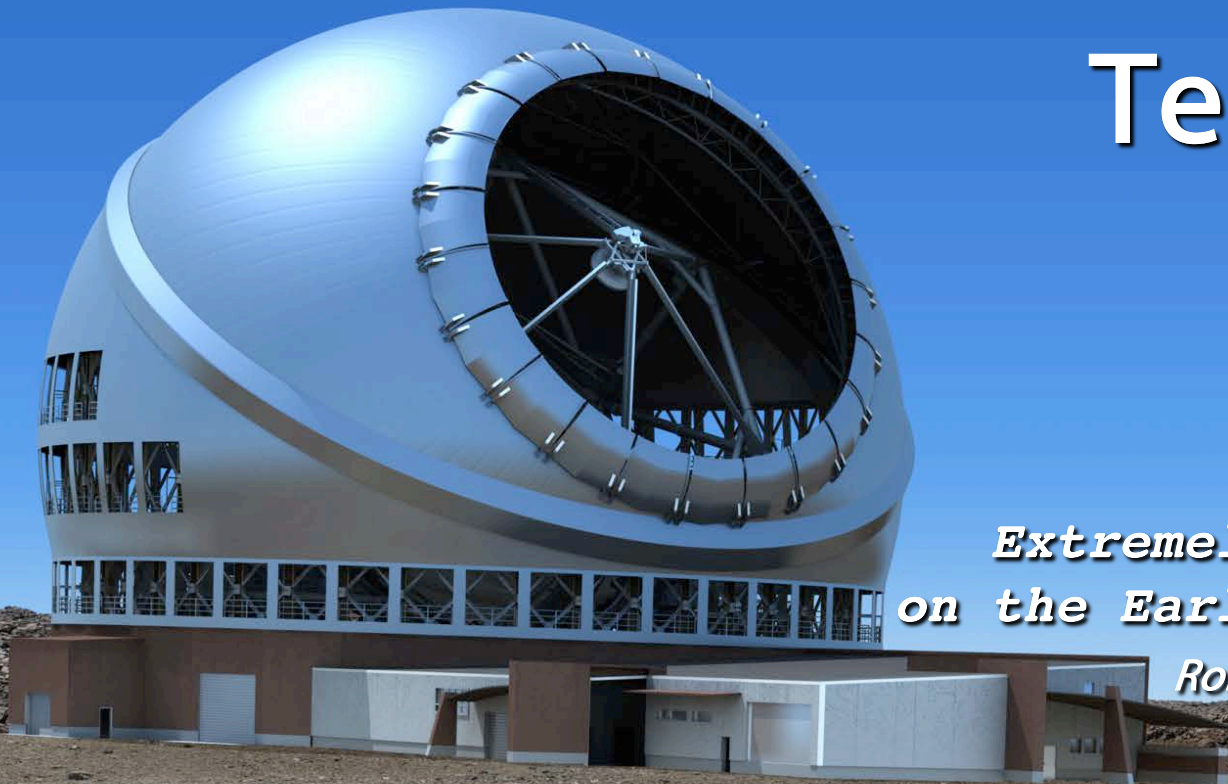
The Thirty Meter Telescope



Extremely Big Eyes on the Early Universe

Rome, Sep. 09, 2019

Christophe Dumas
Observatory Scientist & Head of Operations
TMT International Observatory, LLC

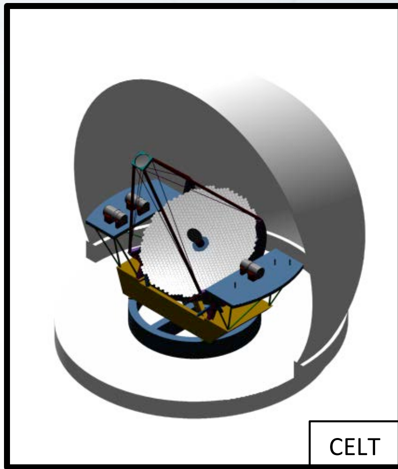
Plan

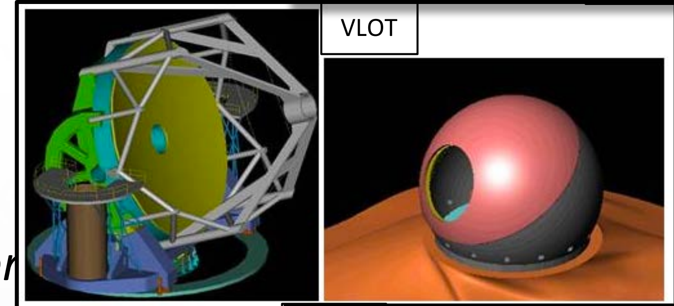
- Introduction to TMT project
  - Partnership
  - Telescope design
  - Construction site(s)
- Science and instruments
- Status of systems design and construction

TMT
Thirty Meter Telescope

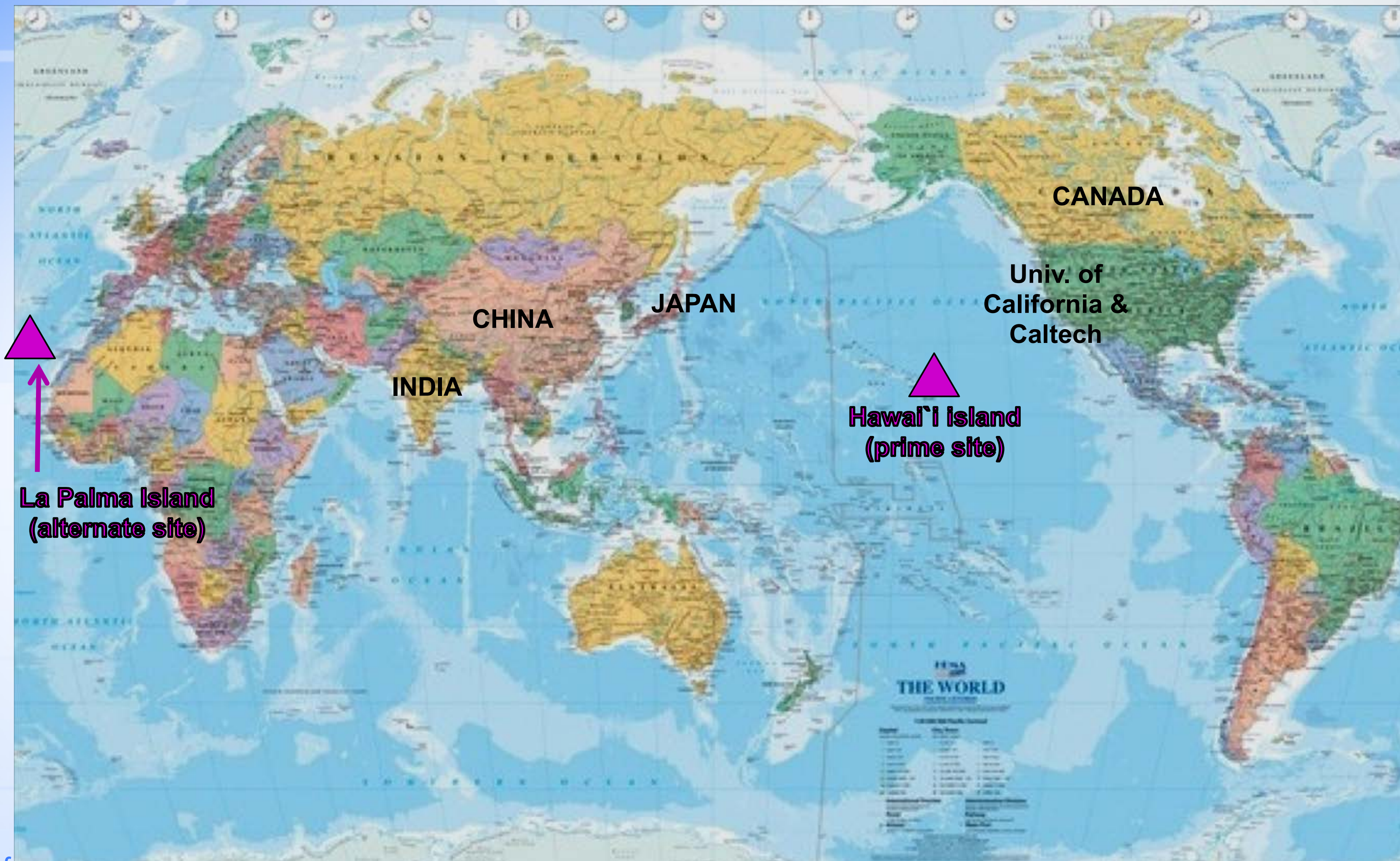
TMT Partnership: Timeline

- Thirty-Meter-Telescope (TMT) = Merging of 3 earlier projects. Current cost ~1,500 M$
  - CELT: California Extremely Large Telescope (30m diameter). Caltech and Univ. California
  - VLOT: Very Large Optical Telescope (20m diameter). Canadian Universities for Research in Astronomy (ACURA)
  - GSMT: Giant Segmented Mirror Telescope (30m). National Optical Astronomical Observatory (NOAO) & Gemini Observatory
- 2003: Foundation of TMT Observatory Corporation (Caltech, UC, ACURA)
- 2008: NAOJ joins
- 2009: Funding provided by *G. & B. Moore Foundation*
- 2014: Chinese & Indian partners officially join
- 2016: TMT becomes TIO: TMT International Observatory



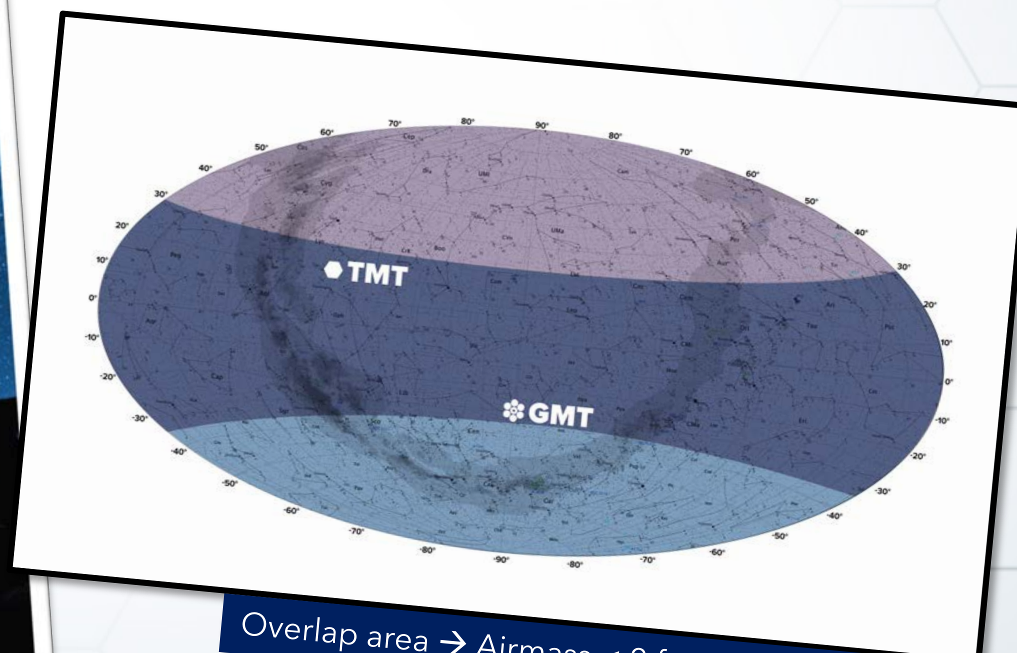


International Partnership and construction site(s)



US-ELT Program

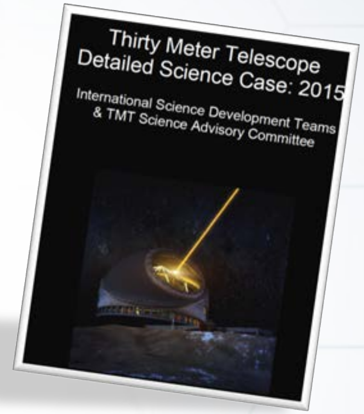
2 telescopes, 2 hemispheres, 1 system
All-sky coverage
Broad instrument suite
US-led Key Science Programs



Overlap area → Airmass < 2 for 2 hours or more

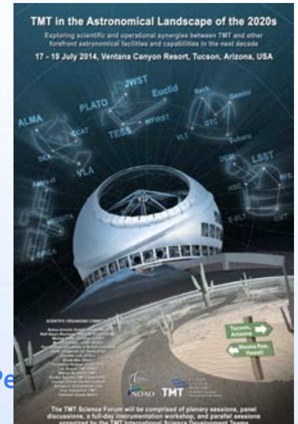
TMT ISDT & TMT Forums

- AURA has been an Associate Member of the TMT on behalf of the US national community
  - Through a cooperative agreement with the NSF, a **model for potential US partnership has been developed:**
    - International Science Development Teams
    - Detailed TMT Science case
    - Organization of TMT science forums

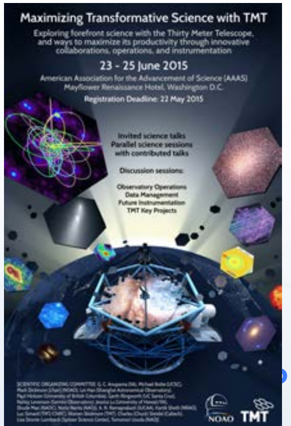


2013 (Hawaii)

2014 (Tucson)



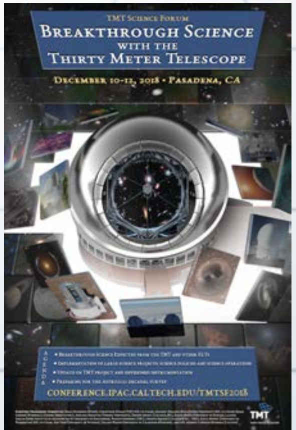
2015 (Wash. D.C.)



2016 (Japan)

2017 (India)

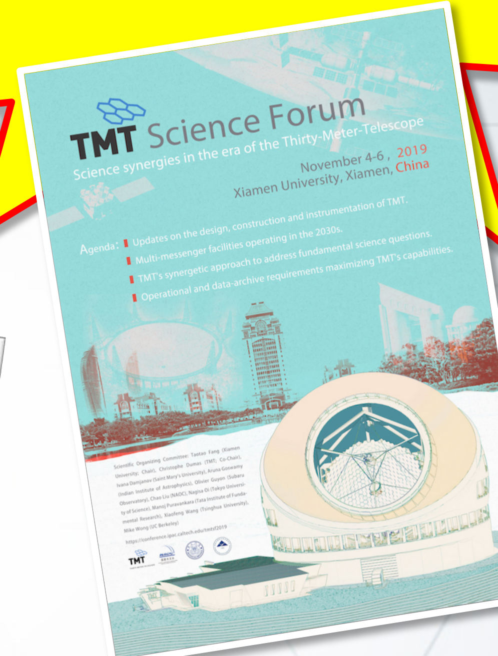
2018 (Pasadena)



TMT
Thirty Meter Telescope

TMT ISDT & TMT Forums

Next TMT Science Forum
Nov. 04-06, 2019
Xiamen, China



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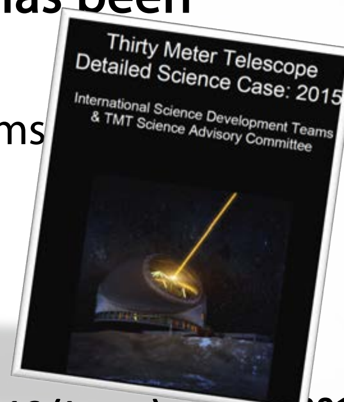

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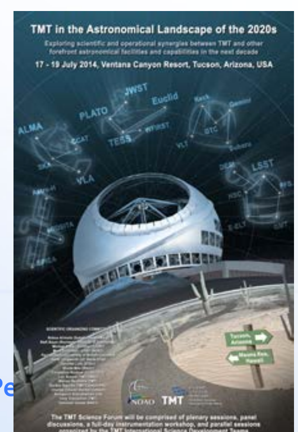
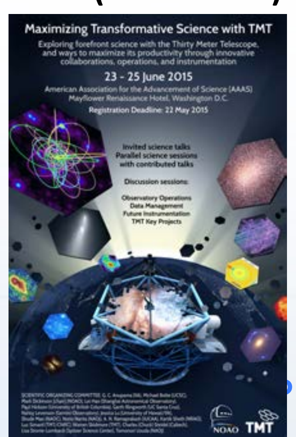
2014 (Tucson)



2015 (Wash. D.C.)



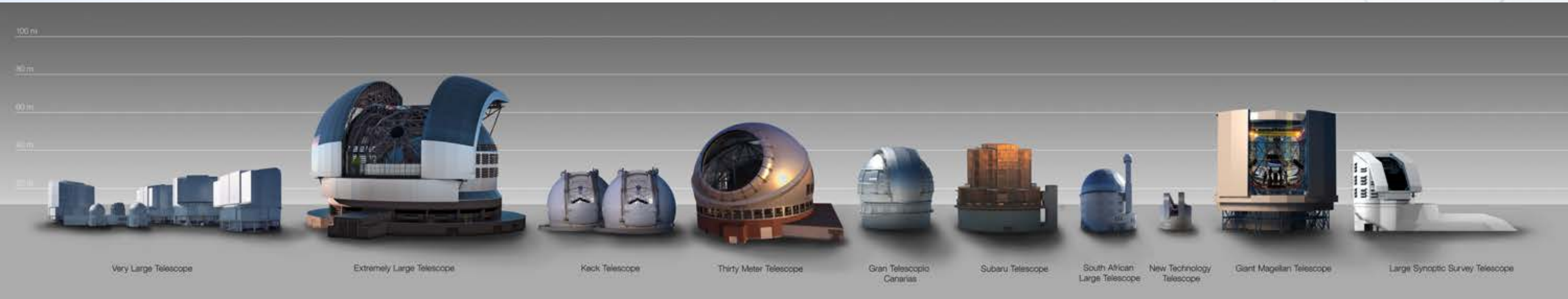
2016 (Japan)

2017 (India)

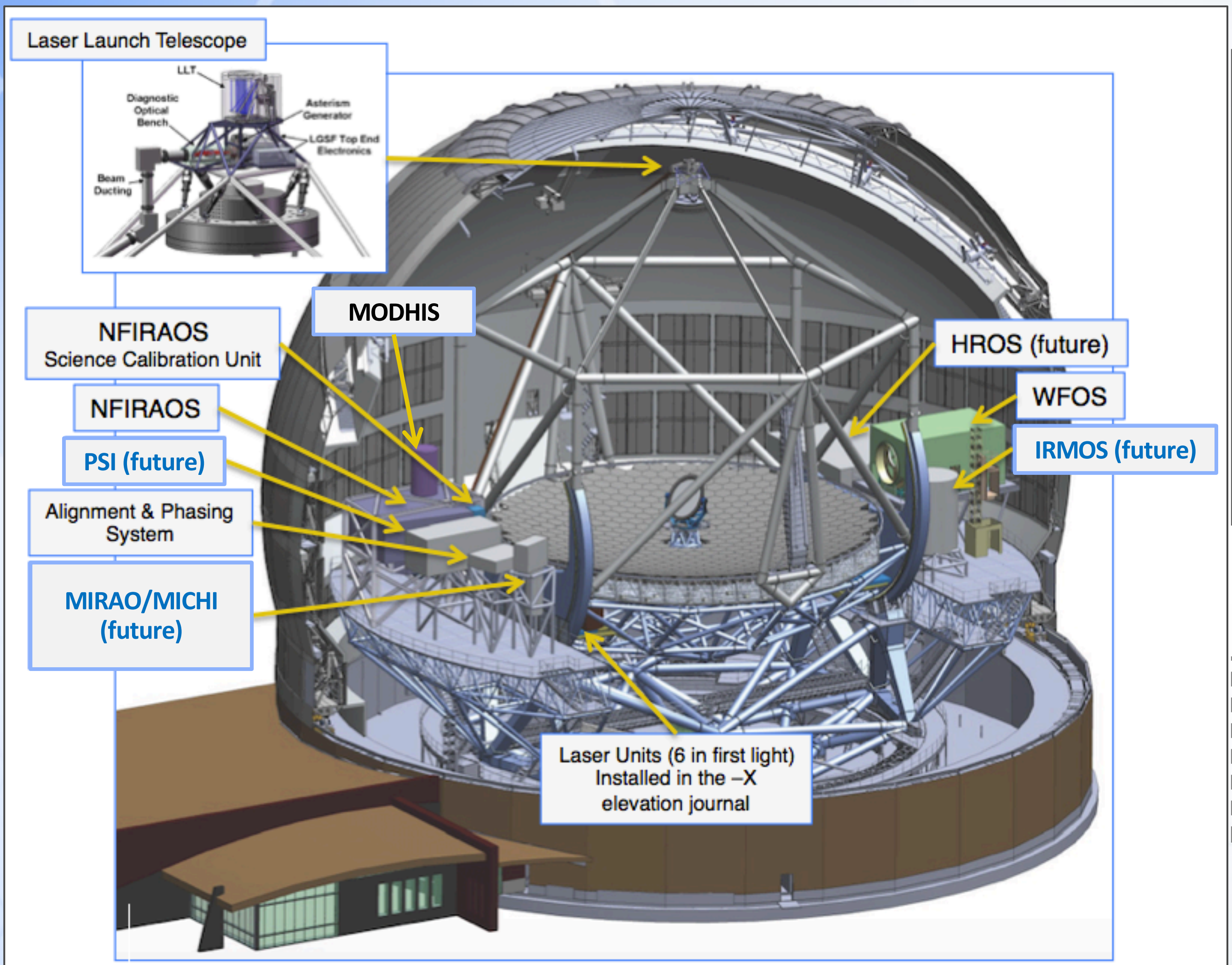
2018 (Pasadena)

TMT in a nutshell

- Wide-field, Alt-Az Ritchey-Chretien telescope
- 30 meter diameter primary mirror (**492 hexagonal segments**, 1.44m across corners)
- Passive secondary mirror
- Flat tertiary mirror beam light to Nasmyth focus
- **Up to 8 instruments** on Nasmyth
- **First-light AO system (NFIRAOS):**
  - Laser Guide Star Facility (LGSF) Multi-Conjugate-AO (MCAO)
  - Diffraction-limit at J, H, and K bands, can feed 3 instruments.



TMT: Optical design & instruments



Optical design:
Ritchey-Chrétien

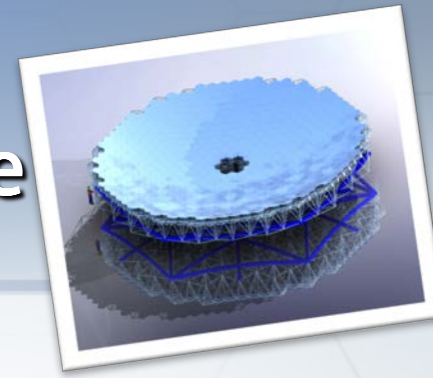
M1:
30m (hyperboloidal f/1)

M2:
3.1m (convex hyperboloidal)

M3:
2.5m x 3.5m (flat)

f/15 final focal ratio
&
20 arcmin FoV (2.62m Ø)

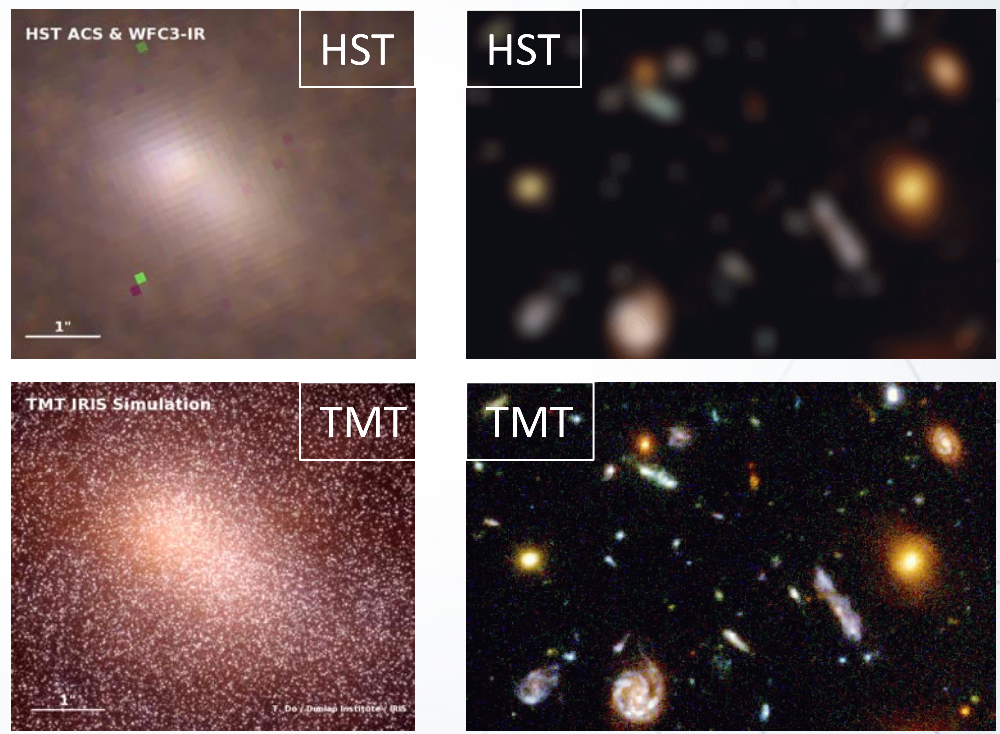
Expected boost in performance



- SENSITIVITY: S~D^2
  - **~10 times the collecting area of Keck, or ~150 times that of the HST**
    - For AO on point sources: **S~ D^4, i.e. ~200 times better than current VLTs**
- ANGULAR RESOLUTION:
  - **12 times better HST**

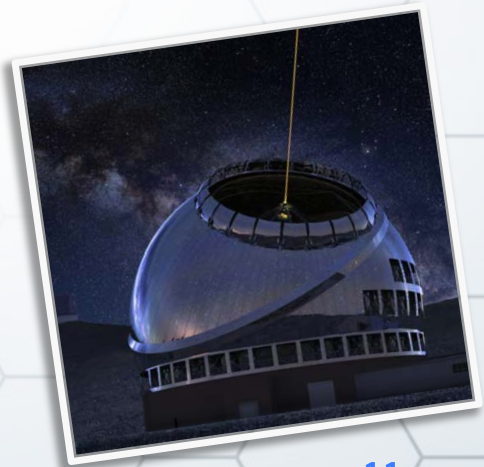
M31 nucleus

Deep Field



TMT operations model

- Similar to VLT operations (phases 1, 2, 3)
- Operations staffing level ~120 persons
- Visitor and service modes + ToOs + eavesdropping + DDTs
- Adaptive scheduling implemented to match program requirements with ambient conditions
- Execution made from science operations headquarters (Hilo or Tenerife) with possibility to eavesdrop from remote locations across TMT partnership
- TMT data will be pushed towards archive (18-month proprietary period)



Construction Site

Thirty Meter Telescope
Site Locations

TMT

Maunakea Observatory

Observatorio del Roque de Los Muchachos

30 m 望遠鏡
三十米望远镜
तीस मीटर दूरबीन
Thirty Meter Telescope
Télescope de Trente Mètres

Caltech
सत्यमेव जयते
DSTI & DAE
Government of India
NAOC
国立天文台
NAOJ
National Astronomical Observatory of Japan
NRC·CNRC
Canada
The University of California 1868

Significant funding provided by the Gordon and Betty Moore Foundation

Thirty Meter Telescope Site Locations

TMT

Maunakea Observatory

Observatorio del Roque de Los Muchachos

Site characteristics (median values, unless stated)	MKO (USA)	ORM (Spain)
Altitude of site (m)	4050	2250
Fraction of yearly usable time (%)	72	72
Seeing at 60m above ground (arcsecond)	0.50	0.55
Isoplanatic angle (arcsecond)	2.55	2.33
Atmospheric coherence time (ms)	7.3	6.0
Precipitable Water Vapor (% of time < 2mm)	54	20
Mean nighttime temperature (ºC)	2.3	7.6
Extinction (V mag/airmass)	0.111	0.137
Ground dust concentration (µg/m³)	0.815	1.006

30 m 望遠鏡
三十米望远镜
तीस मीटर दूरबीन
Thirty Meter Telescope
Télescope de Trente Mètres

Caltech
सत्यमेव जयते
DSTI & DAE
Government of India
NAOC
国立天文台
NAOJ
National Astronomical Observatory of Japan
NRC·CNRC
Canada

Significant funding provided by the Gordon and Betty Moore Foundation

Maunakea & TMT

- **July 2009:** TMT Board of Directors select Mauna Kea as the preferred site for the Thirty-Meter Telescope
- **2015:** Multiple attempts to start construction fail due to opponents' road blockades

- **December 2015:** Hawaii Supreme Court mandates rehearing of construction permit due to flaw in the application process
- **2016-2019:** Going through contested case hearings again & reprocessing permit request
- **Summer 2019:** Still cannot access summit

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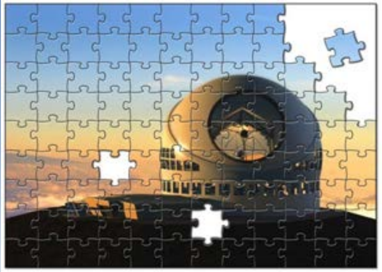
- **Decembe** dates rehearing in the applicatio
- **2016-201** rings again & re
- **Summer 2**

Timeline of construction permit process



- **Maunakea (10-year process):**
  - **2009:** Maunakea selected for TMT
  - **2016-2017:** 1.5 years long contested case
  - **Sep. 2017:** BLNR approves the Construction District Use Permit
  - **2018:** Apparent stronger and more "open" local support than in 2015 … *calm before the storm*
    - Appeal #1 (Feb. 2017): No need for another contested case about the sublease between UH and TMT
    - Appeal #2 (Oct. 2017): Ruling done Oct. 2018. Permit valid and all clear
  - **2019: Re-start blocked again by TMT opponents**
- **La Palma (2.5-year process):**
  - **2016:** La Palma becomes TMT's alternate site
  - **2017:** Hosting Agreement MOU signed between TIO and IAC
  - **2017:** Collaboration agreement signed between TIO, IAC, La Palma government & local municipality
  - **Nov. 2018:** Authorities validated our Environmental Impact Study.
  - **Summer 2019:** Ecologists contest chronogram of admin process wrt land concession (one admin step to be redone)
  - **September 2019:** Will be in a position to formally request building permit by end of September 2019

TMT
Thirty Mete

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      ... permit by end of
      September 2019
  - **20**
    TM

Sites:

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IMAGEN /

UN OJO PARA EL PLANETA

— El Telescopio de Treinta Metros (TMT) ha tenido un pie entre el sagrado cielo de Hawái y el cristalino de la isla canaria de La Palma.

Por **Carlos Risco**
Fotografía de **David Rius y Núria Tuca/Getty**

Para los hawaianos, la montaña sagrada de Mauna Kea está habitada por los espíritus. Durante años, solo la alta nobleza podía visitar la cumbre de este volcán dormido. Por eso, desde que en 2013 comenzó el proyecto para la construcción del telescopio más grande del mundo, el Telescopio de Treinta Metros (TMT), los hawaianos han dicho que ya basta con la ayuda, entre otros, de Leonardo DiCaprio. Este gigante podría ser clave para los intentos del ser humano de descubrir planetas habitables en un entorno de catástrofe climática. Ante el follón de Hawái, el telescopio ha estado semanas debatiéndose entre Hawái y La Palma (en la imagen). Además de Hawái y el desierto de Atacama, el cielo de la isla canaria es uno de los más limpios del mundo para la observación astronómica. Sobre el mar de nubes, que espejan el cielo e impiden la contaminación lumínica, el Roque de los Muchachos es todo un referente. Allí, 13 telescopios internacionales escudriñan el cielo para investigar sobre agujeros negros, estrellas y galaxias. Es el centro del mundo para conocer los demás mundos.

10 / retina.elpais.com

Septiembre 2019

Septiembre 2019

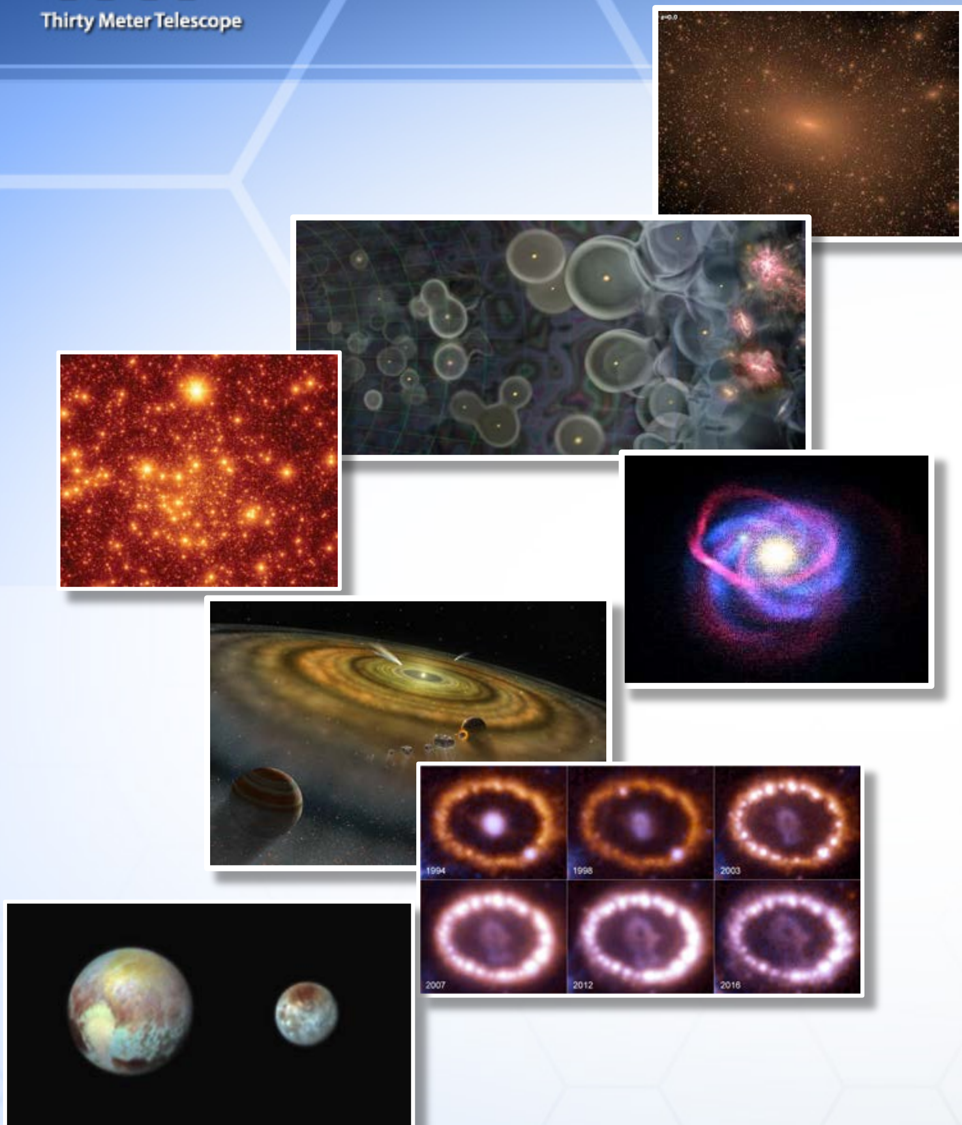
September 2019

Current timeline

- **As of now:** In Hawaii, Maunakea cannot be accessed. Access to La Palma is one admin step away
- **2019 (2020):** Construction starts in Hawaii (or La Palma)
- **2021-2025:** Enclosure base & assembly
  - End 2026: End construction of all summit buildings
- **2025-2027:** Telescope structure integration
- **2027-2030:** AIV, commissioning (partial first-light opportunities)
- **2030: "Full first-light"**

Science instruments

TMT Science & instrumentation



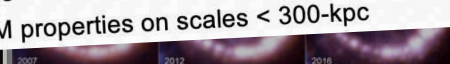
- Contemporary Science
  - Fundamental physics & cosmology
  - Early Universe & galaxy formation
  - Super massive black-holes
  - Nearby-galaxies & Milky-way
  - Star formation & exoplanets
  - Time-domain science
  - Solar-system
- Synergies with other observatories
  - JWST, EUCLID, WFIRST
  - ALMA, LSST, SKA
- Future opportunities
  - 30 m aperture opens new exploration parameter space
    - Gravitational wave's optical transients
    - Multi-wavelengths study programs

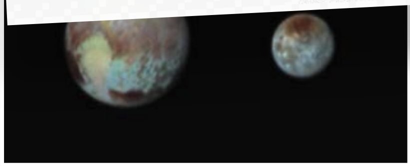
TMT
Thirty Meter Telescope

TMT Science & instrumentation

- Contemporary Scien

Theme	Science Area	Observations	Requirements	Capabilities
Cosmology and fundamental physics	• Dark matter structure on large and small scales • Dark energy/matter effect on cosmic expansion rate • Neutron star equation of state and testing gravity • Variations of physical constants over cosmic time	• Proper motions in dwarf galaxies • Wide-field optical spectroscopy of R = 24.5 galaxies • Transient events lasting > 30 days • High resolution spectroscopy of QSOs and gamma-ray bursts (GRBs)	• Δλ = 0.31–0.62, 2–2.4μm • Seeing-limited FOV > 10′ • 4-mas/pixel K band imaging FOV > 30″ • R = 1,000–50,000 • Very efficient acquisition • 0.05-mas astrometry stable over 10 years	SL/WFOS MCAO/IRIS imager MCAO/MODHIS SL/HROS
The early Universe	• Metal-free star formation in first light objects • Gravitationally lensed first light objects • Early galaxies and re-ionization • Structure and neutral fraction of z > 7 IGM	• Faint object multiplexed, spatially-resolved spectroscopy • High-resolution NIR spectroscopy • Diffraction-limited NIR imaging	• Δλ = 0.8–2.5 μm • R = 3,000–30,000 • J, H, K 4-mas/pixel imaging • F = 3 x 10^{-20} ergs $s^{-1}cm^{-2}Å^{-1}$ • Exposure times > 15 ks	MCAO/IRIS IFS MCAO/IRIS imager MCAO/MODHIS MOAO/IRMOS
Galaxy formation and the IGM	• Connecting the distributions of stars and dark matter • Baryon Cycle at peak galaxy formation epoch • Evolution of velocity, star formation rates, extinction and metallicity maps of z = 5.5 to < 1.5 galaxies • IGM/CGM properties on scales < 300-kpc	• Optical/NIR multiplexed and Seeing-/Diffraction-limited spatially-resolved spectroscopy of distant galaxies, AGNs and R ~ 27 high redshift objects	• Δλ = 0.31–2.5 μm • R = 3,000–5,000, 50,000 • Very efficient acquisition • High multiplexing (goal > 100)	SL/WFOS MCAO/IRIS IFS SL/HROS MOAO/IRMOS





- 30 m aperture opens new exploration parameter space
  - Gravitational wave's optical transients
  - Multi-wavelengths study programs

TMT envisioned instruments suite

Adaptive optics

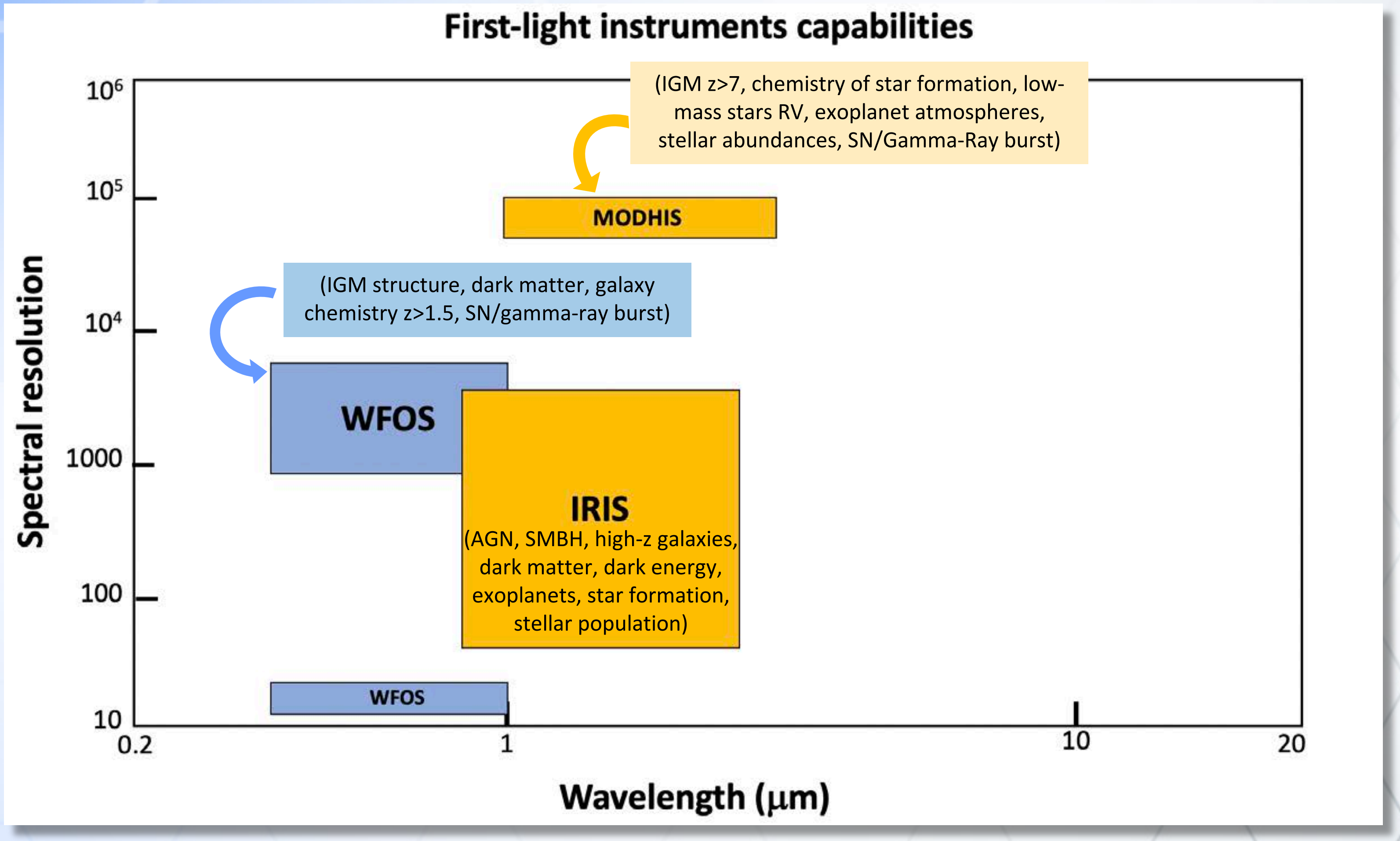
Seeing-limited (or GLAO assisted)

First-light instruments

Instrument and Description	λ Range (μm)	Spectral Resolution	Modes	Field of View
IRIS/Diffraction-Limited NIR Imager and IFS	0.84–2.4	Y, Z, J, H, K, wide and narrow filters. 4,000–8,000 (some modes to 10,000)	NGSAO, MCAO	Imager - 34” x 34” @ 0.004”/pix IFU - 0.51” x 0.51” @ 0.004”/pix to 2.25” x 4.4” @ 0.050”/pix
WFOS/Wide-Field Optical Spectrometer	0.31–1.0	1,500 to 5,000 0.75” slits, 10,000 0.25” slits	SL, GLAO*	25.5 (8.3 x 3)-arcmin^2, 500” total slit length (about 58 targets with 8” slits, 0.5” gaps), 0.05”/pixel
MODHIS/Multi-Object Diffraction-Limited High-Resolution Infrared Spectrograph	0.95–2.5	110,000 - 180,000 < 10 cm/s (goal 2 cm/s)	NGSAO	4 (goal >5) 0.1”x 0.1” collectors, @ 0.02” spatial sampling, 10” diameter field of regard with coronagraph
PSI/Planetary System Instrument	1–5	IFS ~ 5,000, Imager < 100	ExAO	Approximately 1” outer working angle, Approximately 10 mas inner working angle
MICHI/mid-IR Imager, IFU and Spectrometer	7.3–13.8	Imager < 100, IFS 600–1,000, Spectrometer 120,000	MIRAO	Imager: 24”x 24” @ 0.011”/pix, IFU: 5”x 2” Coronagraph
HROS/High-Resolution Optical Spectrograph	0.31–1	50,000–≥ 90,000	SL, GLAO	5” total slit length
IRMOS/IR Multi-Object Spectrograph	0.8–2.5	2,000–10,000	MOAO	> ten 3” IFUs over > 5” diameter field

TMT instruments

First-light discovery space



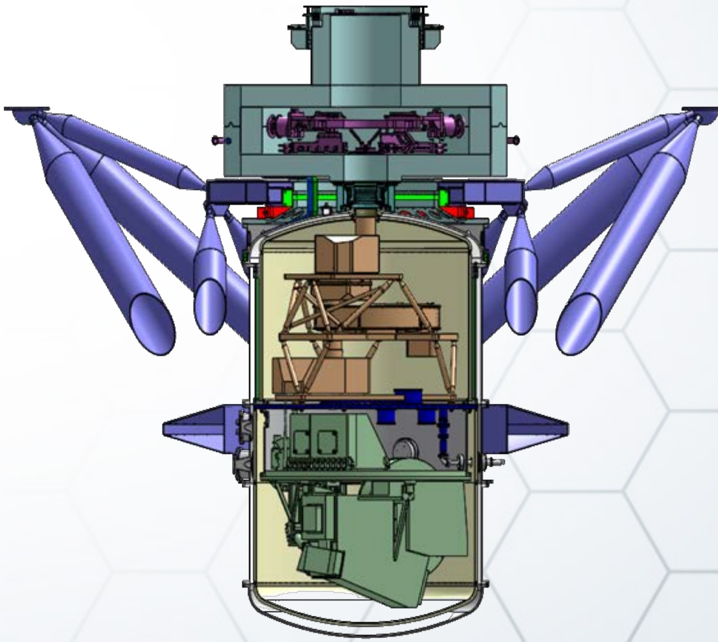
First-light

InfraRed Imager and Spectrograph (IRIS)

TMT Thirty Meter Telescope

Main Characteristics	
Wavelength coverage	0.84-2.4µm
Adaptive optics capabilities	NIRFRAOS/LGS On-instrument wavefront sensors (tip-tilt, focus, distortion)
Wavefront error	< 40nm (fine platescales)
Imaging:	
Imaging FoV	34”x34” (2x2 H4RG-10 arrays)
Filters PSSN	Broad + selection of NB (tbd) (SN~100, 1hr) - H: 26.2, K: 25.6
Spectroscopy:	
Integral-field-spectrograph (IFS) FoV	0.5”, 1.1”, 1.7”, 3.3" (H4RG-15)
Resolution Sensitivity	4000, 8000 (SN~10, 15min) - H: 25.8, K: 24.2

PI: J. Larkin (UCLA)
PM, co-PI: E. Chisholm (TMT)
PS: S. Wright (UCSD)

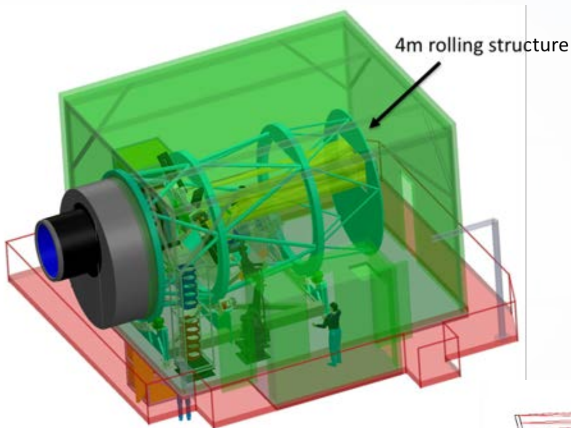


First-light

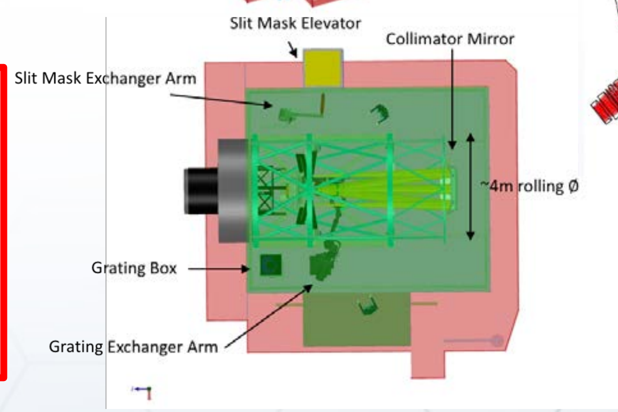
Wide-Field Optical Spectrograph (WFOS)

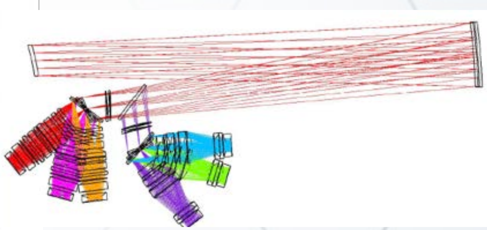
Main Characteristics	
Wavelength coverage	0.31-1.0μm (~700nm continuous coverage @R=1500)
Seeing-limited	(GLAO with deformable M2)
FoV	~25 arcmin^2 (8.3’x3’)
Resolution	1,500-15,000
MOS	500” total slit length

PI: K. Bundy (UCSC)
PM: M. Savage (TMT)
PS: C. Steidel (Caltech)



- Slit-based and fiber-based systems were initially considered.
- Slit-based architecture selected in October 2018.
- **Conceptual Design phase begins.**

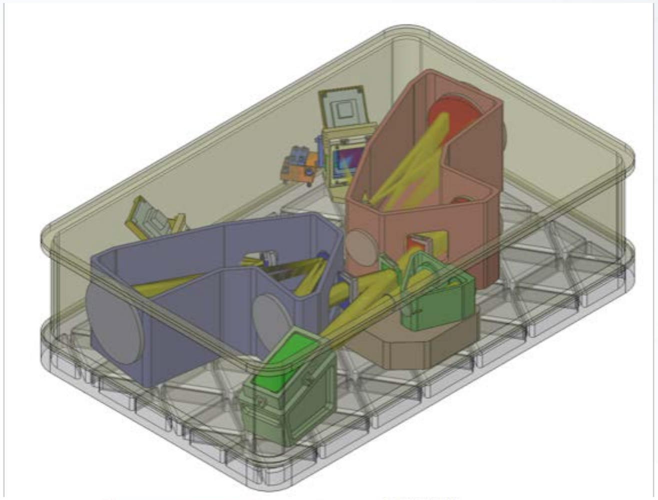


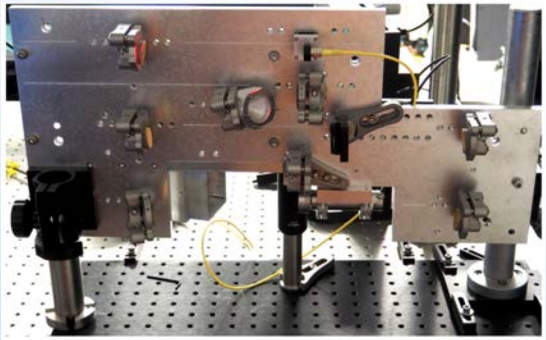


Multi-Object Diffraction-limited High-resolution Infrared Spectrograph (MODHIS)

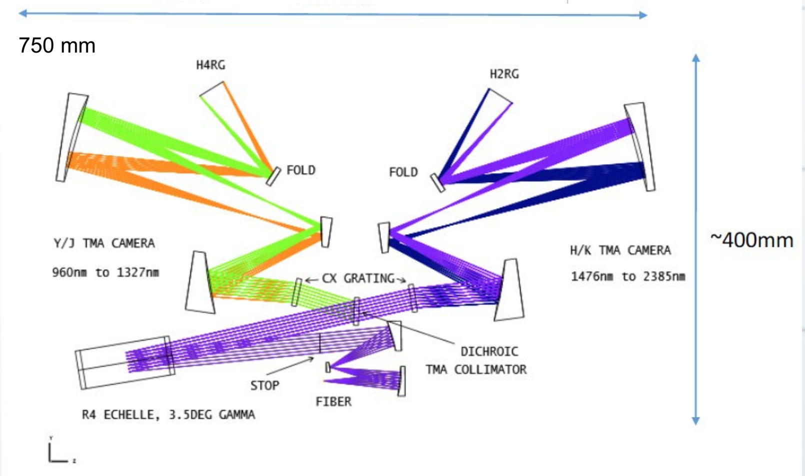
First-light possible

Main Characteristics	
Wavelength coverage	0.95-2.5μm
FIU fed by NFIRAOS 1st light AO system	
Patrol field	2”-5” diffraction limited
Resolution	100,000 and 30 cm/s
MOS	Up to 25 objects with 0.1”IFU@0.02”sampling
Throughput	>10%

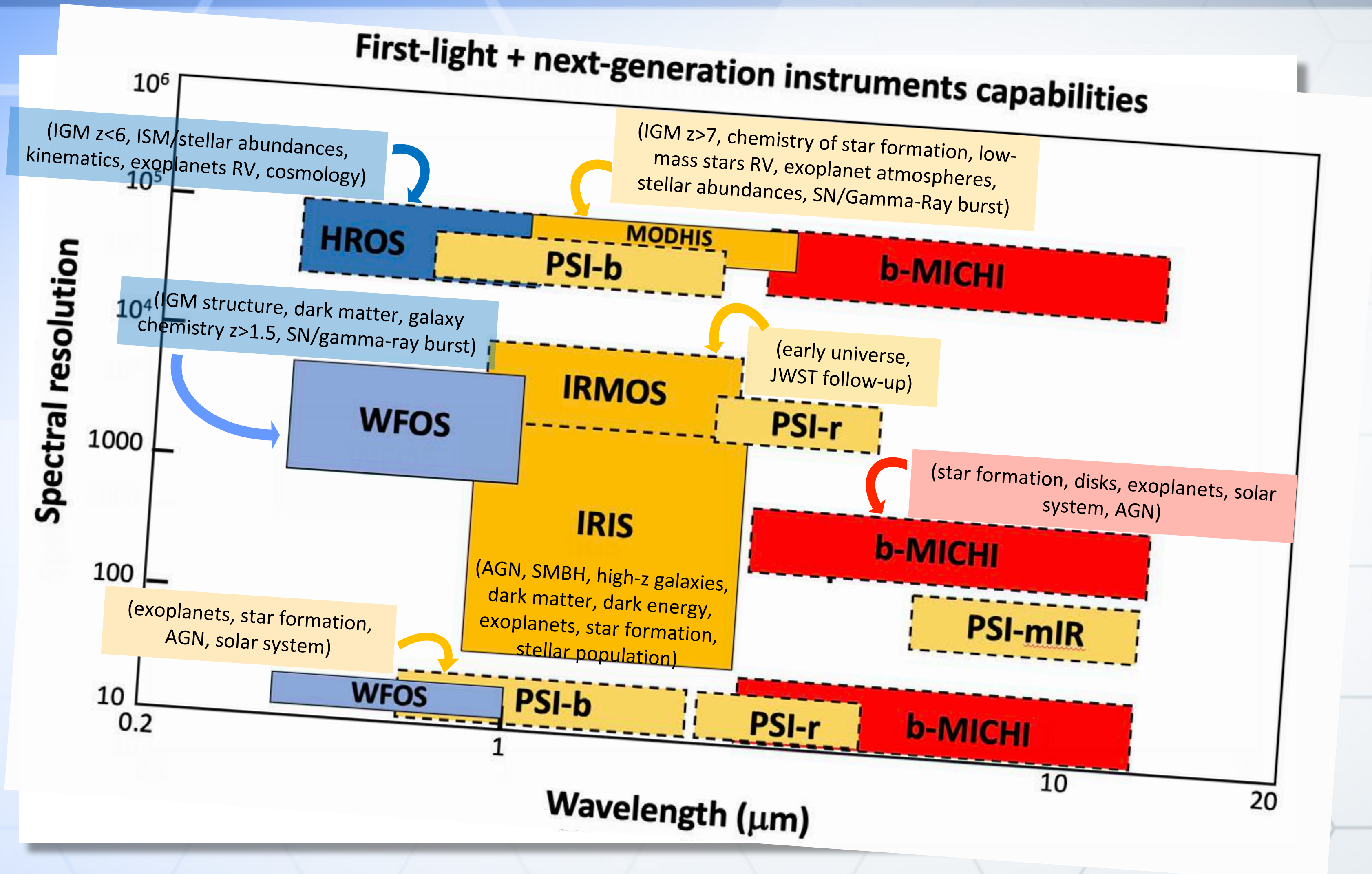




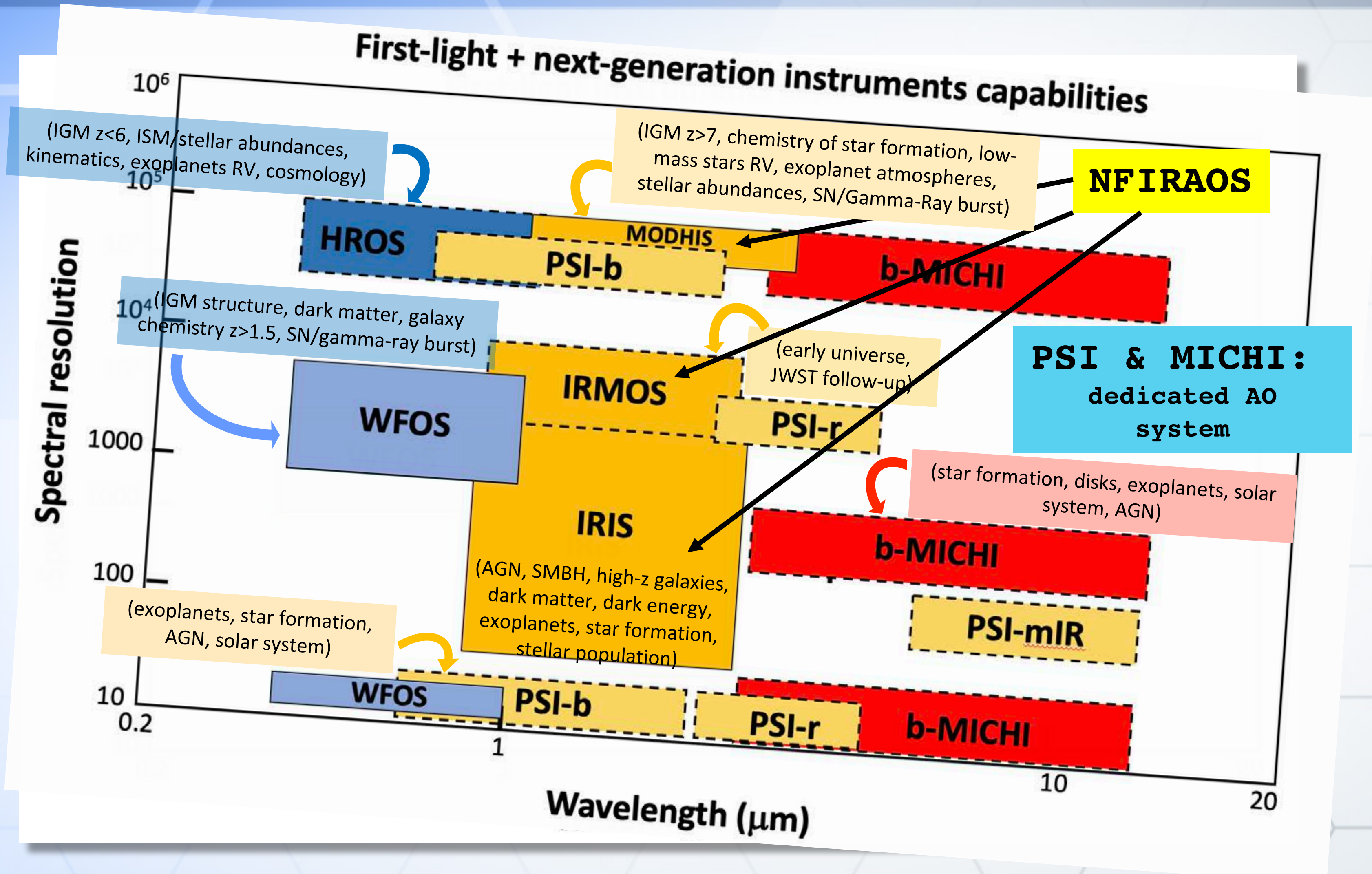
Pathfinder fiber injection unit for KPIC



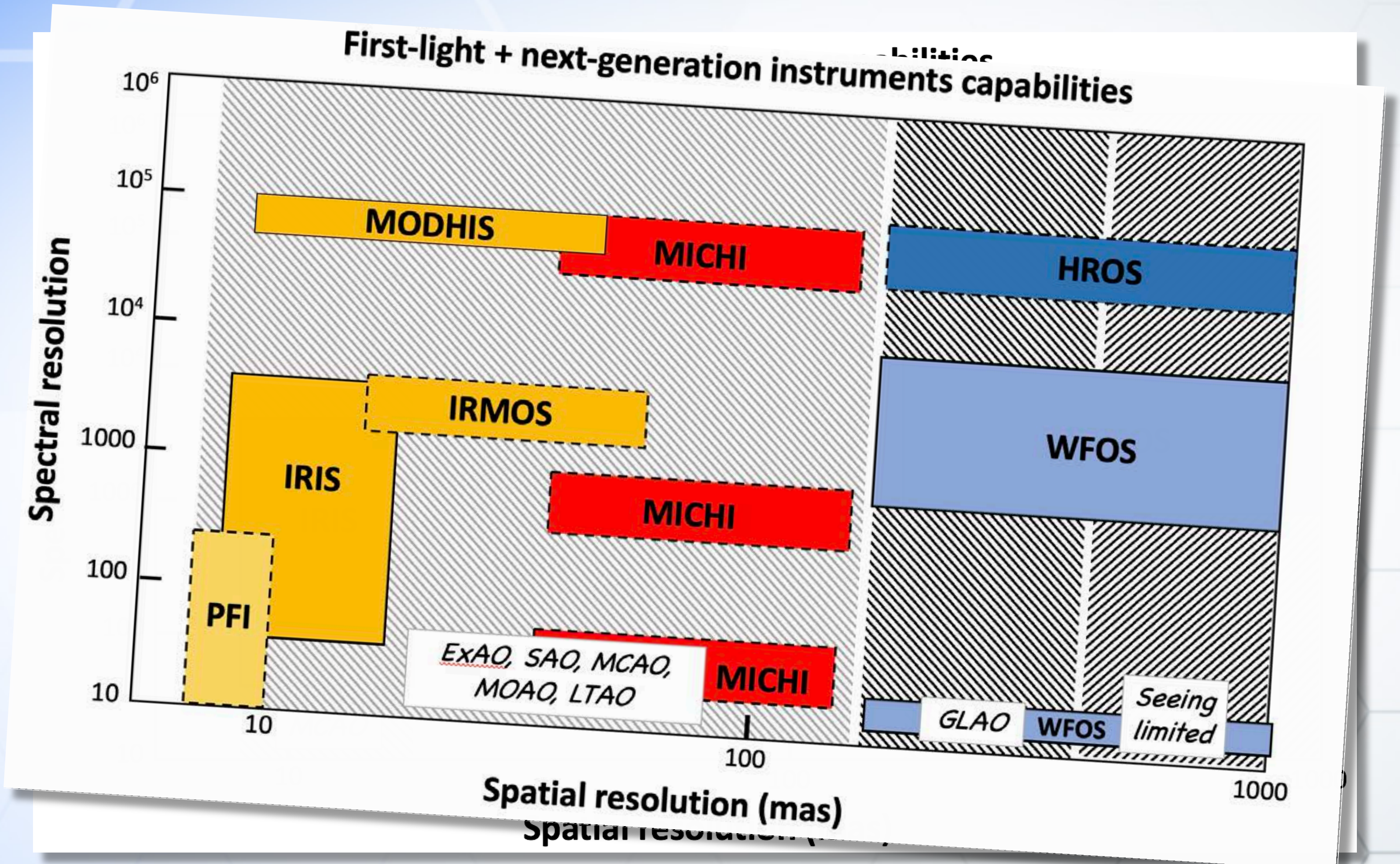
TMT instruments
First-light & next-generation



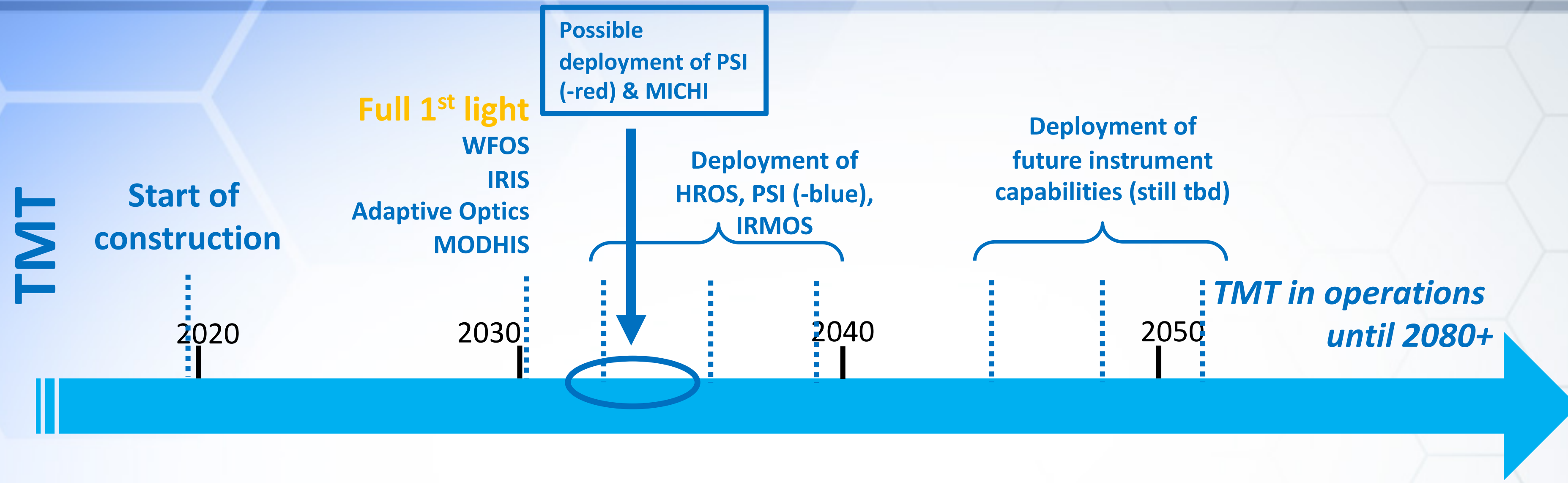
TMT instruments
First-light & next-generation



TMT instruments
Spatial resolution



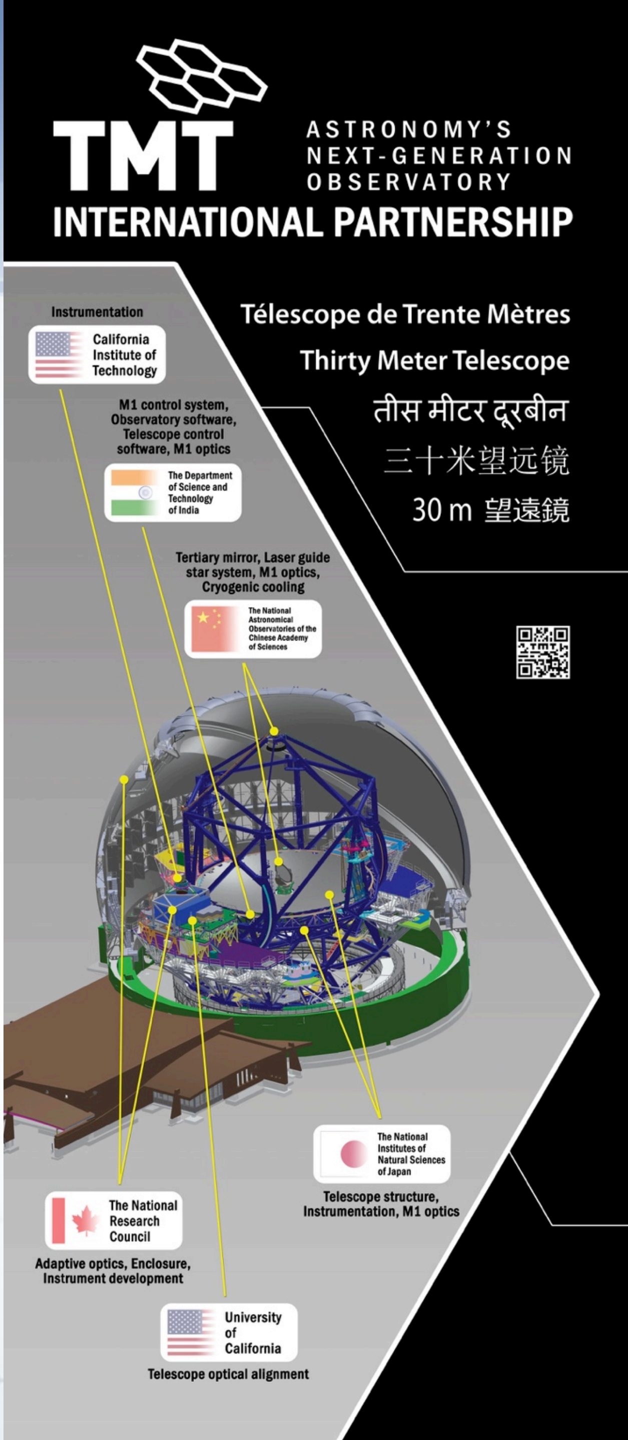
Possible timeline of instrument deployment 1st light and "next-generation"



> **Recommendation: The National Science Foundation (NSF) should invest in both the GMT and TMT and their exoplanet instrumentation to provide all-sky access to the U.S. community.** (Chapter 4)

> **Recommendation: NASA should implement high-contrast starlight suppression technologies in near-term space- and ground-based direct imaging missions.** (Chapter 5)
>
> From "Astrobiology strategy to search for life in the universe", 2018, National Academy Press

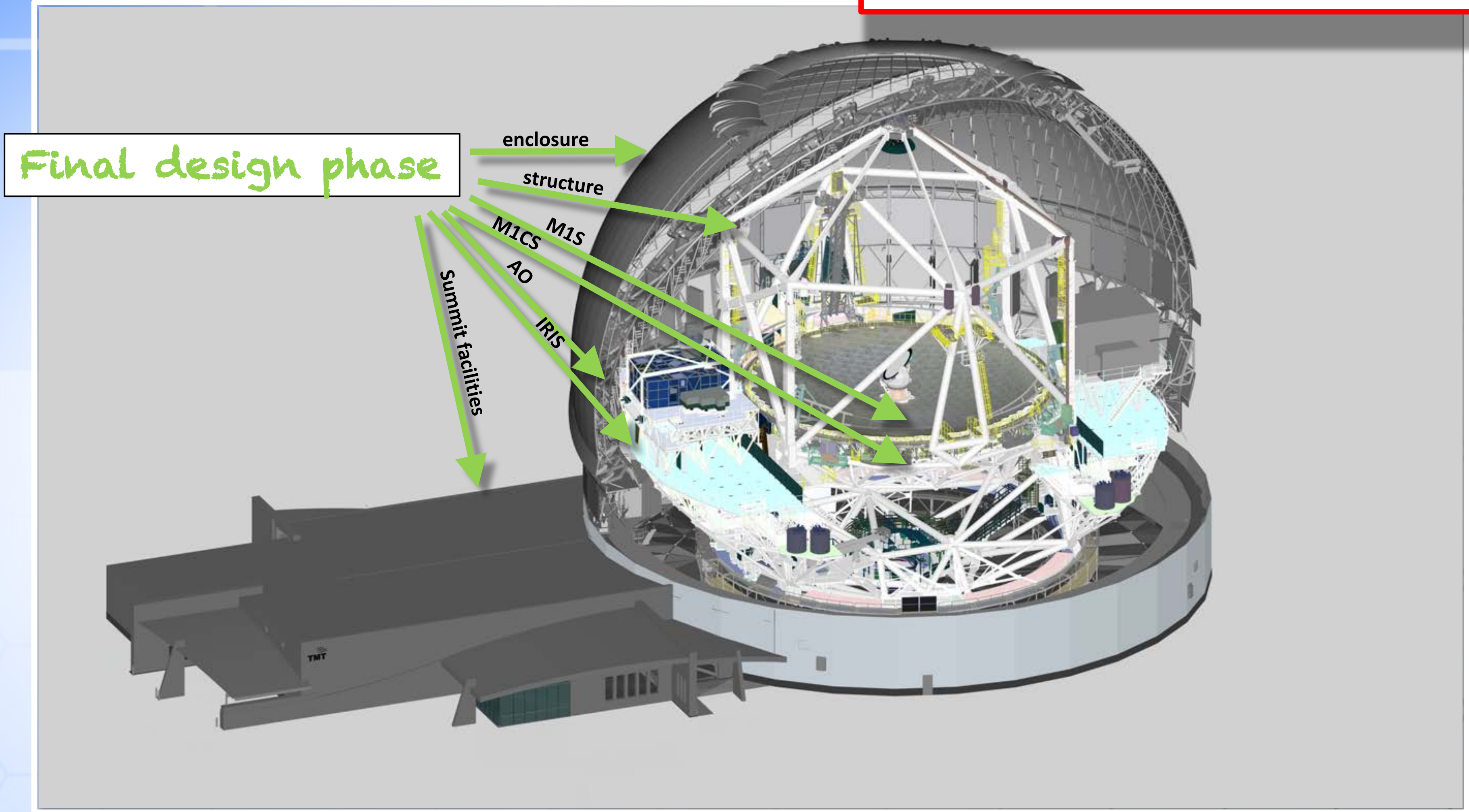
Quick update on Project/system advancement



TMT Thirty Meter Telescope

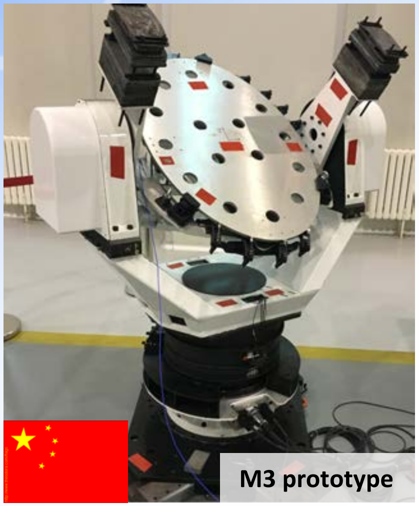
Systems status

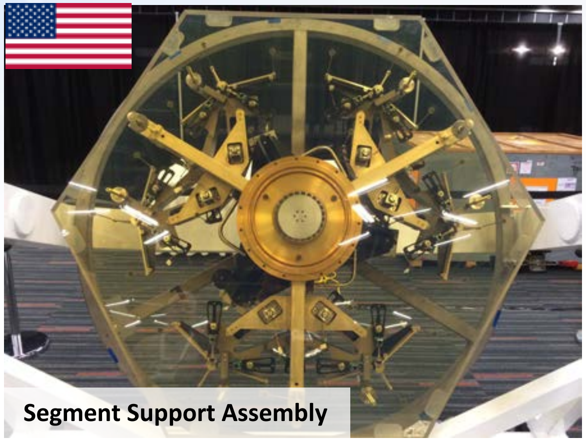
All critical systems are at an advanced state of design, while <u>some are already in production</u>

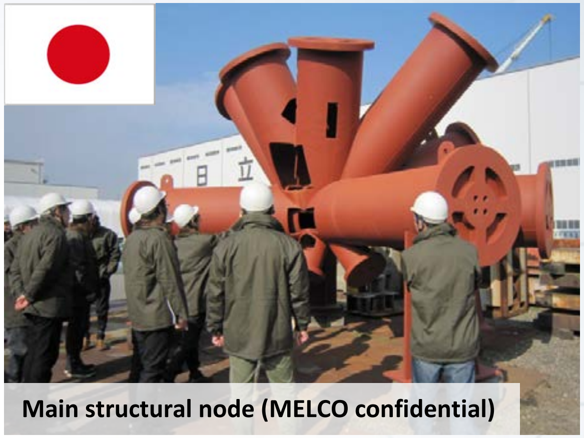


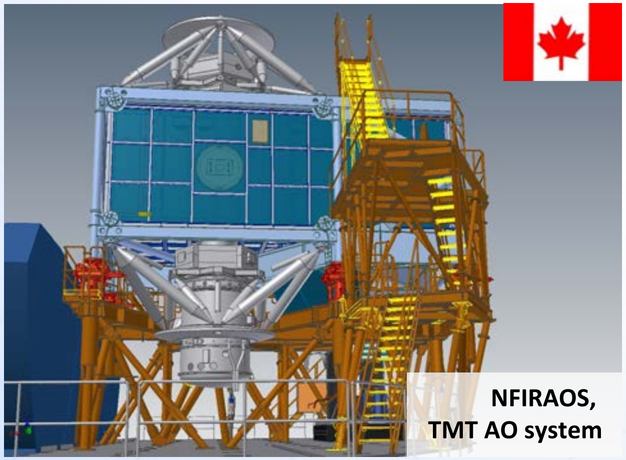
TMT
Thirty Meter Telescope

Snapshot of systems design/production


M3 prototype


Segment Support Assembly

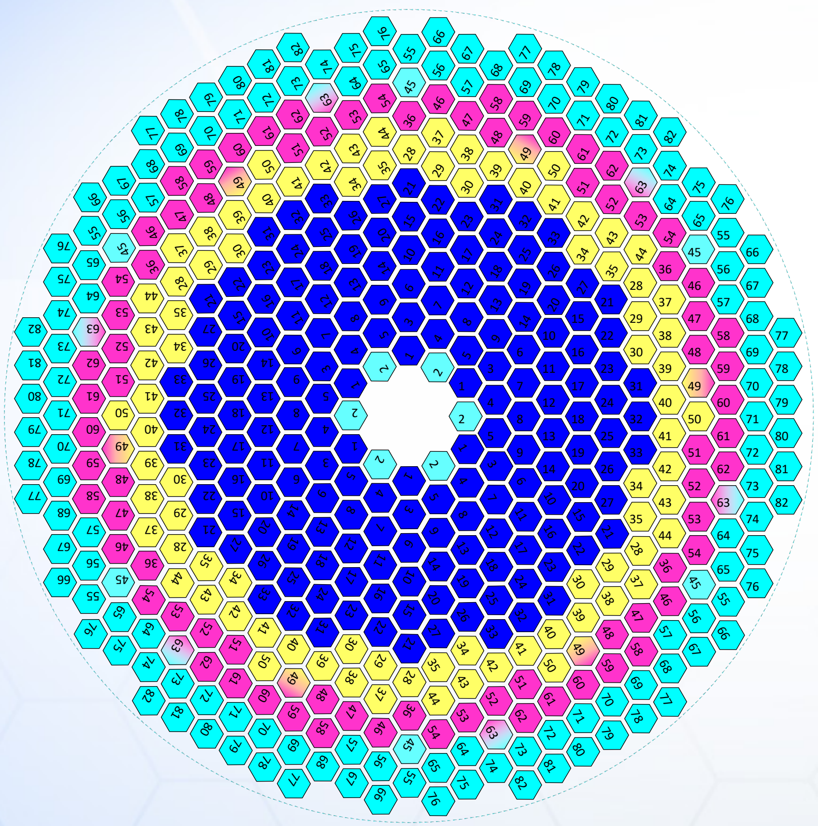

Main structural node (MELCO confidential)


NFIRAOS,
TMT AO system


Actuators components and edge sensors (NASA/JPL: design, India: production)

TMT Global Participants: Mirror segments manufacturing

- 82 types of segments (different curvature) duplicated over 6 sectors
  - 7 mirror segments of each type must be produced (include 1 spare)



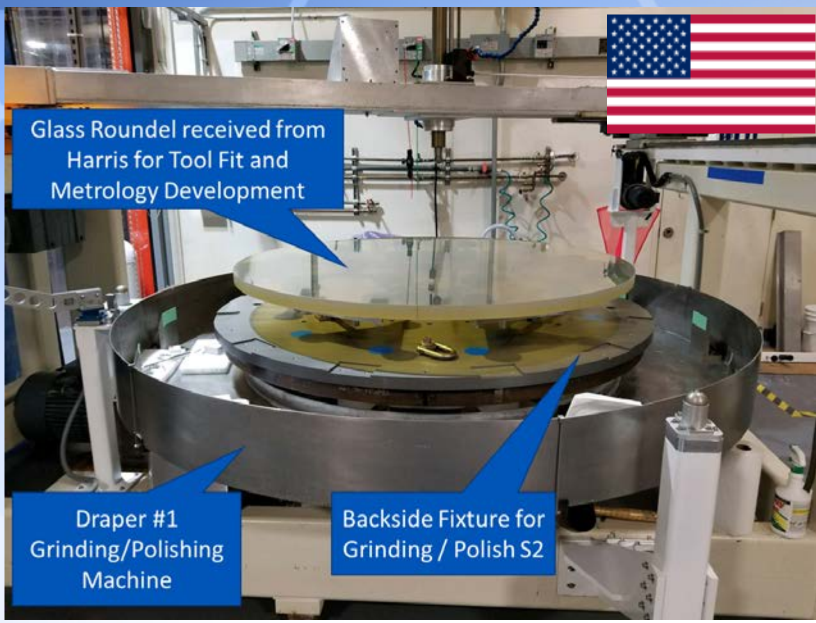
(blue)	Japan:	174
(yellow)	India:	86
(magenta)	China:	86
(cyan)	CIT/UC:	146 + **82**

Total: 492 segments

Spares: 82 segments

Gran Total: 574 segments

Polishing activities starting across partnership




CREST facility, Bengalore

… while waiting for real construction images

Thank you!

Acknowledgments

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