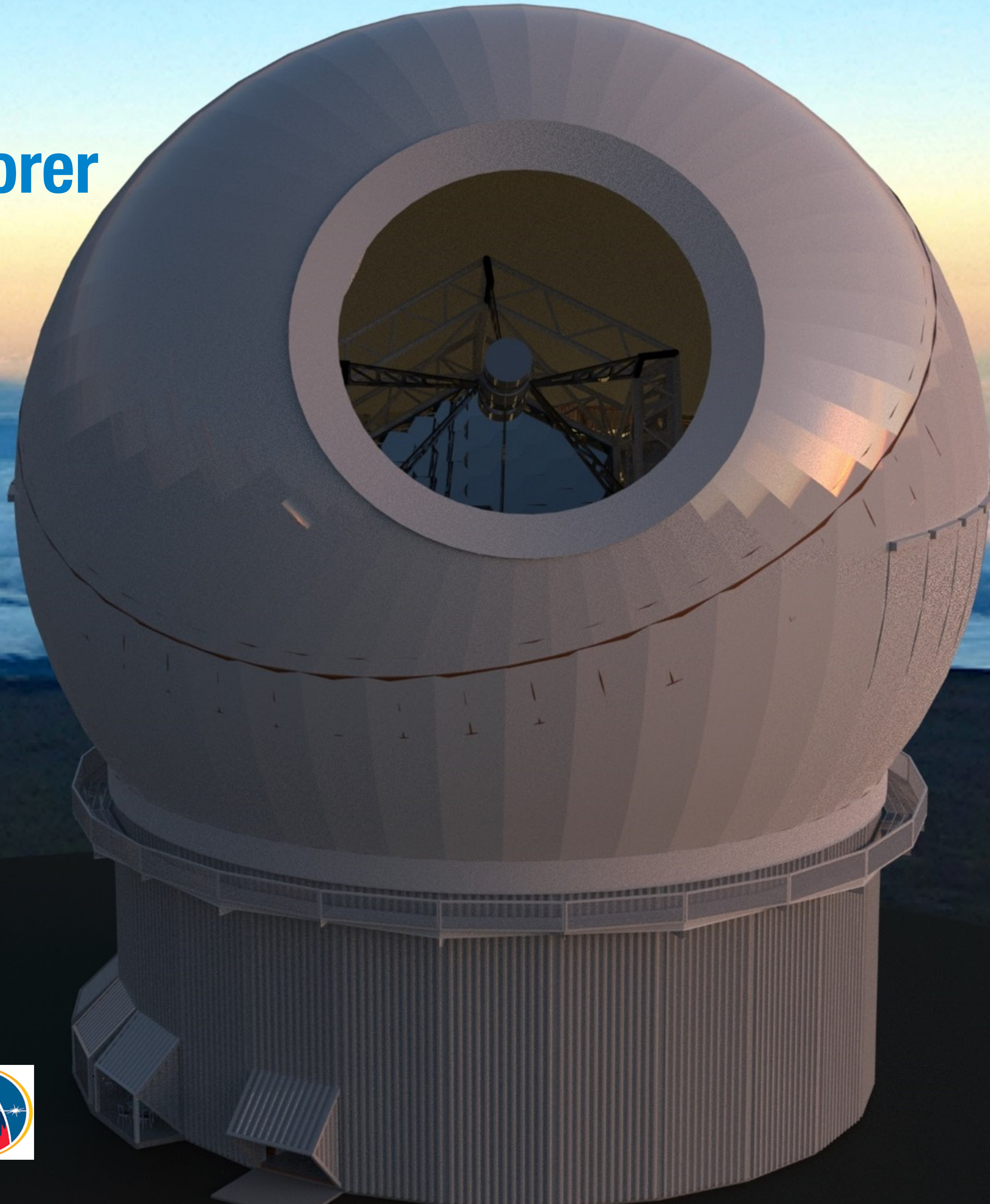
Maunakea Spectroscopic Explorer

Maunakea Spectroscopic Explorer and MSE Pathfinder



Jennifer Sobeck (MSE PO)

VRO-LSST PCW

Session: Follow-Up Facilities for Time-Domain Astronomy

August 10, 2022

AAO MACQUARIE University

NAOC

NRC·CNRC

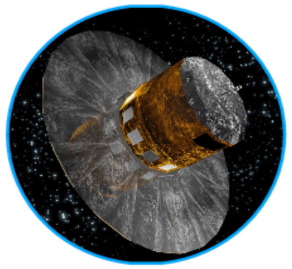
NOIRLab

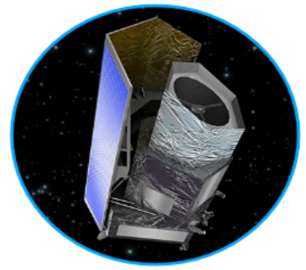
UKRI Science and Technology Facilities Council

UCL

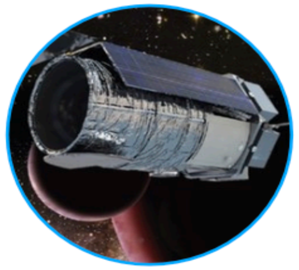
Shortfall of 10-m Class Telescope Spectroscopic Follow-Up

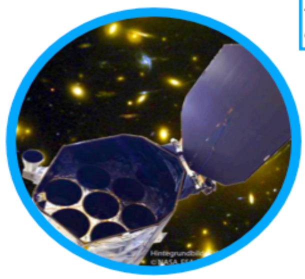
Gaia (Galactic Archaeology)
All-sky point sources to G=20; 1 billion sources; moderate and high resolution follow-up



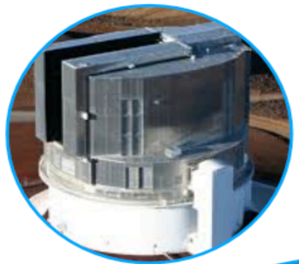


Roman (Cosmology and extragalactic surveys)
>2000 sq. deg to Y>26.7 in multiple surveys; G.O. mode
Euclid (Cosmology and extragalactic surveys)
20000 sq. deg to RIZ=24.5; 40 sq. deg to RIZ=26.5



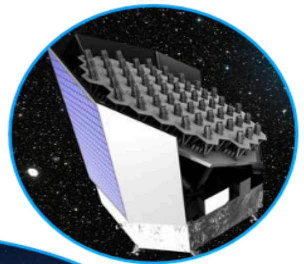


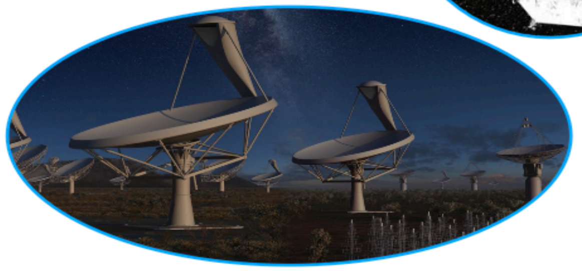
eROSITA (X-ray)
All-sky survey + pointed fields. $>10^5$ galaxy clusters to z>1.5



Ground based OIR imaging
LSST: >10000 sq.deg overlap; Single visit depth of r=24.5; billions of sources; opportunistic transient studies
Subaru/HSC: co-located on Maunakea; 1.5 degree FoV; r=27.2 in 1hr

PLATO (stellar physics and exoplanetary hosts)
>2000 sq. deg to g=16; high SNR@R40K monitoring campaigns of faintest sources



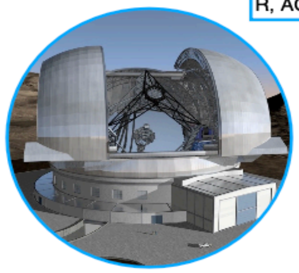


There are many multiwavelength photometric and astrometric astrophysical surveys planned for the next decade.

Currently there is no dedicated spectroscopic facility on a 10m-class telescope to compliment and follow-up these surveys.

For maximum synergy with these surveys, it is highly desirable to begin operation in the 2020s.

Very Large Optical Telescopes
GMT, TMT and E-ELT: Feeder facility for individual sources for study with high SNR, high R, AO-assisted IFUs



Radio, sub-mm, far-IR
Long wavelength synergies including **ALMA, CCAT** and **SPICA**
SKA1: >20000 sq. deg overlap; Billions of sources to r>24; opportunistic transient studies; spectral stacking

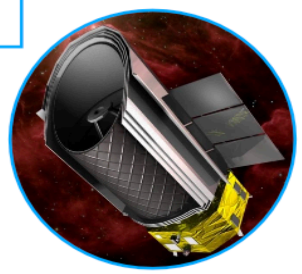
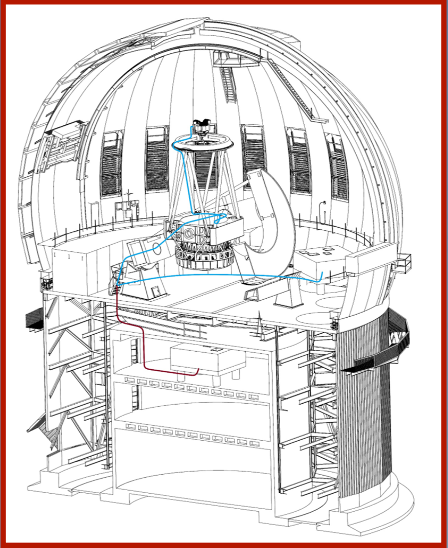


Image Credit: P. Hall

The Future of the CFHT Facility: MSE and MSE Pathfinder



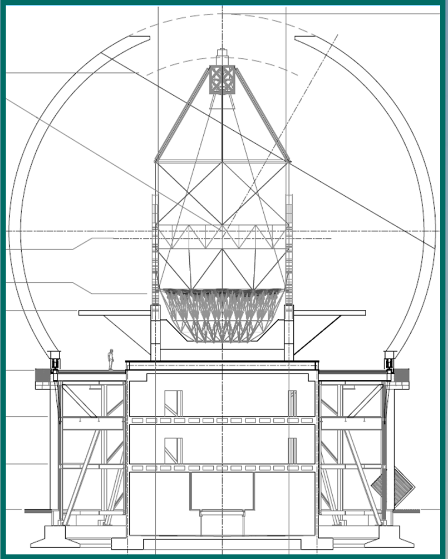
MSE Pathfinder

Late 2020's First Light

Overlap with LSST 10-Year Survey Period

4.0-m Diameter Primary Aperture

Operations Executed Under *Current* Master Lease



Maunakea Spectroscopic Explorer (MSE)

Late 2030's First Light

Follow-up Post LSST Survey Period

>11.0-m Diameter Primary Aperture

Next Generation Instrumentation

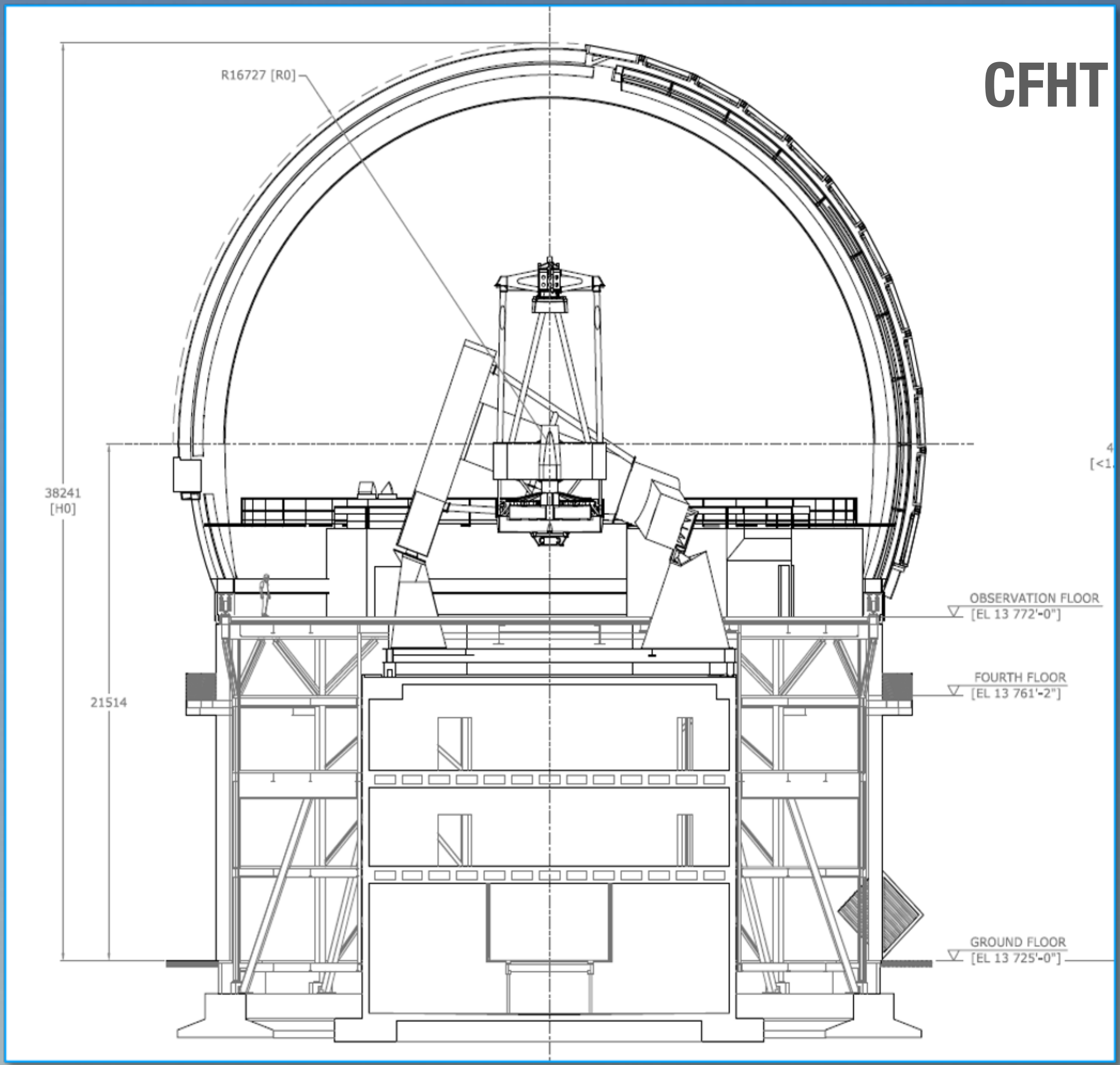
Minimize Any Footprint Extension

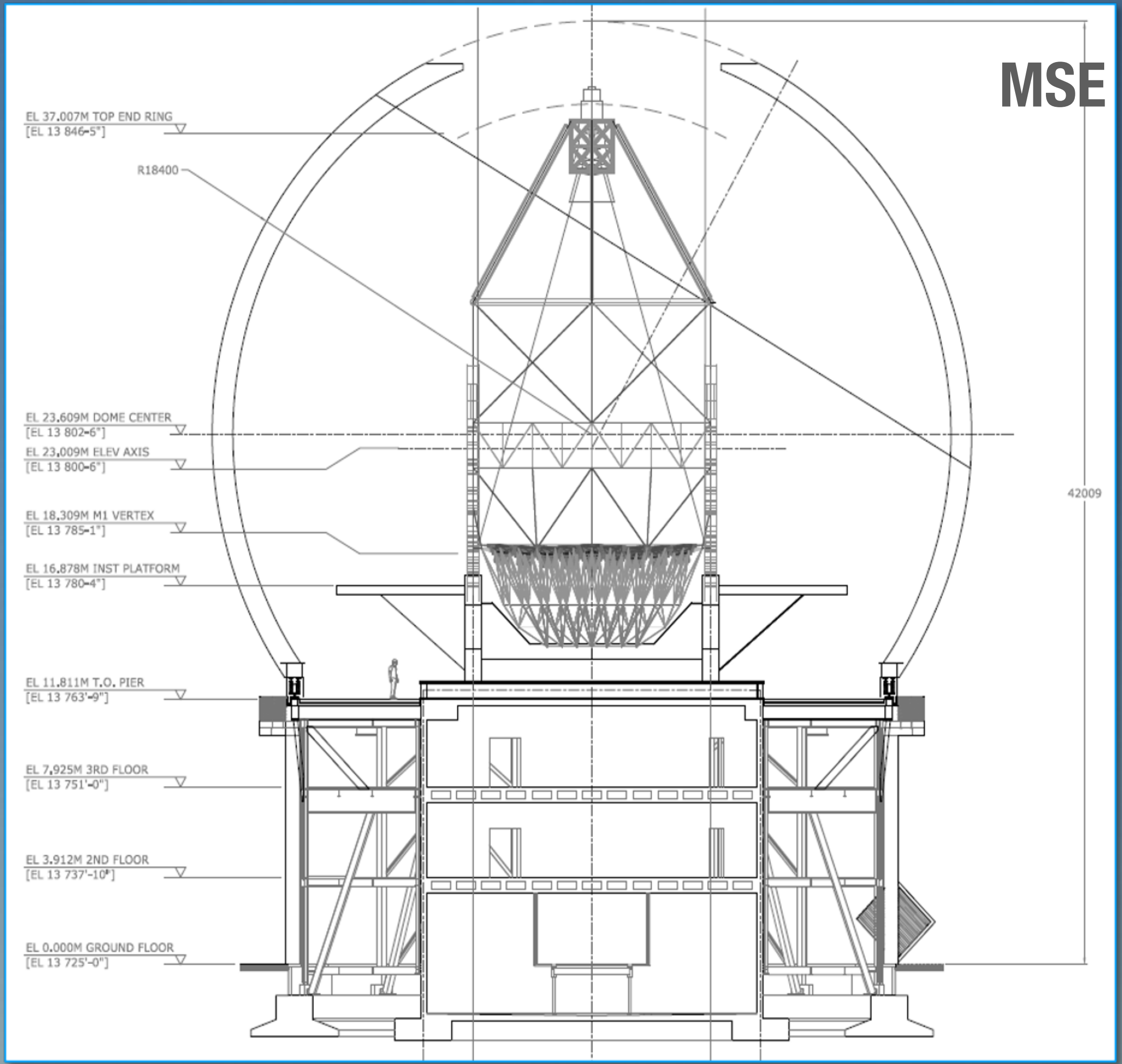
MOS development efforts underway at one of the best sites for Astronomy in the world

MSE Facility Transformation

- **PRIOR HISTORY:** Canada-France-Hawaii Telescope has a 45+ year history of scientific and outreach leadership on Mauna Kea.
- **CURRENT PERSPECTIVE:** Out of environmental and cultural respect along with a strong desire to preserve the external appearance of CFHT after MSE completion.
- **FUTURE PLAN:** We will reuse the CFHT summit building. We will limit the size increase of the new facility building and enclosure to ~10%.

MSE Facility Transformation





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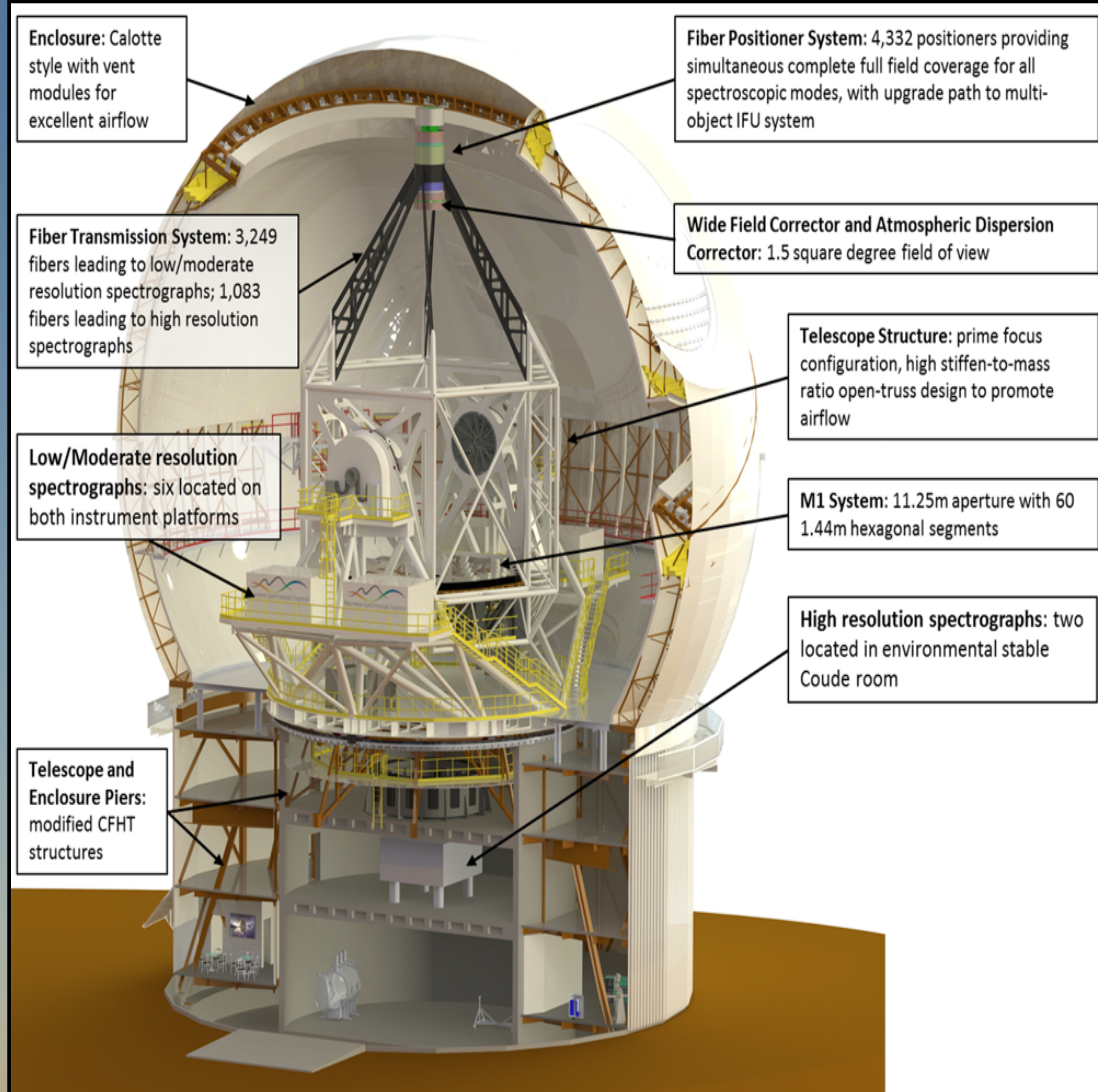
MSE Conceptual Design

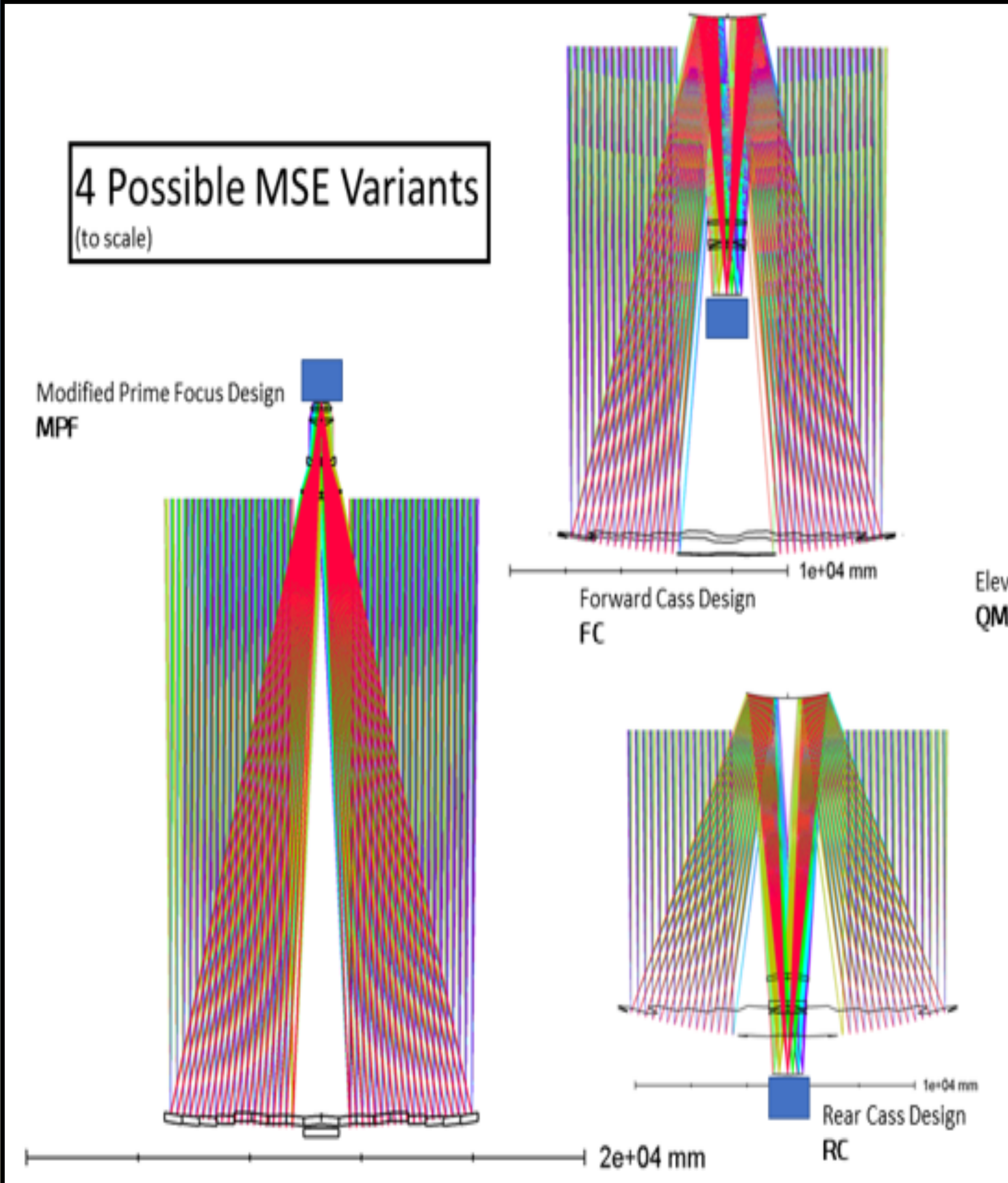
- 11.25m diameter telescope
- 1.5 square degree field of view
- 4,332 fiber positioner feeds two sets of spectrographs
- Low/Moderate Resolution (LMR) Spectrograph:
  - R=λ/Δλ~3000~6000
  - UV to H band
  - 3,249 fibers
- High Resolution (HR) Spectrograph:
  - R~30,000
  - 3 optical (broad) wavelength windows
  - 1,083 fibers

Completely dedicated survey facility!



Faint sensitivity limit of MSE LMR instrument should roughly match the approximate depth of a single-visit LSST pointing (m ~ 24)

MSE Modified Design Proposals



Design	f/#	Normalized 1.5 degree field	Approx fiber count
MPF	1.93	1.00	4330
FC	3.13	2.63	11390
RC	3.20	2.75	11900
QM	3.99	4.27	18490

A system-level trade study to understand the viability, technical and programmatic, of three alternate telescope concepts: two with a two-mirror telescope concept and one with a quad-mirror telescope concept

Compared to the current single-mirror prime focus telescope baseline, the degree of *multiplexing can be increased* by a factor of ~2.7 for two-mirror telescope and a factor of ~4.3 for the quad-mirror telescope

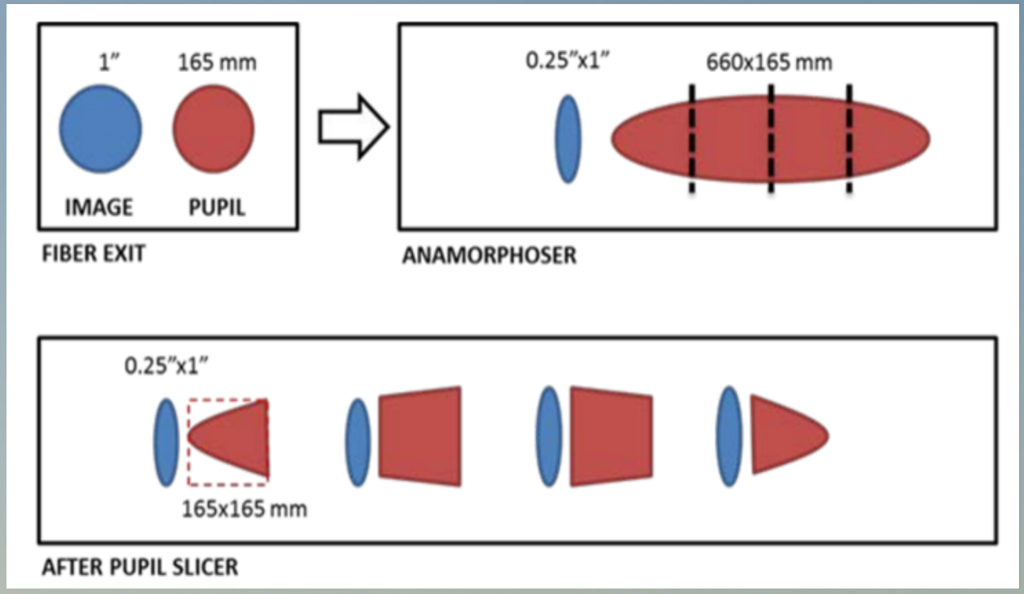
Trade study is motivated by recent Strategic Reviews by various agencies (e.g., Prospective Astronomie-Astrophysique [France; 2020-2025], Decadal Survey on Astronomy and Astrophysics 2020 [USA],…)

Maunakea Spectroscopic Explorer

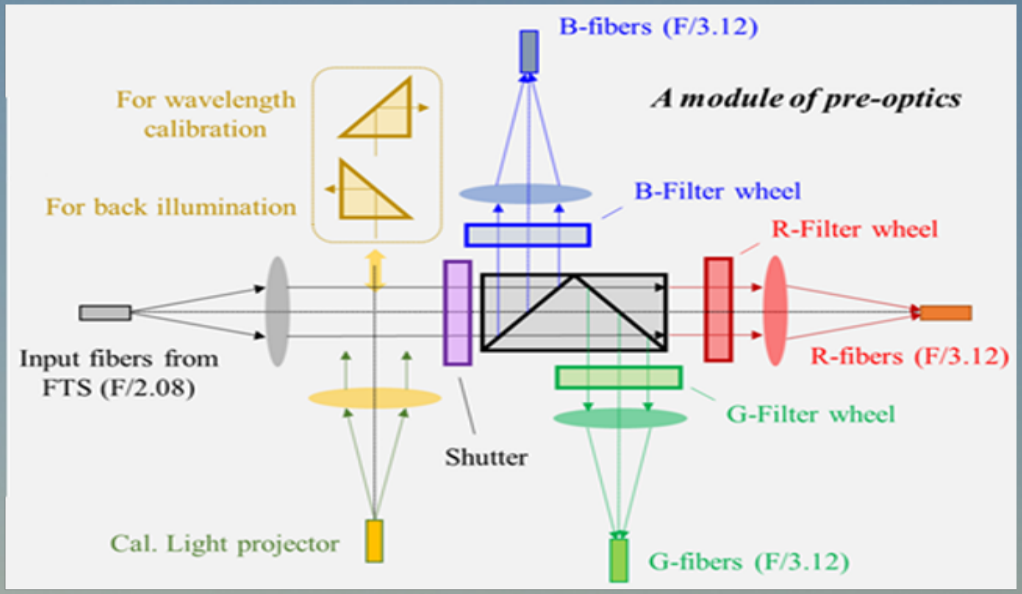
Additional MSE Technological Development Efforts

Design and test an innovative pre-optics design that splits the spectrograph input into a single wavelength band in blue, green, red, J, or H, individually, at reduced pupil size representative of a smaller telescope aperture.

- Narrower wavelength band and smaller pupil will ease the spectrograph optical design and decrease the technical risks of optics.
- Enable modularization of instrument configuration resulting in a spectrograph system that is geometrically compact, space efficient, and compatible with the high degree of multiplexing required cost effectively.



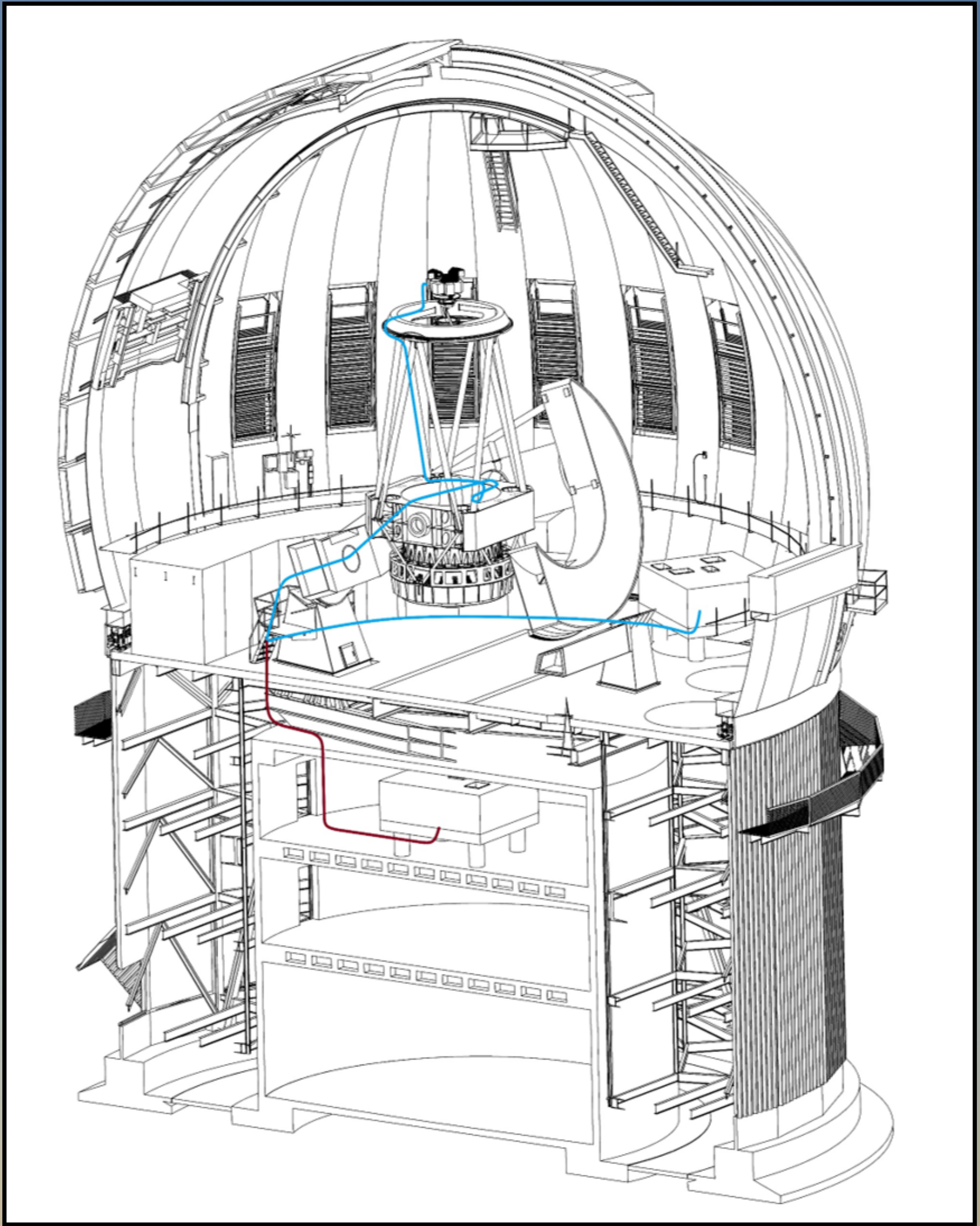
Pupil slicing concept where a deployable anamorphoser pre-optics works in concert with a fixed pupil slicer to enable “switchable” spectral resolutions of the spectrograph.



Wavelength splitting concept where the pre-optics splits the MSE high-resolution spectrograph visible band into three narrower bands with each feeding a separate spectrograph

Maunakea Spectroscopic Explorer

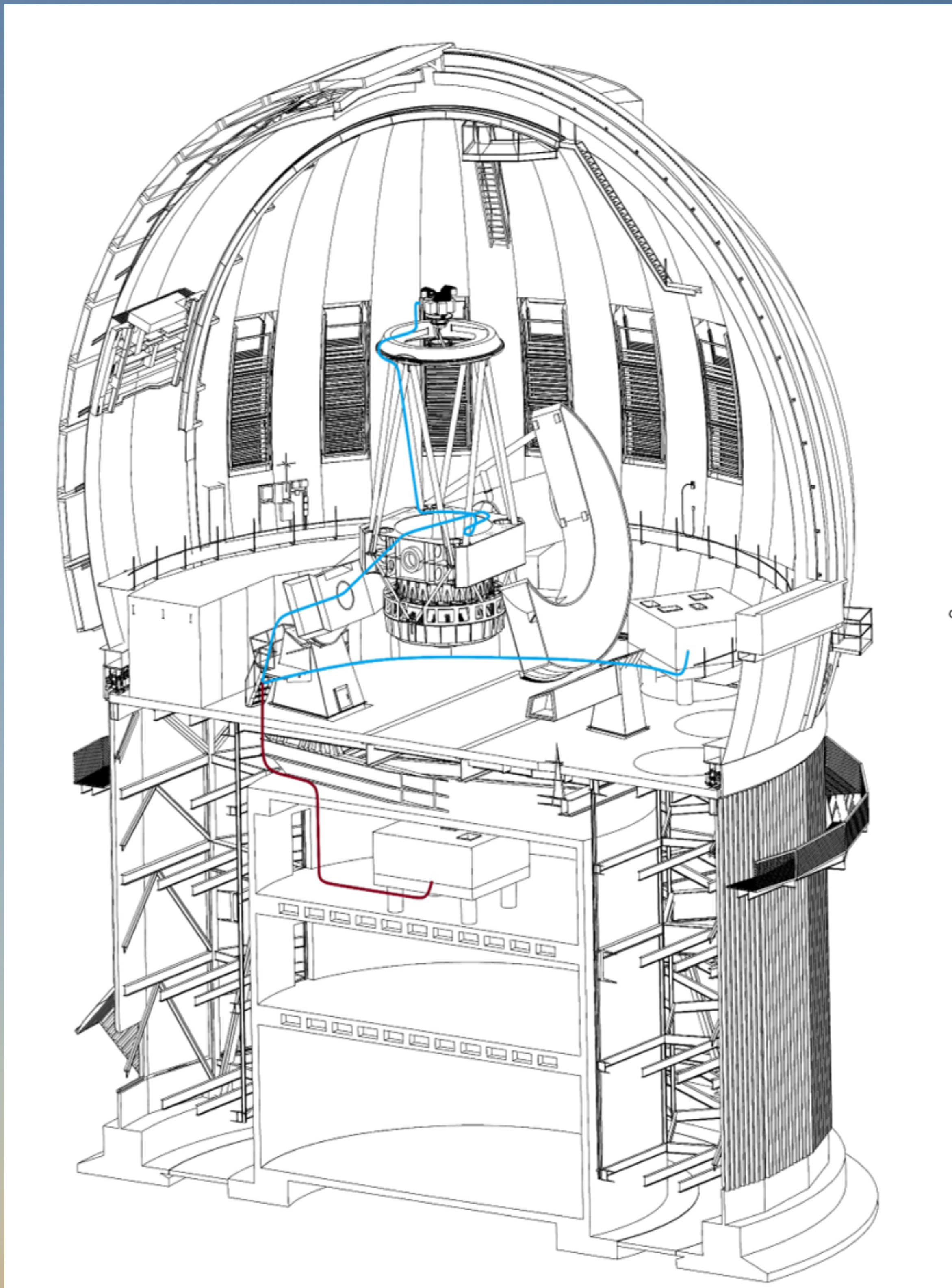
MSE Pathfinder Overview

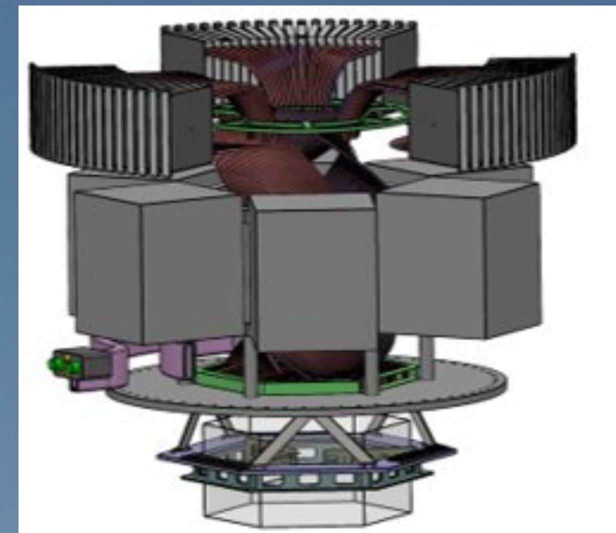


- Primary Configuration: Prime Focus
- Instrument Rotation Scheme: Operates with 3 other instruments (VISION+ MegaCam)
- Time Allocation: 1/4 time
- FOV ~ 1.5 square degrees
- Fiber Number ~ 1000
- Additional Potential Instrument Configuration: Cassegrain IFU (~100 fibers)
  - Time extension: 1/4 additional
- Potential Operational Modes:
  - Limited *Prompt* ToO follow-up
  - Dedicated Fiber Allocation (i.e., small percentage of fibers in any field to be set aside for time-domain/transient follow-up)

Pathfinder does not require a new lease!

MSE Pathfinder Design



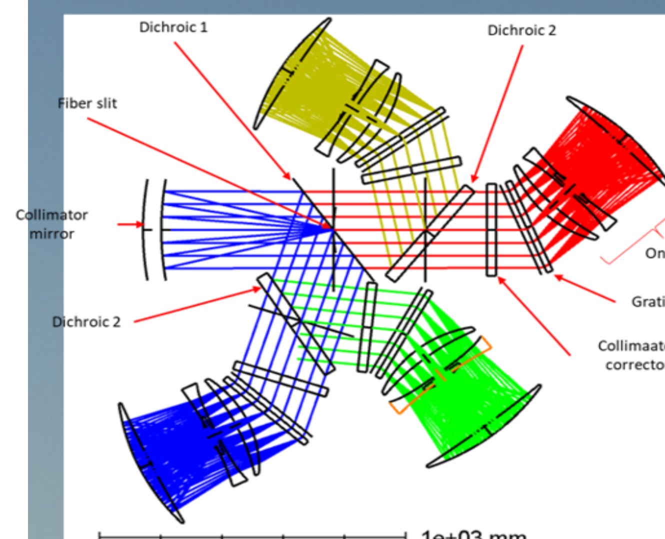


AAO Sphinx Tilting Spine Fiber Positioner

- Same technology at FMOS on Subaru and 4MOST (ESO)

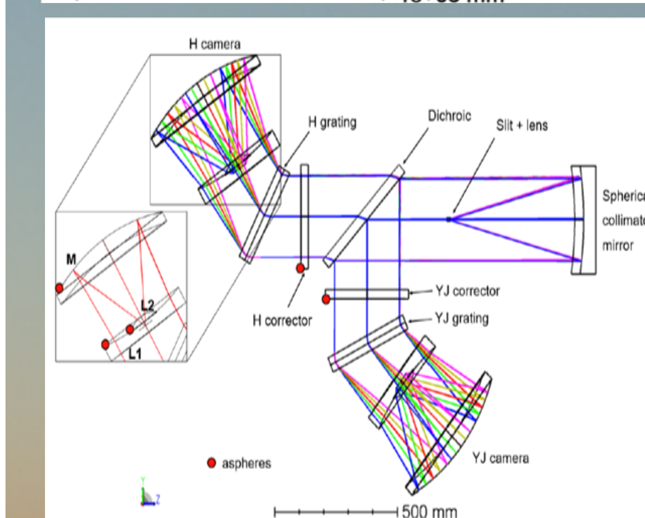
- Very close minimum target separation, < 1mm

- Patrol radius > pitch, so >3-5 fold sky coverage



MSE Low/Moderate Resolution Visible Spectrograph

- Fabrication by Winlight Systems
- Visible wavelength range of ~0.36-1µm
- 4 arms (each with a 4K x 4k detector)
- 2166 fibers in CoDP design



MSE Low/Moderate Resolution Near Infrared Spectrograph

- Fabrication by CRAL+LAM
- Near infrared JH band coverage with 1.0-1.3µm and 1.45-1.8µm
- MOONS-like design
- 1083 fibers in CoDP design

Maunakea Spectroscopic Explorer

Risk retirement will be one likely objective of the Pathfinder

Summary of Potential TVS Spectroscopic Follow-Up Needs

Capability Needs

	Infrastructure	< 3m	3–5m	8m	25m
Characterizing Transients	**Transient Broker** **New observing modes, additional ToO opportunities** Software to coordinate observations	0.3–1μm *R* ≈ 5000 single-object spectrograph > 10 x 10 arcmin FOV OIR imager	0.3–1μm *R* ≈ 5000 single-object spectrograph > 10 x 10 arcmin FOV OIR imager	**0.3–2μm *R* ≈ 5000 single-object spectrograph** > 10 x 10 arcmin FOV OIR imager *0.3–1μm R ≈ 5000 spectropolarimeter*	**0.3–2μm *R* ≈ 5000 single-object spectrograph** > 10 x 10 arcmin FOV OIR imager *0.3–1μm R ≈ 5000 spectropolarimeter*
SNe Ia	**Transient Broker** **New observing modes, additional ToO opportunities** Software to coordinate observations	> 10 x 10 arcmin FOV OIR imager	**0.3–2.3μm R ≈ 5000 single-object spectrograph** > 10 x 10 arcmin FOV OIR imager	**0.3–2.3μm R ≈ 5000 single-object spectrograph** *0.3–1.3μm R ≈ 5000 spectropolarimeter*	
Early Sne	**Transient Broker** **New observing modes, additional ToO opportunities** **Software to coordinate observations**	> 10 x 10 arcmin FOV OIR imager	0.3–2μm *R* ≈ 5000 single-object spectrograph	**0.3–2μm *R* ≈ 5000 single-object spectrograph**	
GW EM Counterparts	**LSST ToO Triggering** **Transient Broker** *Nearby Galaxy Catalog*			**~3 deg^2 FOV NIR imager** 0.3–2.3μm R ≈ 5000 single-object spectrograph	0.3–2.3μm R ≈ 5000 single-object spectrograph

Resource Needs

	Infrastructure	< 3m	3–5m	8m	25m
Characterizing Transients	**High-performance computing for broker**	50 hours spectroscopy 250 hours optical imaging 250 hours NIR imaging	100 hours spectroscopy 125 hours NIR imaging	**300 hours spectroscopy** 125 hours NIR imaging	**50 hours spectroscopy**
SNe Ia	**High-performance computing for broker**	5000 hours optical imaging 5000 hours NIR imaging	2250 hours optical imaging 9750 hours NIR imaging **6500 hours OIR spectroscopy**	2250 hours NIR imaging **7750 hours OIR spectroscopy**	
Early SNe	**High-performance computing for broker**		1500 hours optical imaging 850 hours OIR spectroscopy	200 hours optical imaging **1250 hours OIR spectroscopy**	
GW EM Counterparts	**High-performance computing for broker** **150 hours of LSST time for follow-up**			**900 hours NIR imaging** 80 hours OIR spectroscopy	80 hours NIR spectroscopy
Total On Sky Time		~ 2.9 years	~ 5.7 years	~ 3.5 years	~ 0.1 yr

Maunakea Spectroscopic Explorer

Credit: Najita, Wilman, et al. 2016 (Chapter 4: Characterizing the Transient Sky)

Detailed TVS Spectroscopic Demands and Resultant Science

TVS Science Area	Spectroscopic Follow-Up Requirements	Spectroscopic Information Utility
Microlensing Events	R ~few 1000's on 4-10 m telescopes	Characterize source star and to derive an independent estimate of its angular size and distance
Young Eruptive Protostars	Optical and NIR spectroscopy	Characterize the physical parameters & the mass accretion rate during the rising and peak phases; confirm emission line presence
Eclipsing Binaries	Rapid and "complete" spectroscopic follow-up	Derive absolute parameters and permits conversion to absolute dimensions
Cataclysmic Variables	Follow-up on 4-10m telescopes; medium resolution	Confirm classifications; confirm polar candidates
Neutron Star Binaries	Optical spectroscopy	Derive the donor star's spectral type, the effects of pulsar irradiation, and orbital parameters
Blazars	Multi-wavelength spectroscopy	Determine redshifts; enlarge samples
Pulsating Stars	Some "advance" spectroscopic follow-up possible	Determine radial velocities; derive fundamental parameters
Young Stellar Objects	Medium resolution; planned follow-up with eROSITA, 4MOST, and WEAVE	Confirm classifications; investigate variable YSOs showing accretion/ejection activity
Supernovae	~Medium resolution	Determine redshifts; examine explosion characteristics
ILOTs	Dedicated follow-up; Multi-wavelength (UV, optical, NIR); mid to high resolution	Determine correlations among the observable parameters; understand the ejecta kinematics, density, ionization structure
Brown Dwarfs	NIR wavelength; medium resolution (e.g., Magellan FIRE; SOAR ARCoIRIS)	Determine classifications/spectral types; estimate rotation periods
GW Events	4-10 m telescopes; multi-wavelength; space and ground based (e.g., NTT EFOSC2, JWST)	Determine nature of event; remove contaminants; study properties of emission

Credit: Rubin Observatory LSST Transients and Variable Stars Roadmap (2022; TVS Science Collaboration; eds. Hambelton, Bianco, & Street)

MSE Overlap with VRO-LSST Footprint

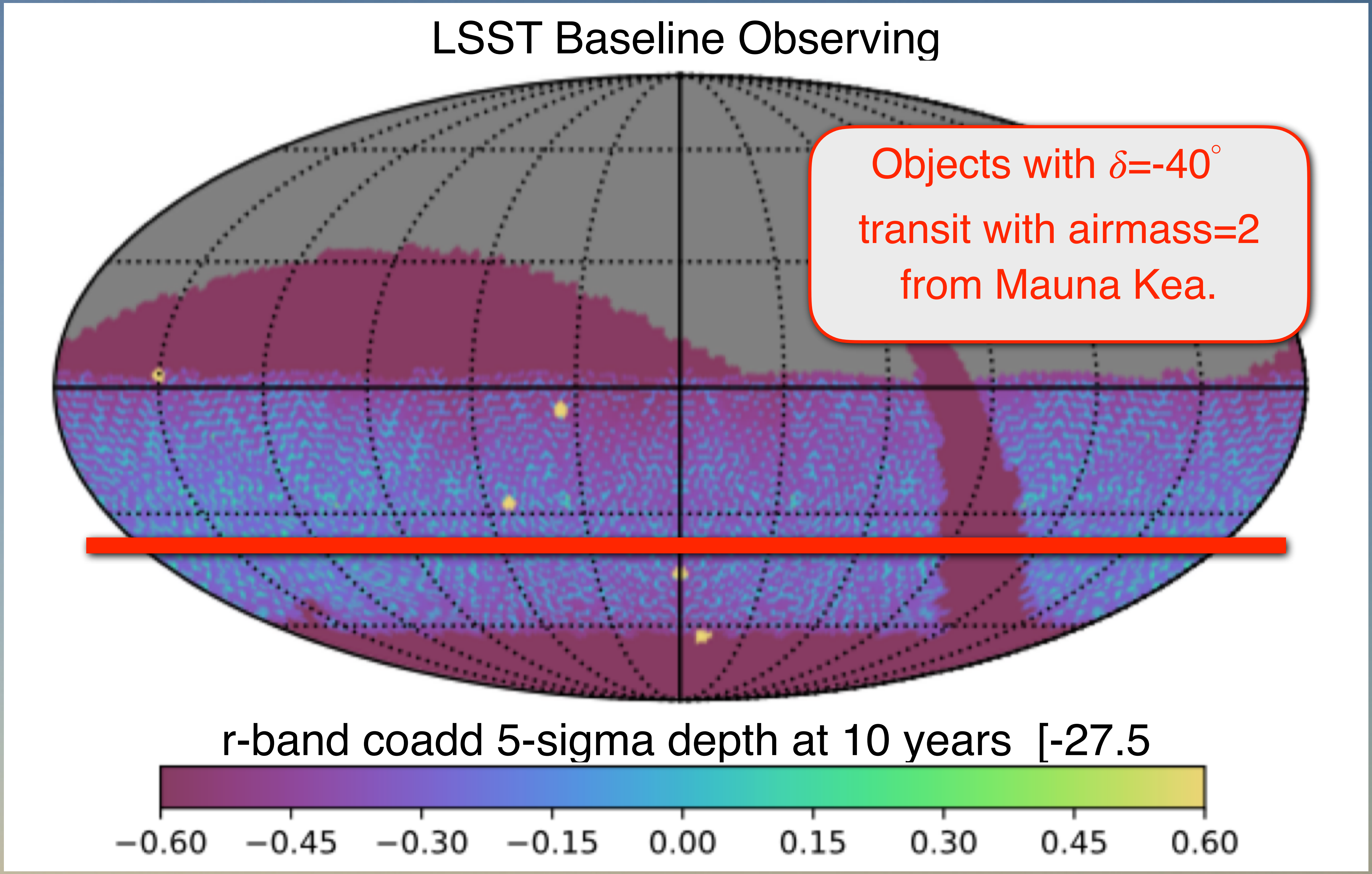


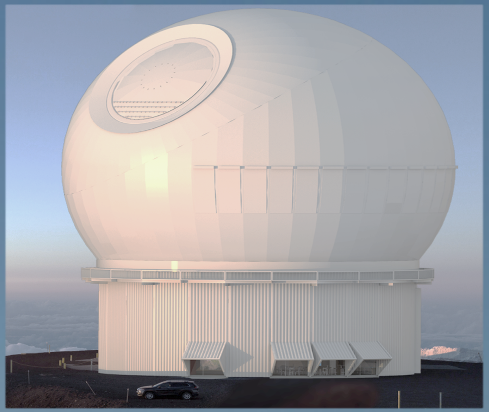
Image Credit: M. Graham

Approximate overlap area is on the order of 4500 square degrees

MSE Overlap with VRO-LSST Footprint

LSST

Primary LSST Footprint (Wide Fast Deep): DEC = -65 to +5



MSE

Zenith Angle Desired Range: < 50 degrees (DEC > -30)

Current Zenith Angle Limit: 60 degrees (DEC > -40)

Note that Zenith angle limit of 70 deg would reach DEC=-50

Current Projected MSE Coverage of LSST Footprint

- MSE will have access to 74% of the primary LSST footprint
- MSE will meet its science requirements over 59% of the primary LSST area
- MSE will observe at airmass < 1.4 over 51% of the primary LSST area

MSE + MSE Pathfinder Rapid Follow-Up Capability

	MSE	MSE Pathfinder	GMT
ToO Proposals Accepted	Potentially	Yes	Yes
Automatic Triggering	Potentially	Highly Likely	likely (when in queue mode)
Instruments Deployed	Hot	Hot	some hot (those w/ <3' field, +1 w/ 3")
Rapid ToO Acquisition Time	~15 minutes (slew, fiber repositioning, cal frames)	~12-15 minutes (slew, fiber repositioning, cal frames)	<10 minutes (slew & instrument change)
Optical Spectroscopy?	Yes	Yes	Yes (GMACS & G-CLEF high-res echelle)
Near Infrared Spectroscopy?	Yes	Highly Likely	Yes (GMTNIRS)
IFU?	Potentially	Highly Likely	Yes
Non-sidereal guiding?	Potentially	Potentially	Yes (up to 6"/min)
Immediate auto-reduction?	Planned; quick-look	Planned; quick-look	quick-look

Adapted from a table by M. Graham

Maunakea Spectroscopic Explorer

Summary and Requested Feedback

MSE-Pathfinder Overview

- 4m primary aperture
- LMR Spectroscopic Instrumentation (optical to NIR wavelength coverage)
- High multiplexing (fiber number: ~1000)
- Likely IFU capability

MSE Overview

- Dedicated spectroscopic facility
- 11m+ primary aperture
- LMR + HR Spectroscopic Instrumentation
- Visible and near-infrared wavelength coverage regimes
- Extremely high multiplexing (fiber number range: 4300~15000)

Questions and Feedback Request

- Is it possible to implement a prioritization scheme to promote spectroscopic follow-up of highest priority targets?
- What should be the sample follow-up sizes? Can a "boot-strap" sample be created for some science cases?
- What is the need for high resolution follow-up of TVS targets (R > 15000)? What is the need for IFU capability?
- ***Will spectroscopic information be employed to inform Rubin-LSST observations?***

Extra Slides

Changes to the Astronomy Landscape in Hawai’i

Actions taken to address the 2019 Protests include:

- Ku'iwalu Independent Review (2020)
- Mauna Kea Working Group (2021)]
- HB2024/Act 255 (2022)

HB2024 Overview:

- Removes the University of Hawai'i from land management role
- Declares Astronomy a policy of the state
- Establishes the Mauna Kea Stewardship and Oversight Authority (MKSOA)
- 11-member MKSOA Authority contains direct representation from the Native Hawaiian community in all aspects of the management of Maunakea
- Transition period from UH to Authority 2023-2028 (or shorter if agreed to by UH and MKSOA)
- MKSOA, the new State of Hawai’i management entity, can negotiate and grant site leases after 2028
- Current lease remains in effect until 2033

Image Credit: A. Hara

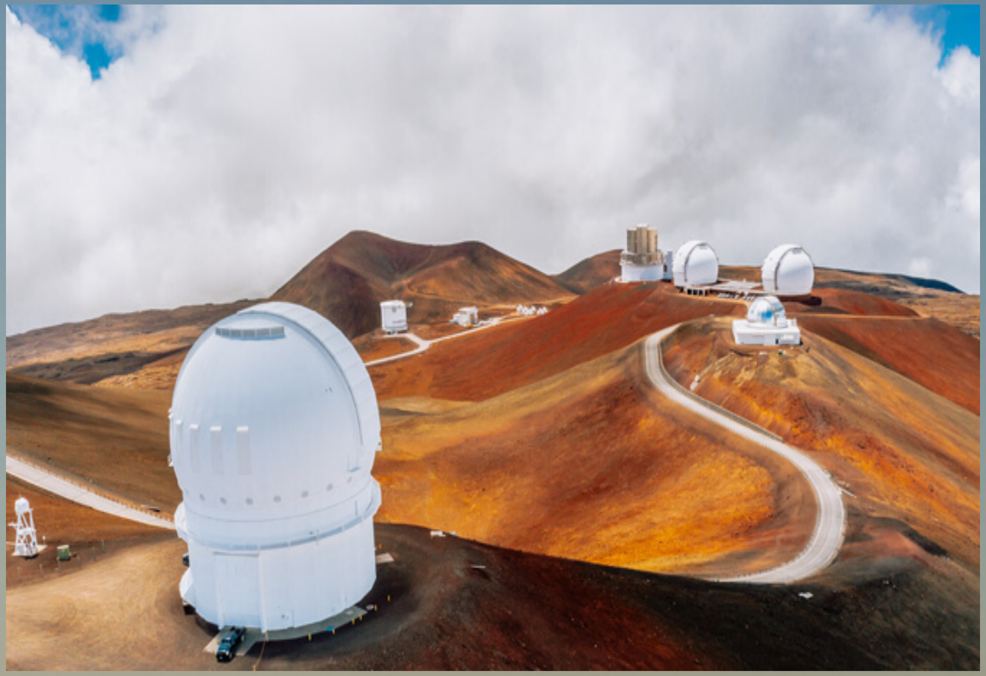


Image Source: UH System

A fundamental requirement for MSE to advance into construction phase is renewing CFHT's land authorization on Maunakea beyond 2033, after the expiration of the current Master Lease.

Maunakea Spectroscopic Explorer

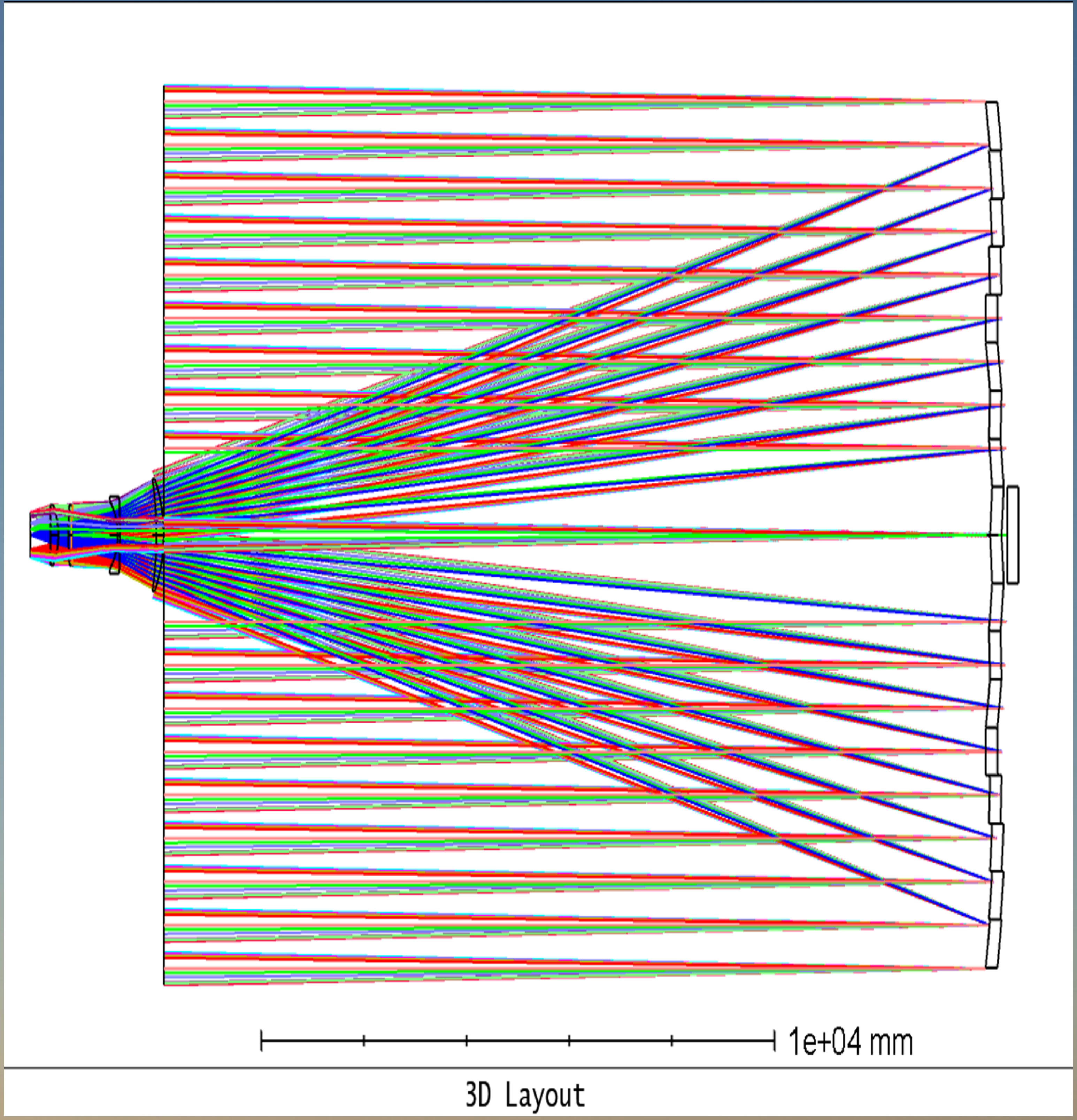
MSE Telescope Design Development: Prime Focus

Prime Focus Design

Characteristics:
- f/1.92
- 11.2-meter
- 105 micron/arc-sec
- ~4,300 fibers

Positives:
- Excellent Light Collection
- Only 1 mirror which is segmented allowing better coating
- Meets current segment production constraints

Negatives:
- Very fast focal ratio
- Requires larger dome
- WFC glass options limited



MSE Telescope Design Development: Elevated Quad Mirror

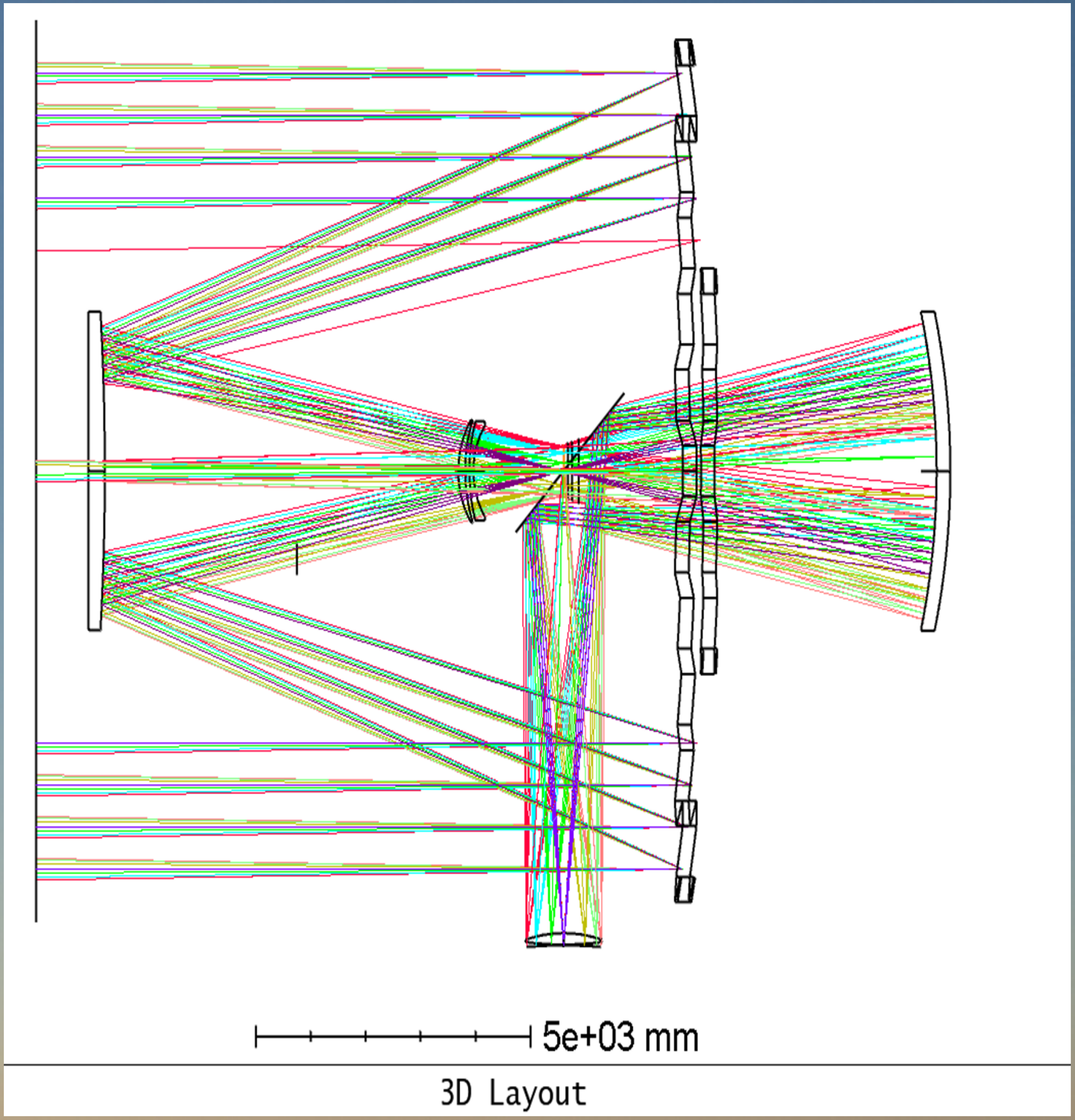
Elevated Quad Mirror Design

Characteristics:
- f/4.0
- 12.5-meter
- 245 micron/arc-sec
- ~23,000 fibers

Positives:
- Excellent Light Collection
- Focus at elevation axis
- Allows Nasmyth-mounted instruments off telescope
- M4 could rotate to illuminate other ports
- M2 is spherical not hyperboloidal
- Long, but still likely fits existing dome volume

Low optical ghosting

Negatives:
- 4 mirrors
- Does not quite meet segment production constraints*

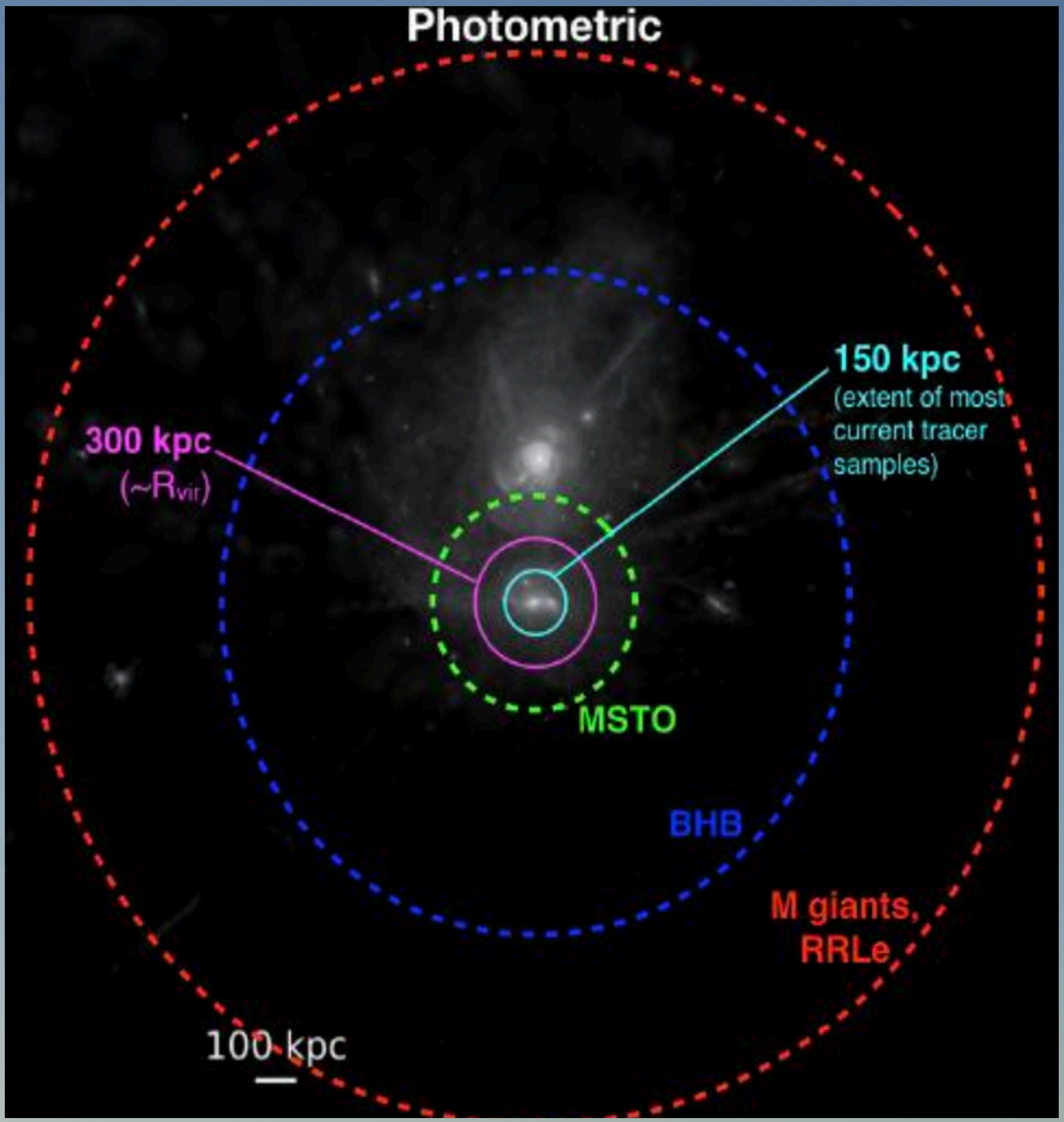


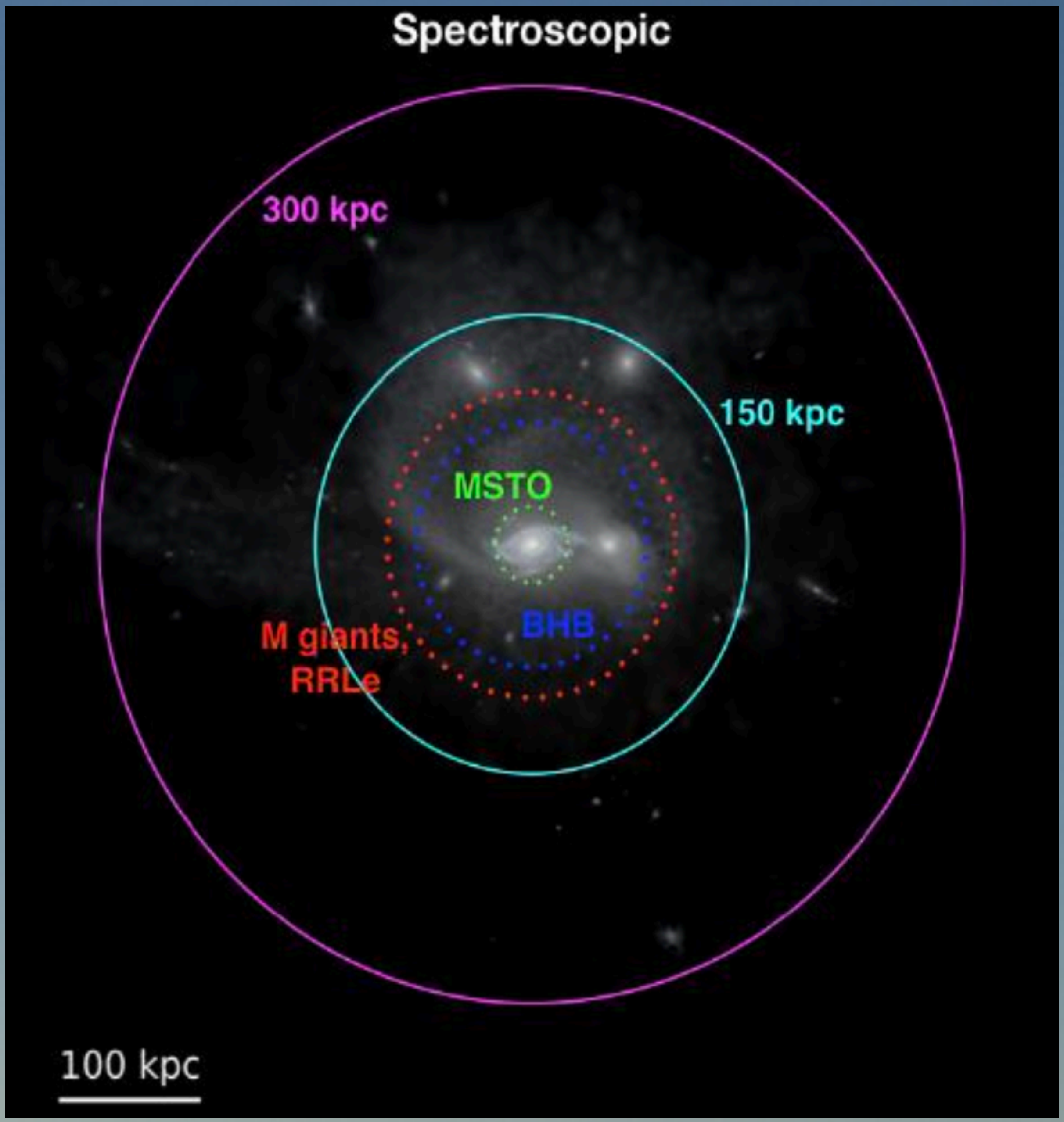
MSE in Strategic Reviews

US Decadal Survey on Astronomy and Astrophysics 2020

- Final report released November 2021: MSE fared very well!
  - MSE science aligns well with main Astro2020 science themes
    - "Worlds and Suns in Context" (exoplanets)
    - "New Messengers and New Physics" (gravitational wave /dark matter/cosmology)
    - "Cosmic Ecosystems" (galaxy formation and cosmic noon)
  - Other key recognitions for MSE
    - Highlight the need for dedicated large-aperture multiplexed spectroscopic facilities like MSE in 2030s
    - Call for augmenting funding at the mid-scale project level near the end of the decade
- State of the profession evaluation
  - Continue effort to increase diversity and inclusion
  - Propose a Community Astronomy model to advance scientific research while respecting, empowering, and benefiting Indigenous and local communities
- Technological foundation for ground- based astronomy development
  - Increase NSF instrumentation funding for Advanced Technologies and Instrumentation program

“Reach” Comparison: LSST + MSE-Pathfinder





Distances to which LSST will detect various stellar tracers in coadded fields (limiting magnitude r ~ 27).

Distances to which MSE-Pathfinder (a 4-m multiplexed spectroscopic instrument) will detect various stellar tracers

Maunakea Spectroscopic Explorer

Credit: MSE DSC 2019; Garrison-Kimmel et al. 2018