TMT Instruments Overview

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(TMT Project, NAOJ)

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TMT Instruments Webinars

- [Motivation]
  - Responding to the questionnaire at TMT Webinar #1.
- [Expected Audience]
  - Group/Individual who is considering use of TMT.
  - Group/Individual who needs new capabilities of TMT instruments.
  - Group/Individual who is interested in TMT instrument development.
- [Plan]
  - TMT Instruments Overview (TMT Webinar #3)
  - TMT First-Light Instrument #1 (TMT Webinar #4 [TBC])
  - *TMT First-Light Instrument #2 (TMT Webinar #5 [TBD])*
  - *TMT First-Light Instrument #3 (TMT Webinar #6 [TBD])*

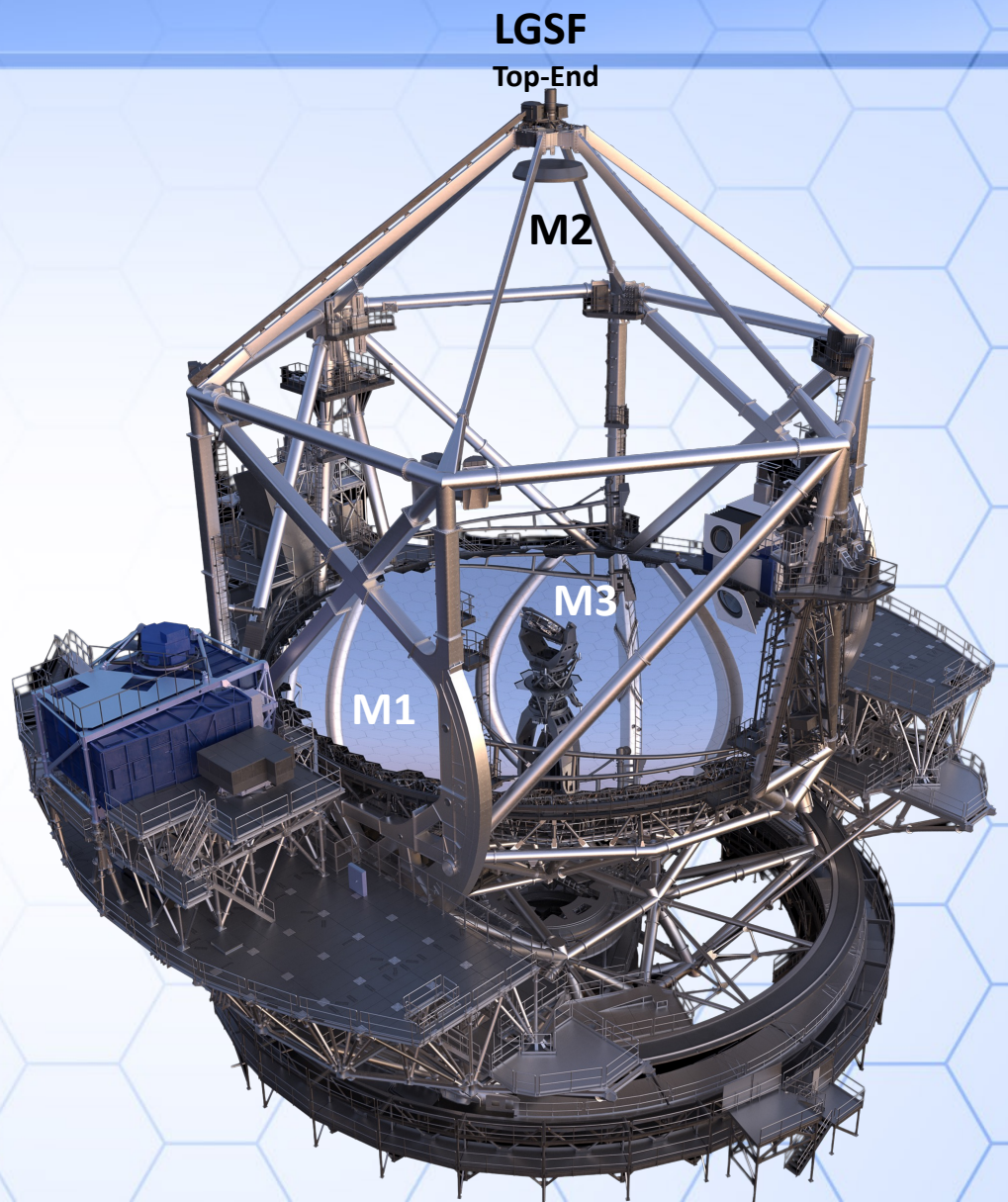
2. 今後のウェビナーで聞きたいこと（複数回答可）

オプション	回答
TMT project update	26/39 (67%)
TMT instruments	22/39 (56%)

TMT: In A Nutshell

- **Telescope: “3” Mirrors reflection**
  - Primary Mirror
    - 30m hyperboloidal mirror with 492 segments
  - Secondary Mirror
    - 3.1m convex hyperboloidal mirror
  - **“Steerable”** Tertiary Mirror
    - 2.5m x 3.5m mirror
  - **Nasmyth hosts Science Instruments**

FoV: **20arcmin** (Unvignetted 15arcmin)
Wavelength: **0.31**--28um (UV-enhanced coating)
Diffraction Limit: **8mas @1μm**



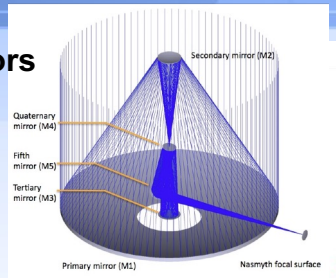
TMT: The Best Atmosphere

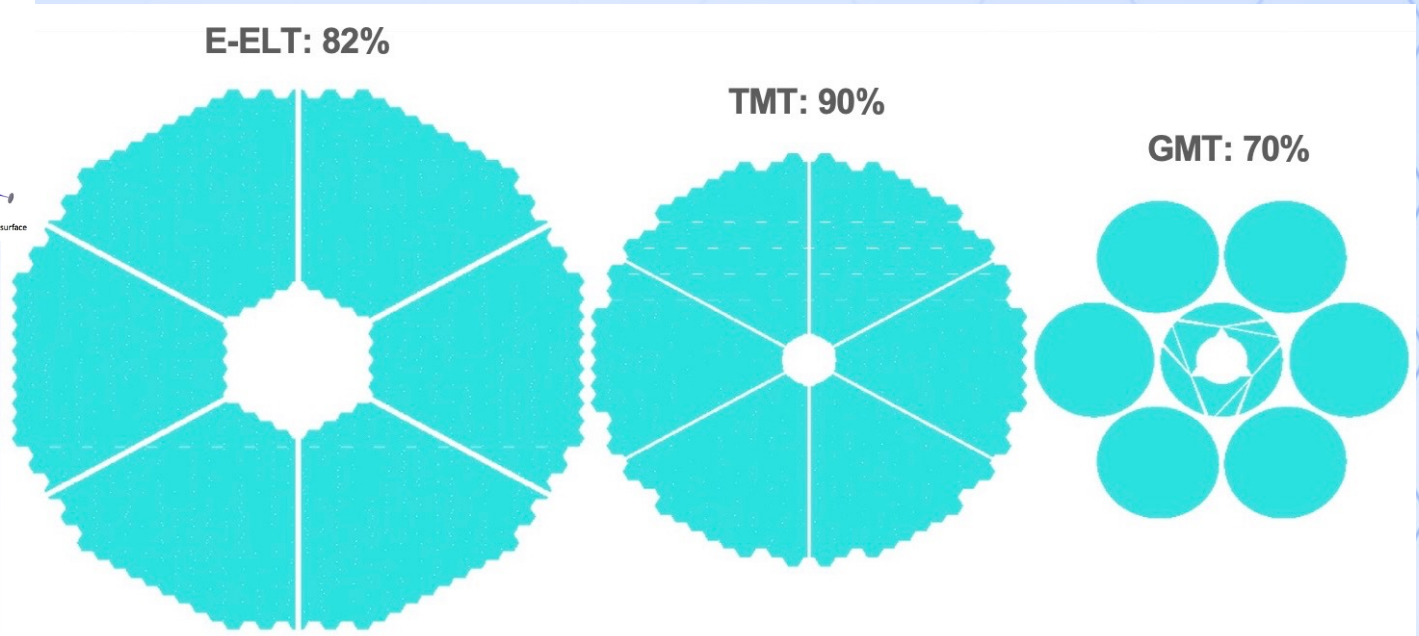
Site Characteristics (Median values, unless stated)	(Units)	TMT MK (USA)	TMT ORM (Spain)	E-ELT Armazones (Chile)	GMT Las Campanas (Chile)
Altitude of site	meters	4050	2250	3060	2415
Fraction of yearly usable time considering all adverse weather conditions	%	72	72	86	75
Seeing at 60 m above ground	arcsec	0.50	0.58	0.50	0.50
Isoplanatic angle	arcsec	2.55	2.31	2.05	2.05
Atmospheric coherence time	ms	7.3	6.0	5.0	5.0
Precipitable water vapor	% time < 2mm	54	20	50	23
Mean nighttime temperature	°C	2.3	7.6	7.5	13

Best atmospheric conditions For AO image correction

TMT: The Cleanest Diffraction-Limited Image among ELTs

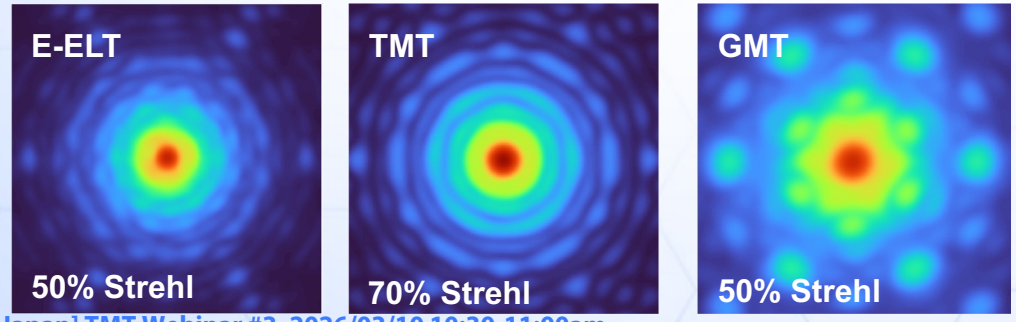
E-ELT:
"5" -Mirrors

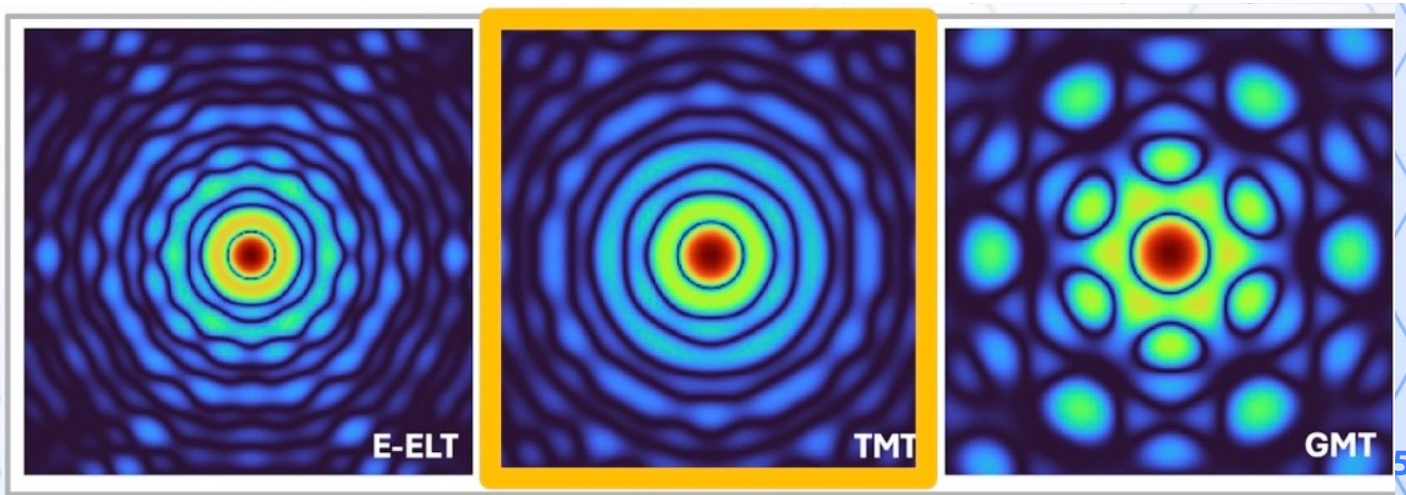




Performance median conditions, 50% sky coverage, 30 degrees zenith angle	E-ELT MORFEO	TMT NFIRAOS	GMT LGS LTAO
Strehl ON AXIS in K band in LGS AO mode	50%	70%	50%

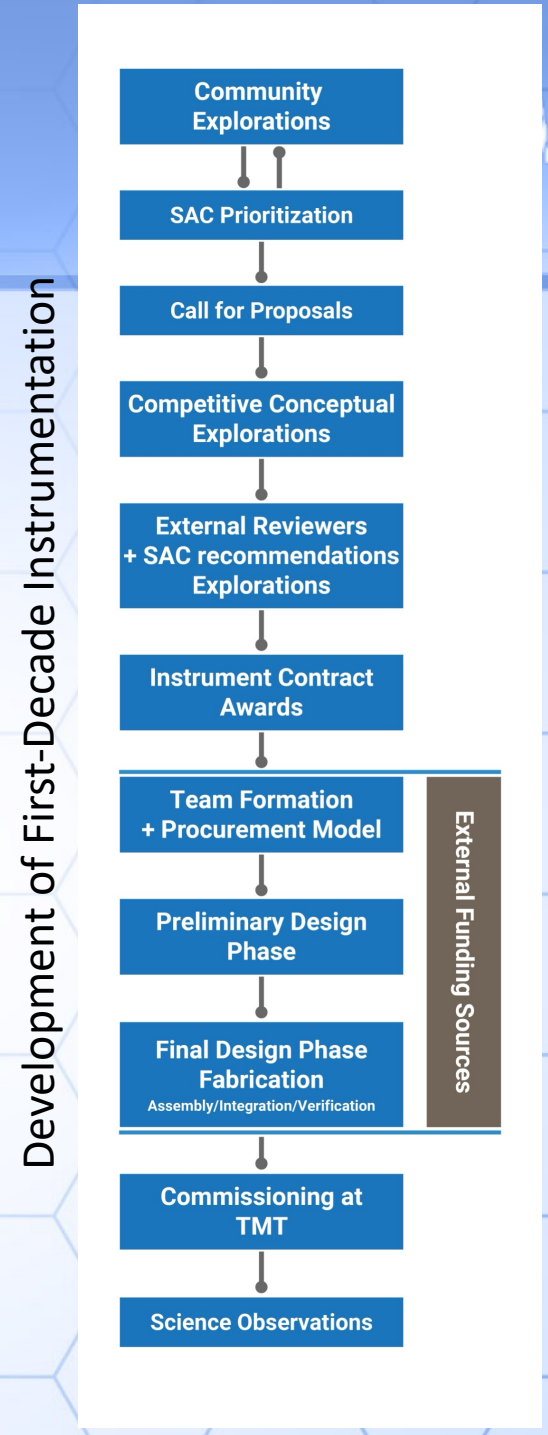
K-band





TMT Instruments Plan

- First-Light Instruments
  - **NFIRAOS**: Facility 1st Gen. Adaptive Optics System
  - **IRIS**: Infrared Workhorse
  - **WFOS** (previously called MOBIE): Optical Workhorse
  - **MODHIS** (replaced IRMS, Keck/MOSFIRE copy): Exoplanet Focused
- First-Decade (Second Generation) Instruments
  - **Community explorations started in Sep. 2017**
    - **White Papers** received through Mar. 2018.
      - Mixture of existing concept instrument and brand-new idea
    - Process hasn't been concluded yet.



TMT First-Light (FL) Instrument Suite

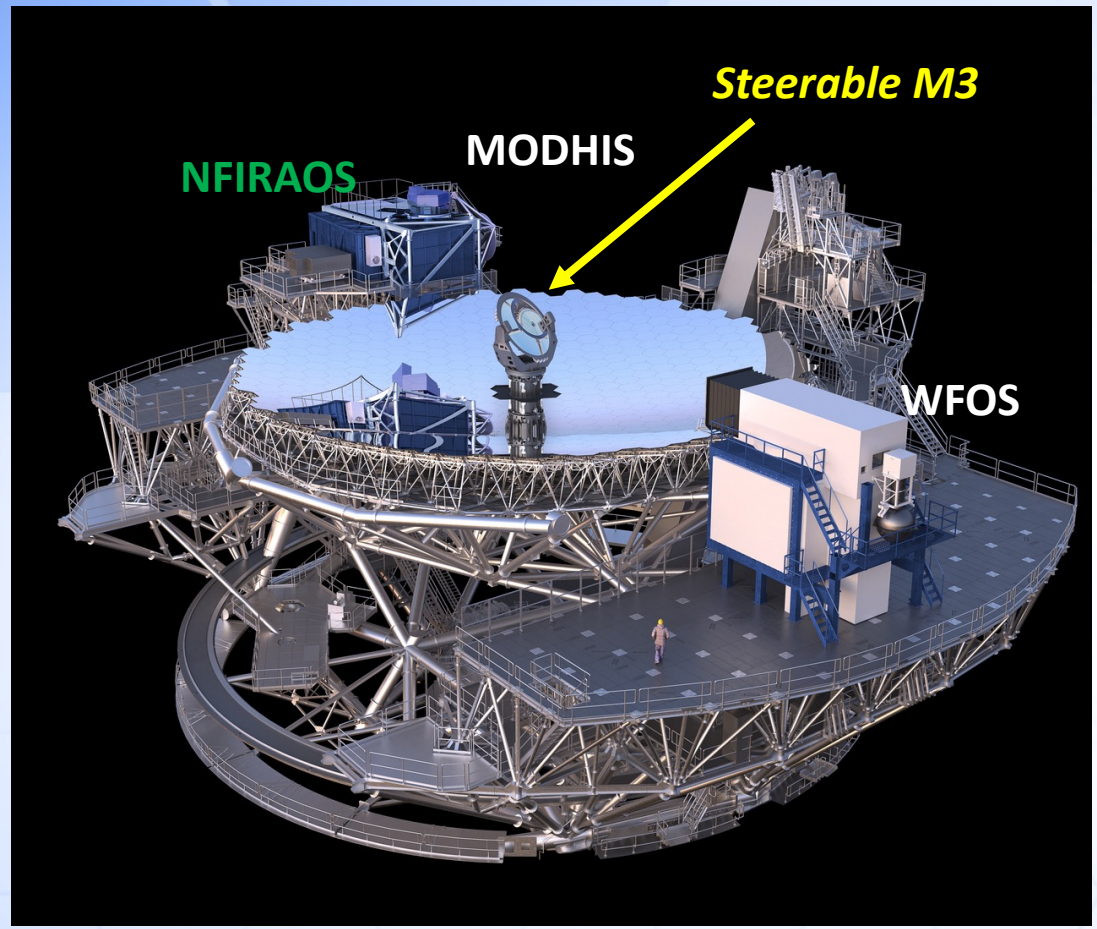
Instrument and Description	λ Range (μm)	Spectral Resolution	Modes	Field of View
NFIRAOS/Narrow Field Infrared Adaptive Optics System	0.8 – 2.4	N/A	NGSAO, LGS MCAO	LGS MCAO 2.0’
IRIS/Diffraction-Limited NIR Imager and IFS	0.84 – 2.4	Z, Y, J, H, K, bandpass filters and multiple narrower band filters. 4,000 and 8,000 (some modes to 10,000)	NGSAO, LGS MCAO	Imager: 34” x 34” @ 0.004”/pix IFU with two slicing techniques Lenslet: 0.512” x 0.512” @ 0.004”/spaxel Slicer: 2.25” x 4.4” @ 0.050”/spaxel
WFOS/Wide Field Optical Spectrometer	0.31 – 1.0	1,500 and 3,500 using 0.75” slits. Goal of 5,000 currently achieved and higher R available with narrower slits.	Seeing-limited GLAO	25 (8.3 x 3)-arcmin^2 500” total slit length (up to 60 targets with 8” slits) Imaging: full field @ 0.05”/pixel
MODHIS/Multi-Objective Diffraction-Limited High-Resolution Infrared Spectrograph	0.98 – 2.46	> 100,000 with 30 cm/s (goal 10 cm/s) Doppler velocity precision	NGSAO, LGS MCAO	4" diameter field of regard with positionable diffraction limited fiber bundle (target, sky, speckle, spare, calibration). 6"x6" imaging guider.

TMT First-Decade (FD) Instrument Suite

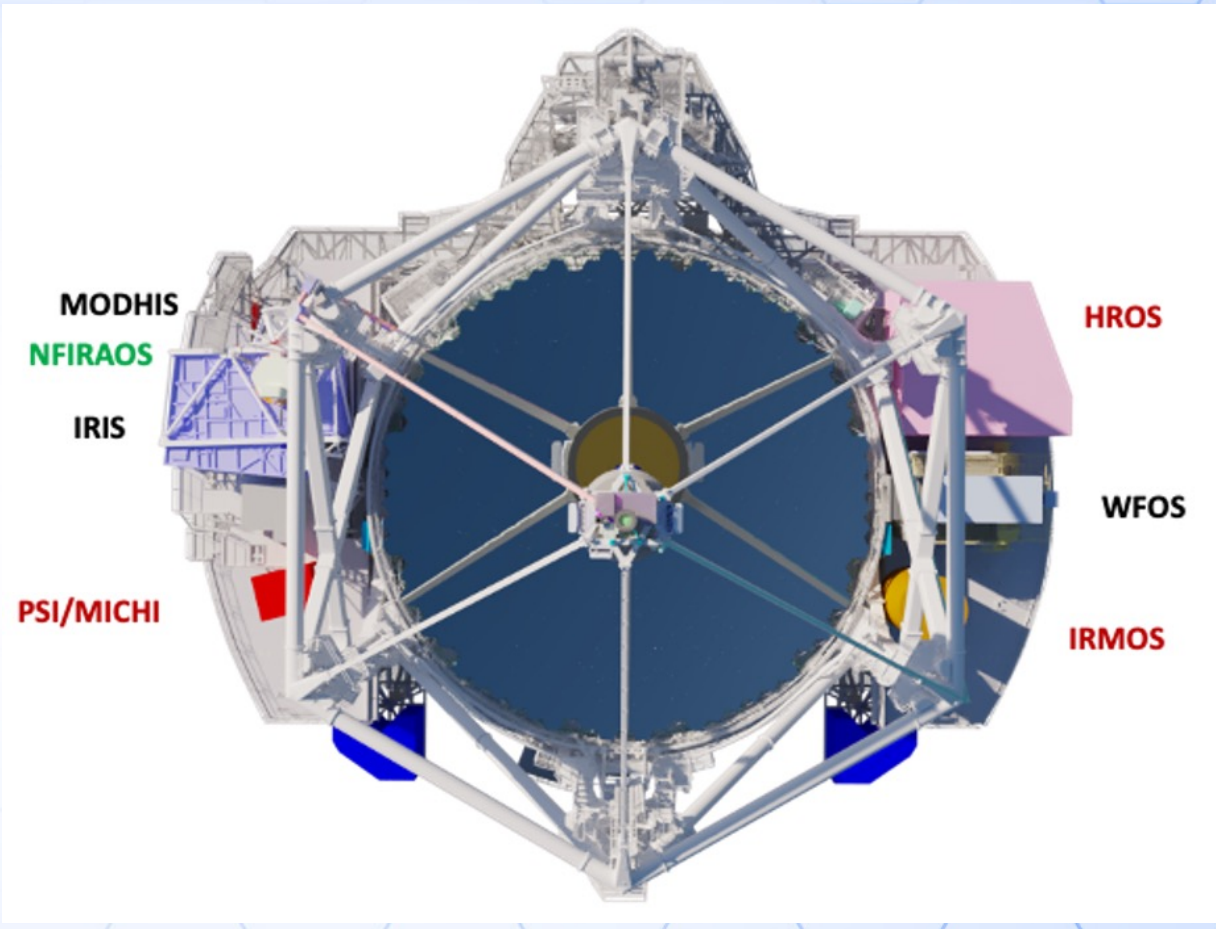
Instrument and Description	λ Range (μm)	Spectral Resolution	Modes	Field of View
GLAO/Ground Layer Adaptive Optics (feeds WFOS and HROS)	0.31–1.0	N/A	GLAO	Large enough to cover WFOS
MIRAO/Mid-Infrared Adaptive Optics (feeds MICHI)	4.5 – 28	N/A	LGS MIRAO, high contrast	>10" (1' goal)
PSI PFI/Planet Formation Instrument	0.6 – 5.3	(fiber fed) High resolution R > 100K (IFS) Medium resolution R > 5,000 (IFS) Low resolution R > 50	ExAO	2–5.3 μm only: 1.2" x1.2" (low resolution) 0.15" x 0.15" (medium resolution)
MICHI MIRES/ Mid-Infrared Echelle Spectrometer	3.4 – 13.8	Imager < 100, IFS 600–1,000, Spectrometer 120,000	MIRAO	Imager: 28.1" x 28.1" @ 11 mas/pix N band IFU: 0.175" x 0.07" (35 mas/spaxel)
HROS/High-Resolution Optical Spectrograph	0.31 – 1	Single Object: 100,000 & 50,000 (fibers) 40,000 & 20,000 (slits) Multi-Object: 25,000	Seeing-limited GLAO	> 10" in diameter (single object mode) 10'–20' diameter (multi-object mode)
IRMOS/IR Multi-Object Spectrograph	0.8 – 2.5	2,000 – 10,000	MOAO	> ten 3" IFUs deployable within a 5' diameter field

TMT Instruments Configuration

TMT First-Light Instruments

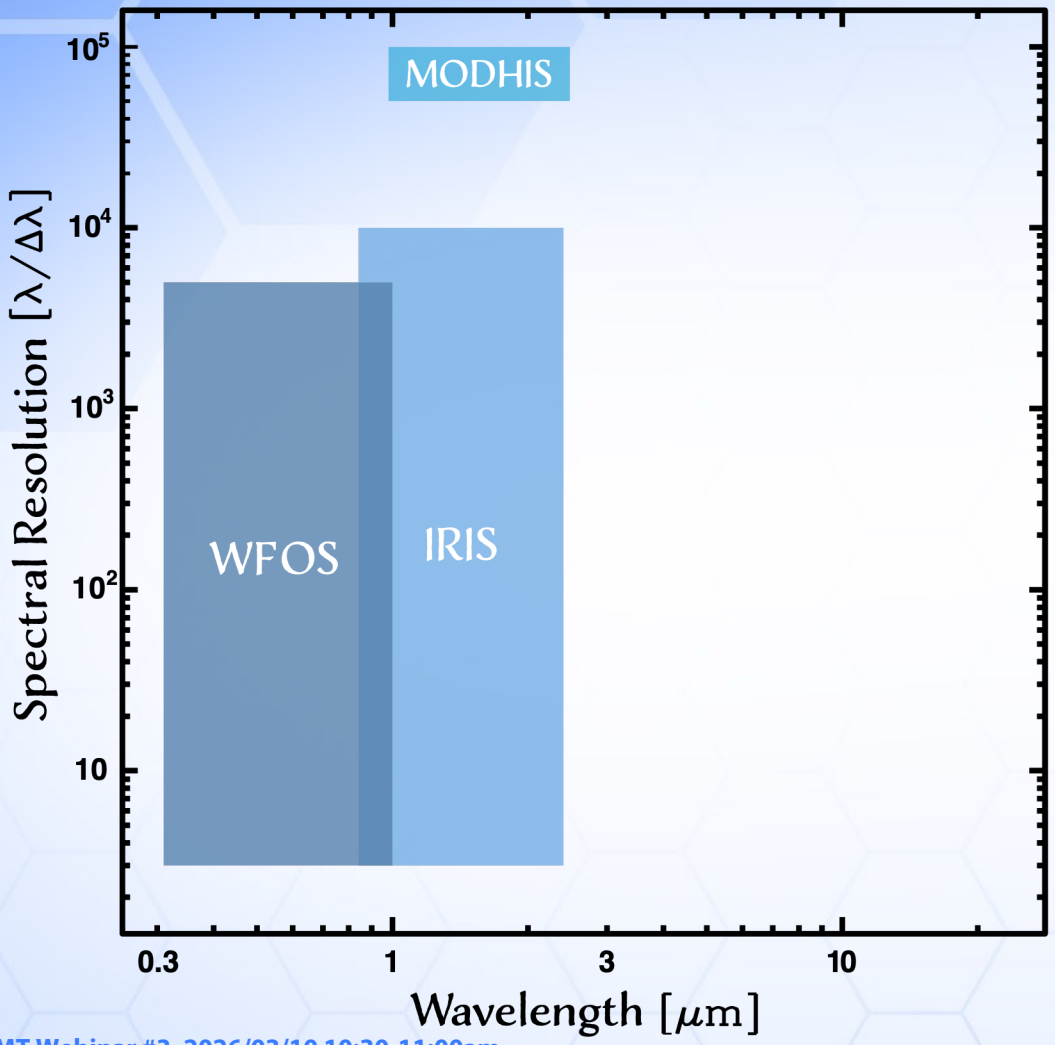


TMT First-Light & First-Decade Instruments

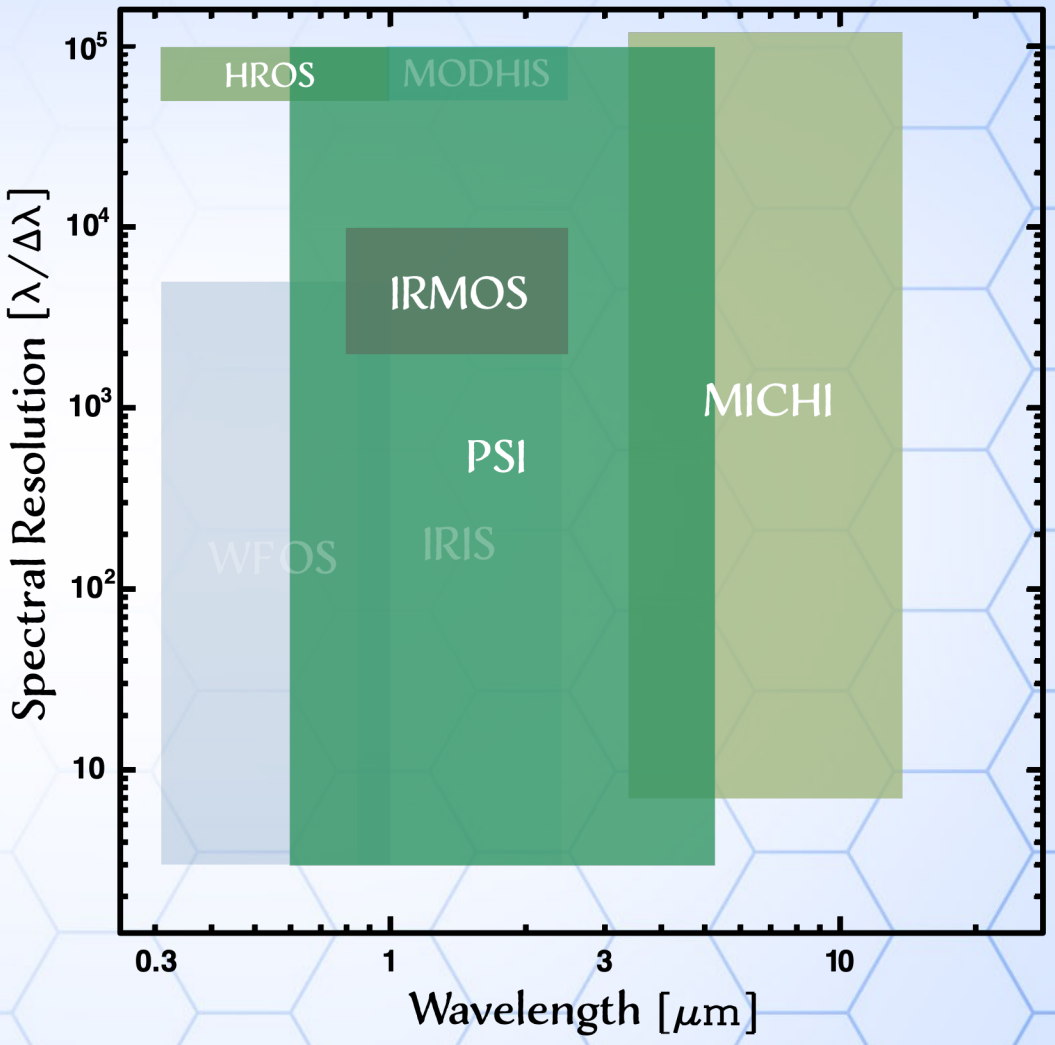


TMT Instrument Capabilities: Summary

TMT First-Light Instruments

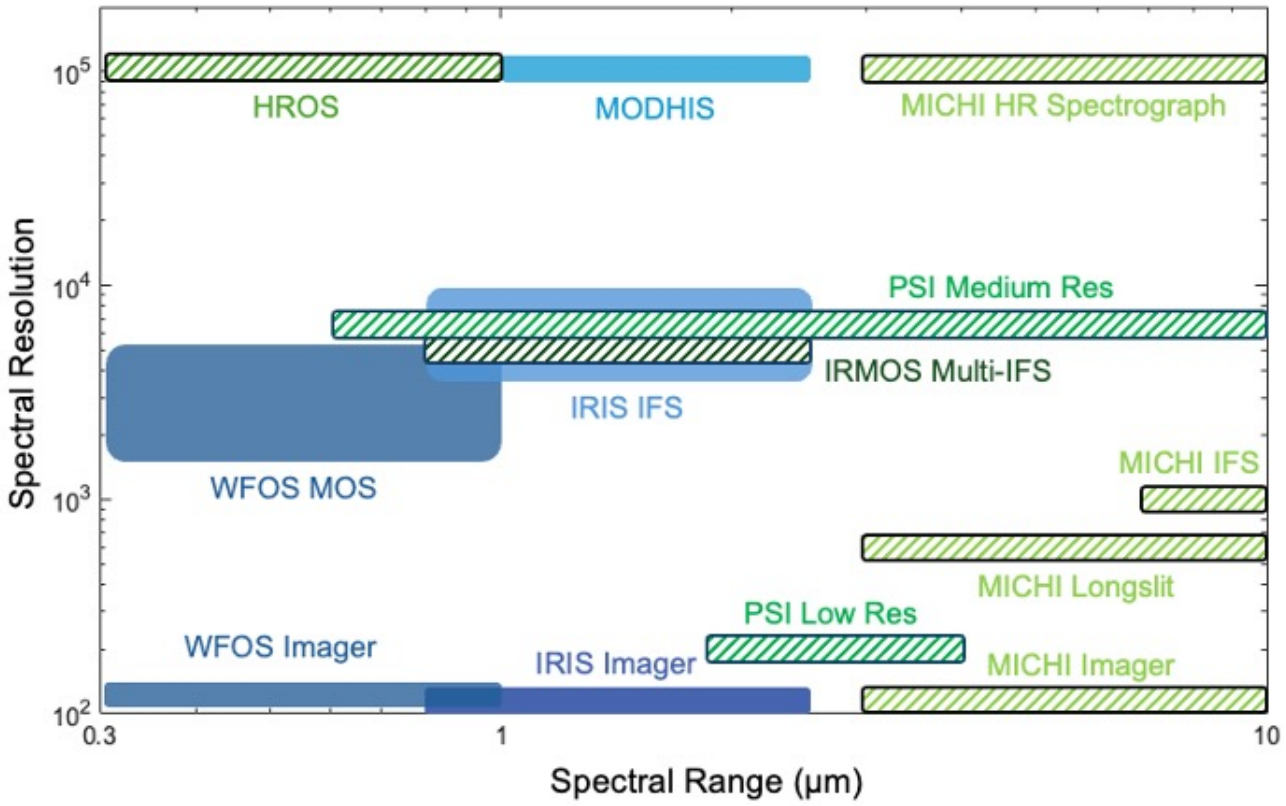


TMT First-Light & First-Decade Instruments

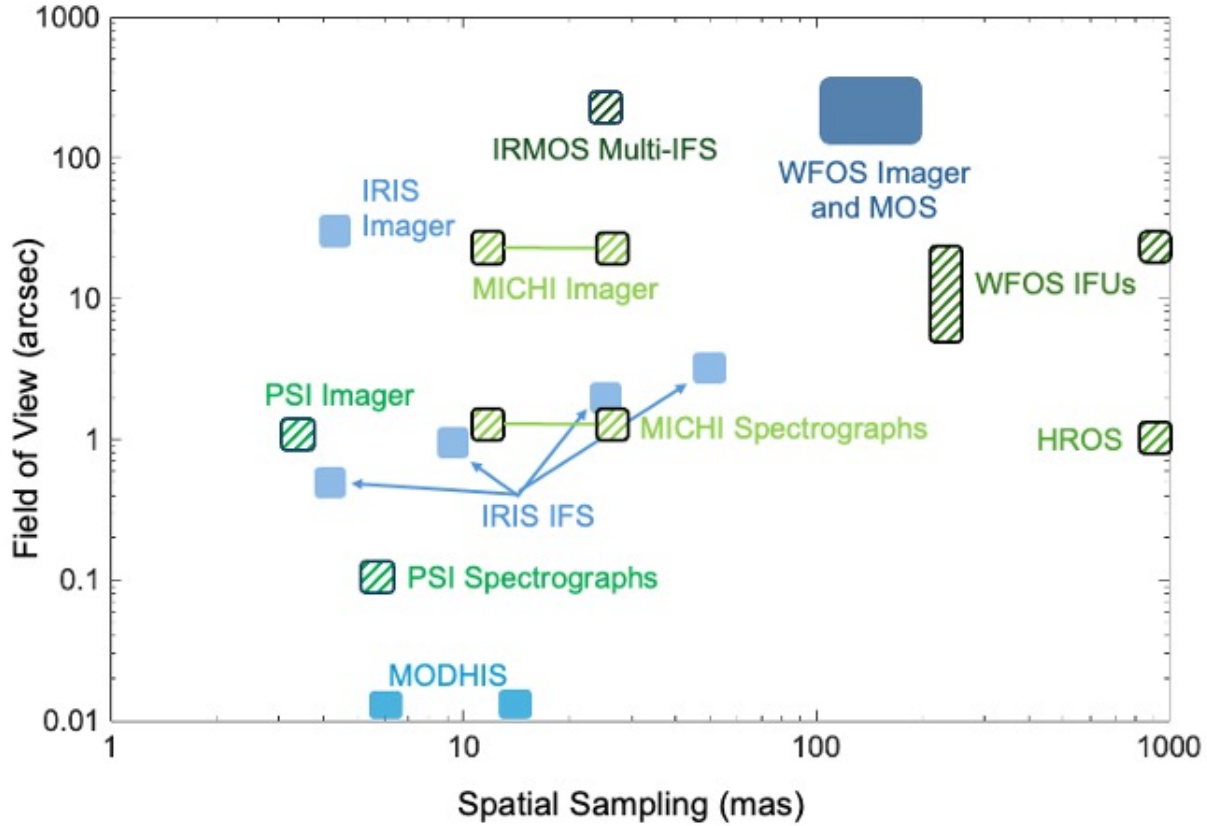


TMT Instrument Capabilities: Details

Spectral Resolution

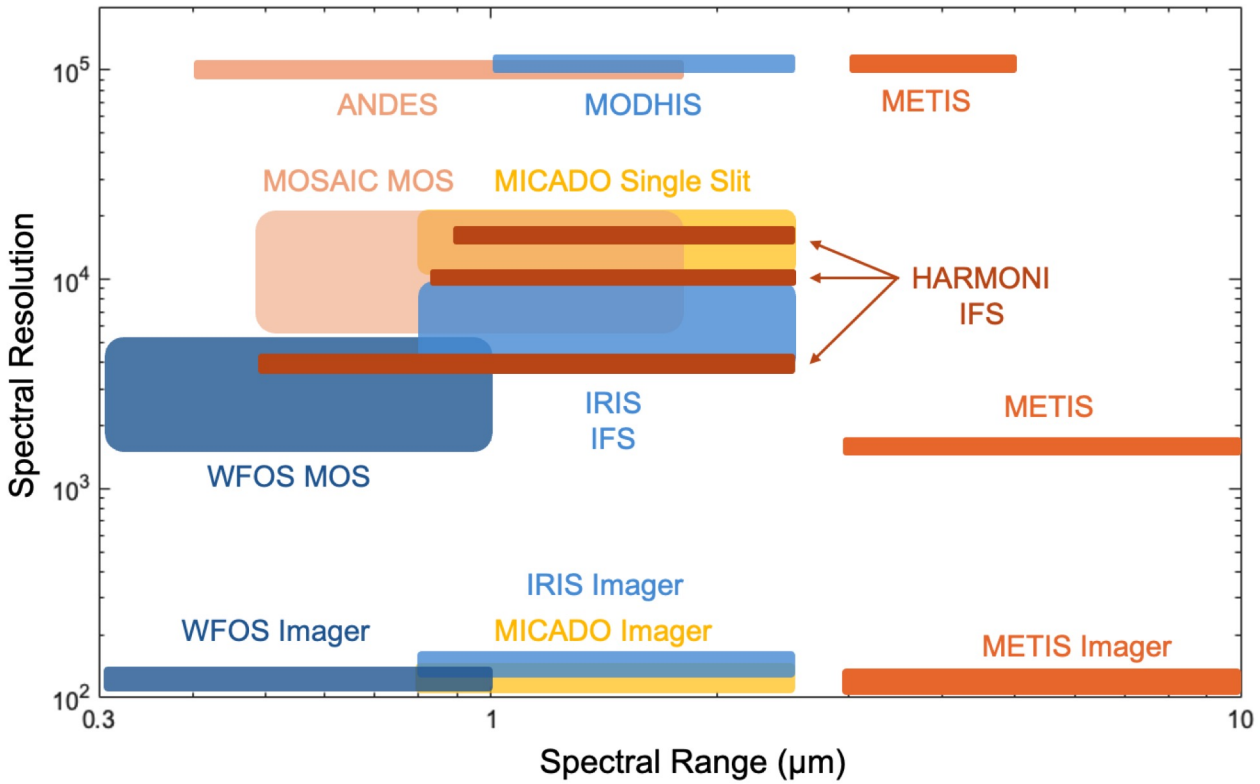


FoV & Spatial Sampling

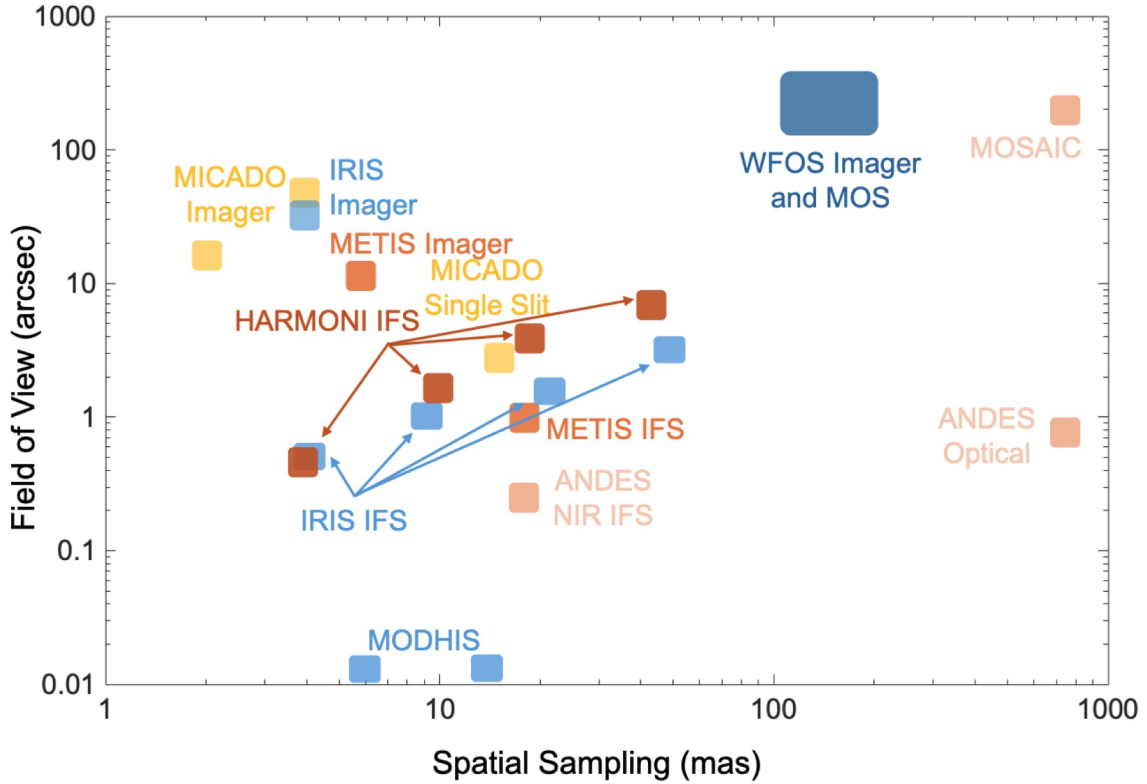


TMT Instrument Capabilities: Comparison against E-ELT in 2030s

Spectral Resolution



FoV & Spatial Sampling



Science Case Development & Requirement Flow-Down

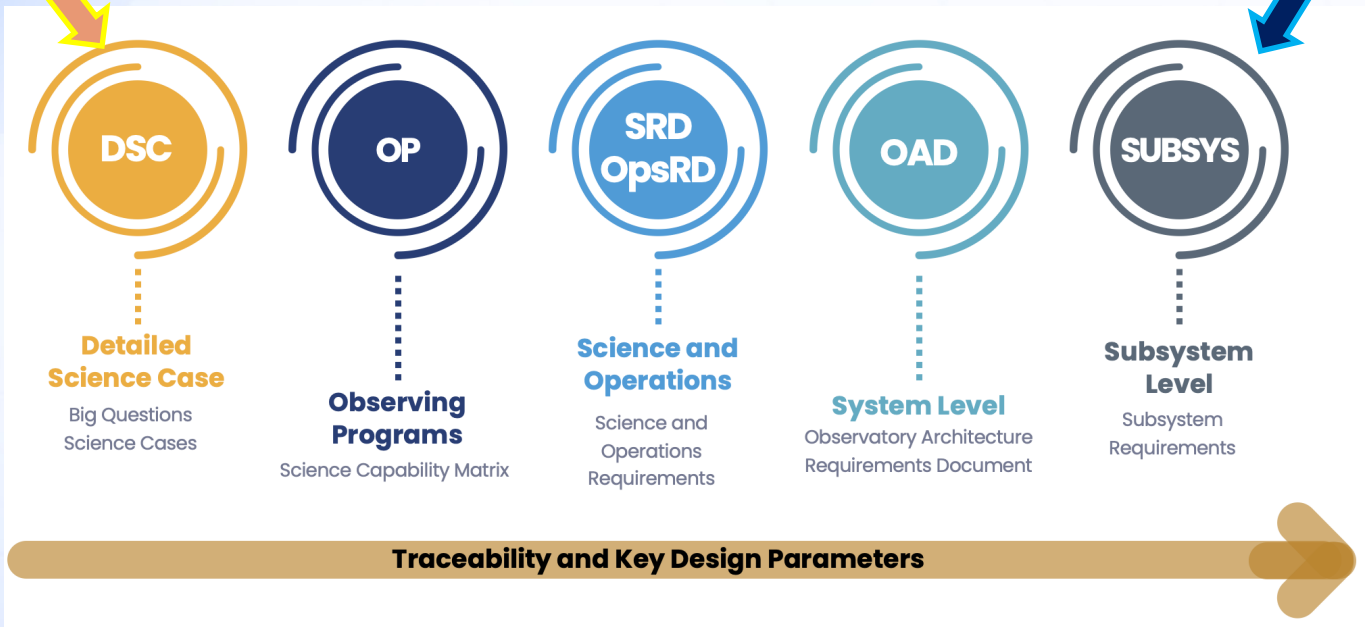
Current membership

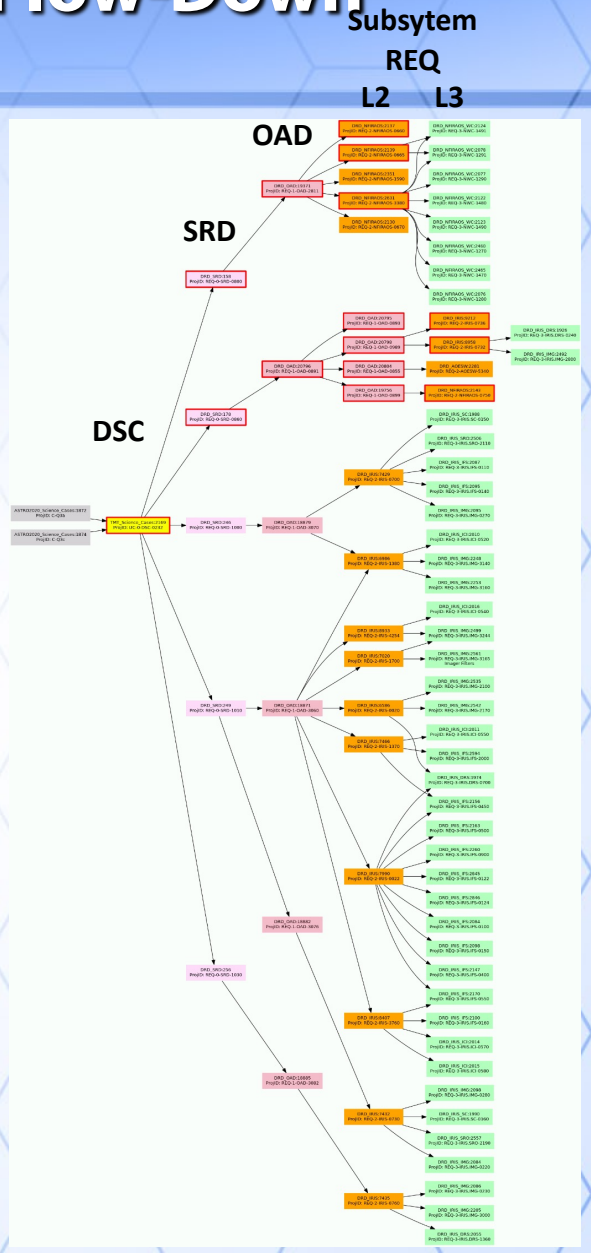
International Science Development Team [ISDT]

- *Fundamental Physics and Cosmology*
- *Early Universe, Galaxy Formation and the IGM*
- *Supermassive Black Holes*
- *Milky Way and Nearby Galaxies*
- *Stars, Stellar Physics and the Interstellar Medium*
- *Formantion of Stars and Planets*
- *Exoplanets*
- *Our Solar System*
- *Time Domain Science*

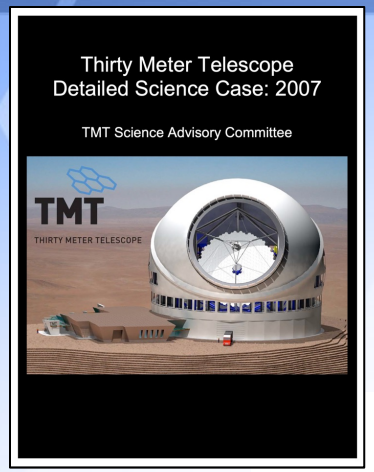
[Design REQ]
e.g.,
IRIS
WFOS
MODHIS

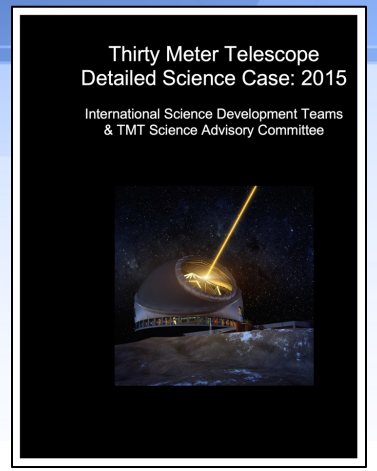
Instrument Science Team

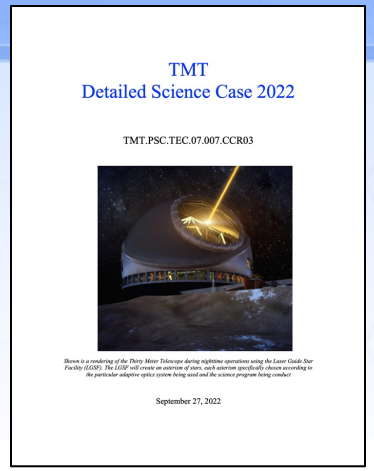


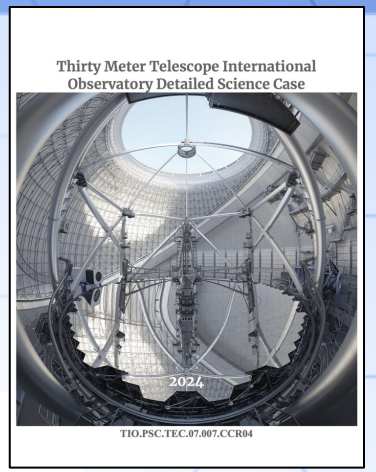


Detailed Science Case Evolution









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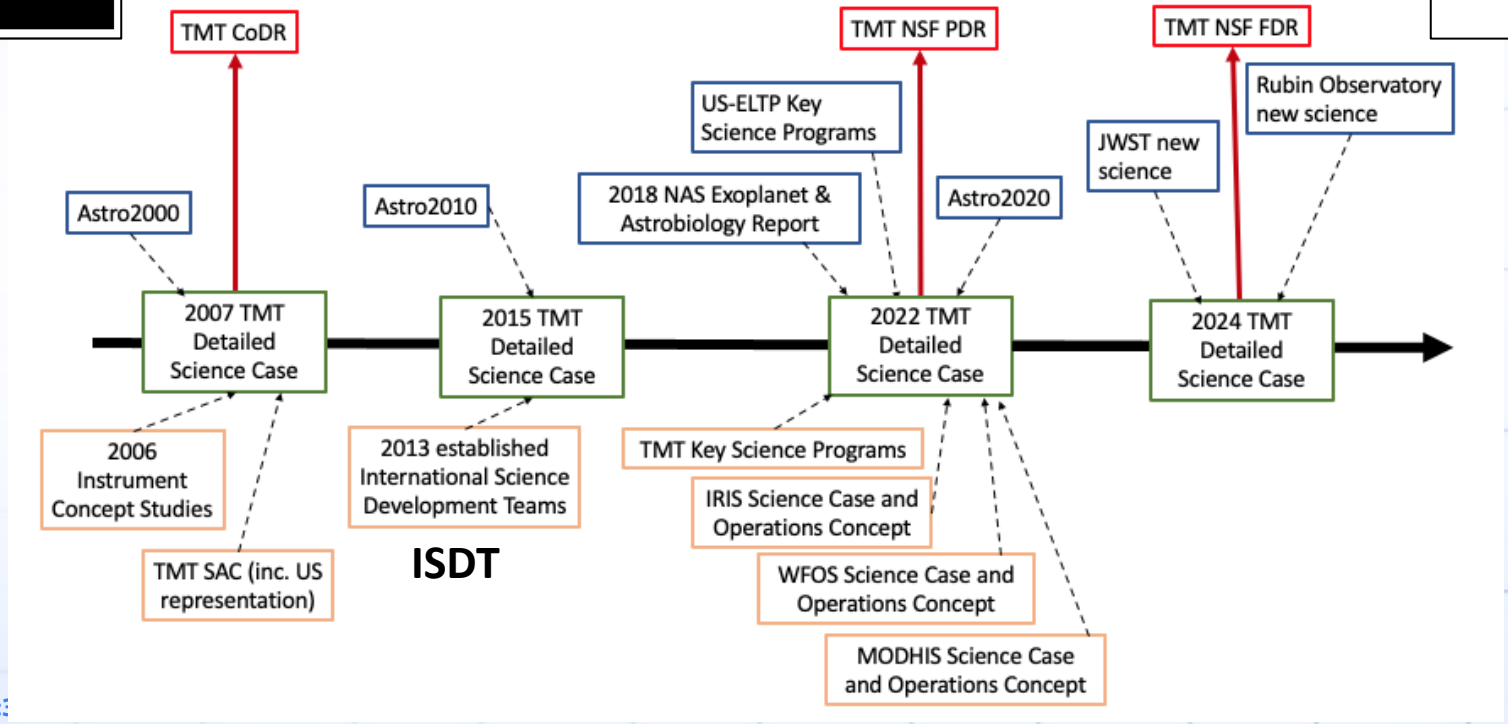
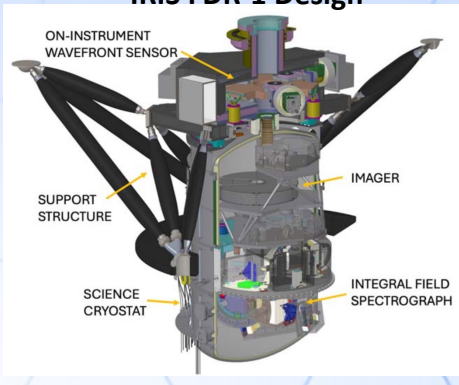


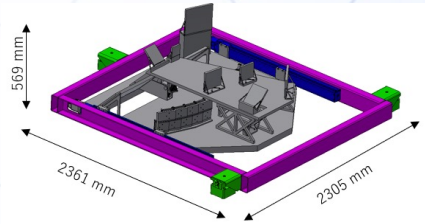
First-Light Instruments: Development Status

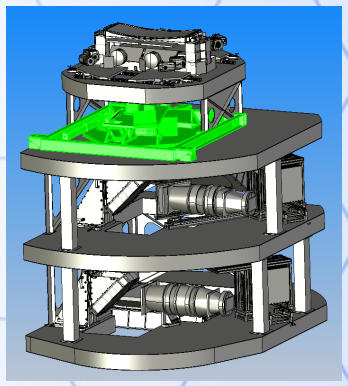
- **IRIS (R. Suzuki@NAOJ+)**
  - [2025 Dec] Passed (system level) FDR-1
    - Gained the System Level Design matuarity for its fabrication readiness.
- **WFOS (for IFU; S. Ozaki@NAOJ+)**
  - [2025 Aug] Passed PDR-1
    - WFOS IFU Endorsed. Design effort is being planned in NAOJ.
- **MODHIS (for HISPEC; T. Kotani@ABC+)**
  - [2025 Sep] Passed CoDR (CoDR-3)
    - Spectrograph location baselined on Nasmyth platform.
    - Spectropolarimetry (y,J,H) endorsed.
    - Now in PD Phase.

IRIS FDR-1 Design

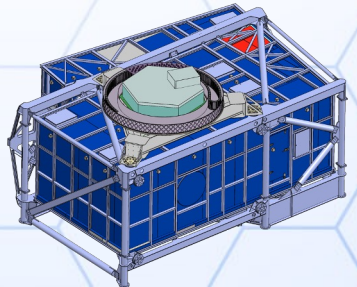


WFOS IFU Design

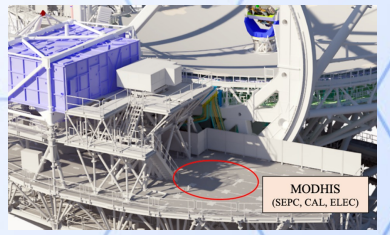




MODHIS Top-End Design



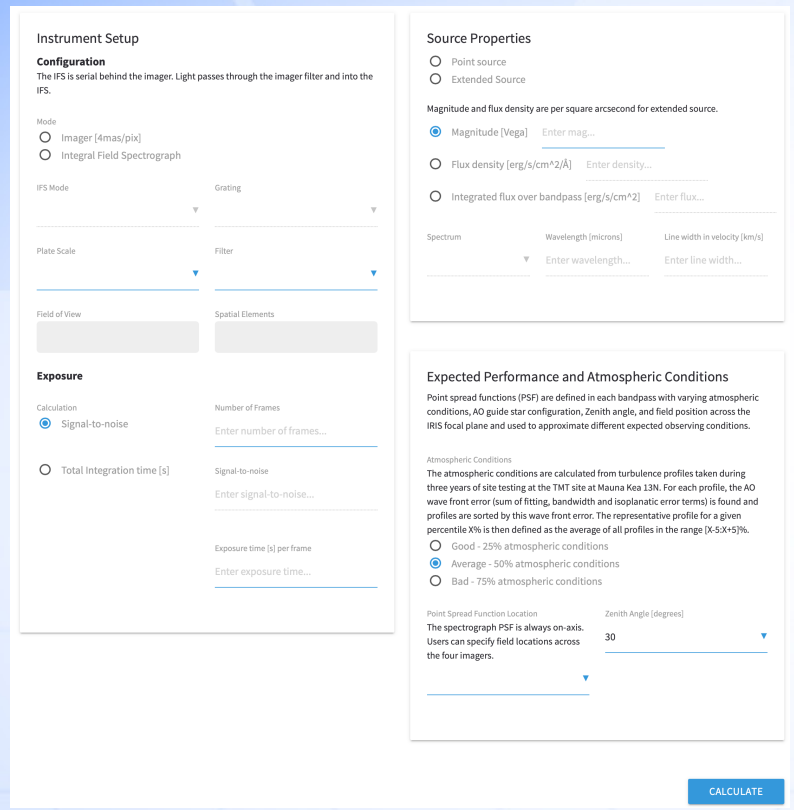
SPEC Location



First-Light Instruments: Performance Simulator

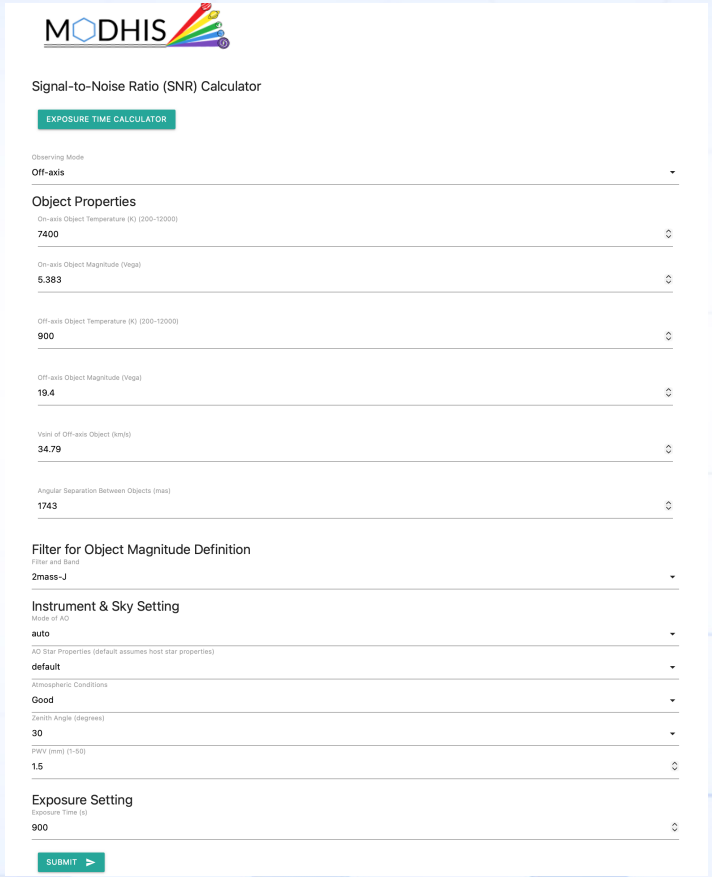
IRIS

- **Exposure Time Calculator (ETC) link:** https://www.tmt.org/etc/iris



MODHIS

- **ETC link** *(still under development):* http://specsim.astro.caltech.edu



WFOS

- ***No ETC prepared yet***.
- Sensitivity information: https://www.tmt.org/page/wfos-sensitivity

First-Light Instruments: Science Team

IRIS

- *[As of 2023 Apr]* 41 members, **5 from Japan**

David Andersen, TMT
Lee Armus, IPAC/Caltech
Aaron Barth, UC Irvine
Shashi Pandey, India Nainital
Jeffrey Cooke, Swinburne
Pat Coté, NRC-Herzberg
Tim Davidge, NRC-Herzberg
Katherine de Kleer, Caltech
Tuan Do, UCLA
Christoph Dumas, TMT
Andrea Ghez, UCLA
Satoshi Hamano
Lei Hao, Shanghai
Yutaka Hayano, NAOJ
Matthew Hosek, Berkeley
James Larkin, UCLA
Michael Liu, U Hawaii
Jessica Lu, Berkeley
Shude Mao, NAOC
Christian Marois, HIA
Anne Medling, Caltech
Anna Nierenberg, UC Irvine
Nils-Erik Rundquist, UCSD
Matthias Schoeck, TMT
Luc Simard, NRC-Herzberg
Warren Skidmore, TMT
Annapurni Subramaniam, Indian IofA
Smitha Subramaniam, India IofA
Arun Surya, UCSD
Ryuji Suzuki, NAOJ
Jonathan Tan, U. Florida
Hiroshi Terada, NAOJ
Tsuyoshi Terai, NAOJ
Tommaso Treu, UCLA
Chao-Wei Tsai, NAOC
Paolo Turri, Berkeley
Takahiro Uchiyama, JAXA
Andrey Vayner, Johns Hopkins
Gregory Walth, Carnegie
Mike Wong, Berkeley
Shelley Wright (PS), UCSD

MODHIS

- *[As of 2025 Aug]* 49 members, **5 from Japan**

Étienne Artigau (U de Montréal)
Ravinder Banyal (IIA)
Thomas Beatty (U of Arizona)
Chas Beichman (Caltech/JPL)
Bjorn Benneke (U de Montréal)
Geoff Blake (Caltech)
Adam Burgasser (UC San Diego)
Gabriela Canalizo (UC Riverside)
Guo Chen (Purple Mountain Obs.)
Richard Dekany (Caltech)
Tuan Do (UCLA)
Greg Doppmann (WMKO)
René Doyon (U de Montréal)
Courtney Dressing (UC Berkeley)
Min Fang (Xiamen U.)
Mike Fitzgerald (UCLA)
Tom Greene (NASA Ames)
Greg Herczeg (KIAA Peking)
Lynne Hillenbrand (Caltech)
Andrew Howard (Caltech)
Nem Jovanovic (Caltech)
Stephen Kane (UC Riverside)
Tiffany Kataria (JPL)
Eliza Kempton (U of Maryland)
Heather Knutson (Caltech)
Quinn Konopacky (UC San Diego)
Takayuki Kotani (ABC / NAOJ)
David Lafrenière (U de Montréal)
Chao Liu (NAOC)
Dimitri Mawet (Caltech)
Stan Metchev (Western U.)
Max Millar-Blanchaer (UC Santa Barbara)
Shogo Nishiyama (Miyagi Education U.)
Gajendra Pandey (IIA)
Peter Plavchan (George Mason U)
S.P. Rajaguru (IIA)
Paul Robertson (UC Irvine)
Colette Salyk (Vassar)
Bunei Sato (Tokyo Inst. of Tech.)
Everett Schlawin (U of Arizona)
Sujan Sengupta (IIA)
Thirupathi Sivarani (IIA)
Warren Skidmore (TIO)
Motohide Tamura (Osaka-U)
Hiroshi Terada (NAOJ)
Gautam Vasisht (JPL)
Jason Wang (Northwestern)
Ji Wang (Ohio State)
Hui Zhang (Nanjing U.)

WFOS

- *[As of 2024 Jun]* 18 members, **2 from Japan**

Chuck Steidel (Caltech)
Eric Peng (NOIRLab, USA)
Erica Nelson (Colorado, USA)
John O'Meara (Keck, USA)
Crystal Martin (UCSB)
Khee-Ghan Lee (IPMU, Japan)
Kimihiko Nakajima (Kanazawa-U, Japan)
G. C. Anupama (IIA, India)
Vivek M (IIA, India)
Roberto Abraham (Toronto, Canada)
Ting Li (Toronto, Canada)
Michael Balogh (Waterloo, Canada)
Evan Kirby (Notre Dame, USA)
Mansi Kasliwal (Caltech)
Guo Chen (PMO, China)
Yong Zheng (UCB)
Karen Meech (Hawaii)
Casey Papovich (Texas A&M, GMACS)

Key Take-Aways

- **For TMT-FL Users:**
  - Check your science by using the IRIS/MODHIS ETC (or WFOS sensitivity info)
  - **Stay tuned for the upcoming Webinar(s).**
- **For TMT-FL/FD Requesters:**
  - Reach out to any science team members with your request/question (FL)
  - Check the latest Detailed Science Case Document.
  - Consider participating in TMT ISDT (FD)
- **For "Potential" TMT Instrument Developers:**
  - **Please contact me (terada@naoj.org) or any TMT Project members.**

Acknowledgments

The TMT International Observatory (TIO) gratefully acknowledges the support of the TIO Members and the Gordon and Betty Moore Foundation. The Members and their respective collaborating institutions are as follows: California Institute of Technology (Caltech); the National Research Council of Canada (NRC-CNRC); the Association of Canadian Universities for Research in Astronomy (ACURA); the Department of Science and Technology, Government of India (DST); the Department of Atomic Energy of India (DAE); the National Institute of Natural Sciences of Japan (NINS); the National Astronomical Observatory of Japan (NAOJ); and the Regents of the University of California (UC). This work was supported as well by the Association of Universities for Research in Astronomy (AURA) and U.S. National Science Foundation (NSF).