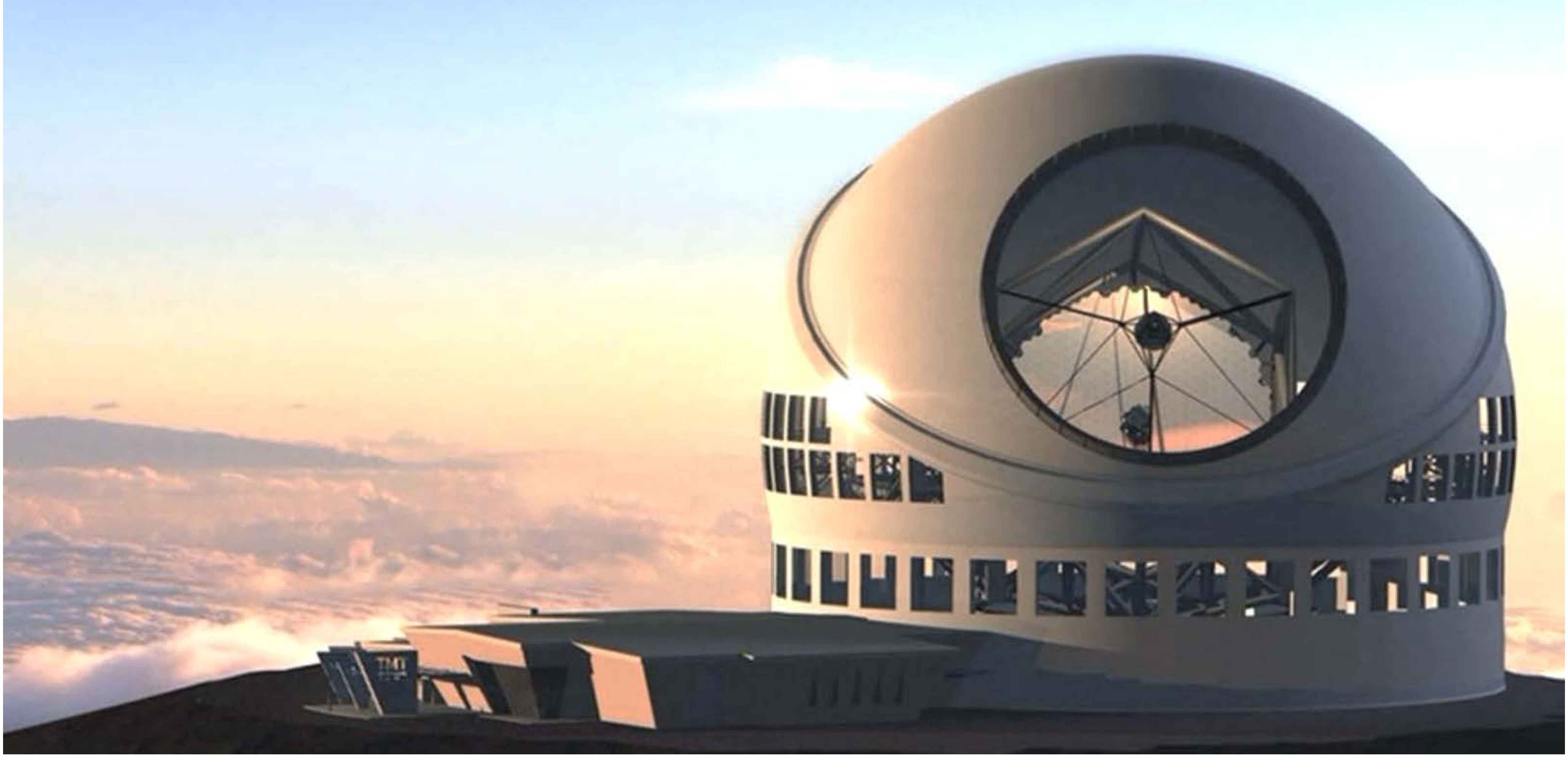
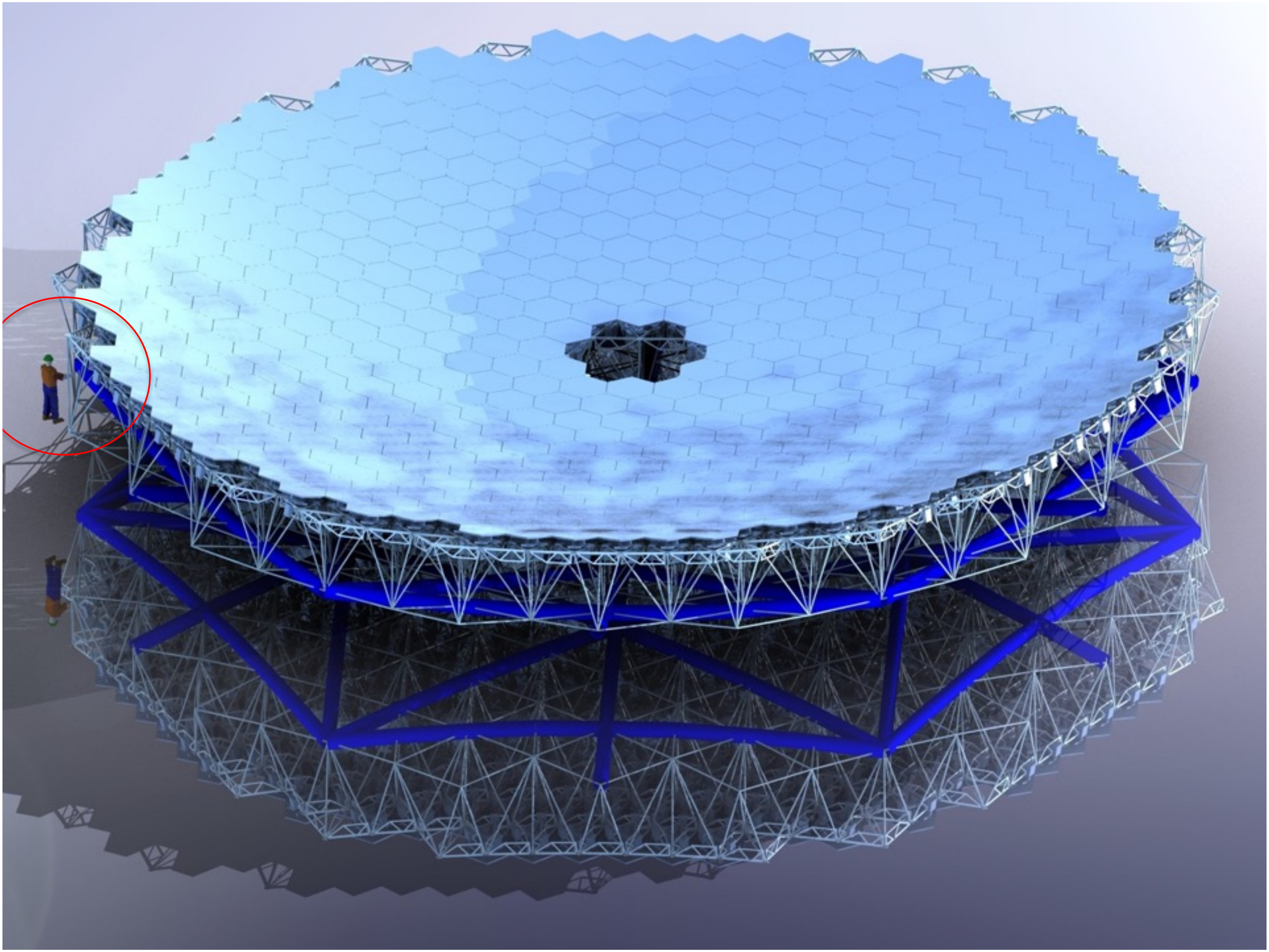
Project Status and Challenges

Fengchuan Liu, NAOJ, 1/16/2020

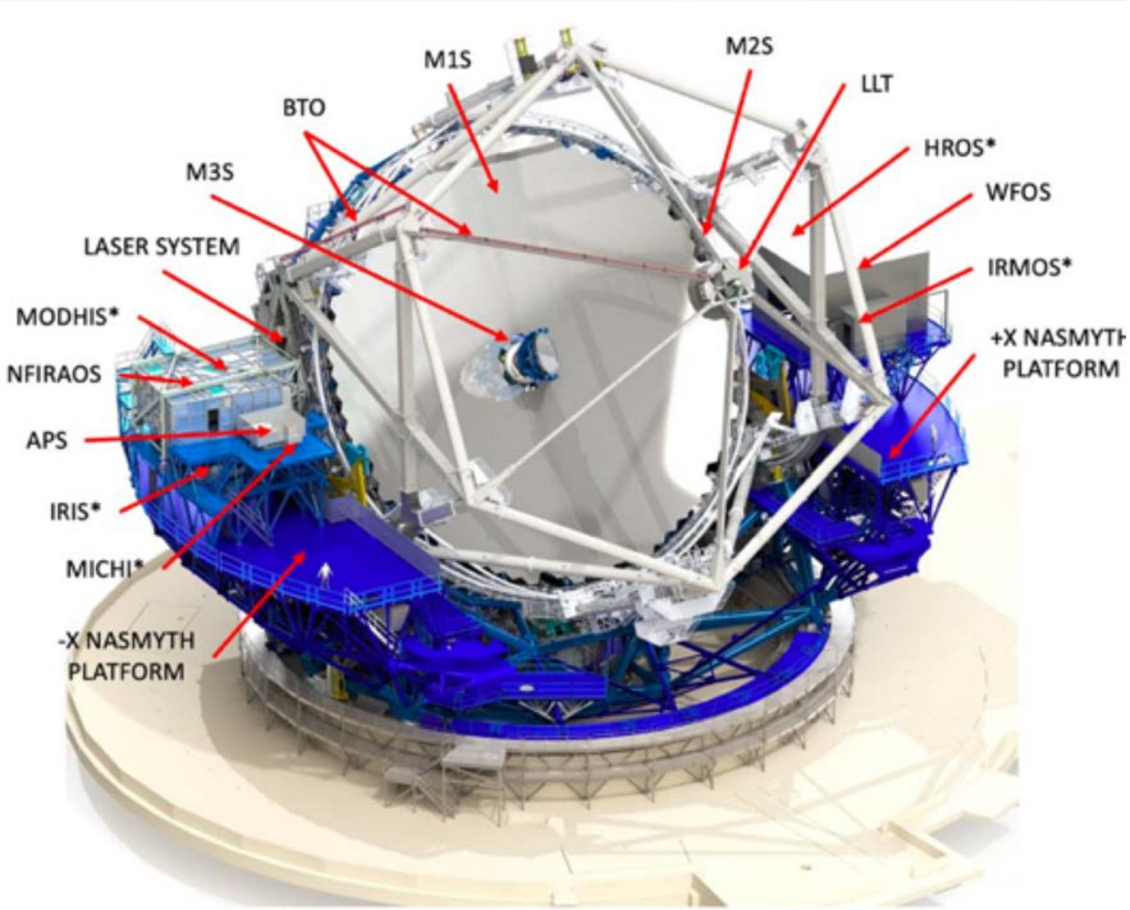
While Mauna Kea site makes news, TMT design and development team makes progress





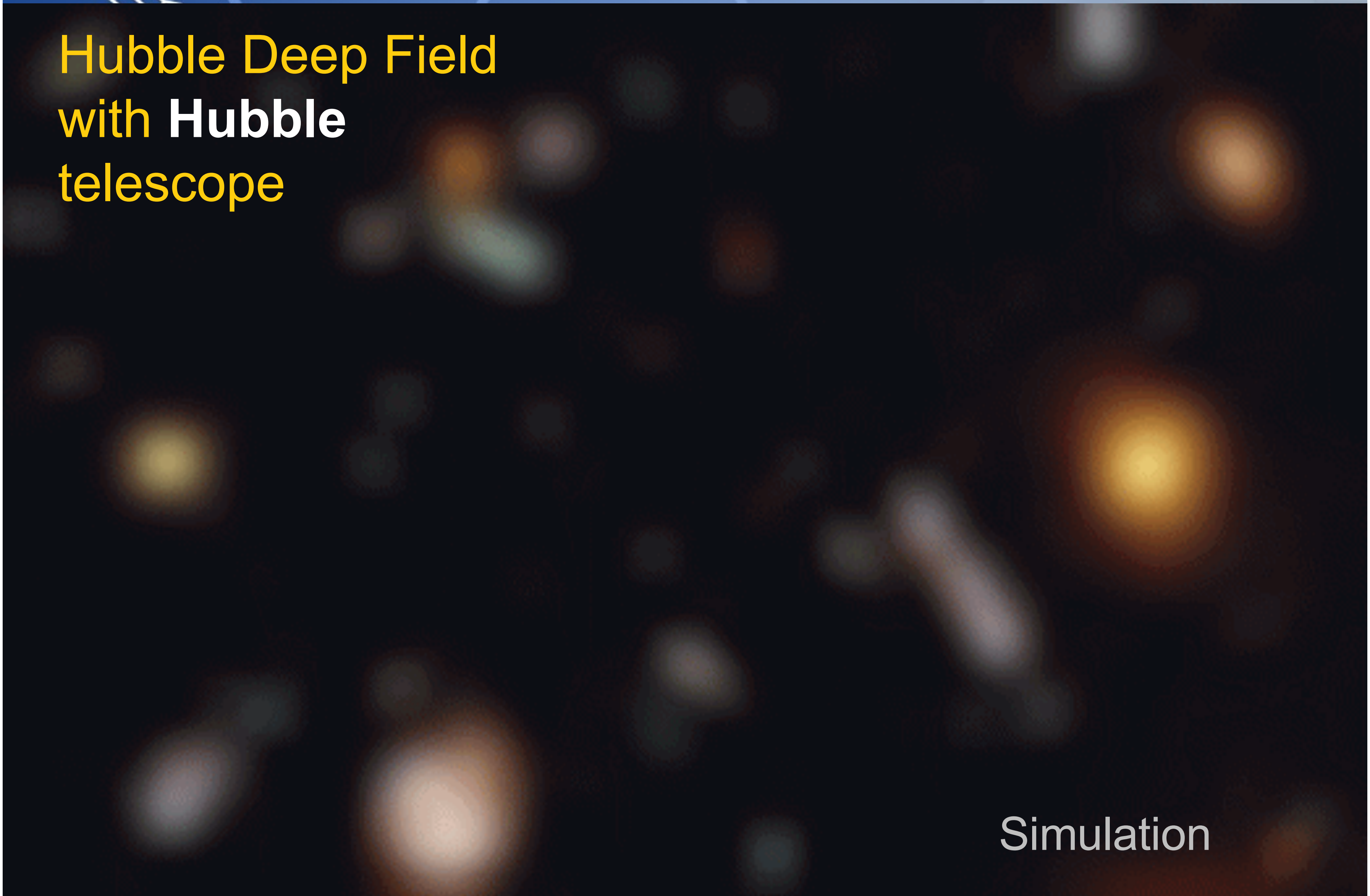
What Make TMT Powerful?

- 30m diameter aperture
  - 492-closed-pack segments
  - Keck heritage
  - 20 arcmin-diameter FOV
- State-of-the-art AO at 1st light
  - 0.007" resolution at 1 micron
- Powerful science instruments
  - Articulated tertiary can select any science instrument on platform in <2 min)

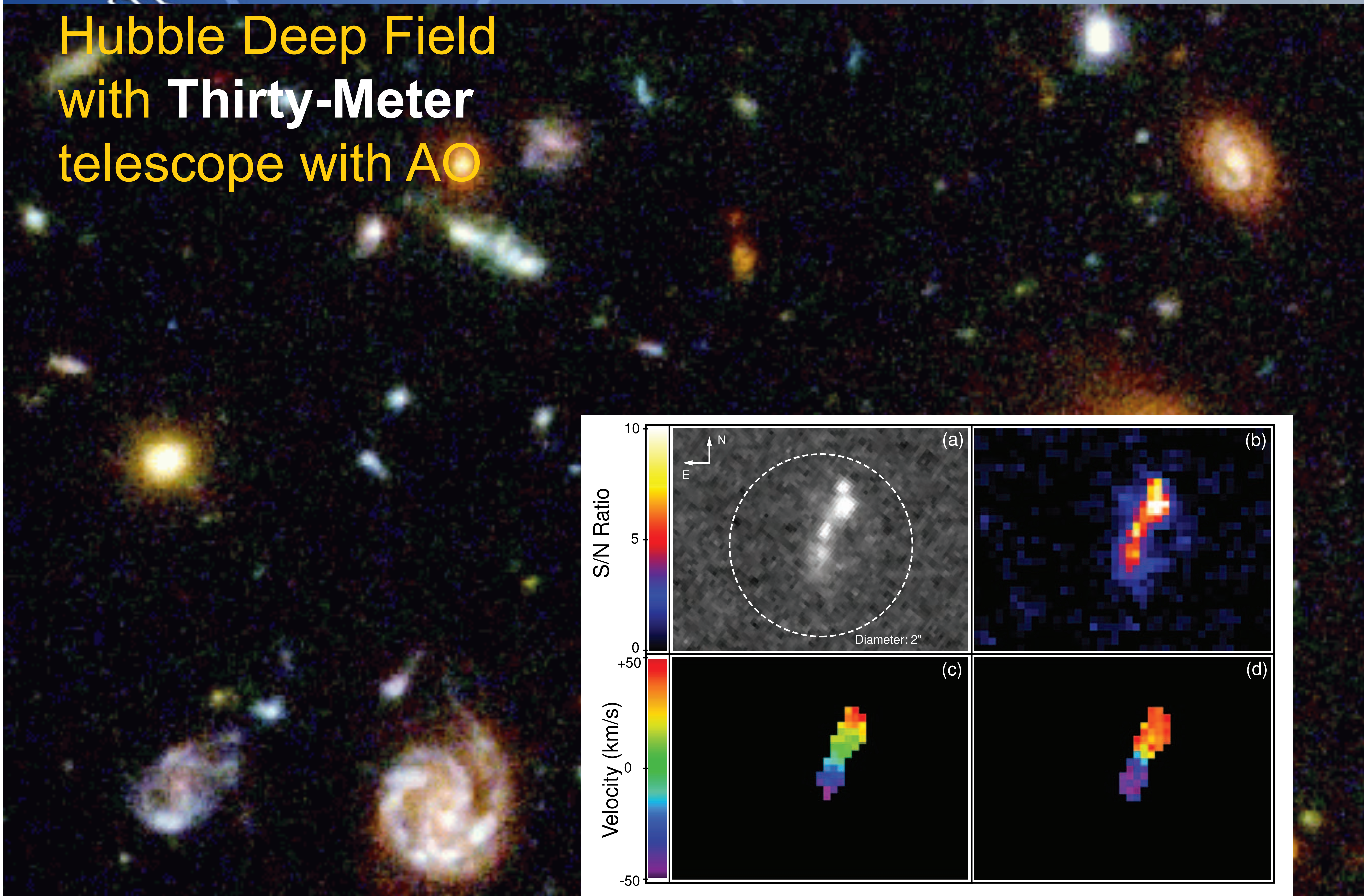


Emphasis on PSF (Point Spread Function): quality, knowledge, and long-term stability

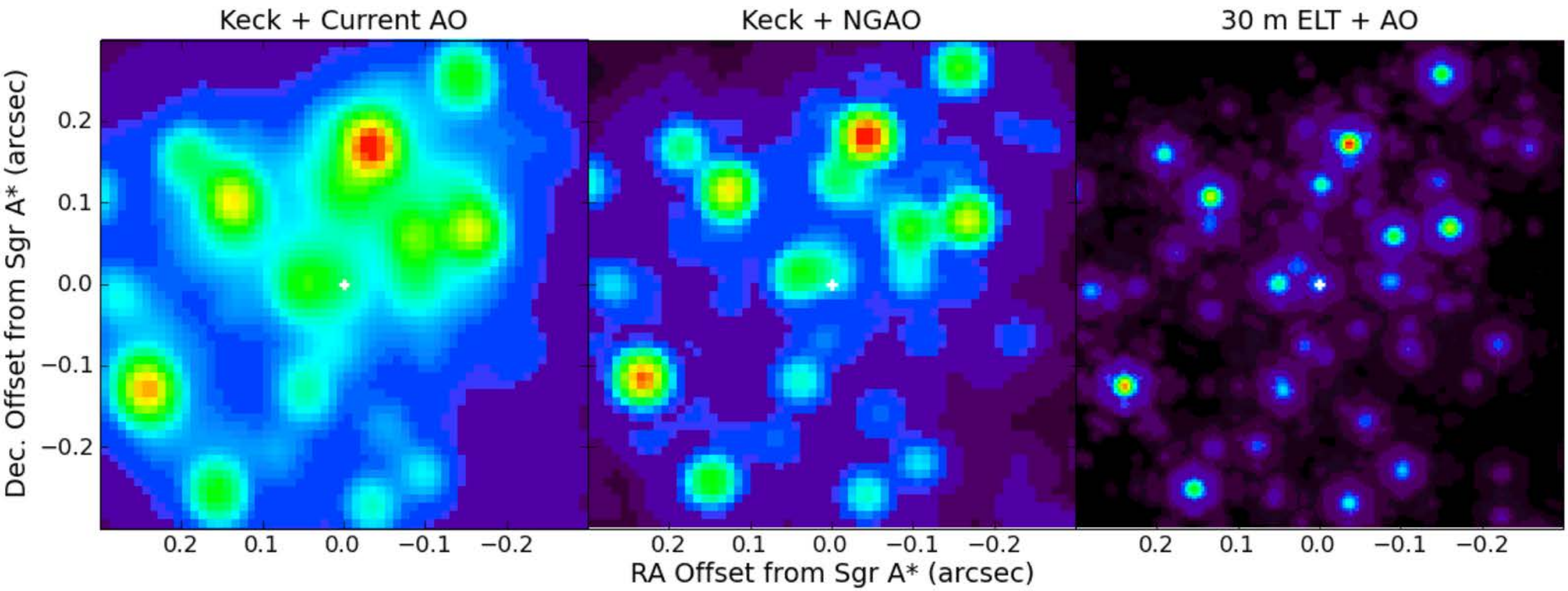
Hubble Deep Field with **Hubble** telescope



Hubble Deep Field with **Thirty-Meter** telescope with AO



Galactic Center

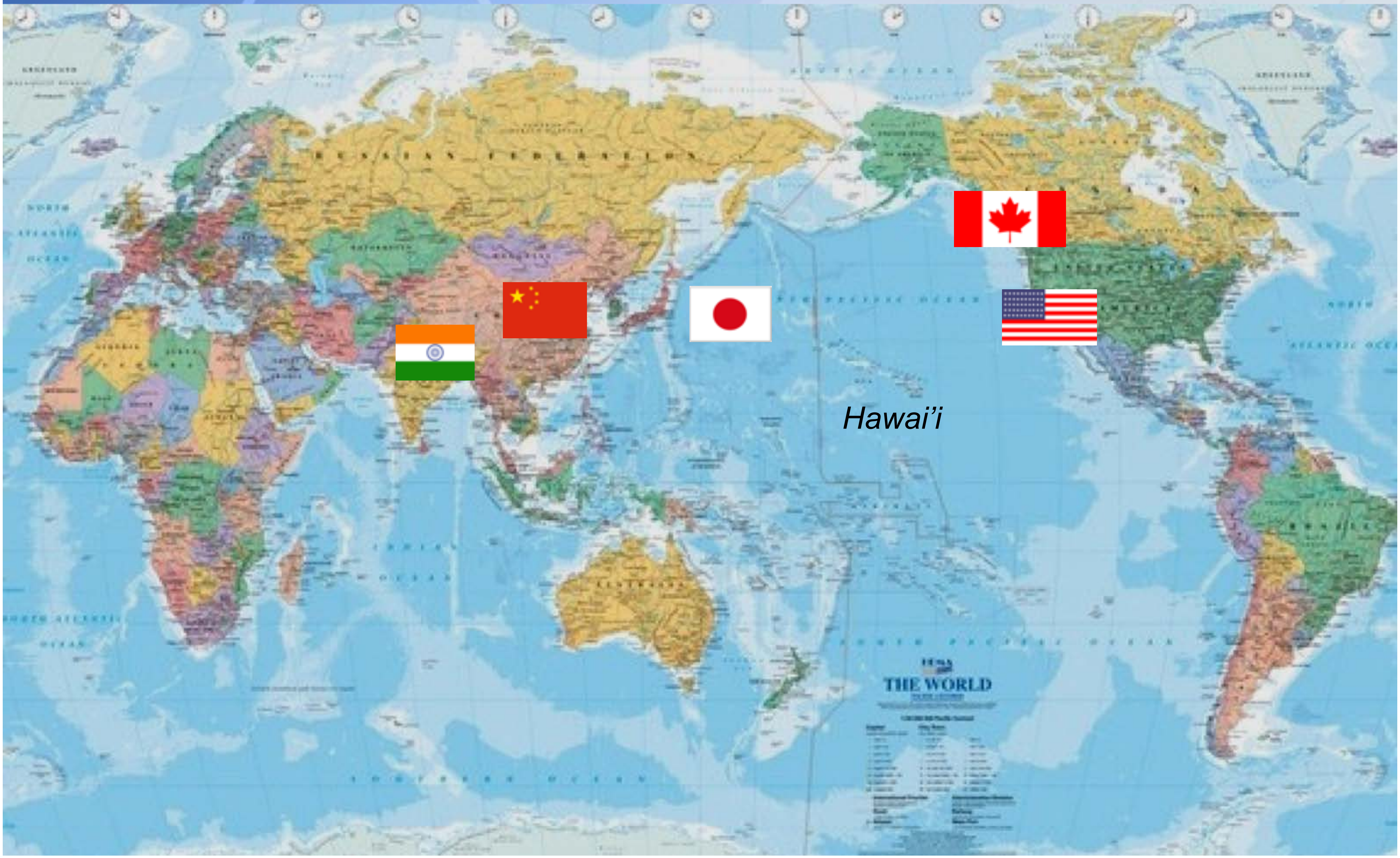


http://www.astro.ucla.edu/~ghezgroup/gc/pictures/Future_GCorbits.shtml

UCLA/Keck Galactic Center Group

- 3X improvement in spatial resolution
- 81X improvement in point source sensitivity

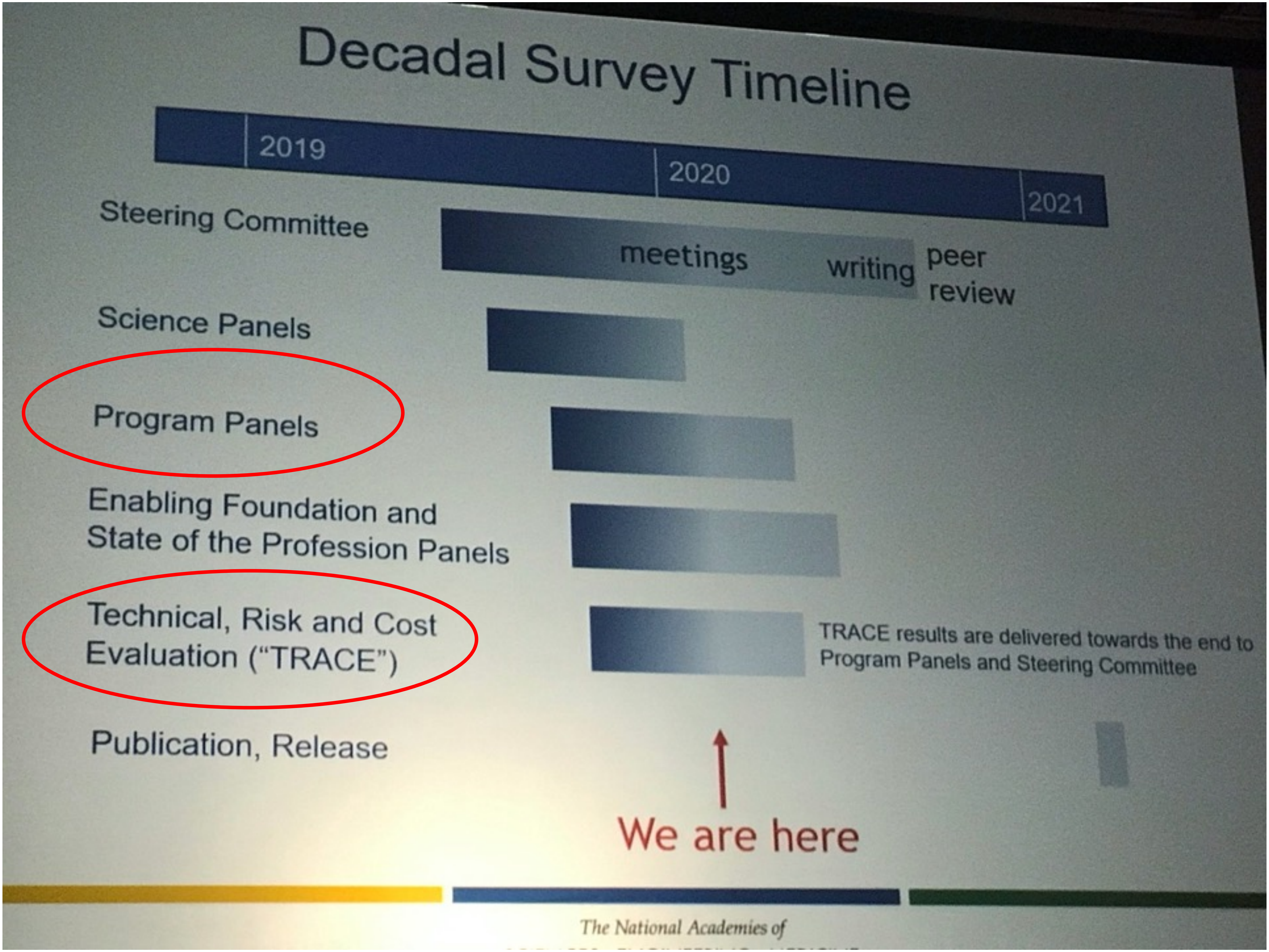
TMT International Observatory (TIO): Current Public-Private Partnership



TIO Public-Private Partnership

- Privately-raised funds:
  - Caltech, U. of California System (Thanks to the Moore Foundation)
  - This was a successful US model in the 20th century (Keck, Palomar…)
- Government funds: in-kind and cash contributions
  - Japan's NINS/NAOJ, India's DST, Canada's NRC
- China: NAOC-led CAS Institutes and universities
- US NSF is interest in funding at least 25% both TMT and GMT (USELT), pending top-ranking from the Decadal Survey (Astro2020).
- All TMT partners contribute to the observatory construction


U.S. EXTREMELY LARGE TELESCOPE PROGRAM
https://nationalastro.org/USELTP
NSF's National Optical-Infrared Astronomy Research Laboratory
TMT
THIRTY METER TELESCOPE
GIANT MAGELLAN TELESCOPE


Decadal Survey Timeline
2019
2020
2021
Steering Committee
meetings
writing
peer review
Science Panels
Program Panels
Enabling Foundation and State of the Profession Panels
Technical, Risk and Cost Evaluation ("TRACE")
TRACE results are delivered towards the end to Program Panels and Steering Committee
Publication, Release
We are here
The National Academies of

Project Implementation Paradigm

- Cost-capped (easier): Keck, WISE
- Schedule-constrained (harder): most planetary missions
- Requirements-driven (hardest): JWST
- Other complicating factors:
  - Politics, international in-kind, manned-mission safety
- TMT's main challenges:
  1. Politics (construction site)
  2. Extensive international in-kind contribution
  3. Requirement-driven

- TMT's main challenges:
  1. Politics (construction site)
  2. Extensive international in-kind contribution
  3. Requirement-driven design

Challenge: Site

MK: have Permit, but no Access

TMT
Thirty Meter Telescope

Design Status Report, Design Development
TMT.SUM.TEC.17.008.DRF01
Thirty Meter Telescope Facilities at Observatorio del Roque de los Muchachos

TMT International Observatory, LLC (TIO)

M3-PN160051 : August 25, 2017 : Revision 0

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Alternate Site: La Palma ORM;
All permits in hand, no major access issue.

TMT
Thirty Meter Telescope

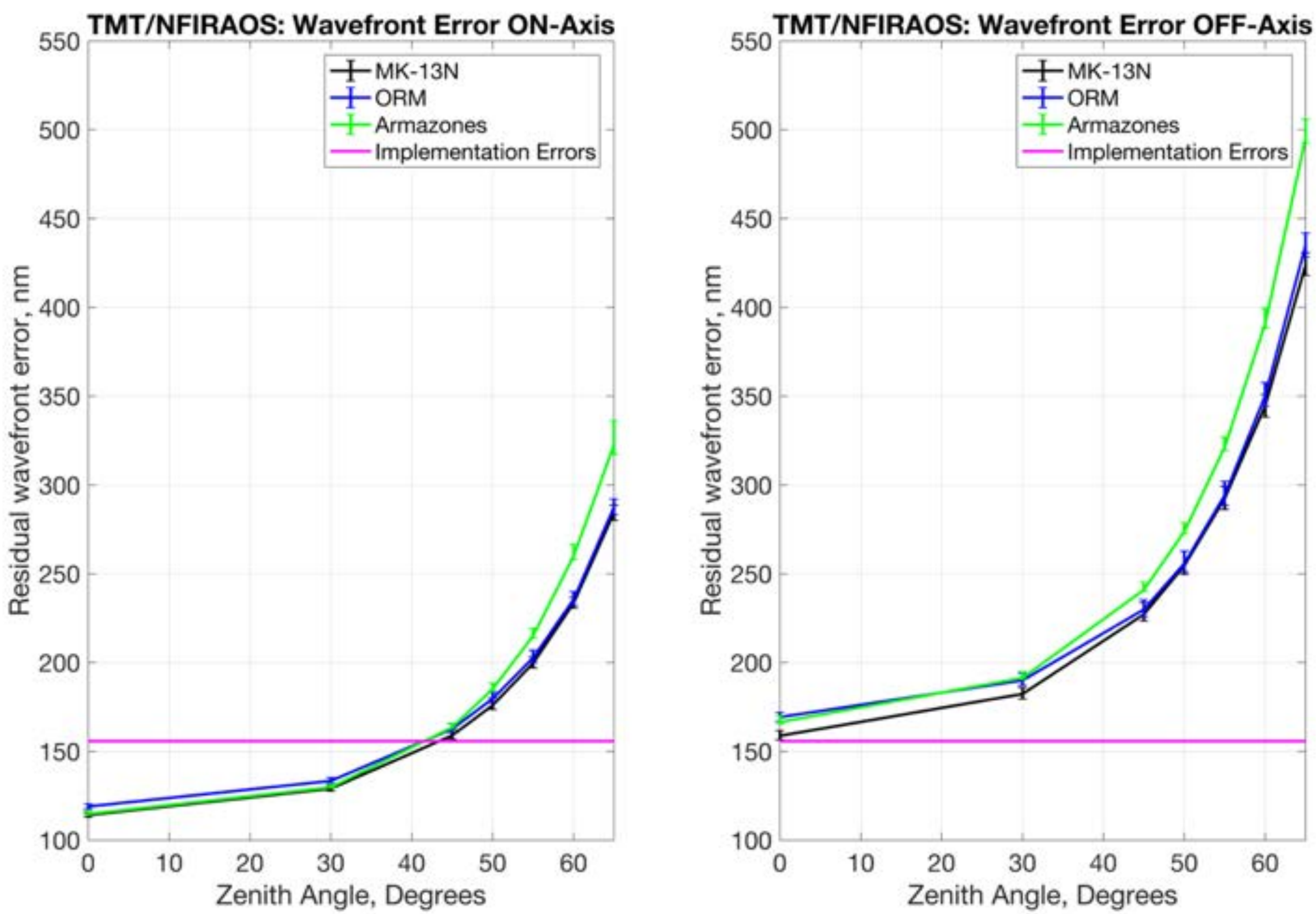
MK vs ORM Characteristics

***Table 2-5** Summary of the main site characteristics that affect the ability to conduct astronomical observations at Maunakea 13N and ORM.*

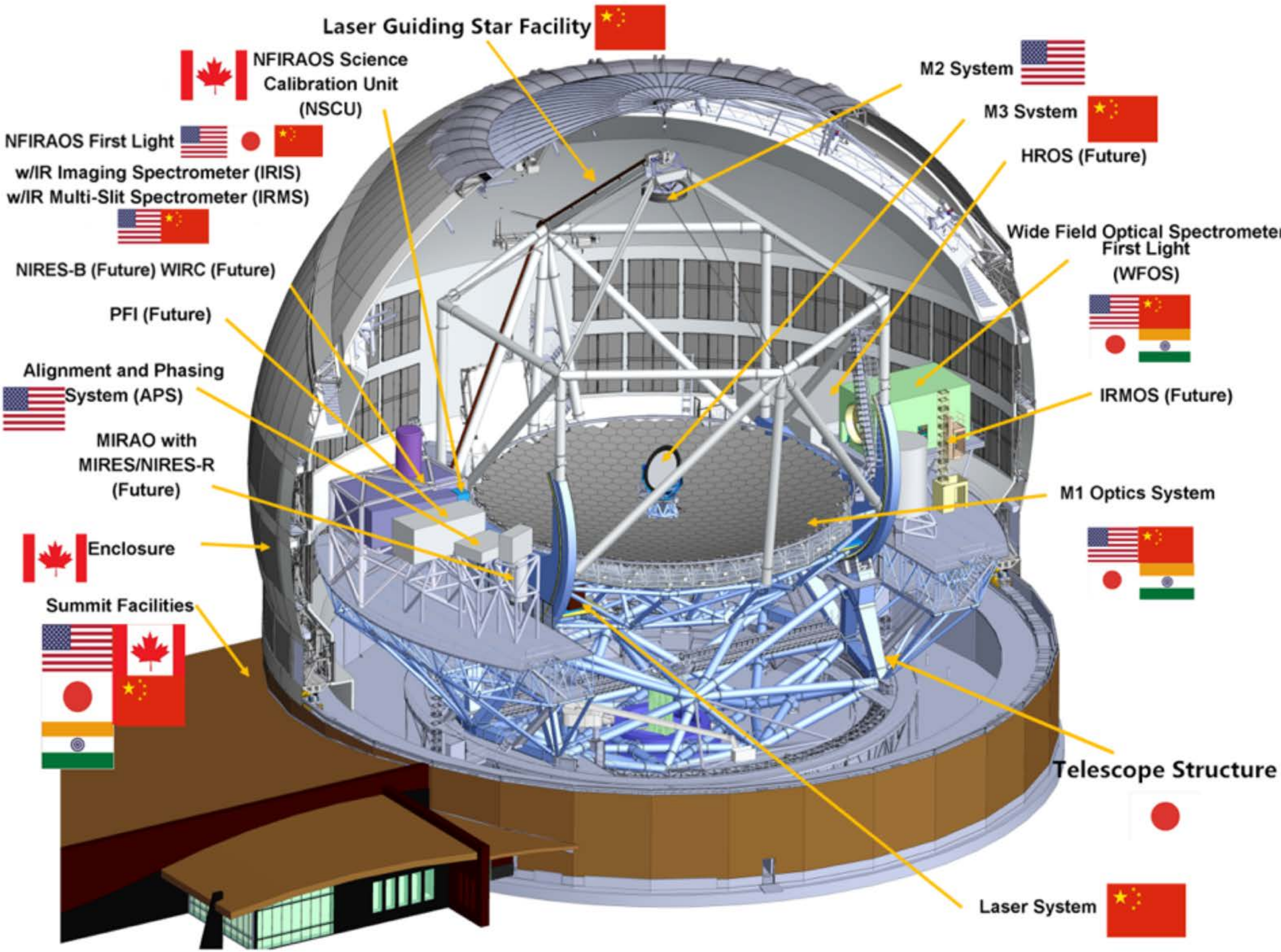
Site Characteristics (median values, unless otherwise stated)	MK13N	ORM
Longitude (deg W)	155.5°W	17.9°W
Latitude (deg N)	19.82°	28.8°
Altitude (m)	4050	2250
Seeing at 60m above ground (arcsec at 500 nm)	0.50	0.55
Isoplanatic angle (arcsecond)	2.55	2.33
Atmospheric coherence time (ms)	7.3	6.0
Adaptive Optics Strehl merit function	1.00	0.93
Precipitable Water Vapor (% time < 2mm)	54	>20
Mean night temperature (˚C)	2.3	7.6
Extinction (V_{mag}/airmass)	0.111	0.132
Dust (μg/m^3)	0.815	1.006
Usable time fraction	0.72	0.72

MK, ORM Atmospheric Turbulence Profile Are Similar

NFIRAOS AO performance similar at MK and ORM, better than Amazones



- TMT’s main challenges:
  1. Politics (construction site)
  2. Extensive international in-kind contribution
  3. Requirement-driven design



Laser Guiding Star Facility
NFIRAOS Science Calibration Unit (NSCU)
M2 System
M3 Svstem
HROS (Future)
NFIRAOS First Light
w/IR Imaging Spectrometer (IRIS)
w/IR Multi-Slit Spectrometer (IRMS)
Wide Field Optical Spectrometer First Light (WFOS)
NIRES-B (Future) WIRC (Future)
PFI (Future)
Alignment and Phasing System (APS)
IRMOS (Future)
MIRAO with MIRES/NIRES-R (Future)
M1 Optics System
Enclosure
Summit Facilities
Telescope Structure
Laser System

Extensive International In-kind (opportunities and challenges)

- Very Different Engineering Cultures:
  - Systems engineering (SE) practice, reviews and documentations;
  - Requirements flow-down and interface definition;
  - Design practice, analysis and simulation;
  - Safety culture and quality assurance;
  - Verification and test;
  - Project control(schedule/cost/contingences); procurement, contract
  - Risk managements and decision-making process
- Mitigations: enforcing (at a cost of extra time and money)
  - Consistent SE practice, reviews, designs, analysis, documentation
  - Lots of prototyping
  - Consistent safety standard and quality control;
  - Consistent management practices and frequent communications
  - Having a plan B for every task with delivery risks

NAOJ Staff in Pasadena

- 6+ NAOJ members re-located to TMT Project office
  - TMT-J office; plus additional NAOJ staff support TMT subsystems.
- Significantly improving communications and English, bridging gaps in engineering cultures
- The NAOJ efforts are very much appreciated, motivating China to do the same.

- TMT's main challenges:
  1. Politics (construction site)
  2. Extensive international in-kind contribution
  3. Requirement-driven design
     - A set of high performance requirements with high confidence of achieving them is a great thing, but it costs time and resources;
     - Fortunately….

82% of the total system level cost is in final design, production/readiness.

Production/Readiness

Final Design

Table 1-1: Technical Maturity Level of TMT Subsystems and Major Components

Subsystem	Major Component	Current Phase	Technical Maturity, Technology Readiness, Risk and Mitigation
Enclosure		Production Readiness	Completed FDR; no new technology; completed prototyping for production risk-reduction.
Summit Facilities		Production Readiness	Completed FDR; Civil Package construction drawings and specifications prepared; no new technology; mitigations in place for adverse geotechnical conditions; alternative site identified.
Telescope Structure	Telescope Structure	Final Design	FDR-Completion review scheduled for Nov.13-15, 2019; no new technology; multiple prototypes (Azimuth wrap, seismic isolators, motor drive, SHS, etc.) completed for production risk-reduction.
Primary Mirror	Glass Blanks	Production	388+ blanks produced to date; all development, production, shipping/logistic risks retired.
	Segments	Production	Passed M1 System FDR and completed extensive qualification programs. Japan and US (2 of 4) polishing suppliers passed PRR, now in production. China polishing Equipment Readiness Review is scheduled for Nov. 8, 2019; India is in final contract negotiation with US supplier (Coherent) to import end-to-end production capability. Can go to First Light with Japan and US segments.
	Segment Support Assembly	Production	Passed FDR (see above); completed all prototyping and testing; built 6 sets in US to finalize production process; India vendor started production in 2019; India production schedule risk is mitigated by more production in US.
Secondary Mirror	Complete System	Preliminary Design	Multiple design studies completed; vendor candidates known, each with heritage and mature technology.
Tertiary Mirror	Complete System	Preliminary Design	PDR scheduled on Nov.21-22, 2019; ¼ -scale prototyping and testing completed; no new technology but programmatic risk exists with the current provider; backup vendor known with demonstrated capability.

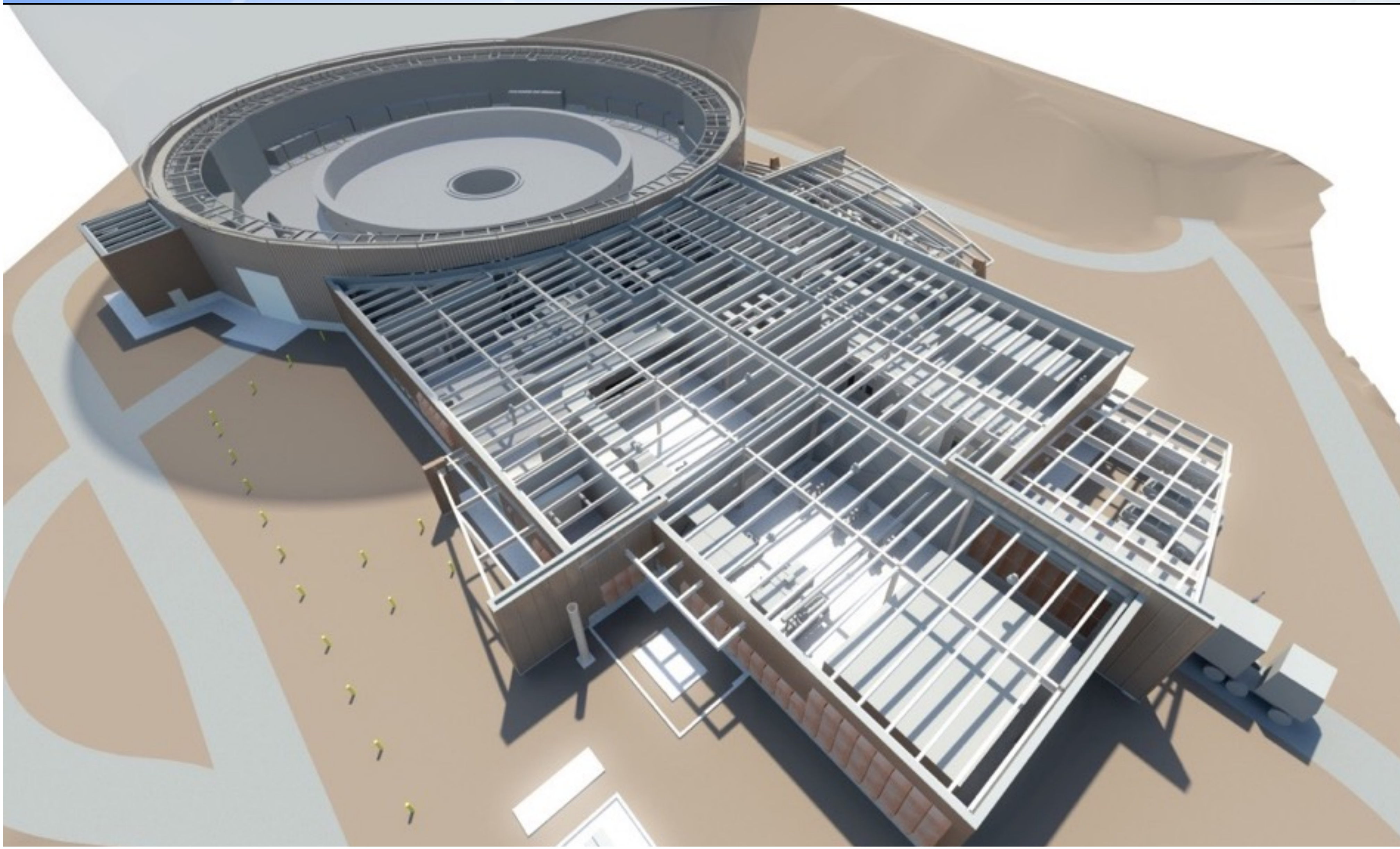
Can release performance margins to accept hardware items narrowly missing requirements

Production/Readiness

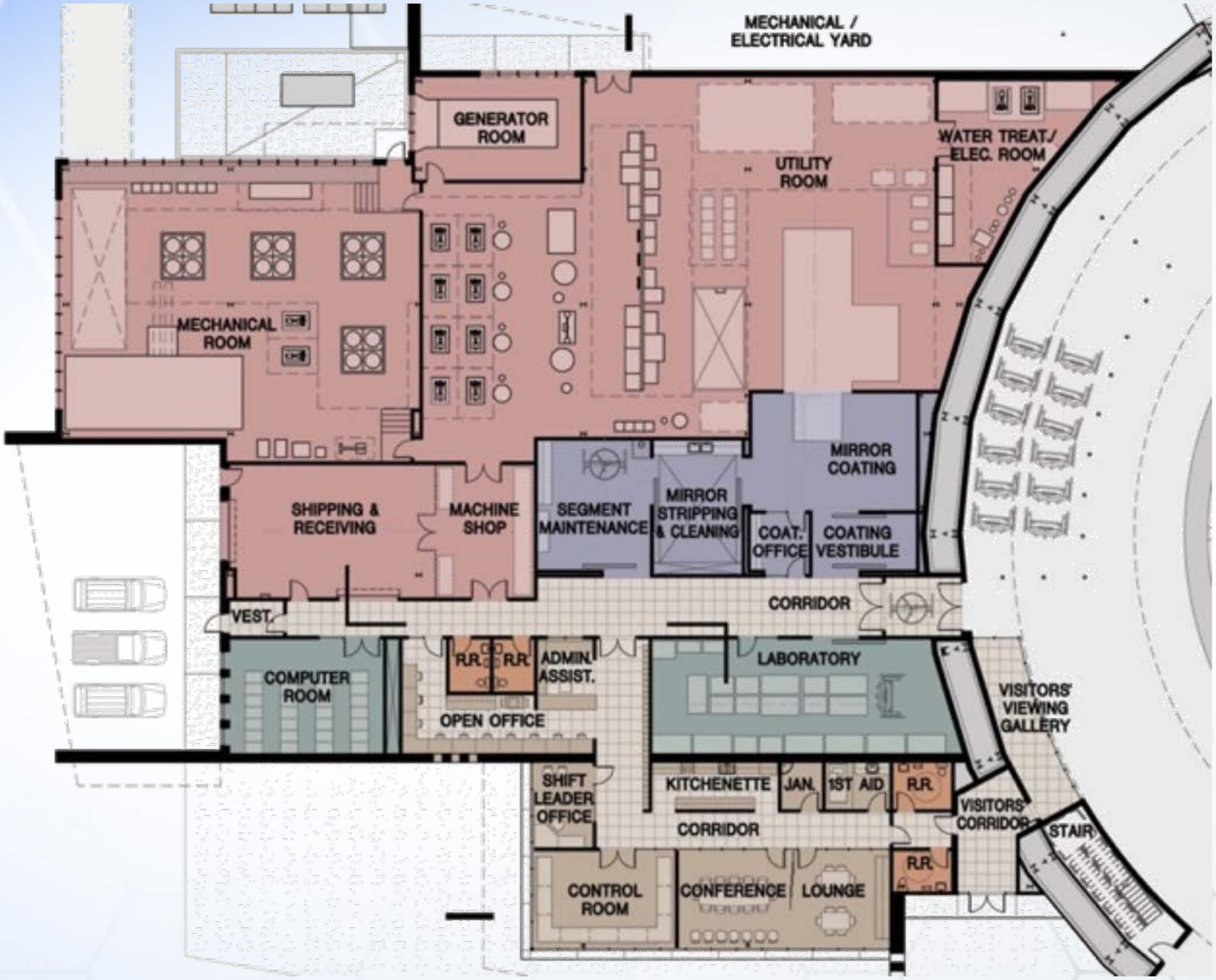
Final Design

Subsystem	Major Component	Current Phase	Technical Maturity, Technology Readiness, Risk and Mitigation
Telescope Coating System	Coating System	Conceptual Design	India partner's HindHiVac coating chamber meets TMT requirements; existing coating recipe needs broadening to meet TMT's wide spectrum coverage requirement and goal. Multiple iterations planned and ample time before First Light for the coating recipe improvement. Re-coating opportunities exist in 2-year cycles after First Light.
Telescope Controls	M1 Control System	Final Design	US design with extensive prototyping and testing to demonstrate design and establish fabrication process; extensive prototyping and testing in India to qualify multiple production vendors; completed dynamic/static testing of integrated segment support and actuators.
	Alignment & Phasing System	Preliminary Design	Extensive Keck heritage and lessons-learned; TMT-Keck joint software development, with TMT software prototype successfully utilized on Keck; lenslets and method tested and successfully demonstrated; active collaboration with EELT.
	Telescope Control System	Final Design	Passed PDR on Sept. 11-12, 2019.
AO Facility Instrument	Facility MCAO System NFIRAOS	Production Readiness	Completed FDR; Optics ready for production; extensive analysis, prototyping and testing on components listed below; large performance margins and graceful degradation.
	Deformable Mirror Drive Electronics	Preliminary Design	Deformable Mirror Drive Electronics Prototype with 7 96-channel boards tested with DM prototype
	Deformable Mirrors	Fabrication	Conducted a technology development program with two competing vendors; successfully tested CILAS prototype, meeting or exceeding all TMT requirements; CILAS on FFP contract, in fabrication of two production DMs.
	Tip Tilt Stage	Fabrication	Production model built and tested; refurbishing of control electronics required
	Visible WFS Detectors	Fabrication	Completed design, fabrication and test of multiple prototype detectors, meeting performance requirements with satisfactory yield; completed processing all production and spare detectors, in final packaging stage.
	Visible WFS Readout Electronics	Final Design	Completed prototyping and testing, demonstrating performance requirements.
	Visible WFS Camera	Final Design	Prototype report completed. INO on FFP contract to complete final design, fabrication through delivery.
	Real Time Controller	Fabrication	PRR completed. Benchmarking tests performed and passed.
Laser Guide Star Facility	Laser Guide Star Facility	Preliminary Design	Completed CoDR; PDR scheduled in 2020; elevated programmatic development risk is mitigated by identifying an experienced and proven backup vendor.

Summit Facility (M3 Engineering)

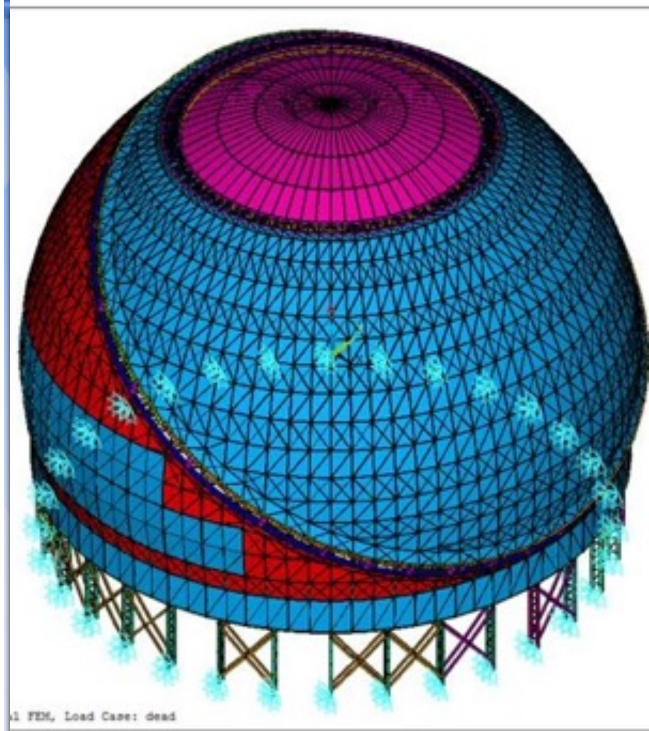


Summit Facility (M3 Engineering)



Ready to build in MK (since 2015), or ORM

Enclosure Passed FDR
(Dynamic Structures Ltd.)



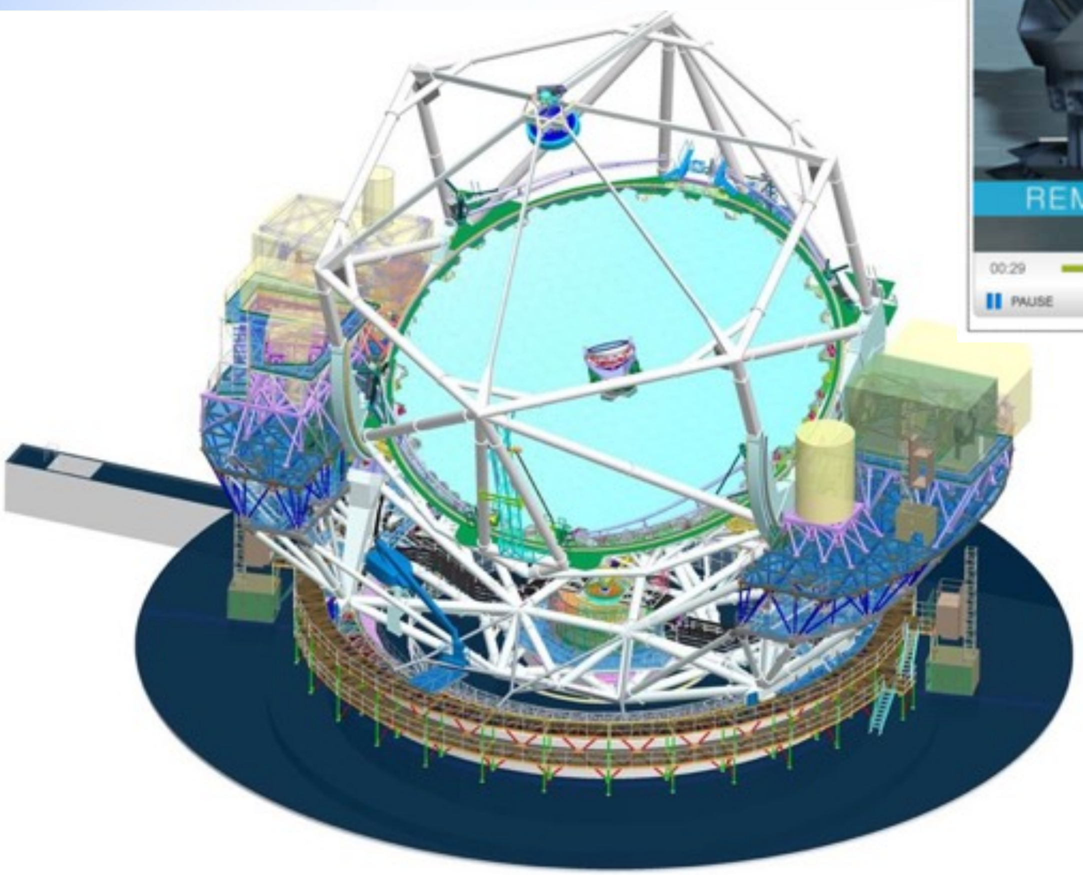
Ready for fabrication

Telescope Structure
Mitsubishi Electric Corp. (MELCO)

TMT
Thirty Meter Telescope

Completed Final Design, ready for fabrication

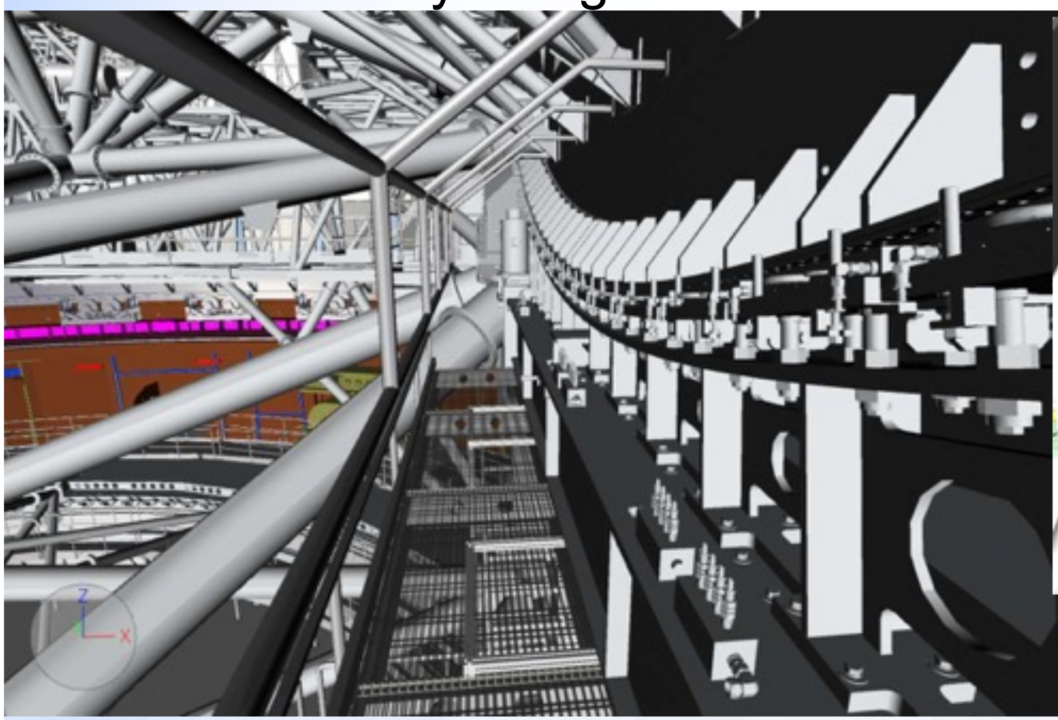
(Masahiro, Masao, Hiroshi, Junji)



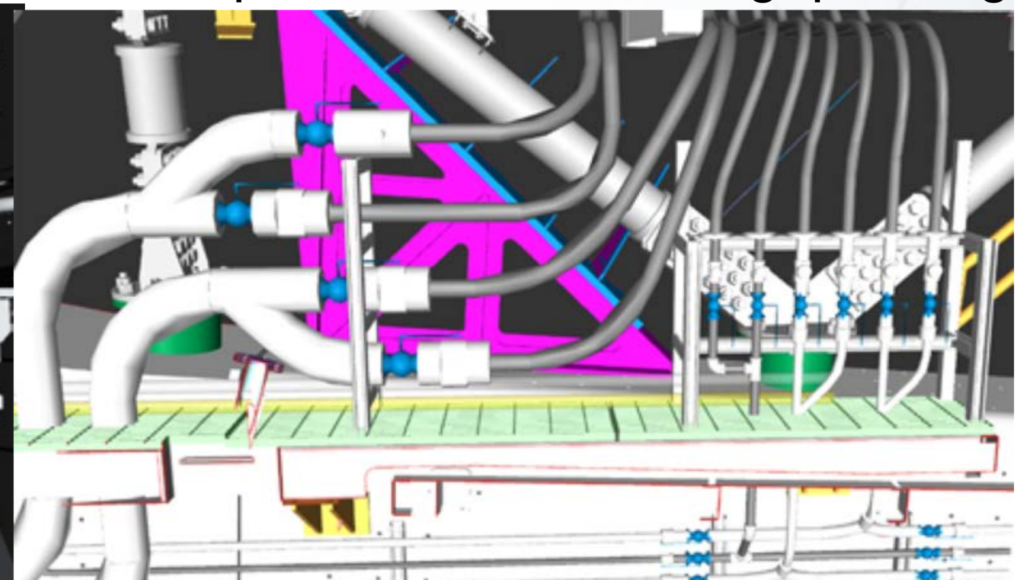
Telescope Utility Services in Final Design (M3E)

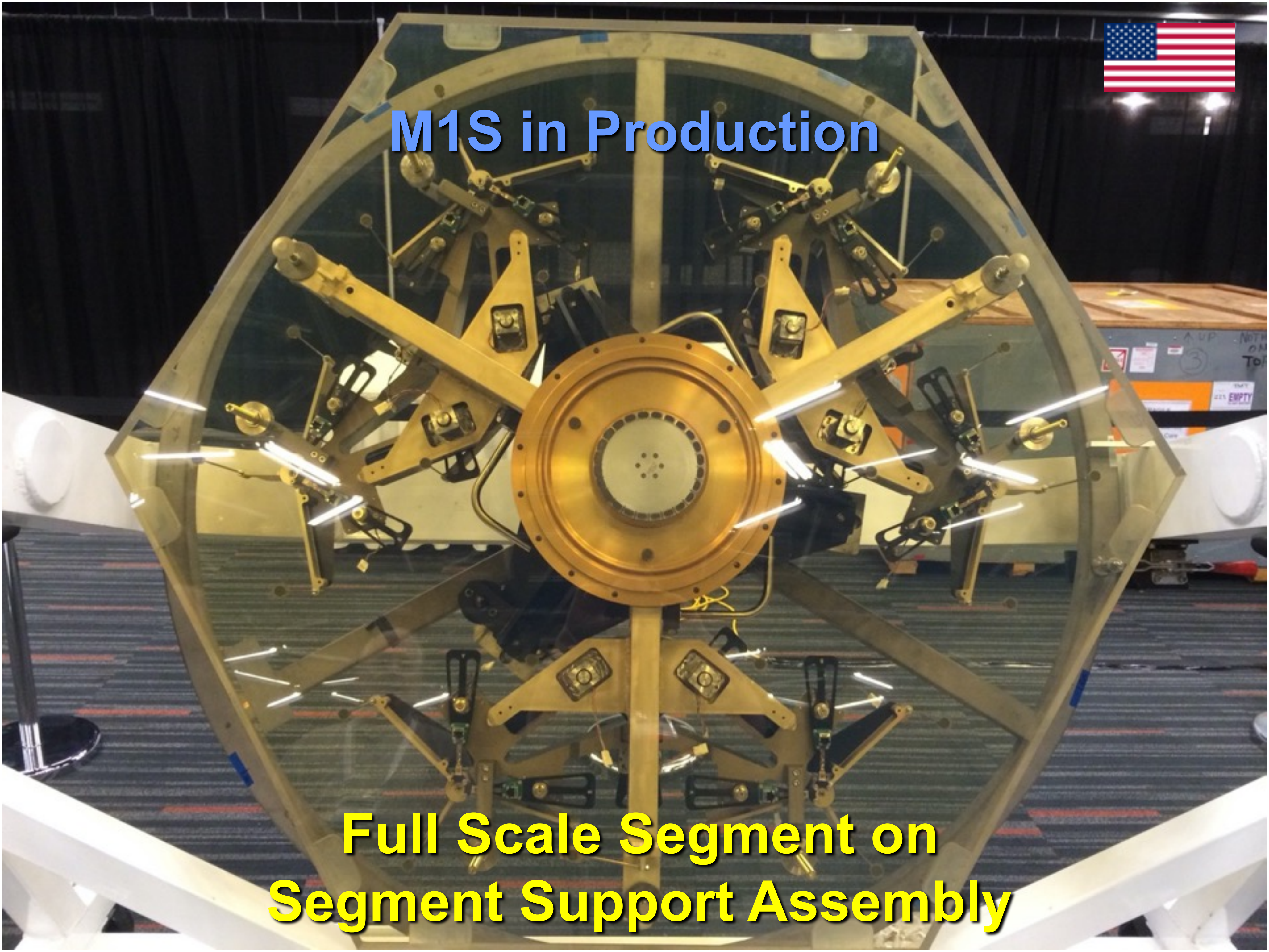
- Power panels, Coolants, Compressed Air, etc. – complex I/F
- TMTPO and M3E preparing for FDR in ~~Jan.~~ June 2020 (Seiichi)

Virtual-reality design view



Complex interfaces, wiring, pluming



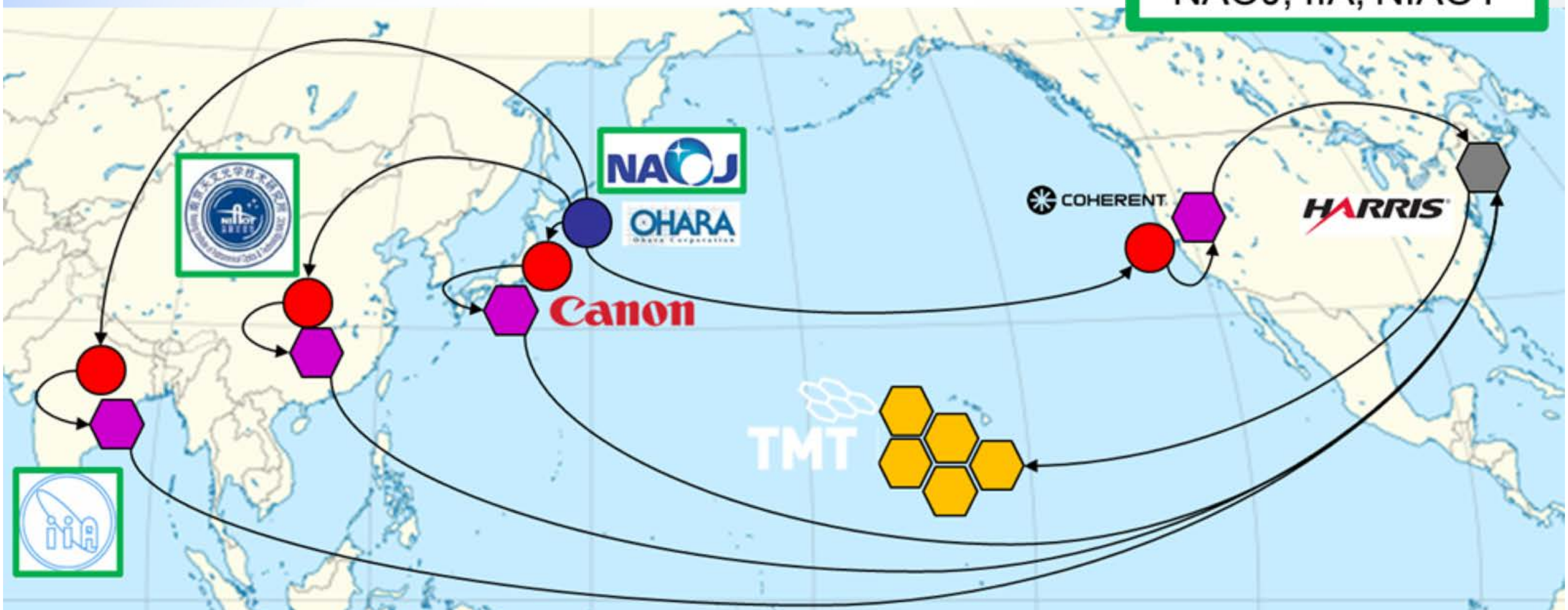

M1S in Production
Full Scale Segment on
Segment Support Assembly

TMT
Thirty Meter Telescope

M1 Optical Fabrication Steps

Blank Fabrication → Roundel Polish → Hex Cut and PMA assy → Final IBF Figuring → Coating / Integration

M1 Performing Institutions: TIO, NAOJ, IIA, NIAOT



TMT Thirty Meter Telescope

Segment Blank Manufacturing
Ohara

388+ M1 mirror blanks (60% +) in hand

Segment Support Assembly (SSA)

In Production at L&T in India; US built 7 sets.

WH Actuators

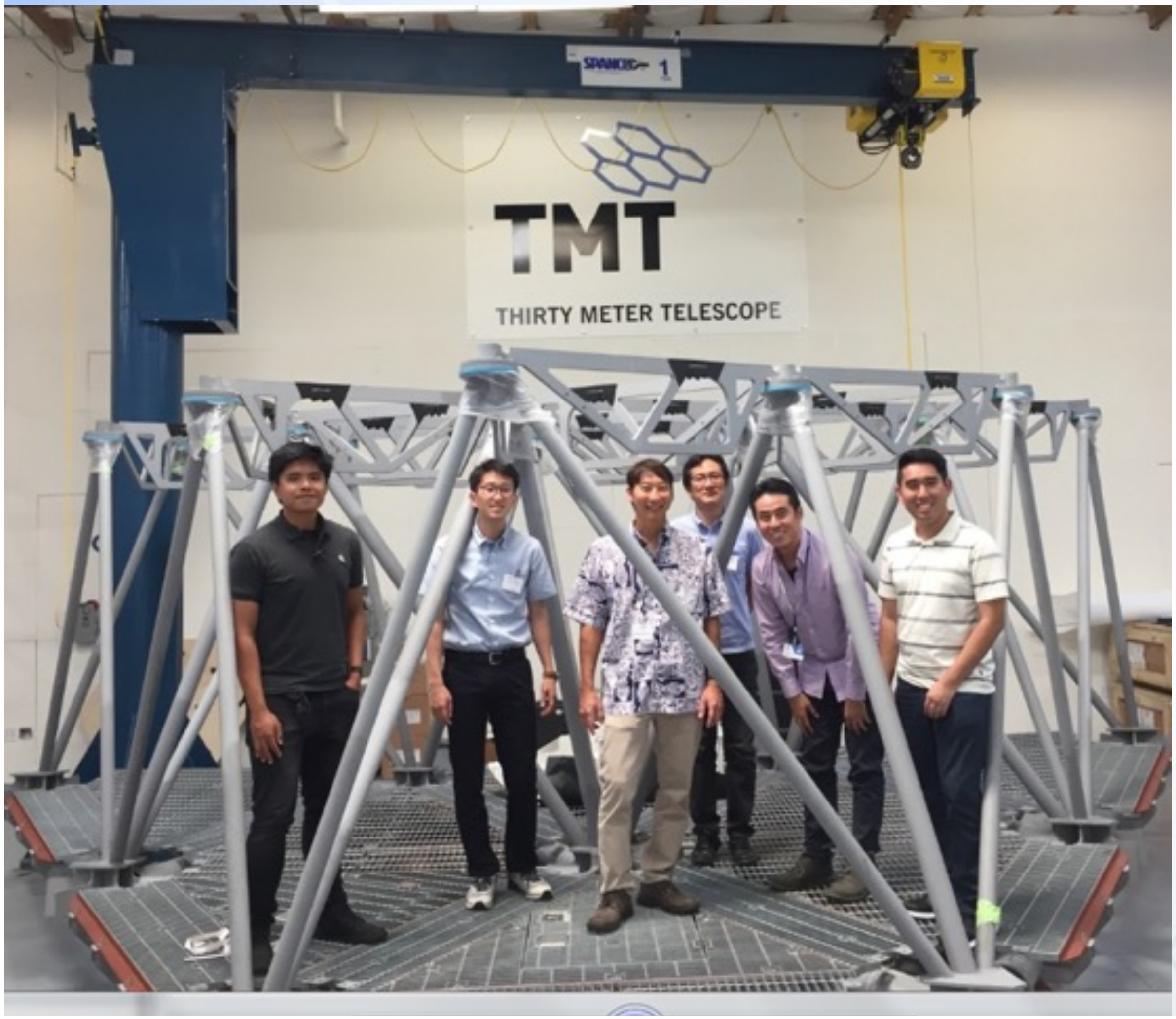
Actuator stall force measurement

WH Leaf Springs

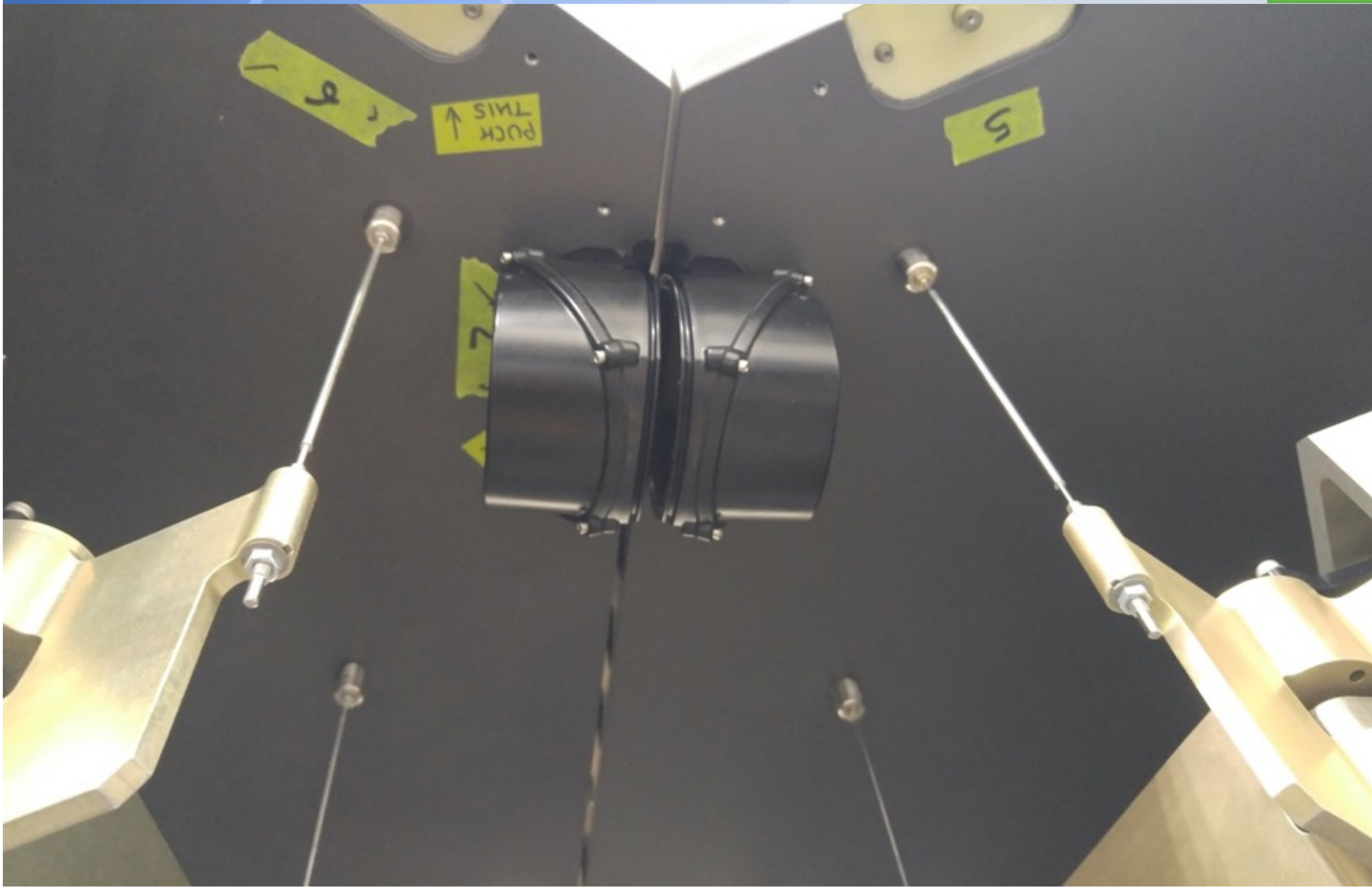
Leaf Spring calibration

Multi-Segment Integration and Test Facility (MSIT)

- Delivered and installed in TIO Monrovia lab, benefiting multiple subsystems in process development, risk reduction.



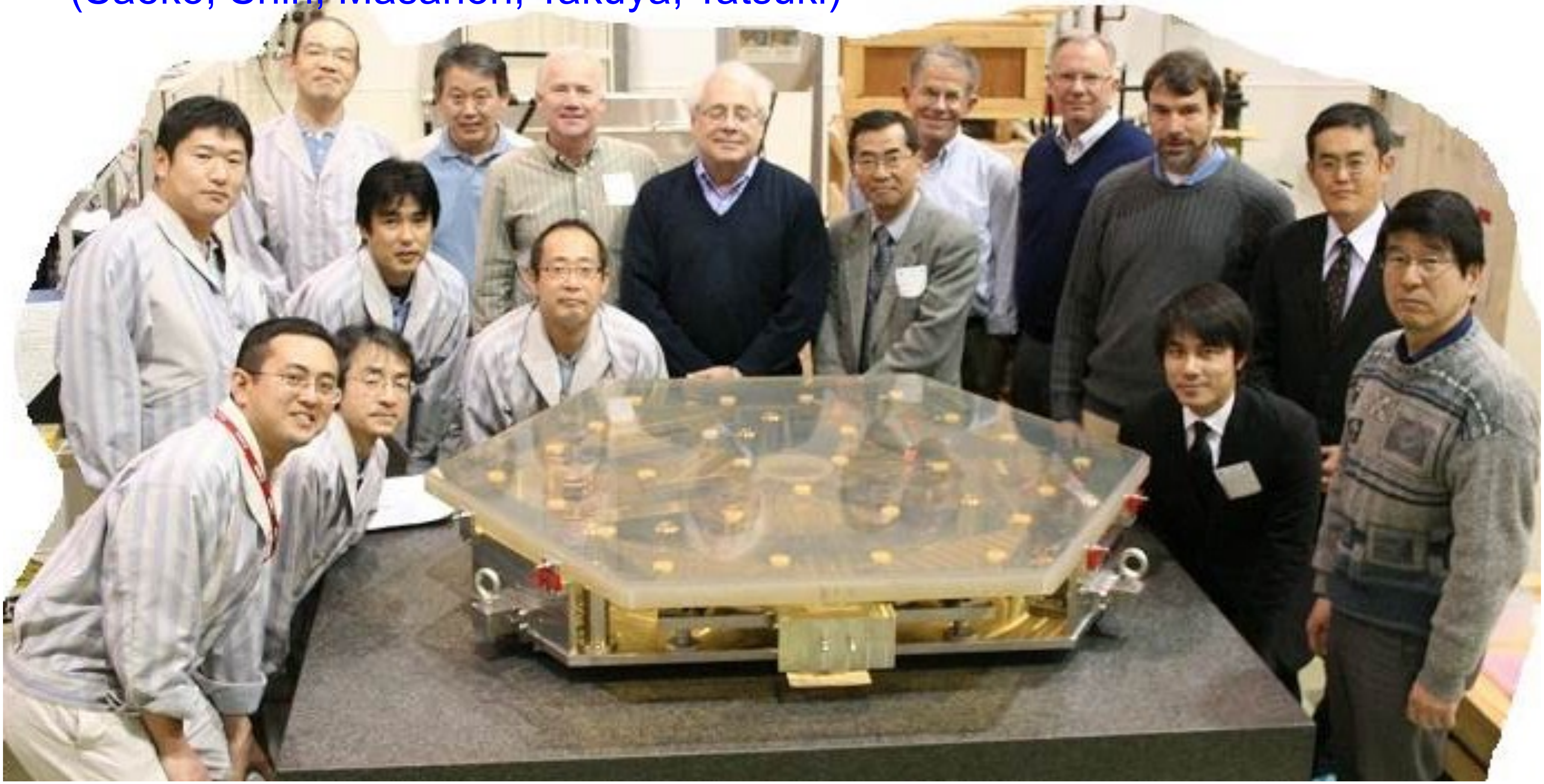
TMT PO and ITCC assembled SSA Module



M1 Segment Polishing – Canon
Hex-cutting – Canon/Shiba

28+ roundels polished; Hex-cutting in early 2020

(Saeko, Shin, Masanori, Takuya, Tatsuki)

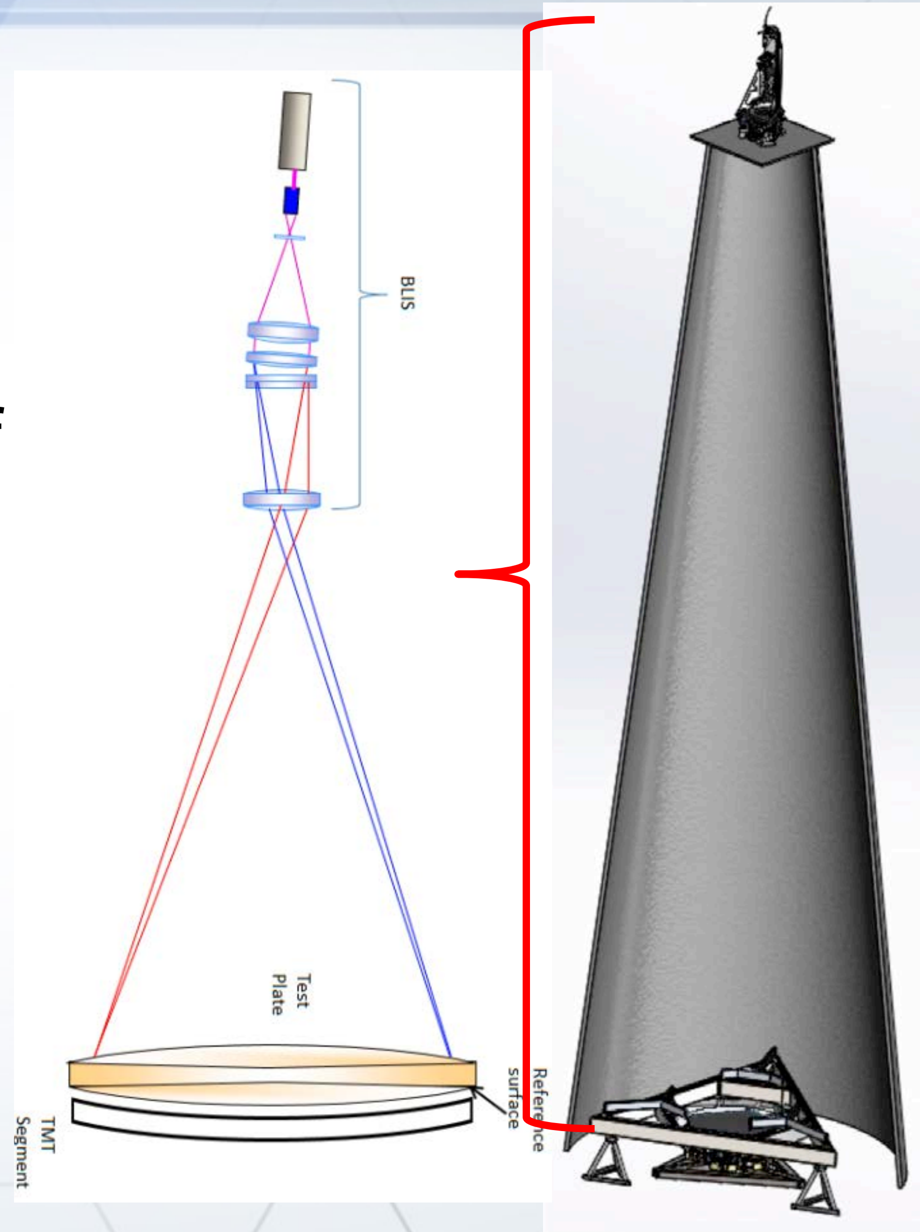


Coherent Polishing

- In Production; passed FRR in Sept. 2019
- Finalizing contract to do hex-cutting.

M1 Final Figuring and Metrology System Near Completion

- Arizona Optical Systems (AOS) producing metrology system
- Final ion beam figuring of all 574 segments
- Completion in 2020.



NIAOT Ready to Polish

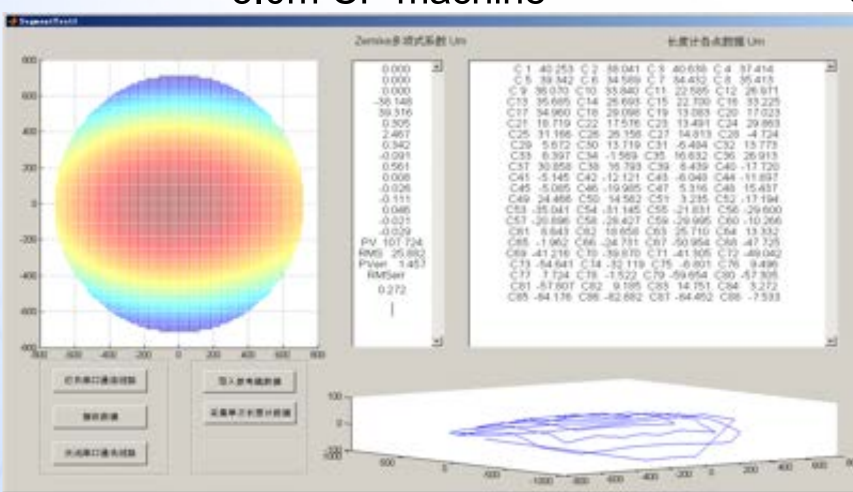
Ready to polish in Feb. 2020

5.0m CP machine

Conditioner

Roundel Lifter

Slurry water heater



Stress loading test results meet requirements

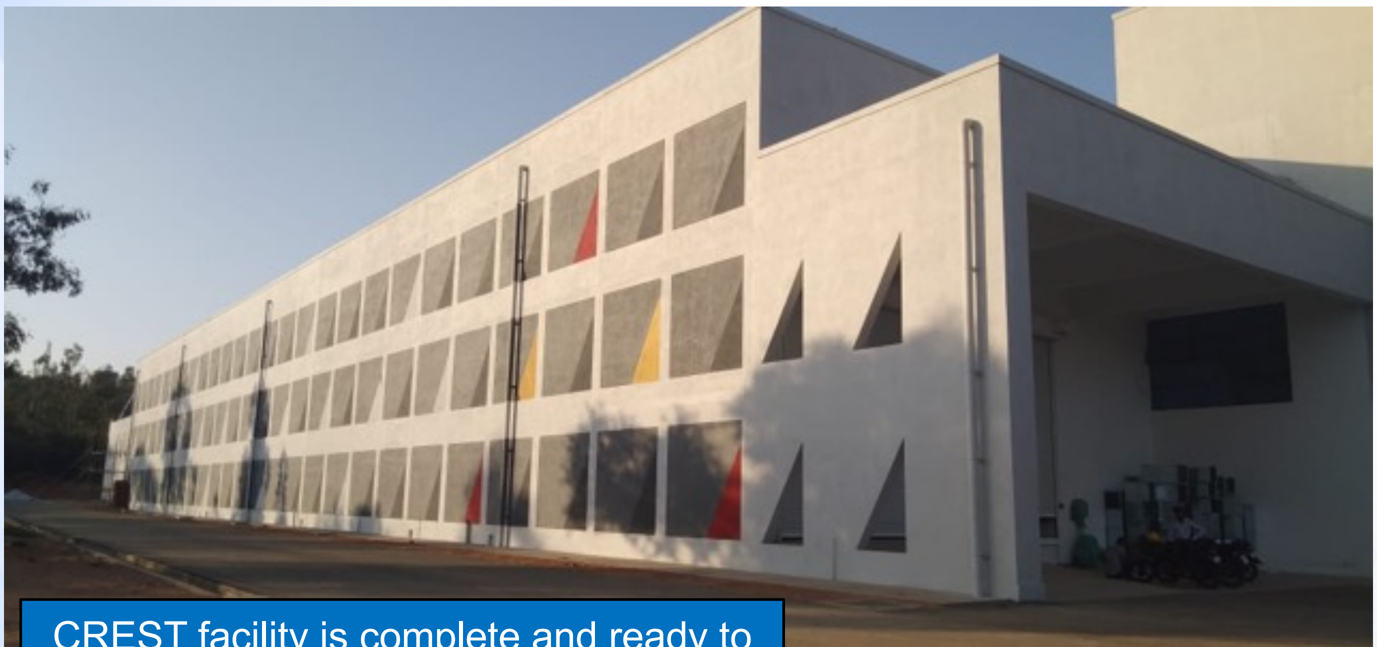
SMP fixtures

polished 1.5m reference mirror

TMT
Thirty Meter Telescope

Polishing in India

- The nearly complete CREST polishing facility expected to be online in October and CMM will be installed in November
- ITCC has sent a letter of Intent to purchase SMP equipment from Coherent, ITCC and Coherent signed the contract.
- ITCC received 18 Ohara blanks from Japan on Jan. 16, 2020.



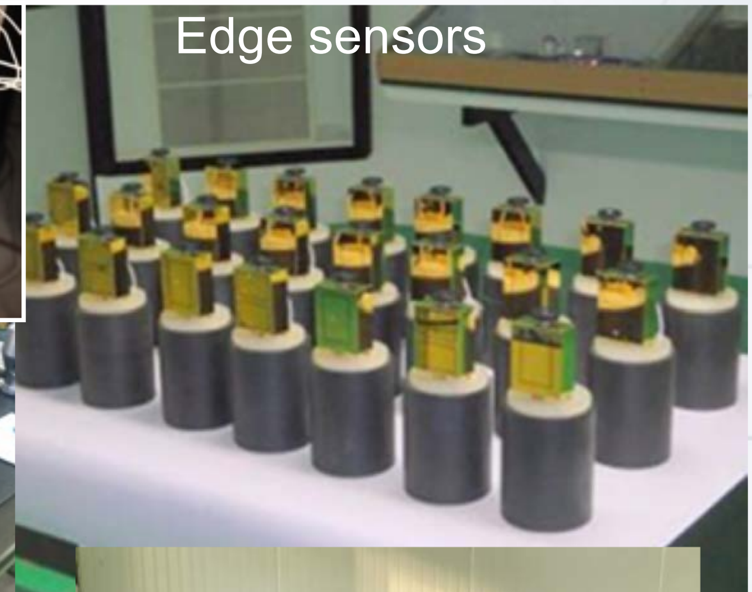
CREST facility is complete and ready to start accepting TMT production equipment

Leitz CMM is complete in Germany and is in transit to ITCC

Primary Mirror Control System (M1CS in Final Design)

- Jet Propulsion Laboratory is responsible for the system design
- India is responsible for production of actuators/sensors/electronics

Actuator components



Edge sensors

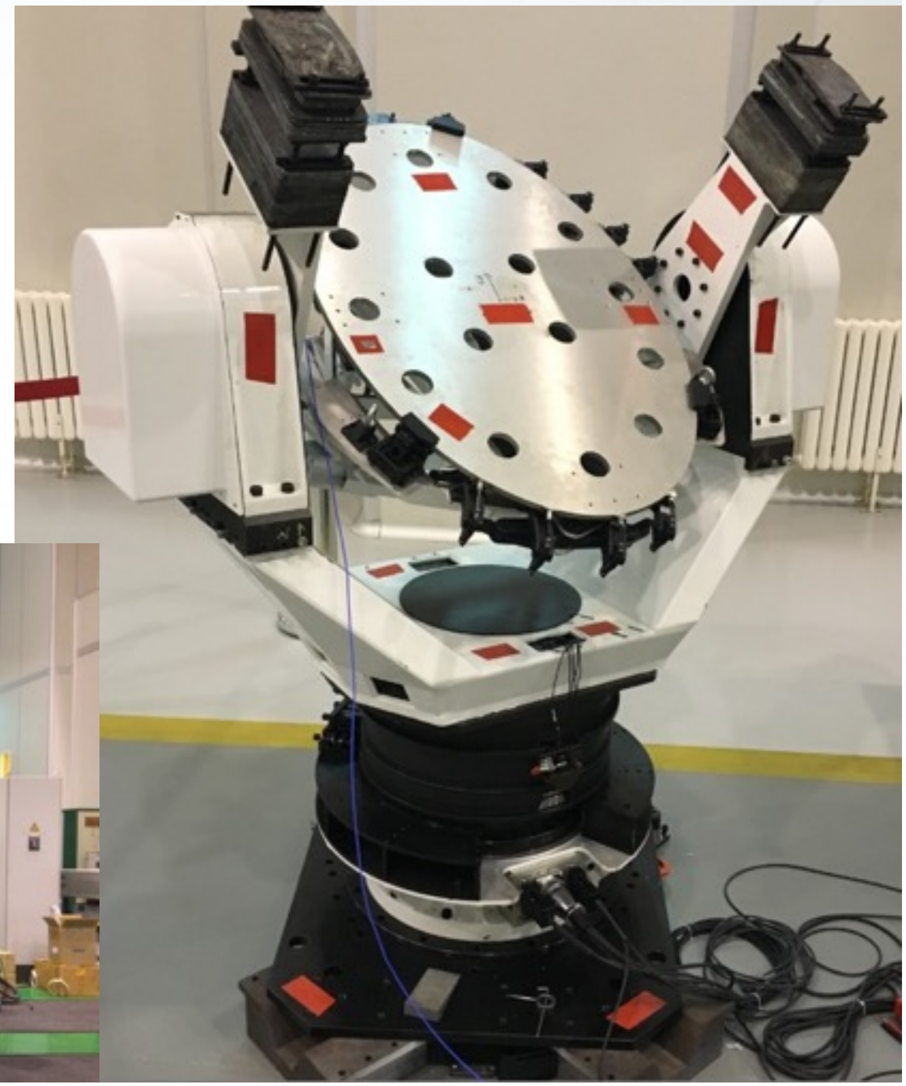
Tamboli

Southern Electric

Tertiary Mirror System (M3) - CIOMP

Full-scale M3 system opto-mech PDR passed in 11/2019

¼ size prototype tested



Prototype Test Review

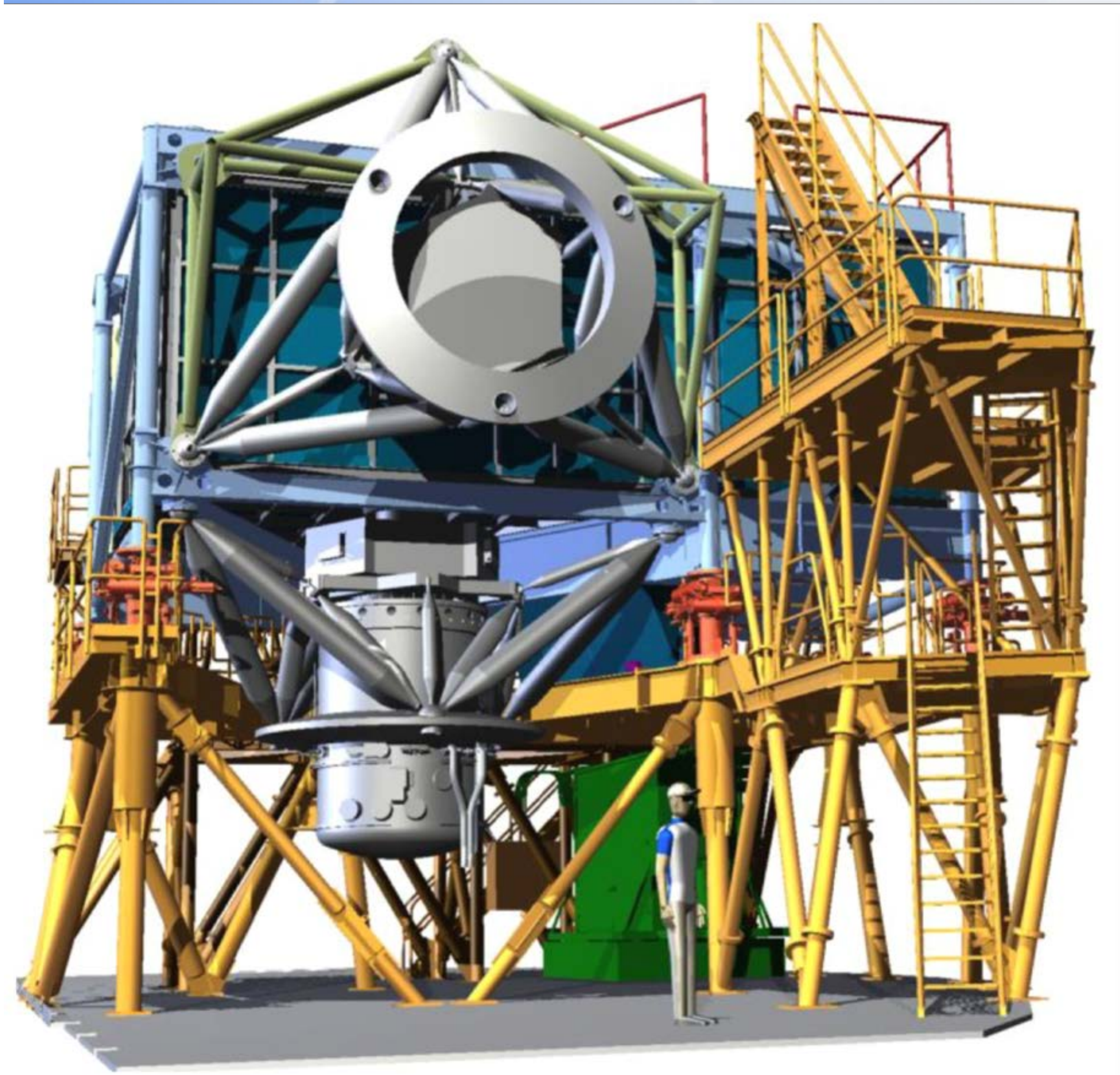
Telescope Control System (TCS in Final Design)

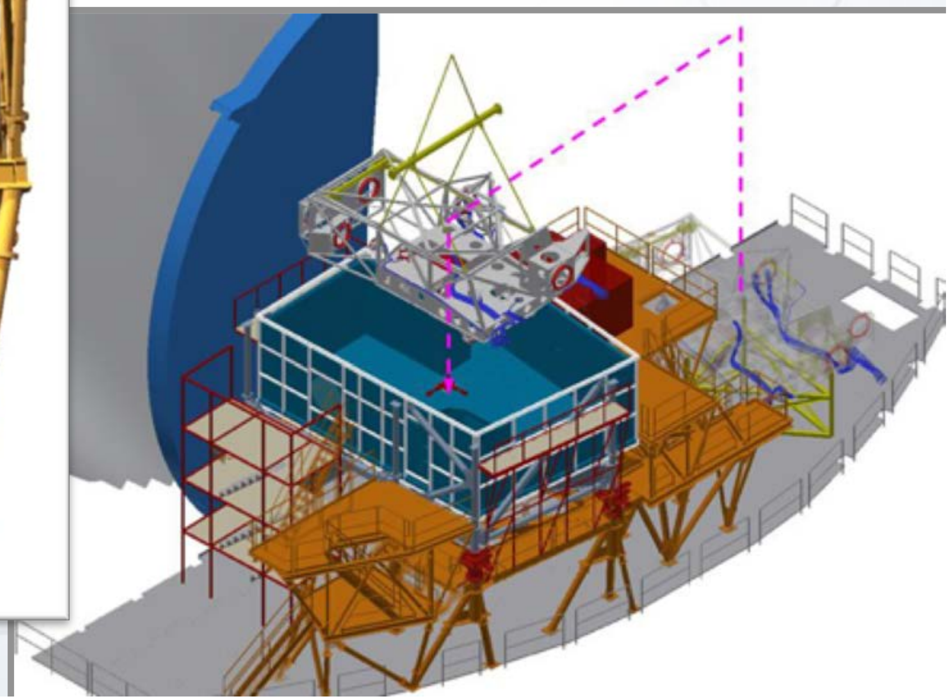
Passed PDR in Sept. 2019, In final design
(Takashi)

Observatory Safety System (OSS, in Final Design)

Passed PDR in Dec. 2019, in final design

NFIRAOS Passed FDR in 2018
(Optics in fabrication)





CILAS Contract for NFIRAOS DMs signed on May 24, 2019

- To deliver two fully qualified deformable mirrors (DM)

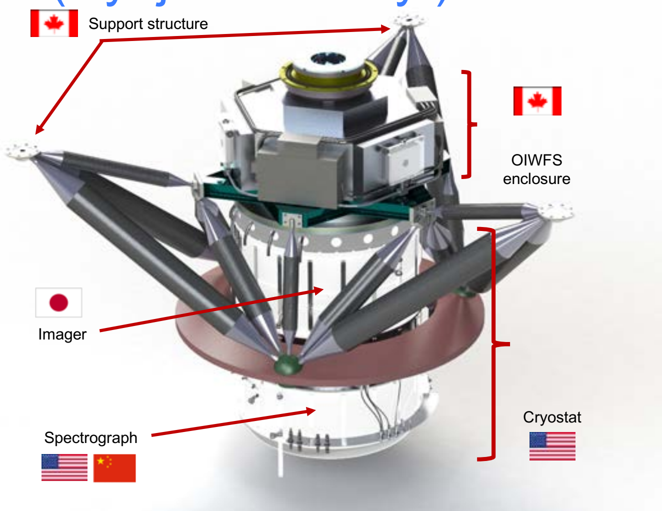
Signature of the contract on May 24, 2019 (D. Goodman and P. Faucoup)

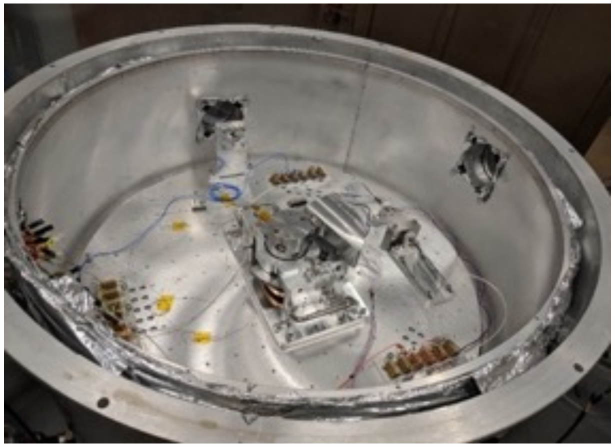
CILAS 28x28 DM Prototype delivered and tested, meeting requirements

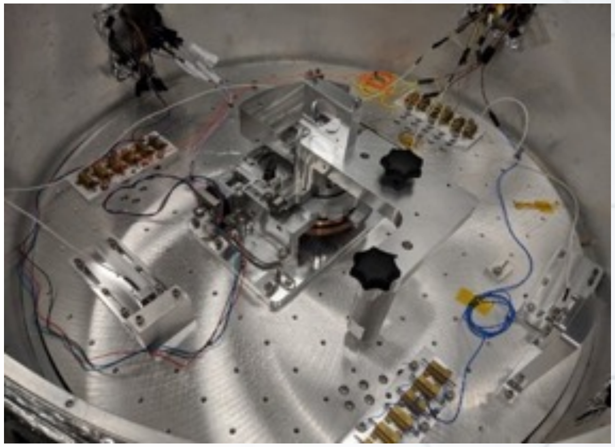
IRIS Instrument in Final Design

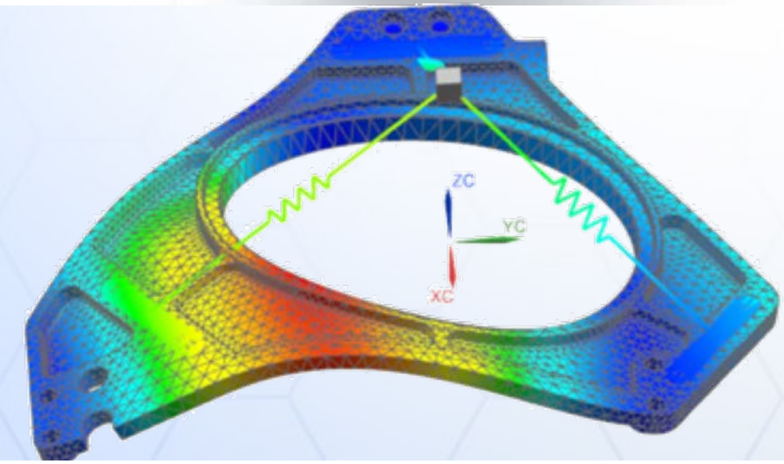
- Successively passed preliminary designs in 2017
- Lots of I/F definition; analysis, detailing, prototyping

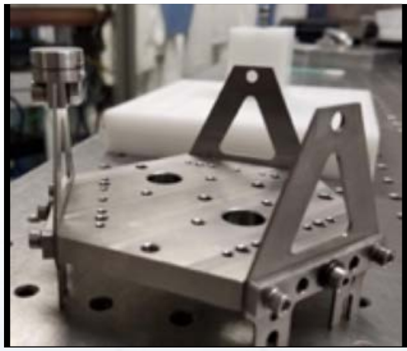
(Ryuji and many)

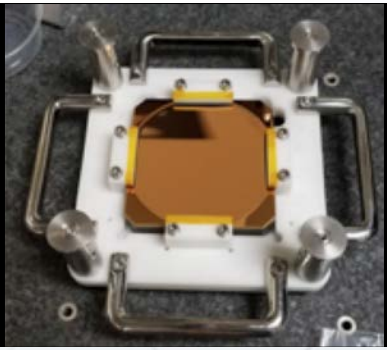


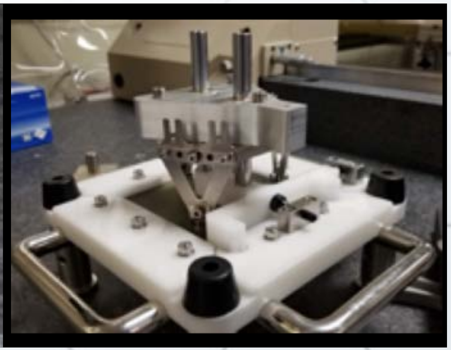








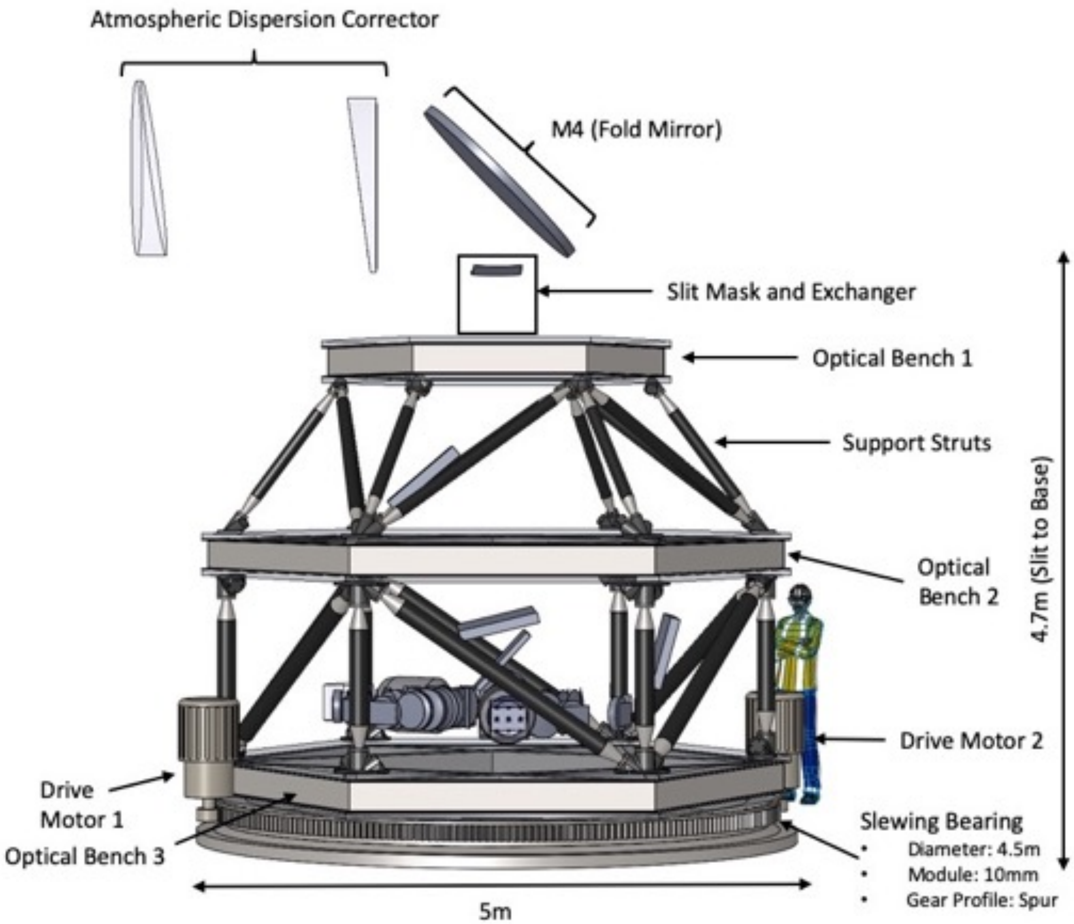


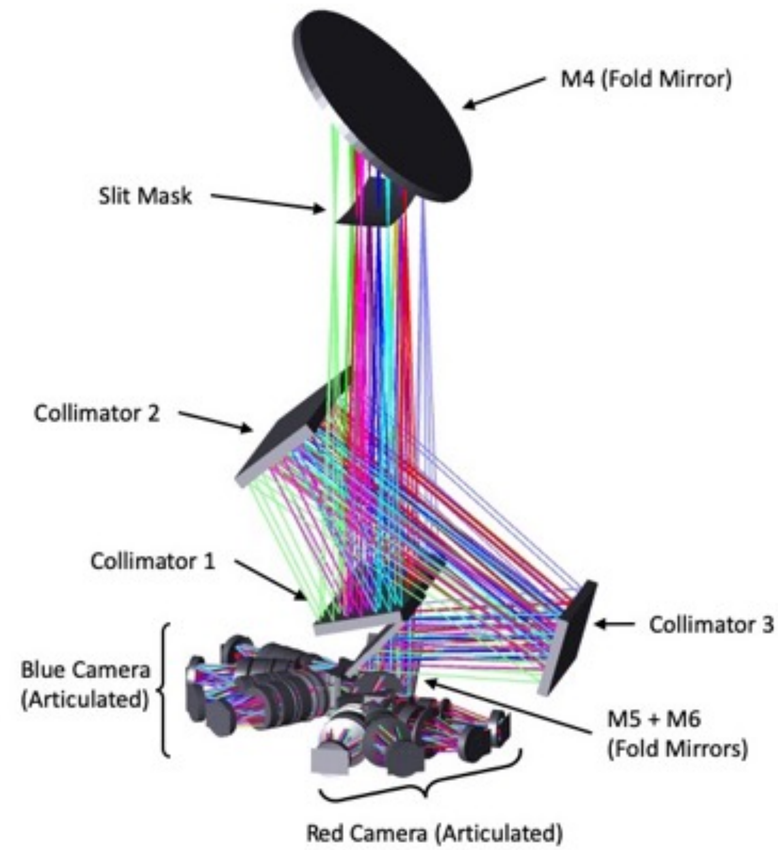


WFOS Completed Trade, in Conceptual Design

- On-axis FOV, more compact, gravity invariant
- Optical-mechanical CoDR in April, 2020

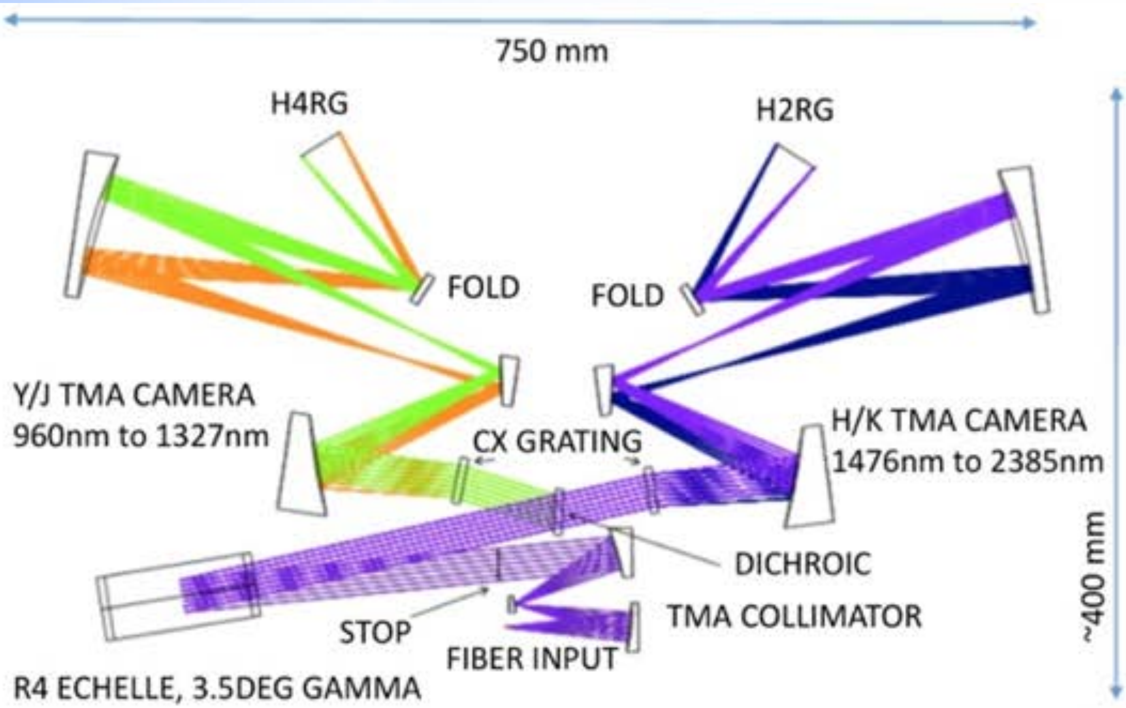
(Satoshi and many)

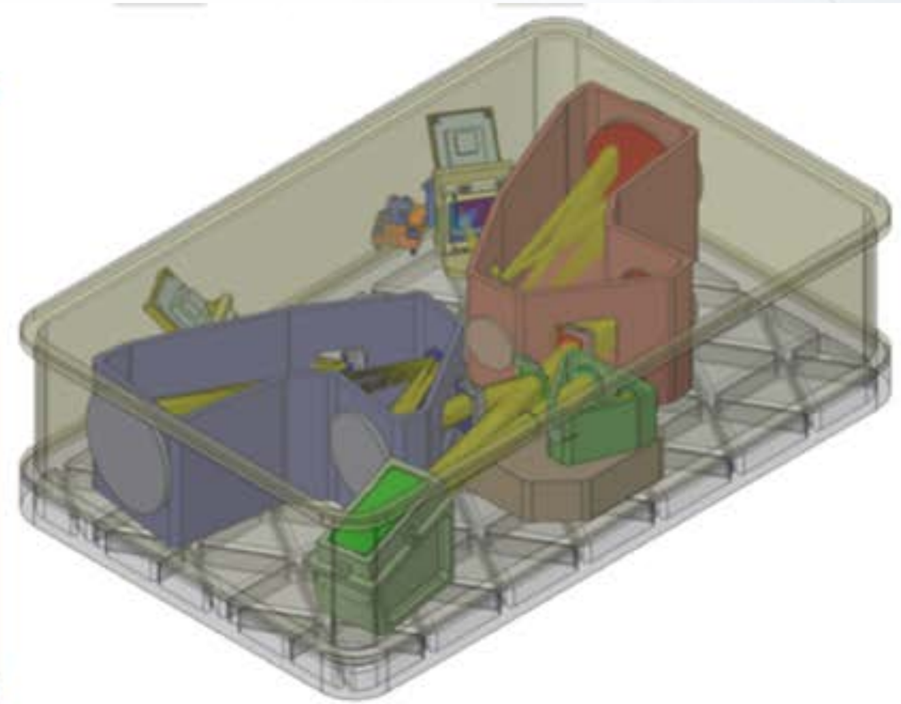




MODHIS in Conceptual Design

- Diffraction-limited high-resolution NIR Spectrograph
- Exoplanet capability, expandable to PFI / MICHI





Essential Ingredients to Success

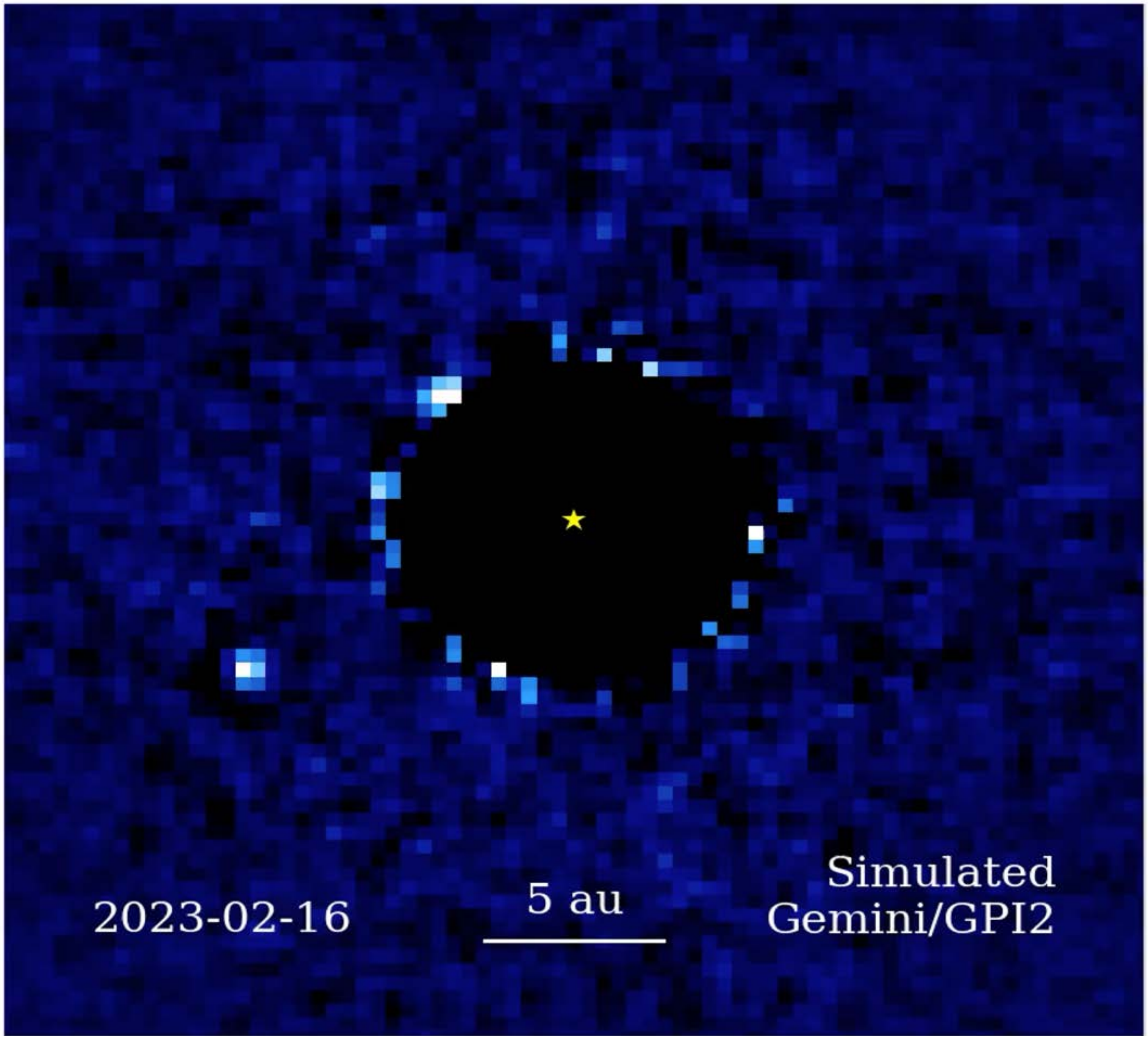
To successfully execute a project of this magnitude and complexity (technical and partnership) requires

- Strong management team, management tools
- Effective communications
- Cost-effective project controls
- Sophisticated Systems Engineering process
- Rigorous design, analysis and reviews
- Mature technology and heritage
- Quality and safety process
- Lots of prototypes, testing early and often

The Most Critical to Success: People

Talented, Experienced, Motivated, Dedicated,
Working Constructively, Towards a Common Goal, All the Time

Exoplanet
(Courtesy of Jessica Lu, UCB)



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