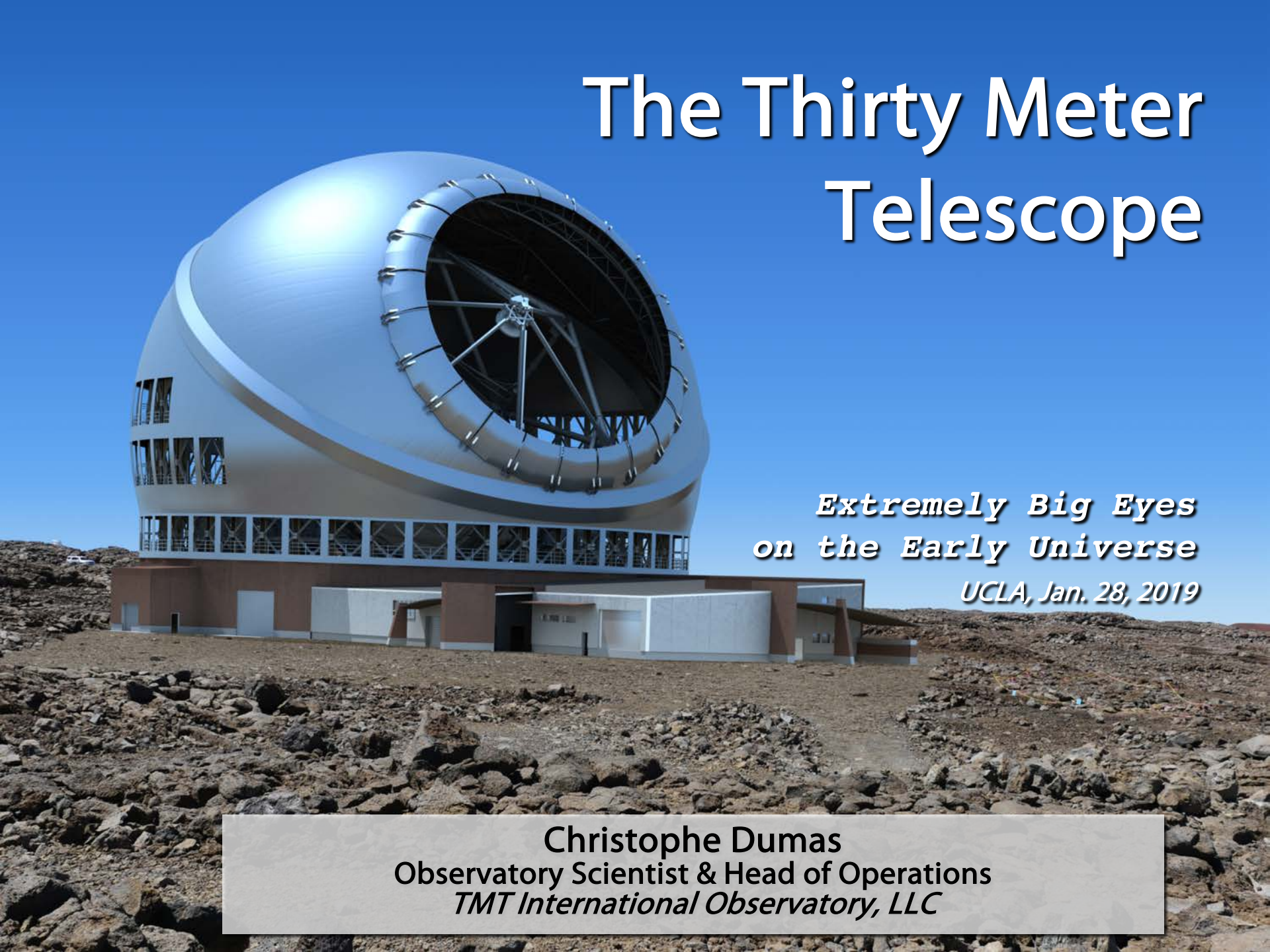
The Thirty Meter Telescope



Extremely Big Eyes on the Early Universe

UCLA, Jan. 28, 2019

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

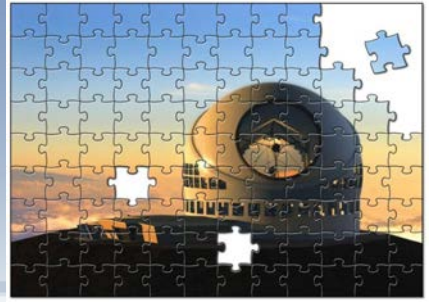
Plan

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

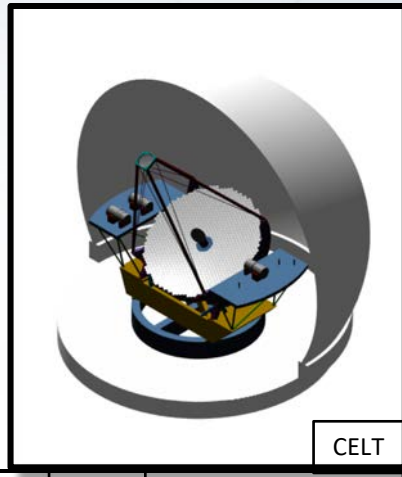
Main points

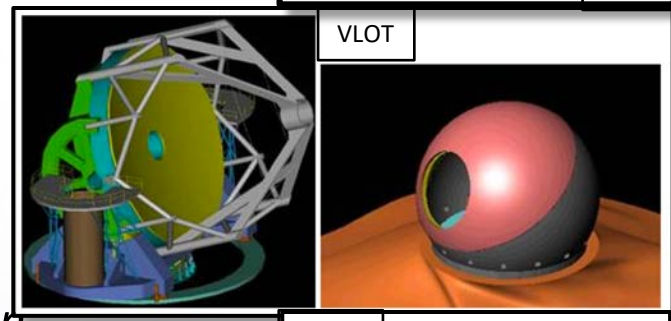
- **Access to Maunakea is just a few** (admin) **steps away**!
  - We will attempt to re-start construction very soon
  - What is the difference between now and 3 years back, in 2015?
    - All legal aspects have been positively ruled on
    - Polls show strong support for TMT in Hawaii
    - We have an alternate site, La Palma (Canary islands), to start construction anytime in case we cannot safely resume construction on Maunakea
- Our two first-light instruments are defined. One of them, IRIS, an AO-fed instrument, is at final design level
- We have identified our suite of next-generation instruments (pre-conceptual design to start soon), and we are building TMT's instrumentation roadmap for the first decade
- While **civil construction** has been halted since 2015, **system construction** (at the design or production level) **has progressed nominally** throughout all Observatory Systems

History of project



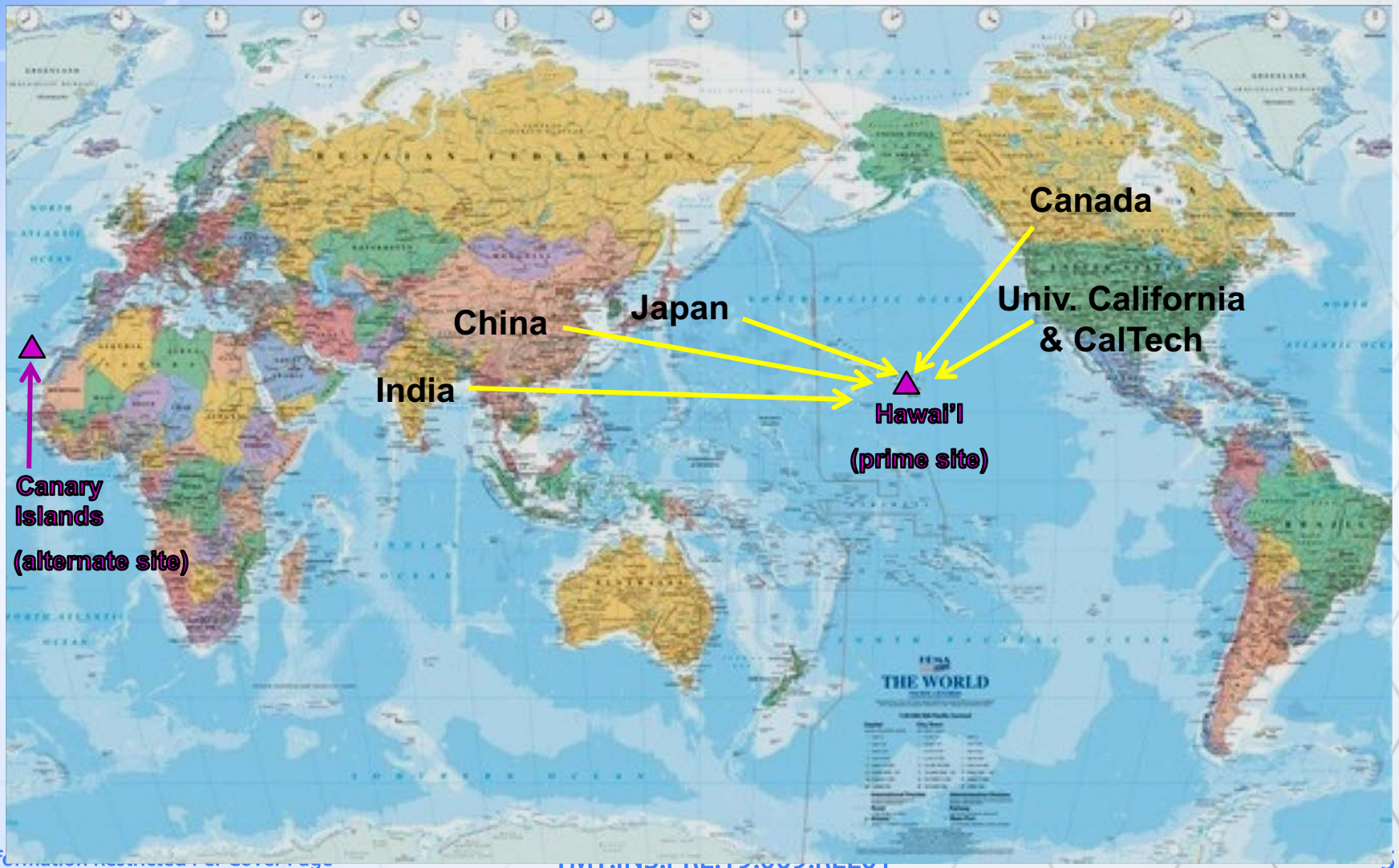
- Thirty-Meter-Telescope (TMT) = Merging of 3 earlier projects. Current cost ~1,500 M$
  - CELT: California Extremely Large Telescope (30m diameter). Caltech and Univ. California
  - VLOT: Very Large Optical Telescope (20m diameter). Canadian Universities for Research in Astronomy (ACURA)
  - GSMT: Giant 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 International Observatory, LLC





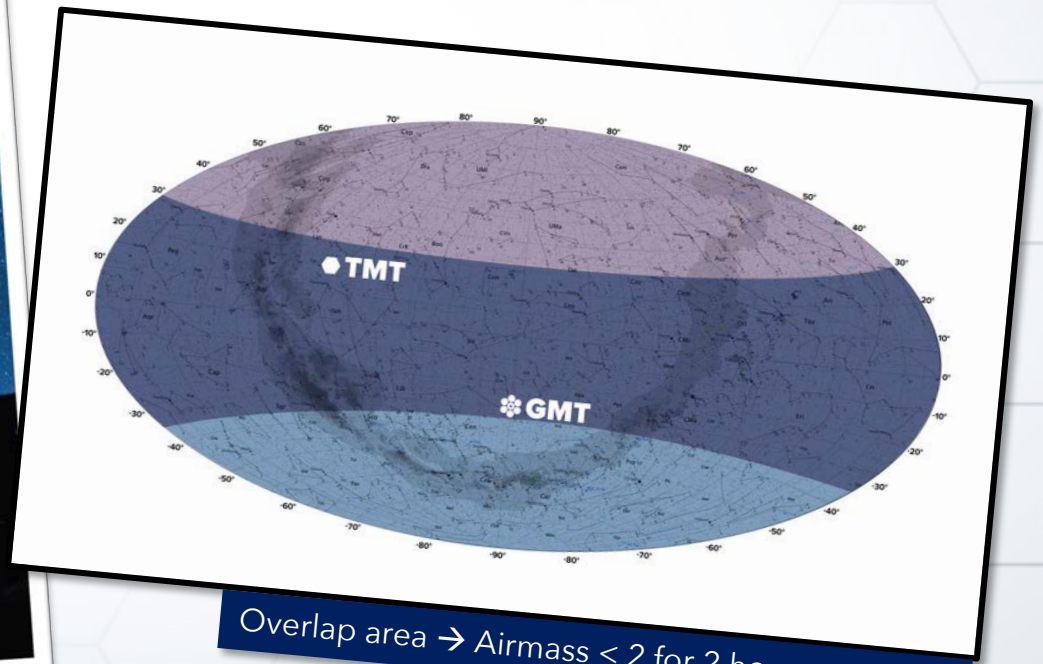
TMT
Thirty Meter Telescope

International Partnership and construction site(s)



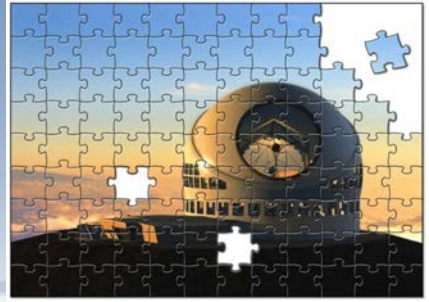
US-ELT Program

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



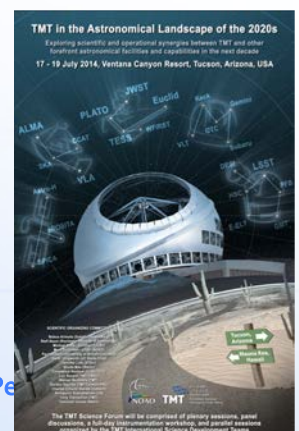
Overlap area → Airmass < 2 for 2 hours or more

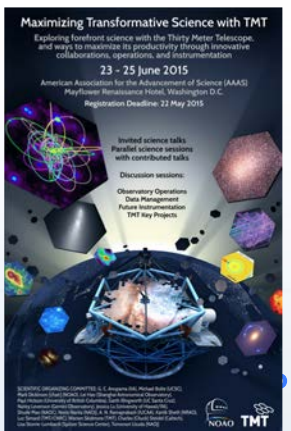
History of project (Cont'd)

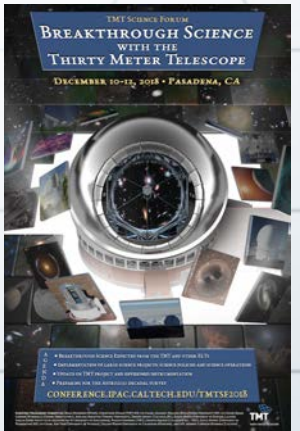


- AURA has already been an Associate Member of the TMT on behalf of the US national community
  - Through a cooperative agreement with the NSF, TMT and a US-SWG have been **developing a model for potential US partnership:**
    - International Science Development Teams
    - Organization of TMT science forums
    - Education & public outreach
    - More info? Check http://ast.noao.edu/system/us-tmt-liaison

2013 2014 2015 2016 2017 2018







History of p

Join 1 (or more) ISDT(s)!
→ Yearly enrollment open until February 8

Go to: "http://TMT.org"

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    - International Science Development Teams
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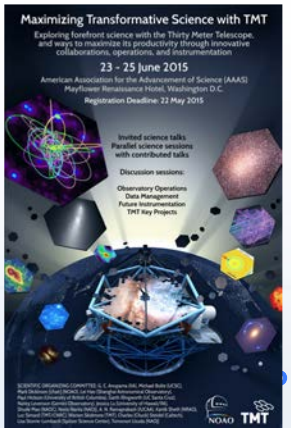
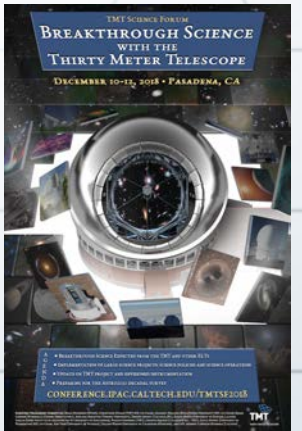
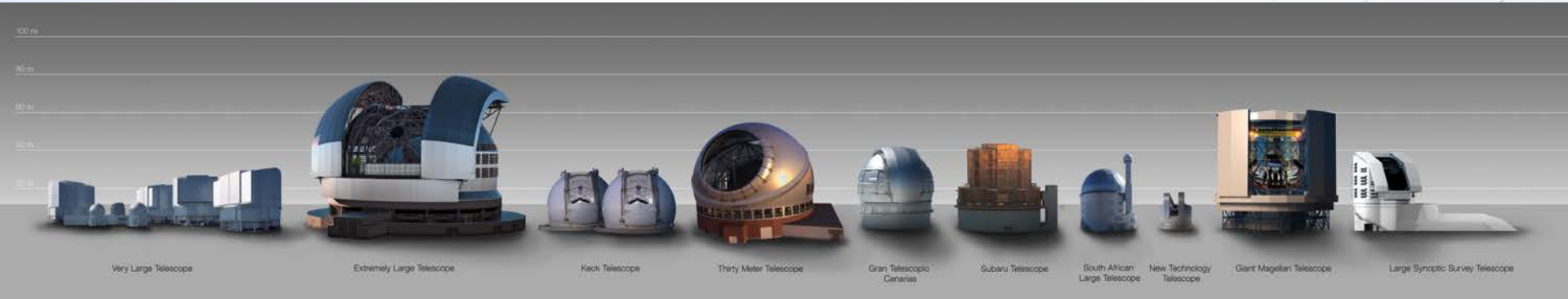


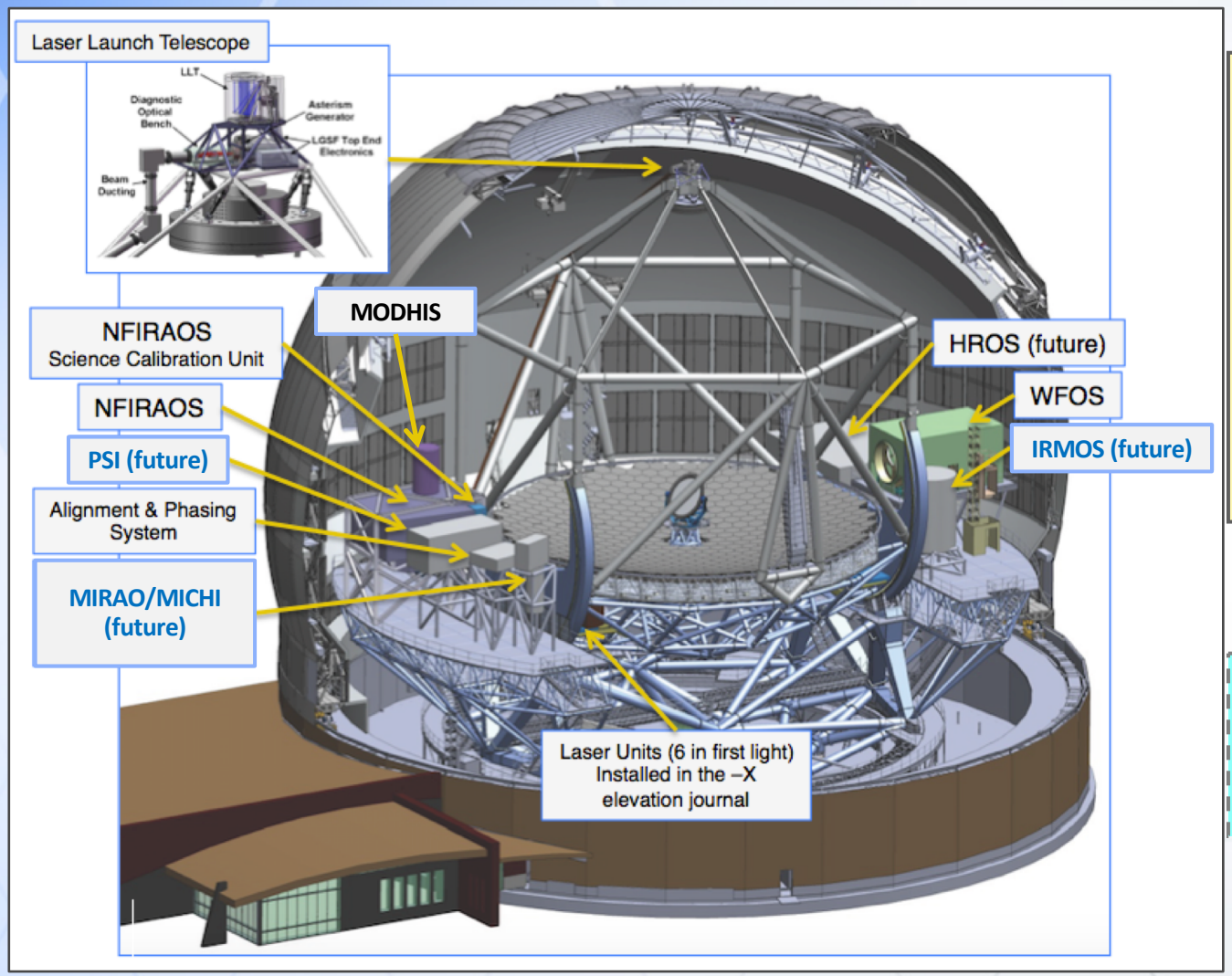


TMT in a nutshell

- 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.
- Expected (re-)start of construction: 2019. First-light: 2027/28



TMT: Optical design & instruments



Optical design:
Ritchey-Chrétien

M1:
30m (hyperboloidal f/1)

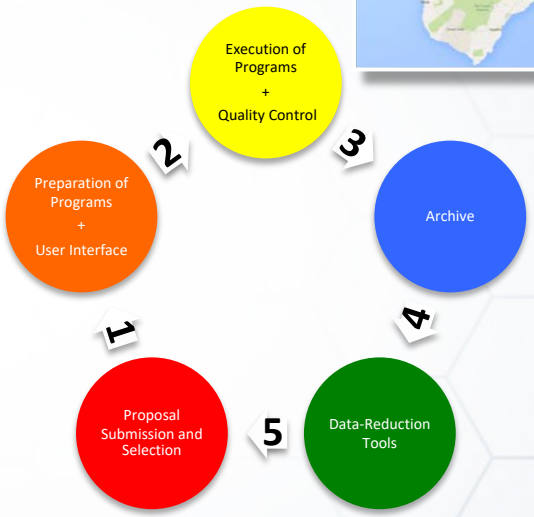
M2:
3.1m (convex hyperboloidal)

M3:
2.5m x 3.5m (flat)

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

TMT operations model

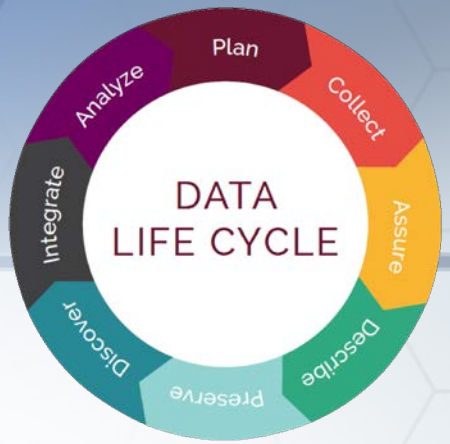
- Model is **customer-oriented** and encompasses **end-to-end** aspects of **science operations**:
  - "Phase 1": Proposal preparation and submission
  - "Phase 2": Science program preparation/optimization
  - Science program execution:
    - Support of both visitor (PI-mode) & service (queue) observing modes
      - Including support for Target of Opportunity, Rapid-Response mode, Eavesdropping



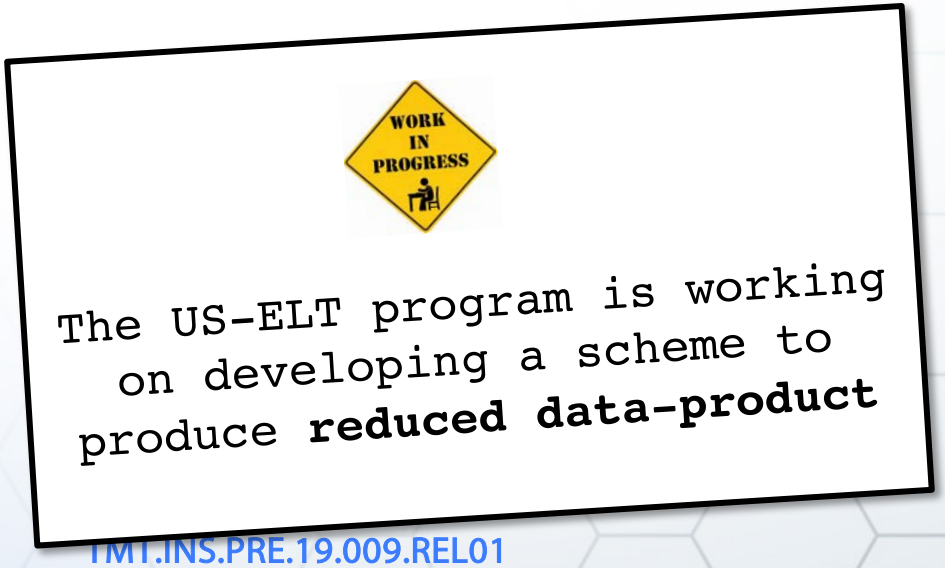
TMT operations model

- Science operations
  - **All observations are done remotely from HQ (sea-level)**
    - Operations plan also foresees remote operations sites distributed throughout partnership (concept to be developed)
  - **Support operations staff** will be engaged in <u>all aspects</u> of science operations:
    - Proposal support, observing preparation/execution, instrument performance-monitoring/upgrades, quality control, data-reduction
  - **Use of flexible scheduling** to match science program constraints with ambient conditions (goal)
    - Expected share of time between various wavelength regimes
      - 40% visible/seeing-limited, 50% near-IR with AO/LGS, 10% mid-IR

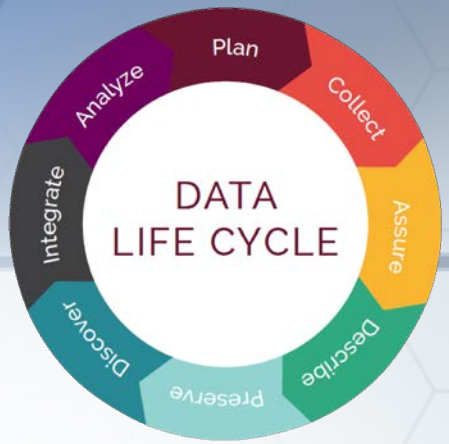
TMT operations model



- Data management
  - All science data are archived (raw science and calibration files, metadata comply with IVO standards). Query tools provided
  - Data-reduction pipelines are provided by instrument teams, maintained by Science Ops staff, improved by inst. teams and science users



TMT operations model



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Product	Proprietary Period	Comments
PI Science Data frames	Y	Baseline is 18 months
Science header metadata	N	Header data is immediately available to TMT users community
Associated metadata	N	This includes weather data, AO PSF or other ancillary data that we associate with science data frames
Calibration data frames	N	Immediately accessible through archive
Proposal title, PI/co-I, partner, instrument, hours allocated, scheduled run dates or scheduled visits	N	Only these parts of the proposal are public
All other proposal information	Y	

TMT operations model

- Data policy (work in progress)
  - Proprietary period: 18 months.
    - Flexibility for each partner to adapt policy *vs* program-type
    - After proprietary period, science data are made available to all partners and then (possibly) to science community at-large
  - Proposal cycle: 6 months
    - *Note*: Could be extended to 1 year, with **implementation of "fast-track" proposal type**, enabling fast/continuous TAC response
  - Data access:
    - All science data stored indefinitely in centralized archives (e.g. "cloud")
    - Archive can be accessed through data portal (login credentials)
    - Multiple copies kept at summit (temporarily) and HQs (indefinitely)

Construction Site

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 (°C)	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

he 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
- **February 2016:** TIO board launches search and characterization of an alternate site
- **October 2016:** TIO Board announces La Palma as the selected backup site for TMT
- **January 2017:** Start the process to apply for permits in the Canary Islands

Maunakea & TMT

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Strong TMT presence in Hawaii with huge positive impact on:

STEM education
Workforce development
Public Outreach

Sites:
Construction to start *very* soon

- **Maunakea:**
  - **2009:** Maunakea selected for TMT
  - **2016-2017:** 1.5 years long contested case
  - **Sep. 2017:** BLNR approves the Construction District Use Permit
  - **2018:** Stronger and more "open" local support than in 2015
    - 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. All clear.
  - **Now: **Attempt re-start of construction ASAP****

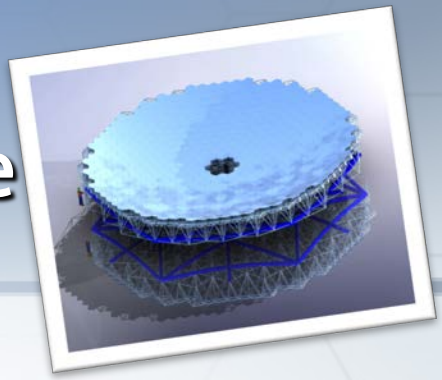
- **La Palma:**
  - **2016:** La Palma becomes TMT's alternate site
  - **2017:** Hosting Agreement MOU signed between TIO and IAC
  - **2017:** Collaboration agreement signed between TIO, IAC, La Palma government & local municipality
  - **Nov. 2018:** Authorities validated our Environmental Impact Study.
  - **Now:** All legal approvals have been published. Free path to request construction permit.

Current timeline

- **Today:** Access granted in Hawaii and Spain (*only a few admin steps away in Hawaii*)
- **2019:** Start of Construction in Hawaii (*La Palma is backup site*)
- **2020 -2022:** Enclosure assembly
  - End 2023: End construction of all summit buildings
- **2022-2024:** Telescope structure integration
- **2024 -2027:** AIV, commissioning
- **2028: "First-light"**

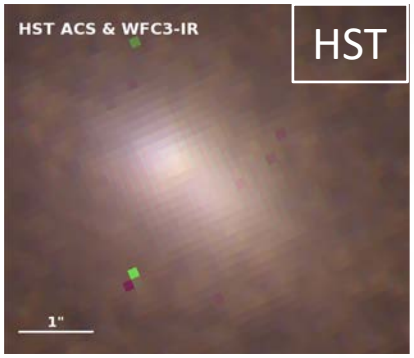
Science instruments

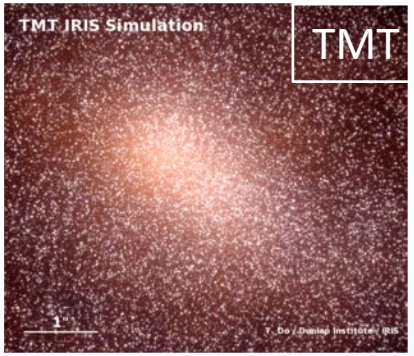
Expected boost in performance



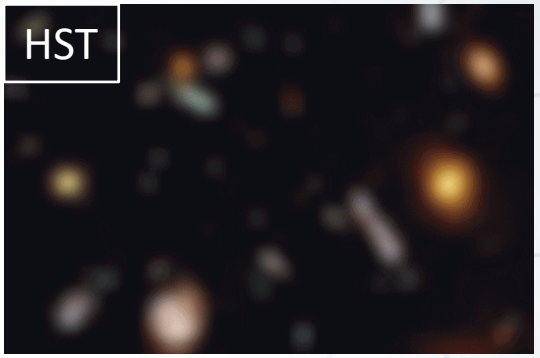
- SENSITIVITY: $S \sim D^2$
  - **~10 times the collecting area of Keck, or ~150 times that of the HST**
    - For AO on point sources: **$S \sim D^4$, i.e. ~200 times better than current VLTs**
- ANGULAR RESOLUTION:
  - **12 times better HST**

M31 nucleus



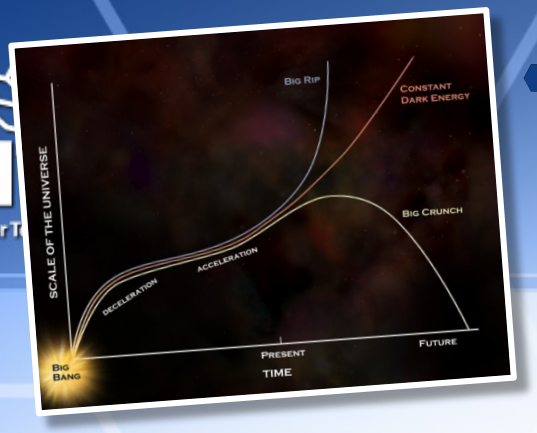


Deep Field



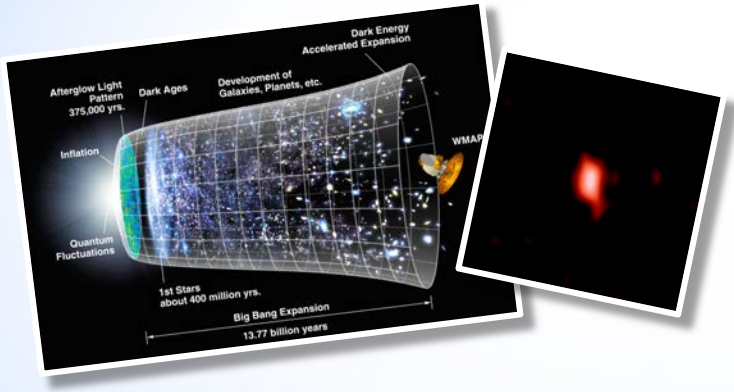
TMT Science & instrumentation

- 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



- Fundamental physics
  - Are the physical constants *really* constant? Nature of dark matter? Dark energy?

- Exoplanet science
  - Is our Solar System unique? How many terrestrial planets are habitable? Are there exoplanets harboring life?



- Getting closer to the ”dark ages”
  - What was the nature of the first stars, first galaxies?

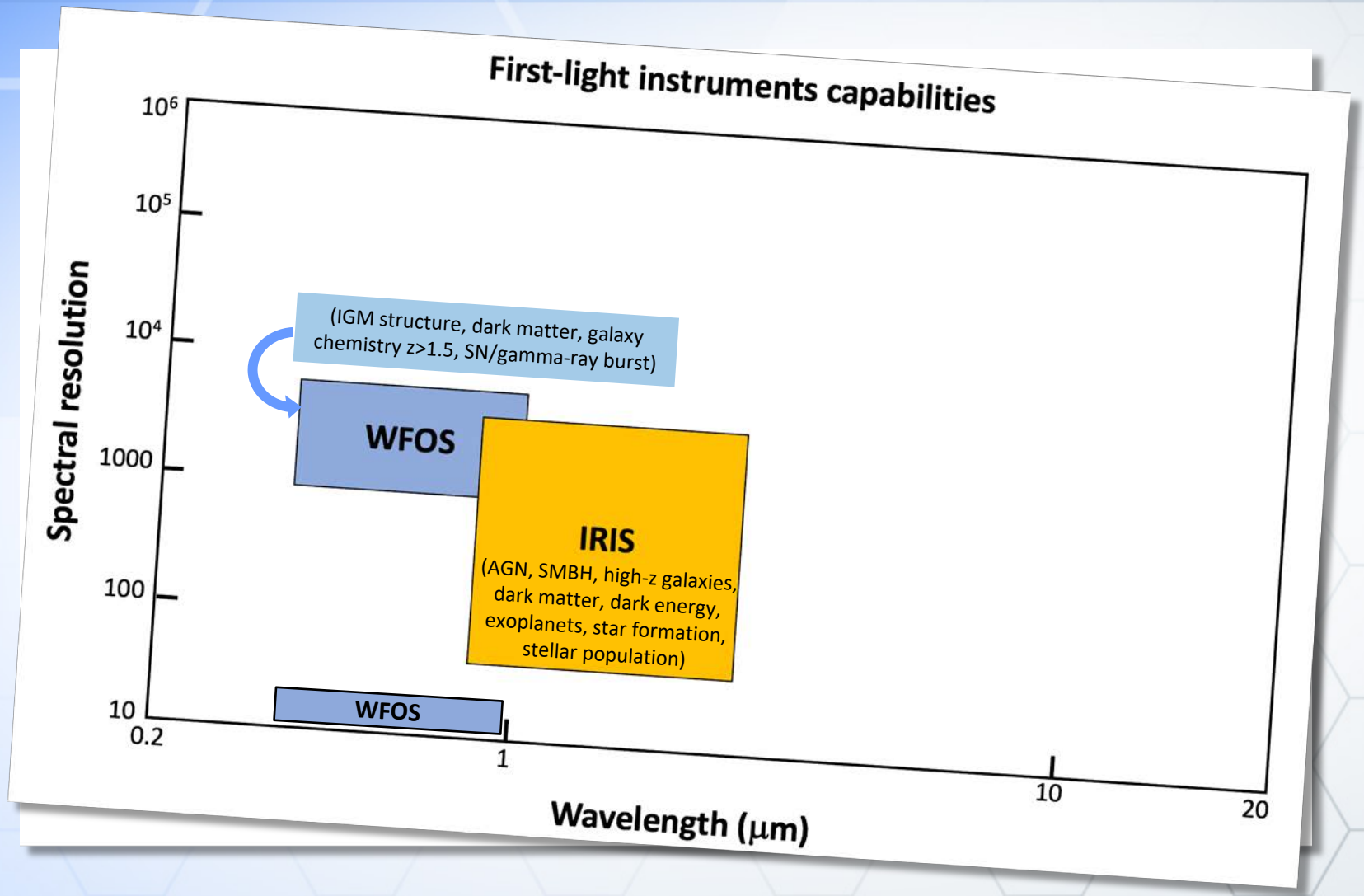
- Understanding our own solar system
  - Where does the Earth water come from? Is there life elsewhere in our system?

TMT envisioned instruments suite

First-light instruments

Instrument	λ (μm)	Field of view/ Slit length	Spectral resolution	Science Cases
InfraRed Imager and Spectrometer (IRIS)	0.8 – 2.5 0.6 – 5 (goal)	<3″ IFU >15″imaging	> 3500 5-100 (imaging)	• Assembly of galaxies at high z • Black holes/AGNs/Galactic Center • Resolved stellar populations in crowded fields
Wide-field Optical spectrometer and imager (WFOS)	0.31 – 1.0	>40 arcmin^2 >100 arcmin^2 (goal) Slit length>500″	1000-5000@0.75″ slit >7500 @0.75″ (goal)	• IGM structure and composition at 2 < z < 6 • Stellar populations, chemistry and energetics of z > 1.5 galaxies
InfraRed Multislit Spectrometer (IRMS)	0.95 – 2.45	2 arcmin field, up to 120″ total slit length with 46 deployable slits	R=4660 @ 0.16 arcsec slit	• Early Light • Epoch of peak galaxy building • JWST follow-ups
Deployable, multi-IFU, near-IR spectrometer (IRMOS)	0.8 – 2.5	3″ IFUs over >5′ diameter field	2000-10000	• Early Light • Epoch of peak galaxy building • JWST follow-ups
Mid-IR AO-fed Echelle spectrometer (MIRES)	8 – 18 4.5 – 28 (goal)	3″ slit length 10″ imaging	5000-100000	• Origin of stellar masses • Accretion and outflows around protostars • Evolution of gas in protoplanetary disks
Planet Formation Instrument (PFI)	1 – 2.5 1 – 5 (goal)	1″ outer working angle, 0″.05 inner working angle	R≤100	• 10^8 contrast ratio (10^9 goal) • Direct detection and spectroscopic characterization of exoplanets
Near-IR AO-fed echelle spectrometer (NIRES)	1 - 5	2″ slit length	20000-100000	• IGM at z > 7, gamma-ray bursts • Local Group abundances • Abundances, chemistry and kinematics of stars and planet-forming disks • Doppler detection of terrestrial planets around low-mass stars
High-Resolution Optical Spectrometer (HROS)	0.31 – 1.1	5″ slit length	50000	• Doppler searches for exoplanets • Stellar abundance studies in Local Group • ISM abundance/kinematics • IGM characteristics to z~6
"Wide"-field AO imager (WIRC)	0.8 – 5.0	30″ imaging field	5-100	• Precision astrometry (e.g., Galactic Center) • Resolved stellar populations out to 10 Mpc

TMT instruments
Discovery space



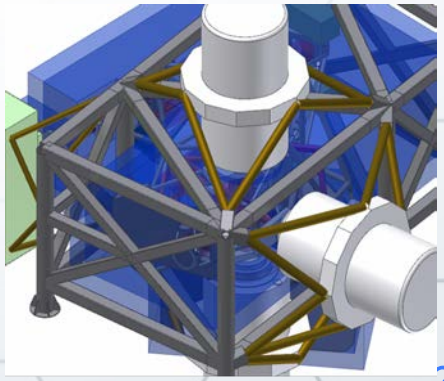
NFIRAOS Requirements & Architecture

First-Light

- **Diffraction-limit:** J, H, K (Strehl > 50% at 1μm)
- **High throughput:** min. 80% at 0.8-2.4μm
- **Low background:** Thermal emission < 15 % of sky and telescope
- **FOV:** 30" science-field with 2' clear FoV
  - WFS FoV ~ 1arcsec (limitation for extended object!)
- **Differential photometry** 2% for a 2 minute exposure on a 30" FoV at λ = 1 μm
- **Differential Astrometry** 50 μas for a 100 s exposure on a 30" FoV in the H band
- **Available** from **standby** <10 minutes
- **Acquire** a new field < 5 minutes
- **Downtime** unscheduled < 1 per cent
- **Track non-sidereal** targets up to 15 arcsecond/sec (i.e. Near-Earth Objects can be observed)

Main architecture components:

- Multi-conjugate wavefront correction
- Cooled at -30deg C
- 6 LGS for atmos. tomography
- 3 NGS WFS for tip-tilt/focus within instruments
- Polar coordinates detectors for LGS WFS



TMT's center-launched Laser Guide Star

First-Light

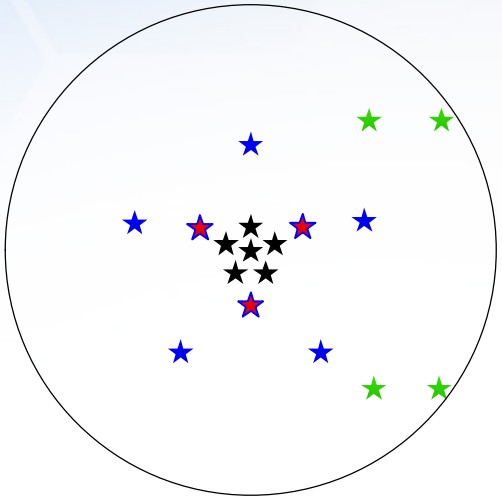
4 ASTERIMS

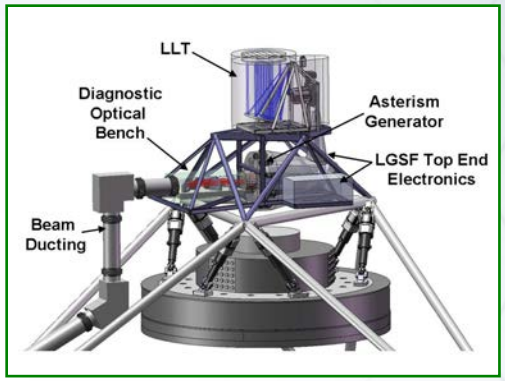
MCAO: 5 on a circle of 35 arcsec and one additional on-axis

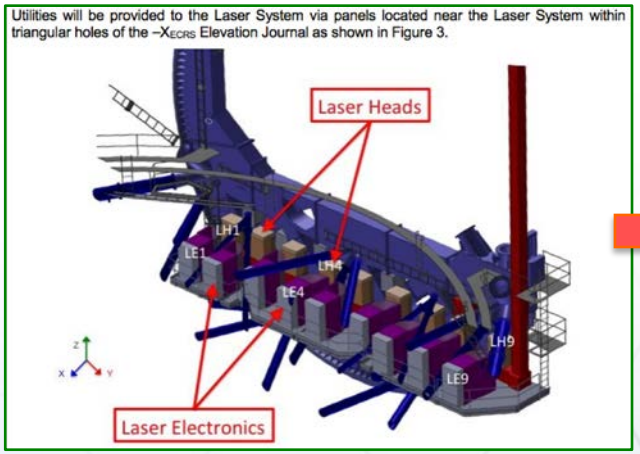
MIRAO: 3 on a circle of radius of 70 arcsec

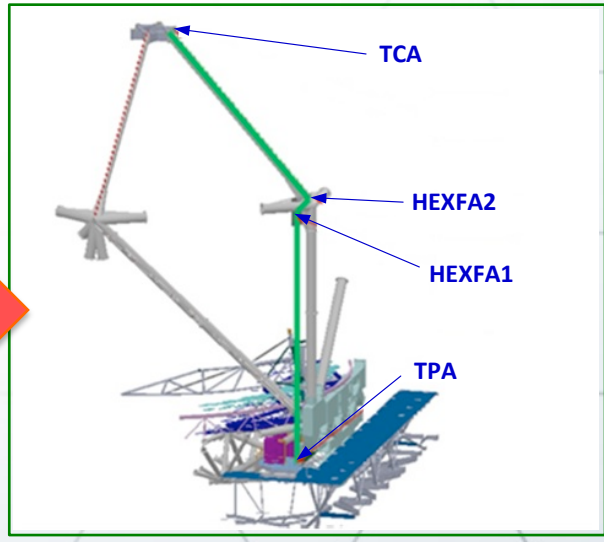
MOAO: 3 on a circle of radius of 70 arcsec and 5 on a concentric circle of radius of 150 arcsec

GLAO: at the corners of a 240 arcsec x 558 arcsec rectangle, offset by 288 arcsec







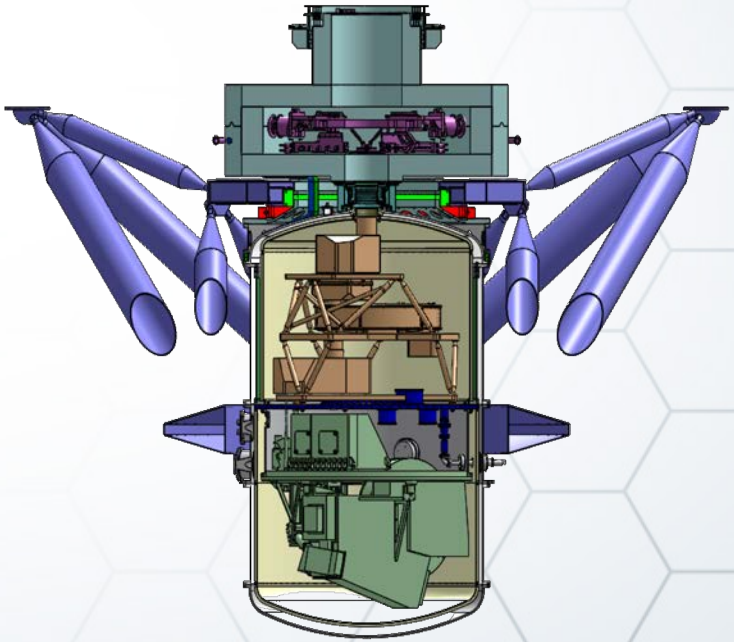


InfraRed Imager and Spectrograph (IRIS)

First-Light

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

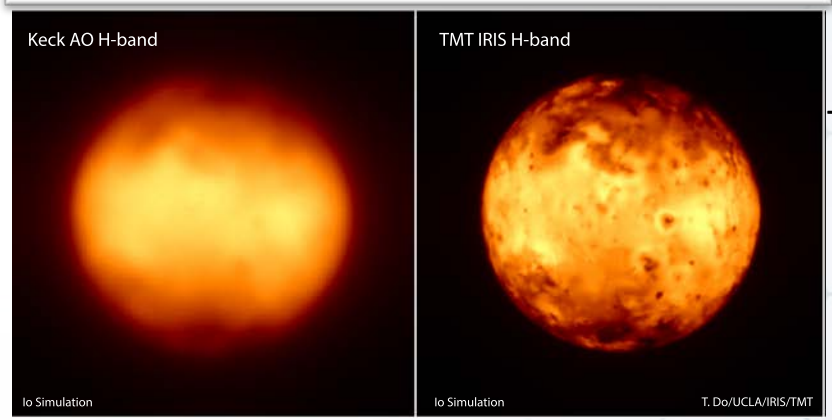
PI: J. Larkin (UCLA)
PM, co-PI: E. Chisholm (TMT)
PS: S. Wright (UCSD)



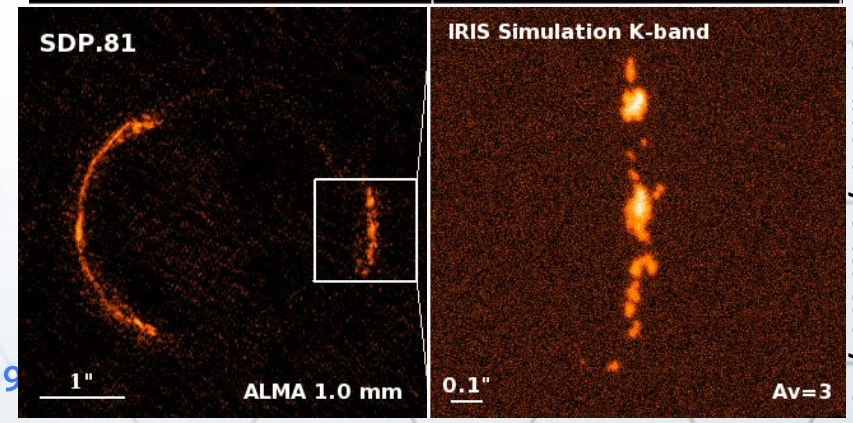
IRIS: A broad range of science goals

- Solar system
- Extrasolar planets
- Stellar structure & evolution with microlensing
- Star formation
- Galactic Center
- Nearby galaxies & stellar populations
- Supermassive black holes
- High-redshift galaxies
- First light galaxies

Pluto-Charon



Jupiter's moon - Io



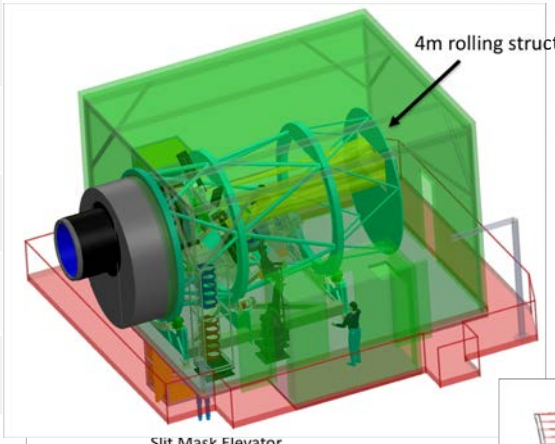
Gravitationally-lensed Galaxy z=3

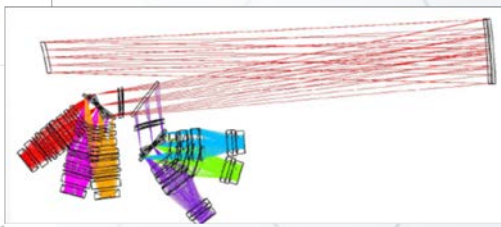
Wide-Field Optical Spectrograph (WFOS)

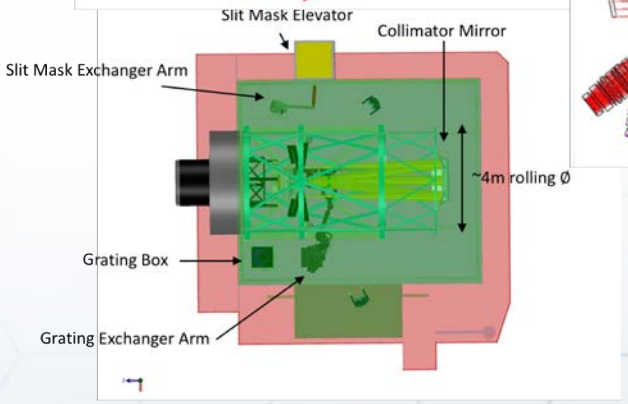
First-Light

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 this October 2018.
- **Conceptual Design phase begins.**

TMT envisioned instruments suite

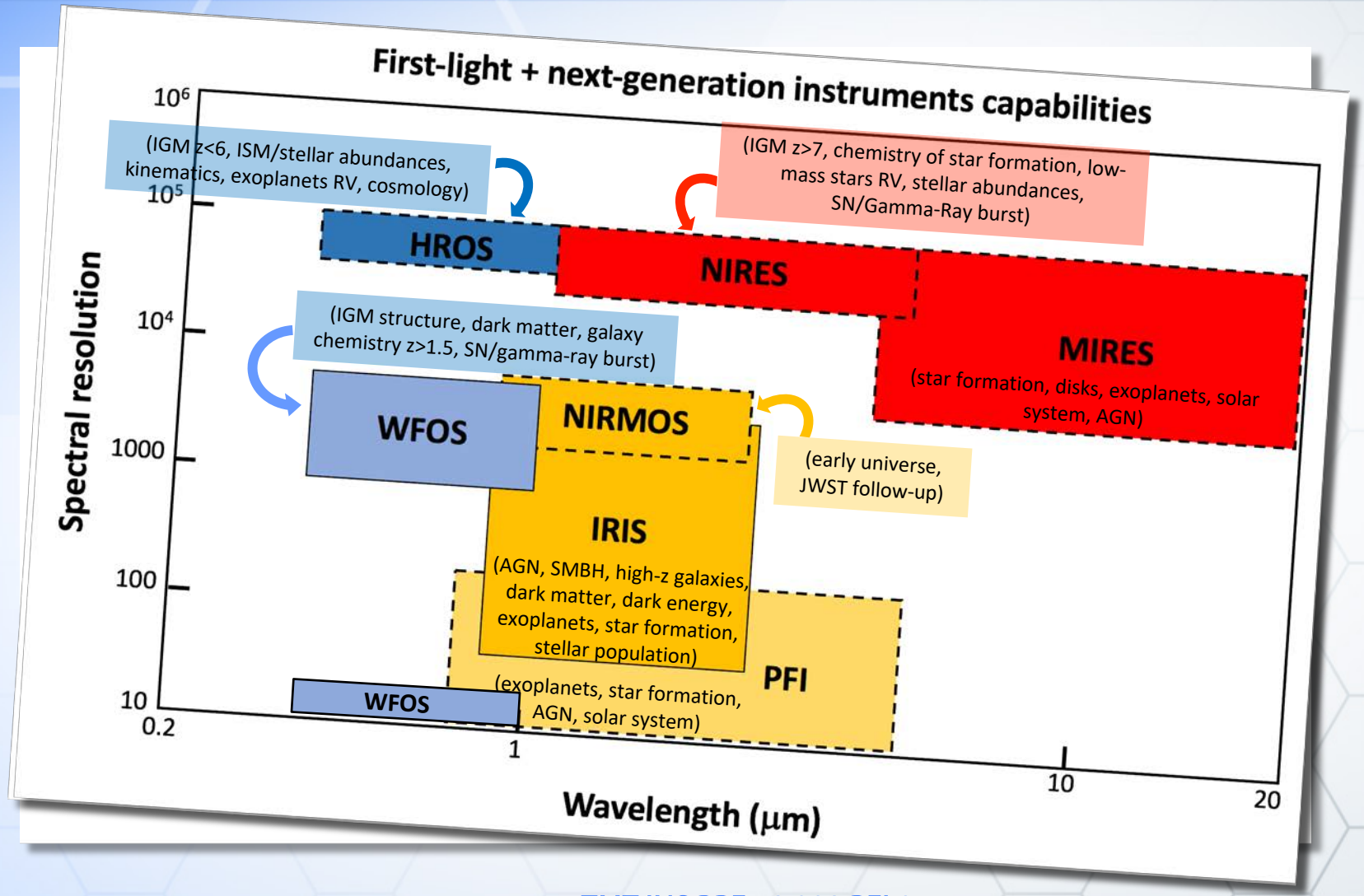
Adaptive optics

Seeing-limited (or GLAO assisted)

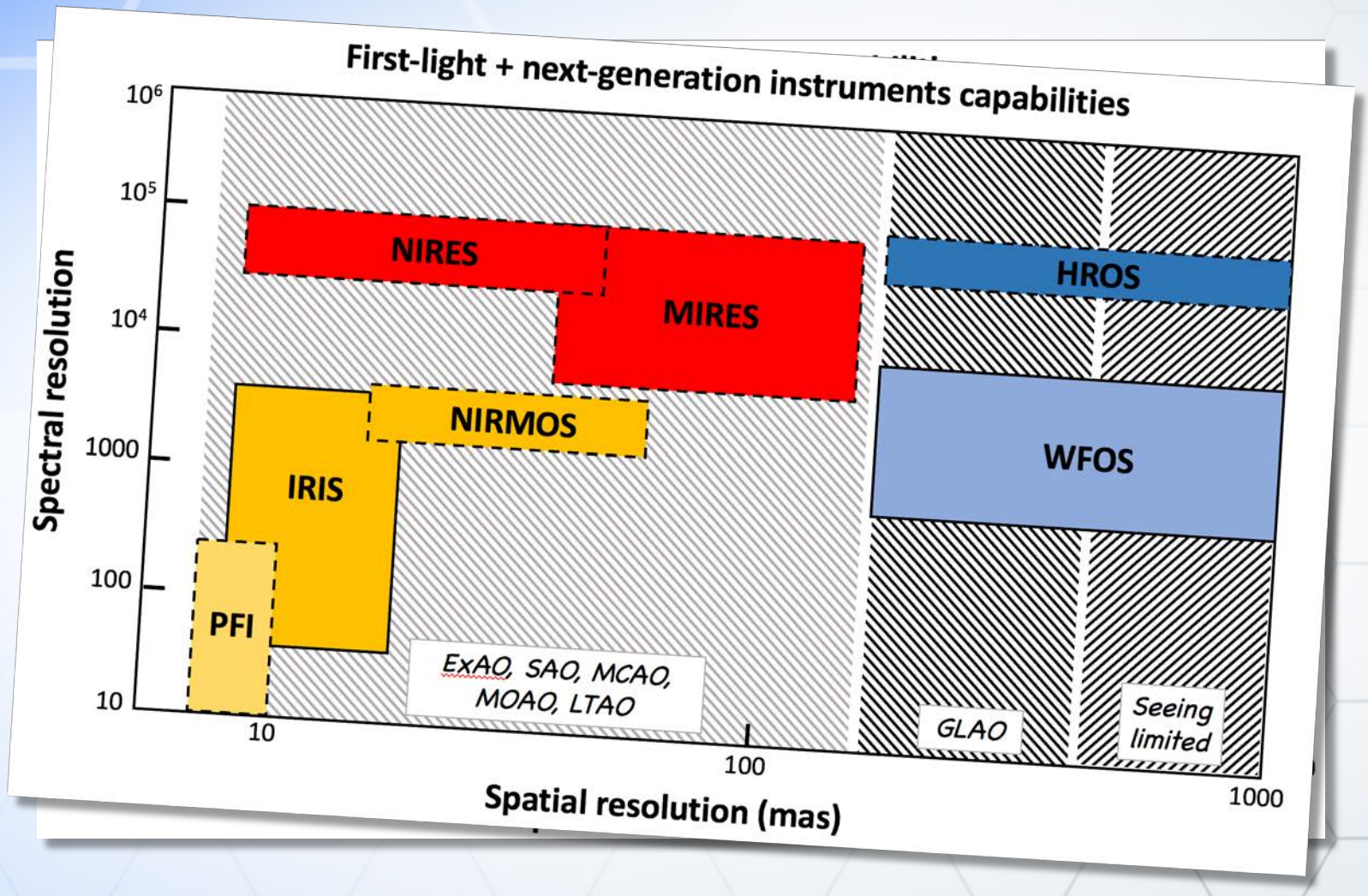
First-light instruments

Instrument	λ (μm)	Field of view/ slit length	Spectral resolution	Science Cases
InfraRed Imager and Spectrometer (IRIS)	0.8 – 2.5 0.6 – 5 (goal)	<3″ IFU >15″imaging	> 3500 5-100 (imaging)	• Assembly of galaxies at high z • Black holes/AGNs/Galactic Center • Resolved stellar populations in crowded fields
Wide-field Optical spectrometer and imager (WFOS)	0.31 – 1.0	>40 arcmin^2 >100 arcmin^2 (goal) Slit length>500″	1000-5000@0.75″ slit >7500 @0.75″ (goal)	• IGM structure and composition at 2 < z < 6 • Stellar populations, chemistry and energetics of z > 1.5 galaxies
InfraRed Multislit Spectrometer (IRMS)	0.95 – 2.45	2 arcmin field, up to 120″ total slit length with 46 deployable slits	R=4660 @ 0.16 arcsec slit	• Early Light • Epoch of peak galaxy building • JWST follow-ups
Deployable, multi-IFU, near-IR spectrometer (IRMOS)	0.8 – 2.5	3″ IFUs over >5′ diameter field	2000-10000	• Early Light • Epoch of peak galaxy building • JWST follow-ups
Mid-IR AO-fed Echelle spectrometer (MIRES)	8 – 18 4.5 – 28 (goal)	3″ slit length 10″ imaging	5000-100000	• Origin of stellar masses • Accretion and outflows around protostars • Evolution of gas in protoplanetary disks
Planet Formation Instrument (PFI)	1 – 2.5 1 – 5 (goal)	1″ outer working angle, 0″.05 inner working angle	R≤100	• 10^8 contrast ratio (10^9 goal) • Direct detection and spectroscopic characterization of exoplanets
Near-IR AO-fed echelle spectrometer (NIRES)	1 - 5	2″ slit length	20000-100000	• IGM at z > 7, gamma-ray bursts • Local Group abundances • Abundances, chemistry and kinematics of stars and planet-forming disks • Doppler detection of terrestrial planets around low-mass stars
High-Resolution Optical Spectrometer (HROS)	0.31 – 1.1	5″ slit length	50000	• Doppler searches for exoplanets • Stellar abundance studies in Local Group • ISM abundance/kinematics • IGM characteristics to z~6
"Wide"-field AO imager (WIRC)	0.8 – 5.0	30″ imaging field	5-100	• Precision astrometry (e.g., Galactic Center) • Resolved stellar populations out to 10 Mpc

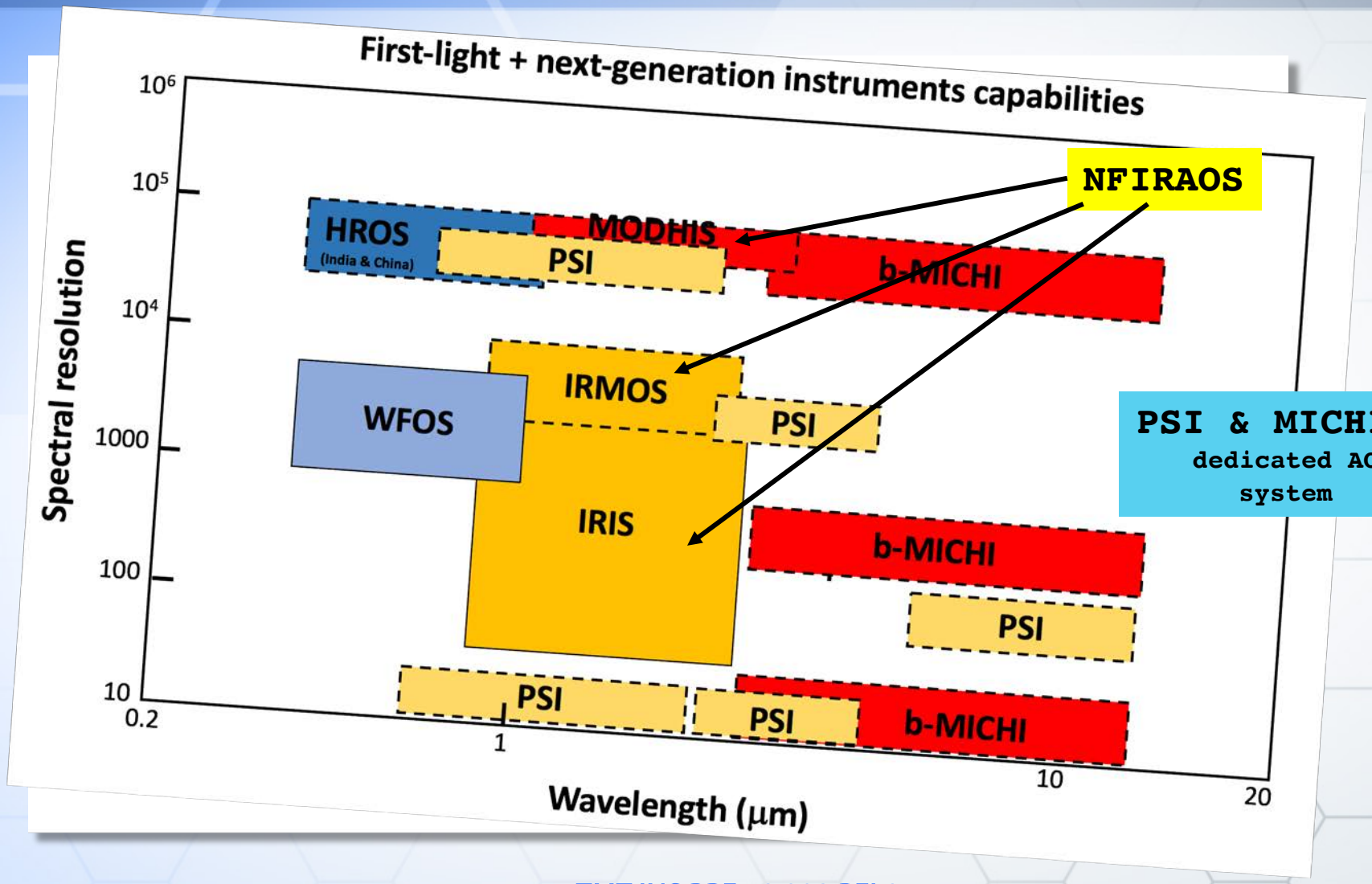
TMT instruments
Discovery space



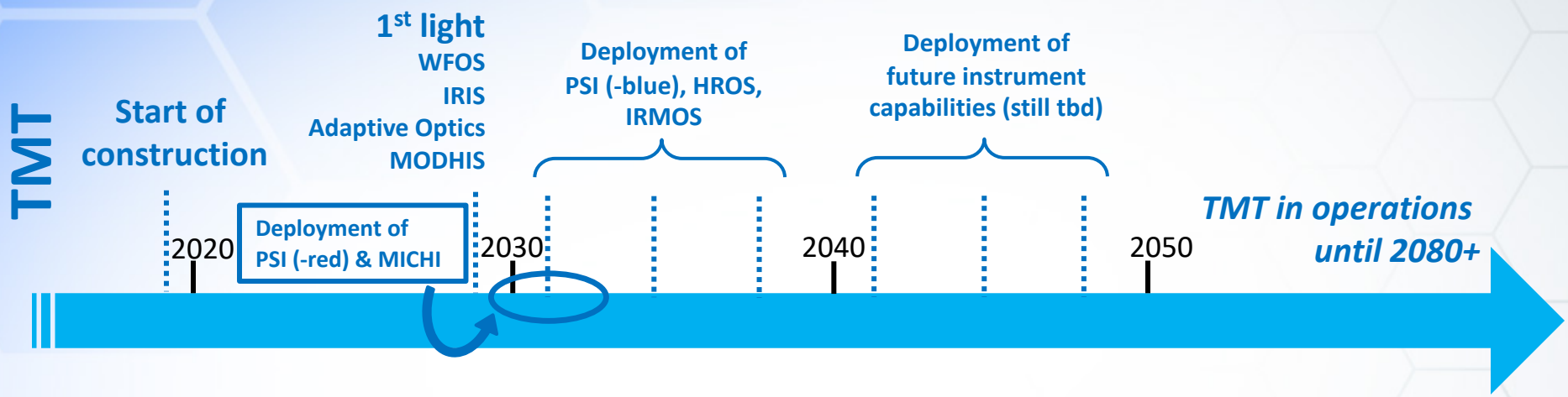
TMT instruments
Discovery space



Response to call for next-generation instrument white papers



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)

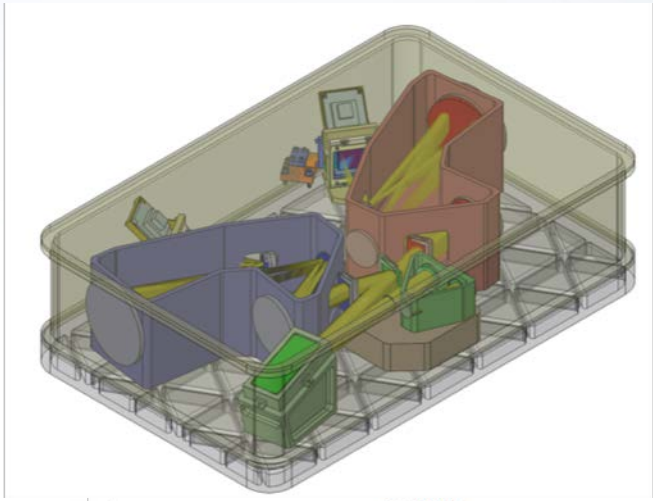
Recommendation: NASA should implement high-contrast starlight suppression technologies in near-term space- and ground-based direct imaging missions. (Chapter 5)

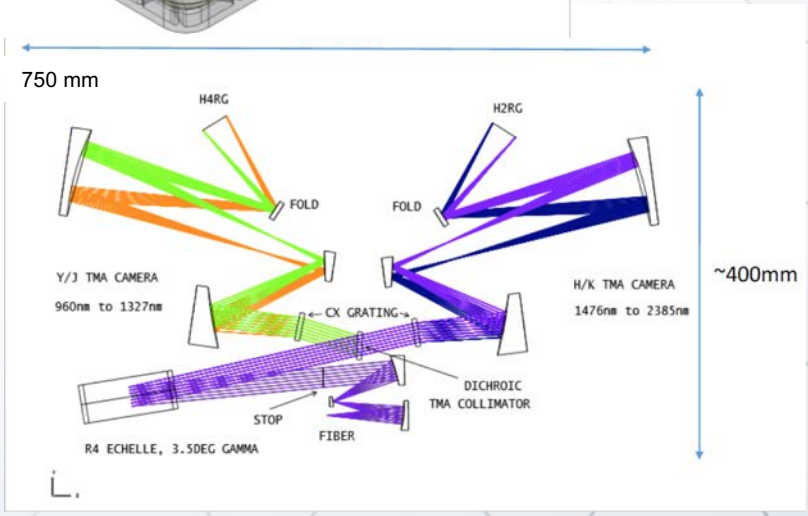
From "Astrobiology strategy to search for life in the universe", 2018, National Academy Press

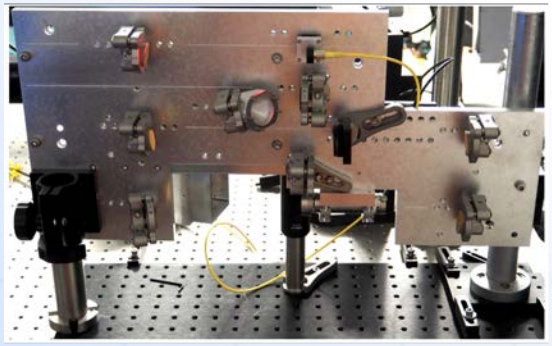
Multi-Object Diffraction-limited High-resolution Infrared Spectrograph (MODHIS)

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

Other instrument to be deployed after first-light

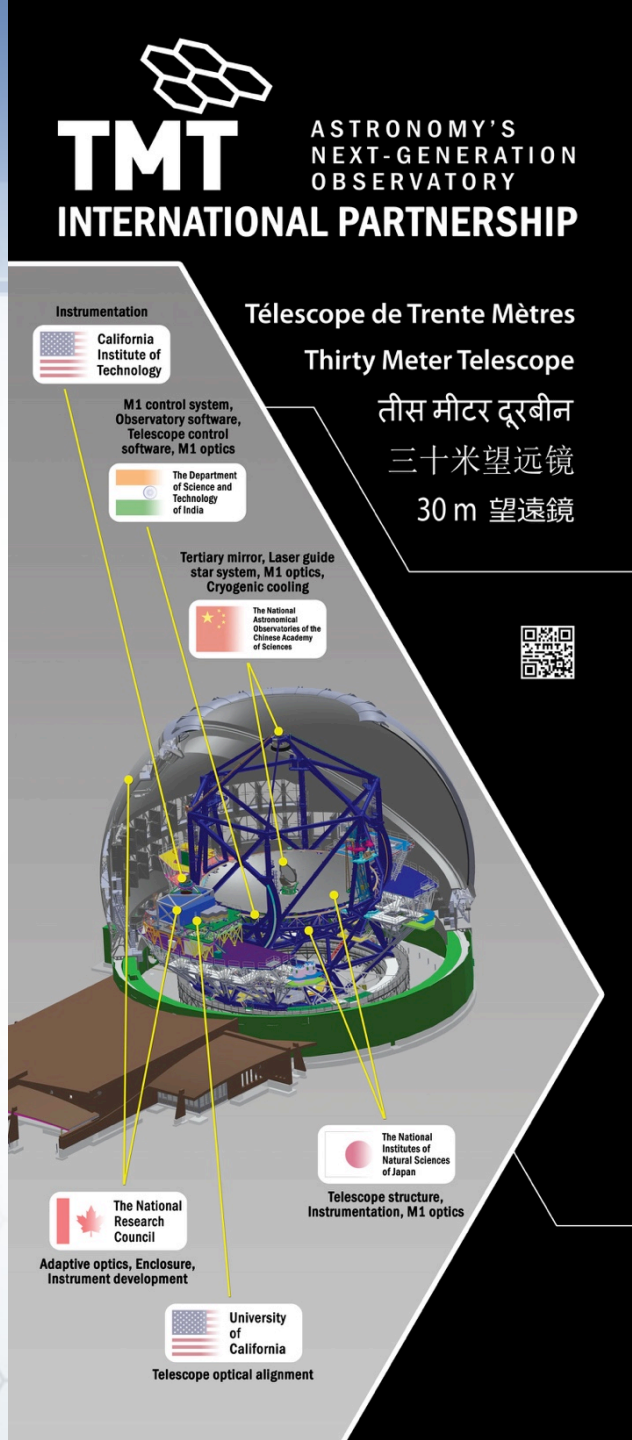
Instrument		FoV, slit length, pixel scale	Wavelength range	Resolution ($\lambda/\Delta\lambda$)	Remarks
HROS High-resolution visible spectrograph Seeing-limited (GLAO = upgrade)		5" slit	0.31-1.0μm	50,000 to 100,000	MOS, R~25,000
MICHI mid-IR AO-fed	Imager	L&M: 24.4"x24.4" N: 28.1"x28.1"	3.4-14μm (L, M, N) 16-25μm (Q)	10-100	Synergy with PSI being explored
	Spectro	High-res: 2" long Low-res: 28" long		600-120,000	
		IFU: 5"x2"	**7.3-7.8μm**	**1000**	
IRMOS Near-IR MOS AO-fed		> 10 IFU over 5" diameter field	0.8-2.5μm	2,000 - 10,000	Multi-IFU MOAO or other concept: MOS trade-studies

Other instrument to be deployed after first-light

Instrument	FoV, slit length, pixel scale	Wavelength range	Resolution ($\lambda/\Delta\lambda$)	Remarks
HROS High-resolution visible spectrograph Seeing-limited	5” slit	0.31-1.0μm	50,000+	
Spectro	Low-res: 28” long	16-25μm (Q)	600-120,000	Synergy with PSI being explored
	IFU: 5”x2”	**7.3-7.8μm**	**1000**	
IRMOS Near-IR MOS AO-fed	> 10 IFU over 5” diameter field	0.8-2.5μm	2,000 - 10,000	Multi-IFU MOAO or other concept: MOS trade-studies

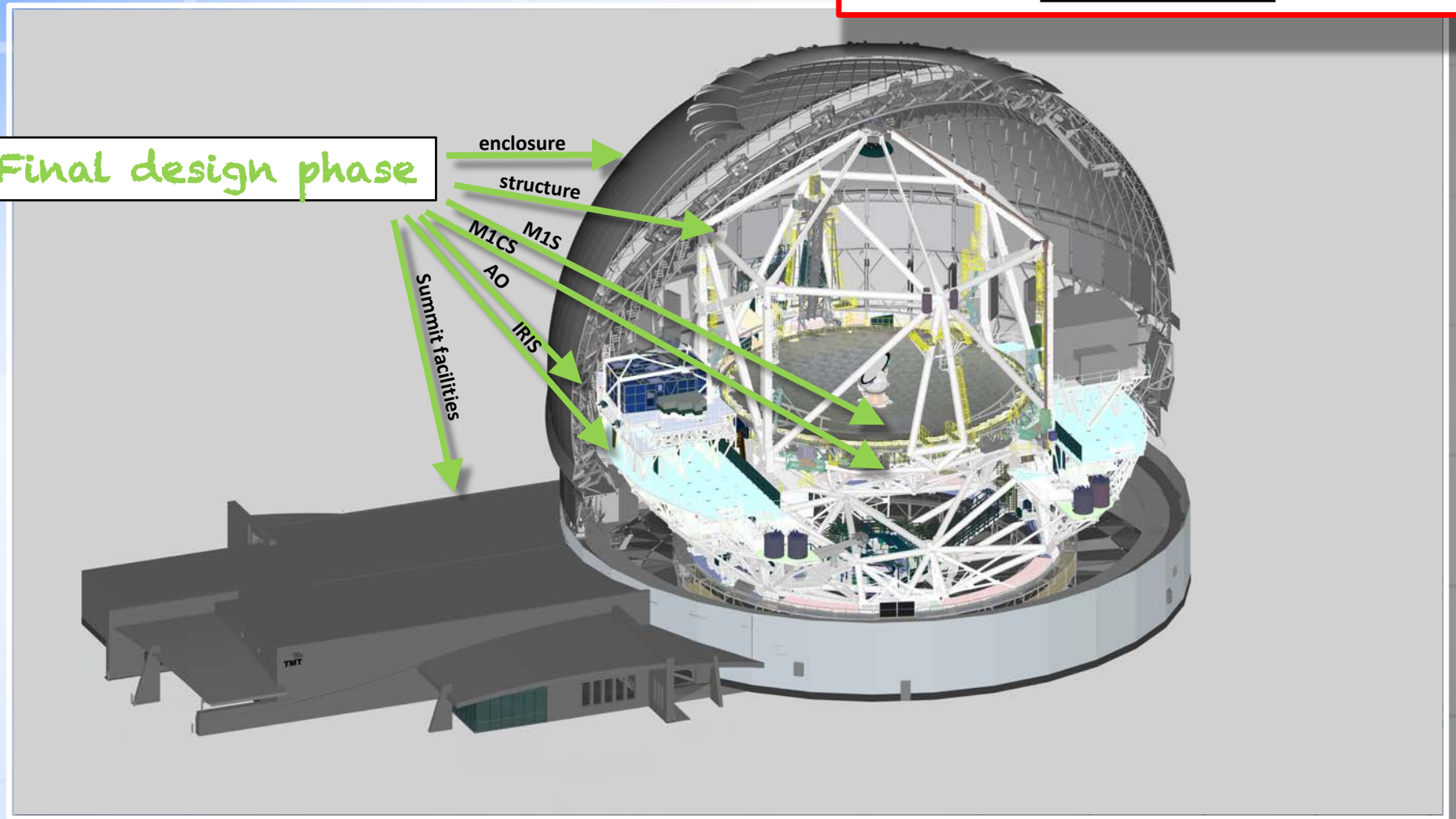
- Instrument science teams being formed (time to join!)
- Conceptual studies to start this year
- Perfect time to discuss science requirements to get your science done

Project/system update

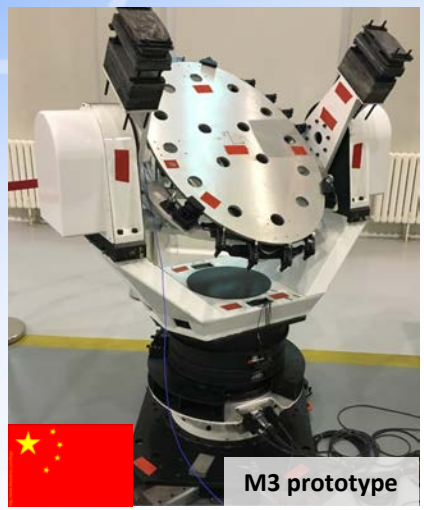


Systems status

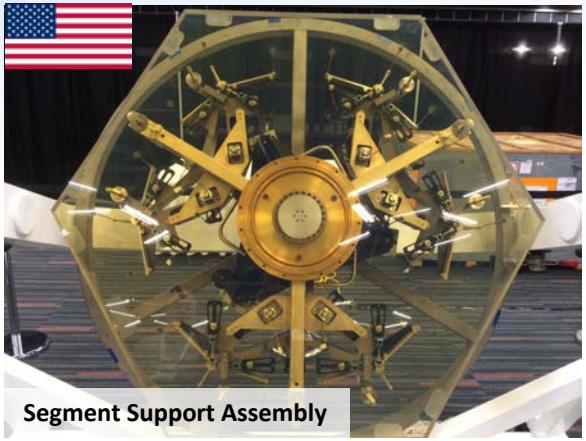
All critical systems are at an advanced state of design, while <u>some are already in production</u>



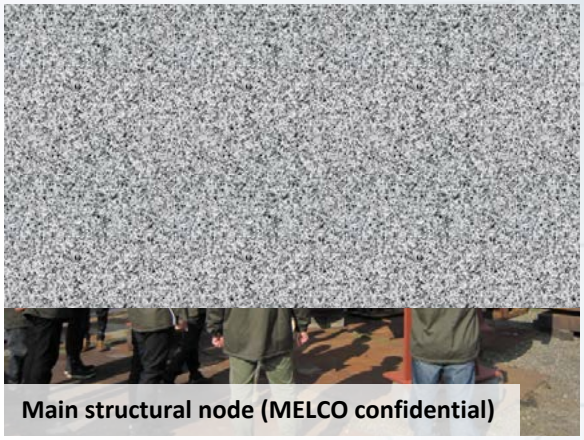
Snapshot of systems design/production



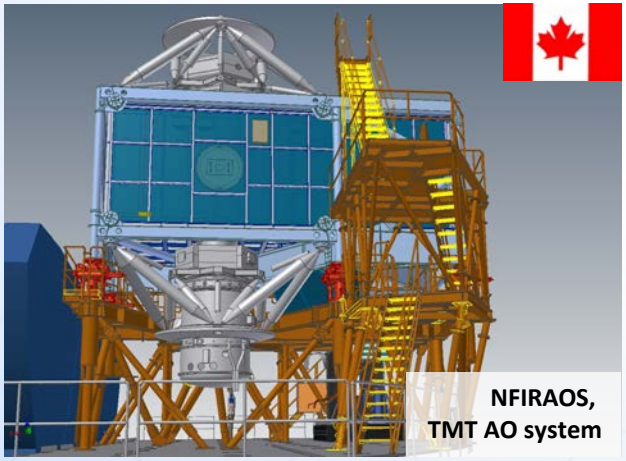
M3 prototype



Segment Support Assembly



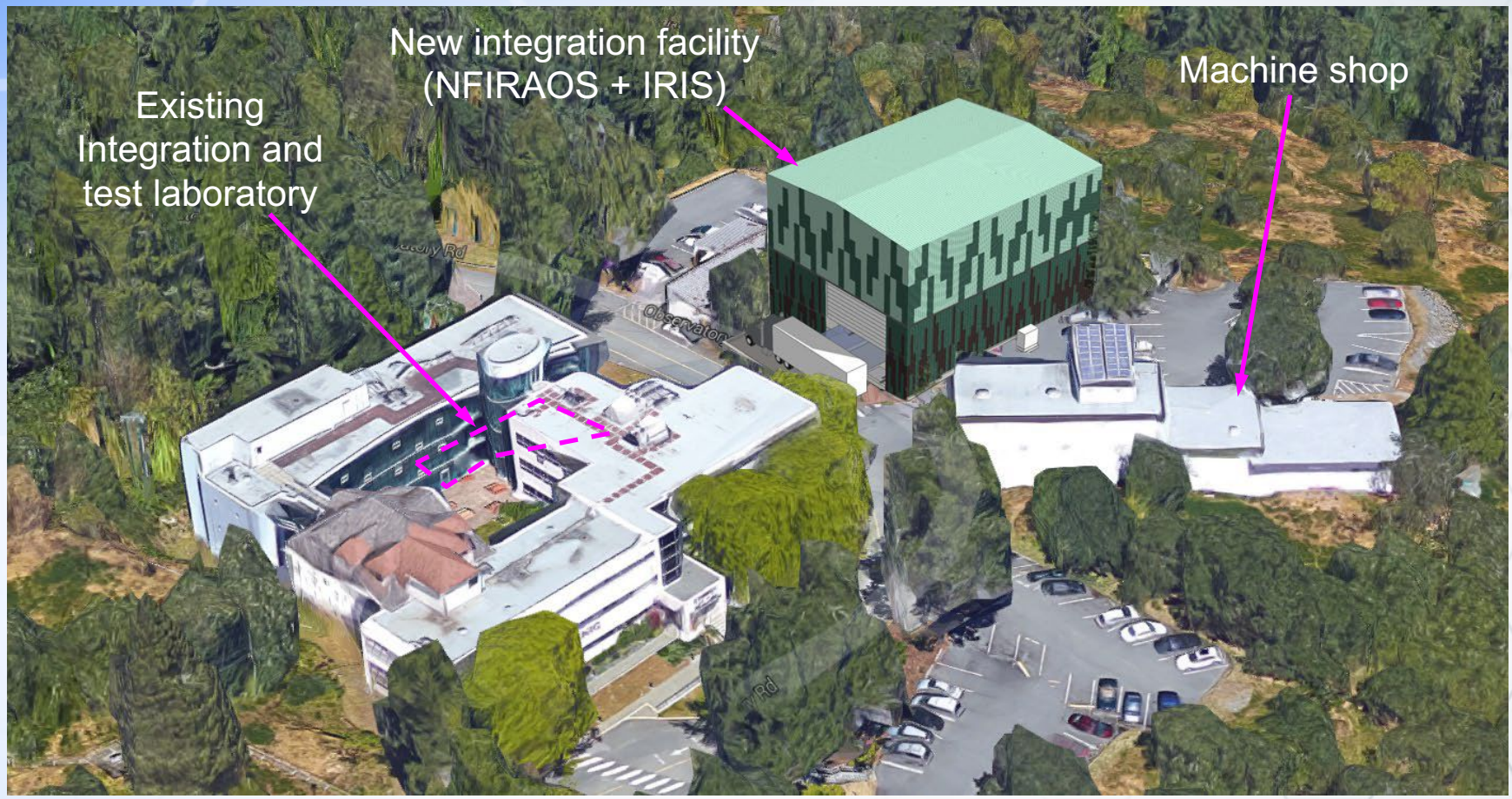
Main structural node (MELCO confidential)



NFIRAOS,
TMT AO system

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

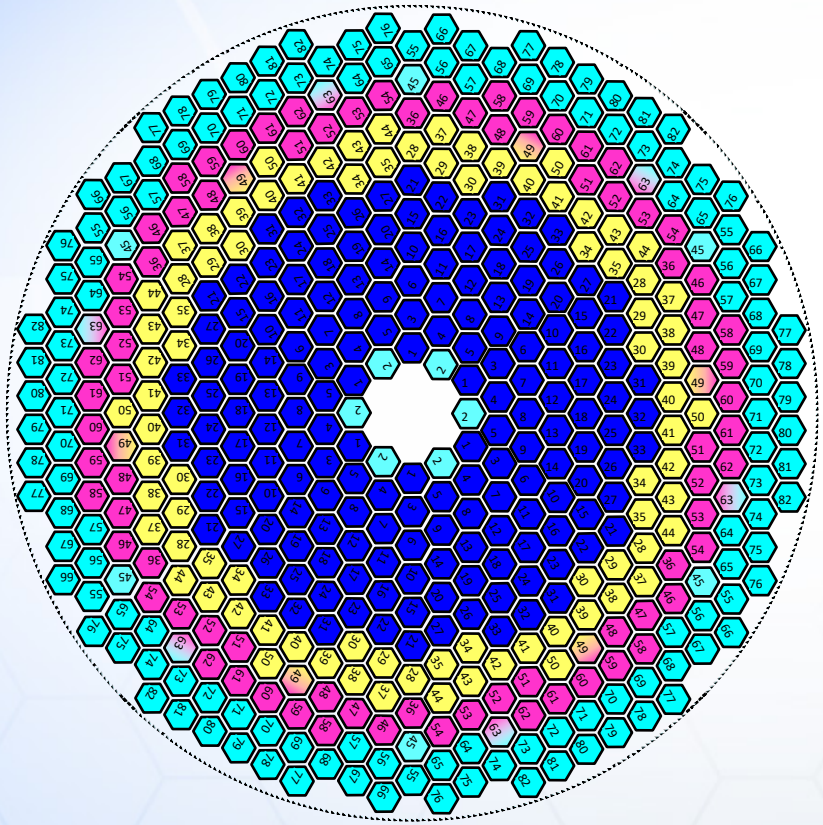
NFIRAOS/IRIS - Planning
IRIS Integration



Caption: Aerial view of NRC-H depicting the location of the envisioned integration and test facility that will accommodate both NFIRAOS and IRIS. Similar planning is being undertaken for IRIS integration at NAOJ and CIT and then finally for delivery, integration and verification at the Observatory.

TMT Global Participants: Mirror segments manufacturing

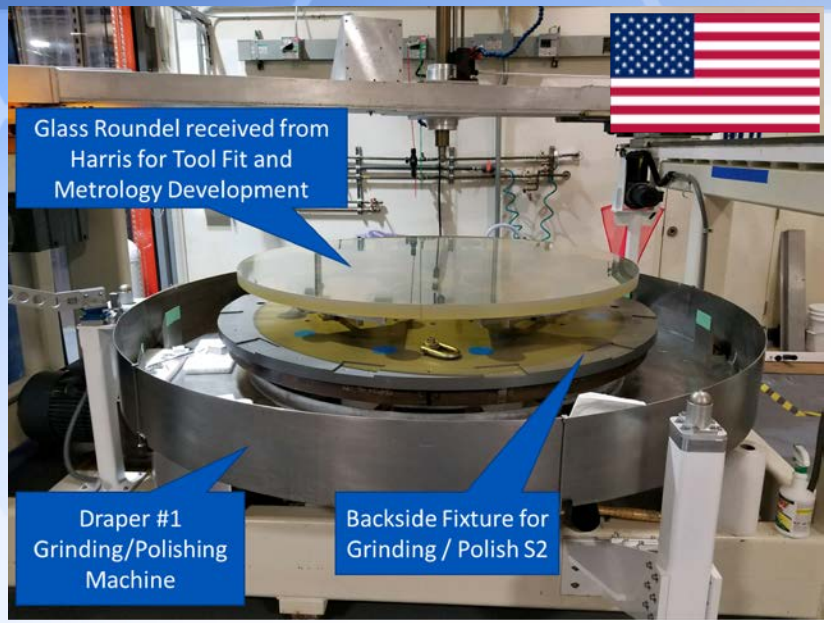
- 82 types of segments (different curvature) duplicated over 6 sectors
  - 7 mirror segments of each type must be produced (include 1 spare)



Japan:	174
India:	86
China:	86
CIT/UC:	146 + **82**
Total:	492 segments
Spares:	82 segments
Gran Total: 574 segments	

Blank Acceptance at Canon

Polishing activities starting across partnership



OPT: Prototype Segment installed in MSIT

… while waiting for real construction images

Thank you!

Acknowledgments

The TMT Project gratefully acknowledges the support of the TMT collaborating institutions. They are the Association of Canadian Universities for Research in Astronomy (ACURA), the California Institute of Technology, the University of California, the National Astronomical Observatory of Japan, the National Astronomical Observatories of China and their consortium partners, and the Department of Science and Technology of India and their supported institutes. This work was supported as well by the Gordon and Betty Moore Foundation, the Canada Foundation for Innovation, the Ontario Ministry of Research and Innovation, the National Research Council of Canada, the Natural Sciences and Engineering Research Council of Canada, the British Columbia Knowledge Development Fund, the Association of Universities for Research in Astronomy (AURA), the U.S. National Science Foundation and the National Institutes of Natural Sciences of Japan.