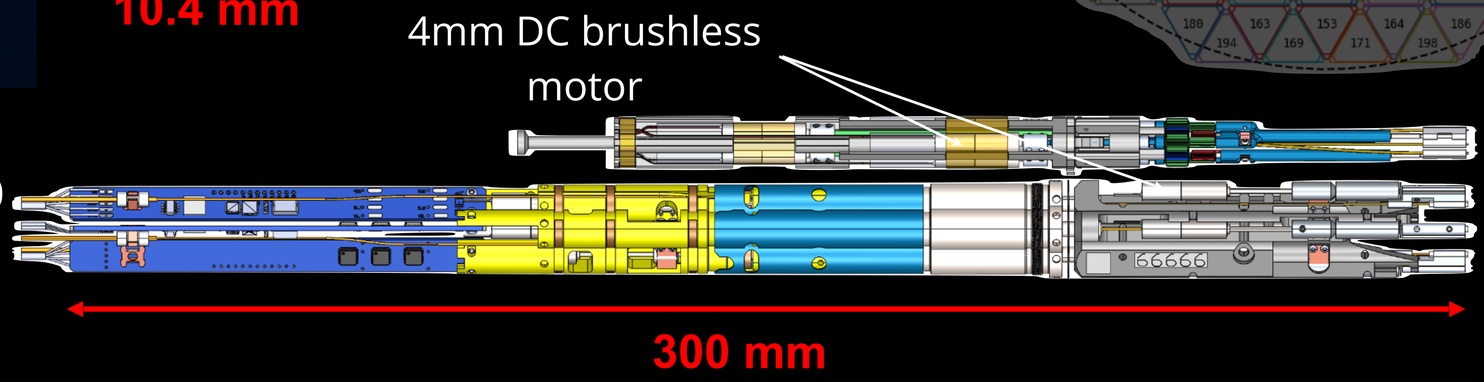








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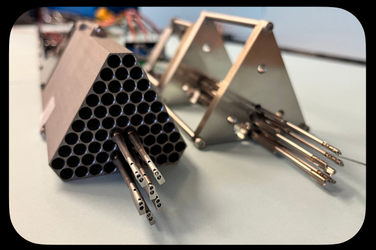
Higher denisty through improved mechanical integration - no new actuator technology

Multiple Positioner Concepts Under Evaluation

Lessons learned from DESI driving design

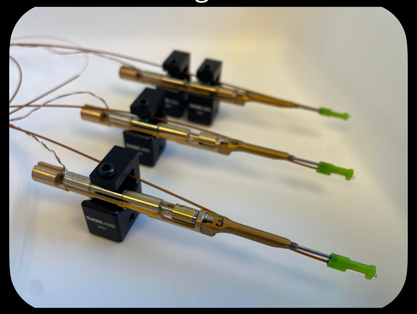
Early prototypes

- Developed and prototyped designs relying on transfer gears to transmit rotation to the eccentric axis
  - “O-Bot” design (2020), Trillium (2020, 2023), MPS (2024)
- Demonstrated feasibility of 6.2 mm pitch robots



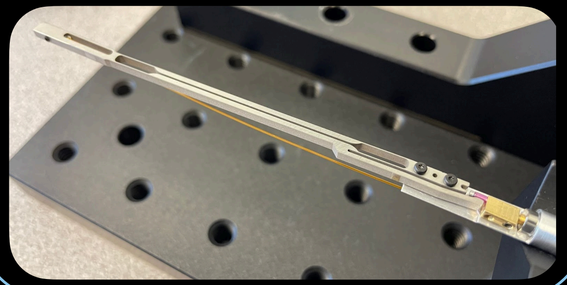
ECStar

- Novel compact gearbox design: Uses an eccentric-star planetary gearbox with offset output and a 4 mm motor to achieve a 5.8 mm actuator envelope while maintaining the required arm length.
- ≤5 µm RMS accuracy over >180° travel
- Scalable, reliable design



R-flex

- flexure-based radial positioning mechanism
- ≤5 µm RMS positioning precision, <0.1 deg angular error, and ~50 µm defocus over a >4 mm travel range

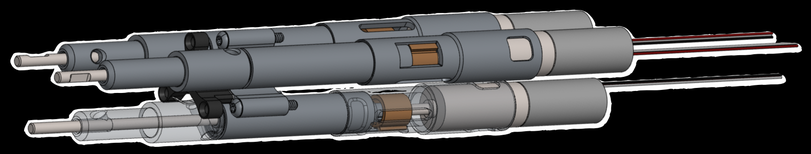


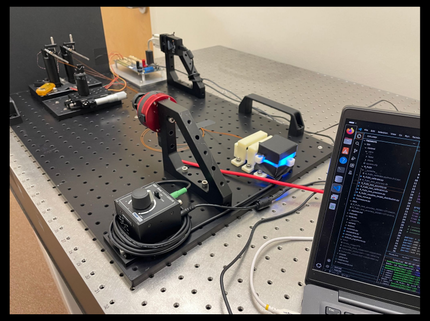
Iris Theta Stage

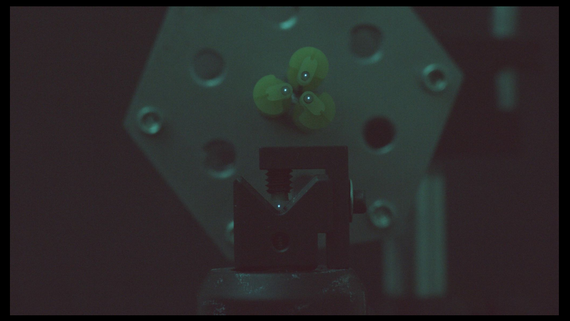
- Improved friction tab reduces backlash

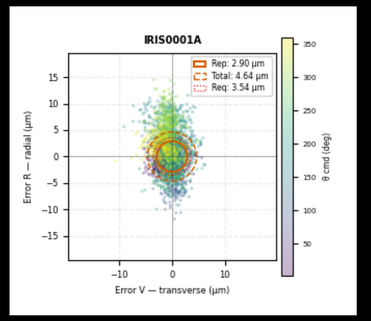


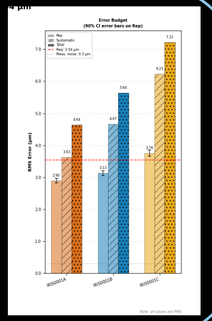




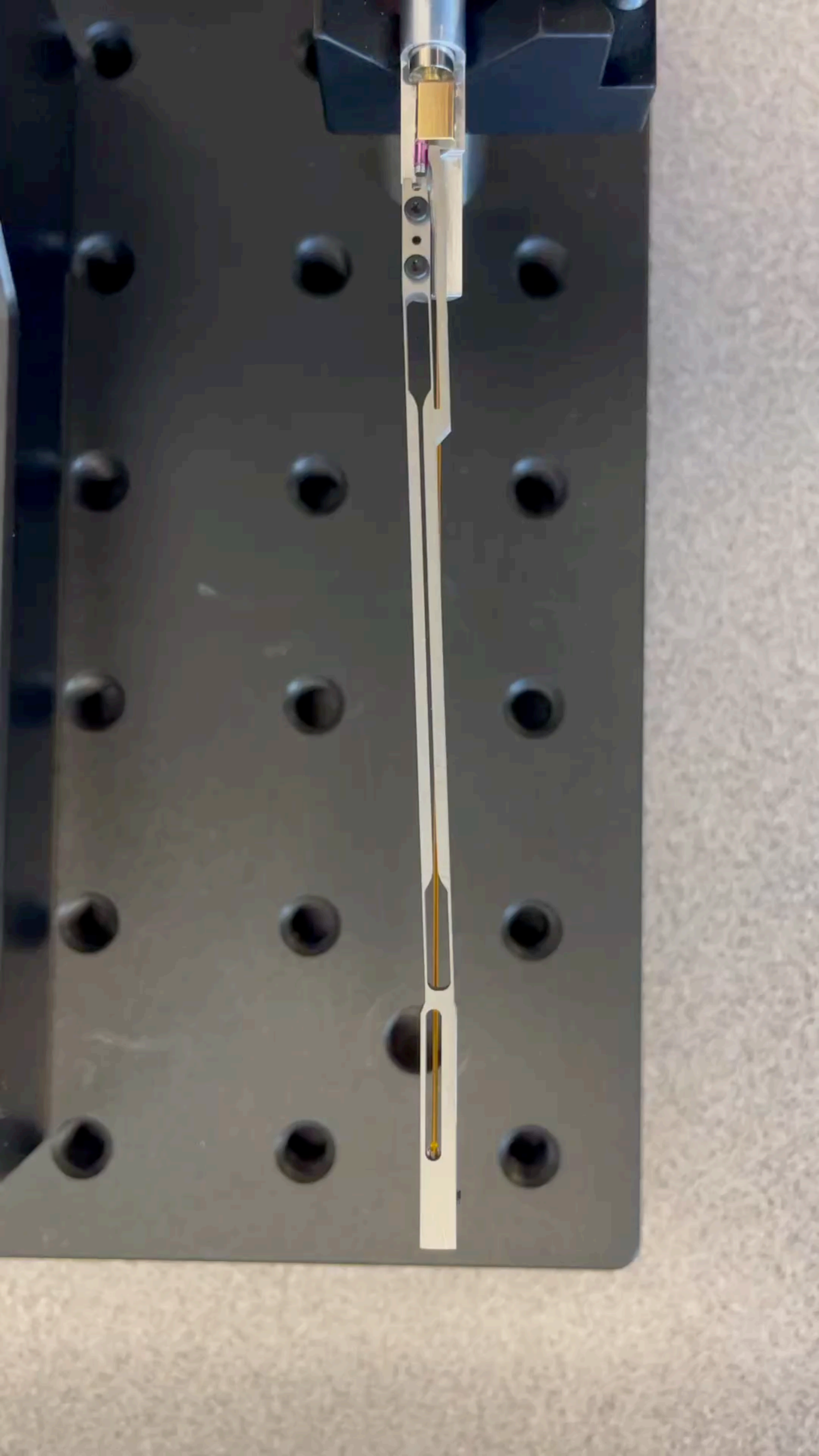




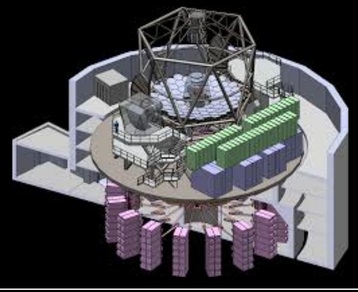
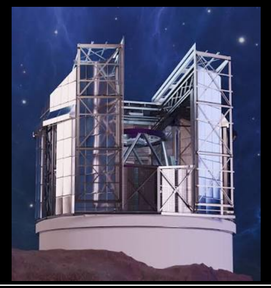
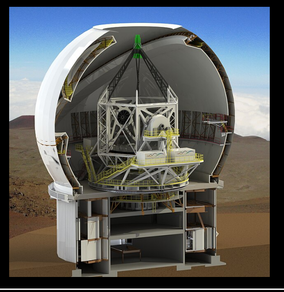
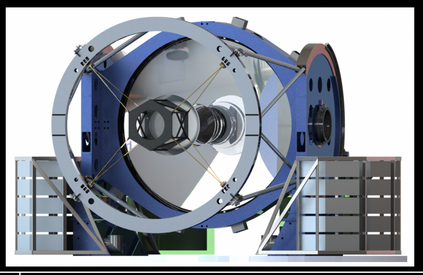




Spec-S5 increases multiplexing from ~5,000 to ~13,000 (x2!) fibers while improving serviceability and reducing downtime through a modular focal plane architecture



Rubin Spectroscopy Landscape: Powering the next generation of spectroscopy

	Spec-S5	WST	MUST	MSE	MegaMapper
					
First Light	~2030s	~2040s		~2037	TBD
Aperture	2 x 6m	12m	6.5 m	11.25 m	6.5 m
Telescopes	2 (Blanco & Mayall)	1	1	1	1
Field of View (diamater)	2 x 2.5 deg	3 deg	~3 deg	1.5 deg	3 deg
Multiplex (# targets)	~26,000	~20,000	10,000-20,000	4,332	~20,000
Hemisphere / Region	US (N&S)	Europe	China	Canada / Hawaii	US
Program Type	Dedicated survey	Community Faciliy	Dedicated survey	Community Faciliy	Dedicated survey
Core Science	Dark Energy & Dark Matter	Galaxy evolution / Cosmology / Transients	Dark Energy & Dark Matter	Galaxy Evolition Stars & Milky Way Deep Spectroscopy	High-z cosmology Dark energy

Highest multiplex
Spec-S5

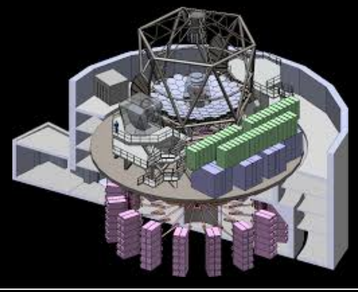
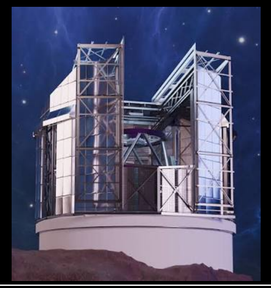
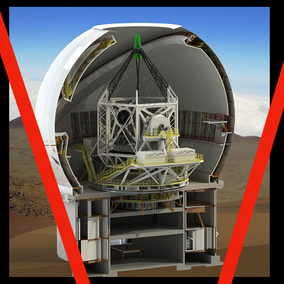
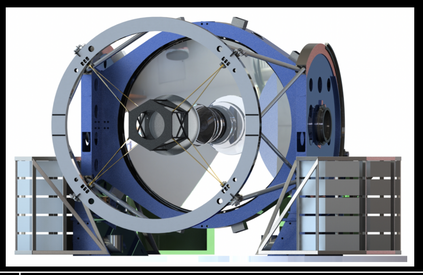
Largest aperture
WST

Deepest spectroscopy
MSE

Full sky coverage
Spec-S5

Lowest technical risk
Spec-S5

Rubin Spectroscopy Landscape: Powering the next generation of spectroscopy

	Spec-S5	WST	MUST	MSE	MegaMapper
					
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Highest multiplex
Spec-S5

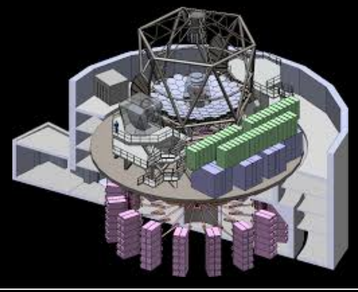
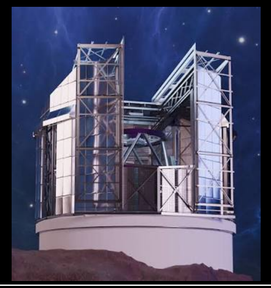
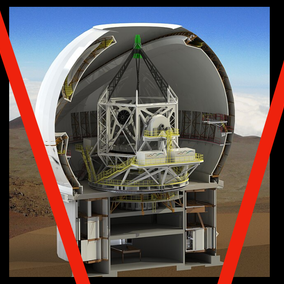
Largest aperture
WST

Deepest spectroscopy
MSE

Full sky coverage
Spec-S5

Lowest technical risk
Spec-S5

Rubin Spectroscopy Landscape: Powering the next generation of spectroscopy

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Highest multiplex
Spec-S5

Largest aperture
WST

Deepest spectroscopy
MSE

Full sky coverage
Spec-S5

Lowest technical risk
Spec-S5

Spec-S5 in the Rubin Era: Complimentary capabilities for the next decade of discovery



RUBIN OBSERVATORY

- Deep, wide, multi-band imaging
- Time-domain alerts across the southern sky
- Photometric redshifts and catalogs

TARGET SELECTION
Using Rubin imaging and catalogs (+custom/auxiliary filters when optimal)



SPEC-S5

- Precision spectroscopy
- Milky Way stars and dark matter studies
- Rapid ToO follow-up of transients of rare events

SCIENCE IMPACT
Precision cosmology, Galaxy evolution, Dark matter, time-domain astrophysics, Milky Way archaeology

SPEC-S5 ENABLES

- Precision cosmology: 110M galaxy & quasar spectra
- Rubin calibration: Spectroscopic training for photometric redshifts
- Time-domain science: Rapid follow-up of transients
- Galaxy evolution: Metallicity, kinematics, and stellar populations
- Milky Way & dark matter: 150M stellar spectra

FLEXIBILITY BY DESIGN

Spec-S5 can evolve with Rubin - adapting target selection, incorporating new imaging, and enabling critical follow-up.

RUBIN REMAINS AN IMAGER

- Rubin is optimized for wide, deep, time-domain imaging.
- Spec-S5 provides the complementary spectroscopy.
- Together they enable transformational science.
- Preserve Rubin's unique imaging capability—the lowest-risk path.

SYNERGIES

Rubin is optimized for imaging. Spec-S5 provides the spectroscopy needed to maximize its scientific return.