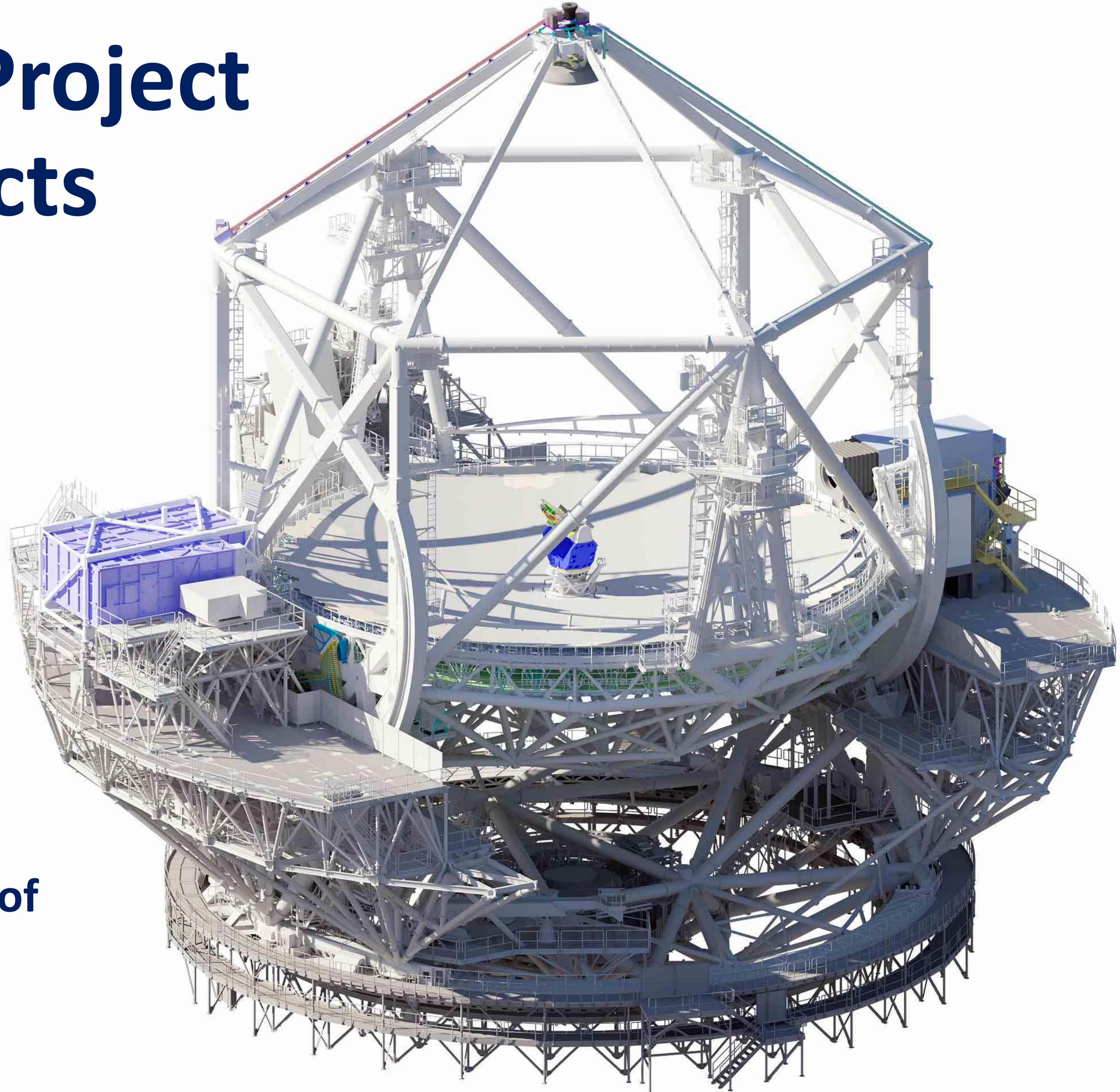
TMT Science and Project Status/Prospects



Wako Aoki

National Astronomical Observatory of Japan (NAOJ) TMT Project

TMT Science and Project Status/Prospects

- TMT Science
  - TMT's capability: high-resolving power and sensitivity
  - Construction site: comparison with ELT site
  - Science instruments lineup
  - Operation plan
  - Ongoing science activities

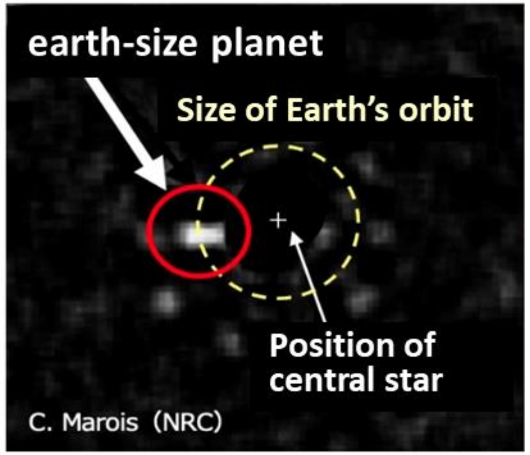
- Project Status and prospects
  - Japan's contribution: achievement and status
  - Frontier Program evaluation and application for Roadmap 2023
  - Progress in Hawai'i
  - NSF's process toward US funding

TMT
THIRTY METER TELESCOPE

TMT science goals

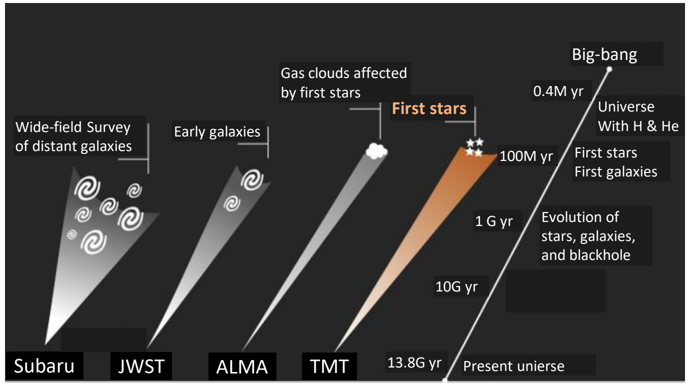
国立天文台 NAOJ
National Astronomical Observatory of Japan

Searches for signature of life in exoplanets



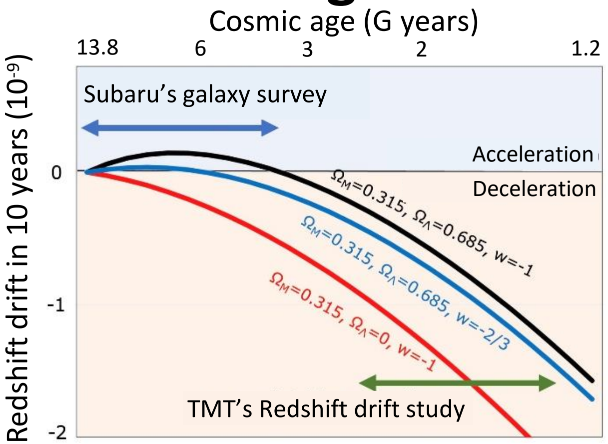
TMT will challenge detection of molecules related to life (e.g., O_2, O_3, CH_4) through direct imaging of earth-like exoplanets and spectroscopic study of their atmosphere.

Detection of light from first stars



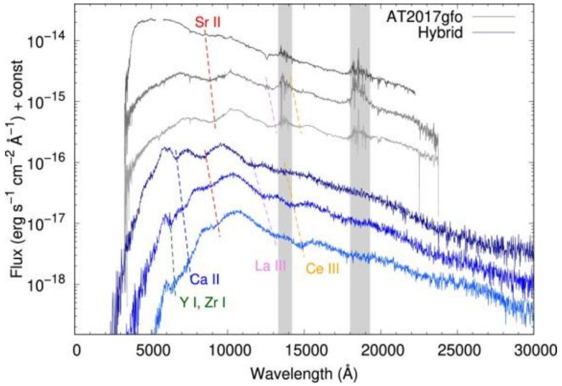
Detection of He emission line expected from first stars constrains the timescale of first star formation and their nature, as well as their role in galaxy formation.

Constraining the nature of dark energy



Direct measurement of the universe expansion by the redshift drift of intergalactic matter will constrain the nature of dark energy.

Multi-messenger astronomy



Domoto et al. (2022)

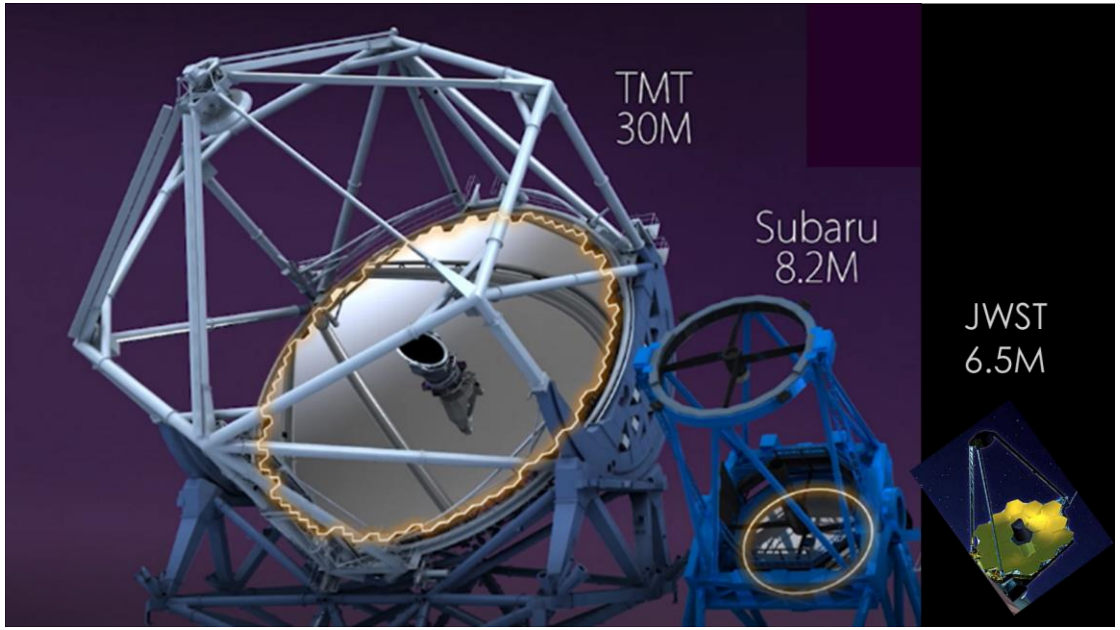
TMT will play crucial role in optical-infrared spectroscopy for events detected by gravitational wave or neutrino to explore physics in extreme environment and origins of heavy elements

TMT's extremely high resolving power and sensitivity

Comparison with JWST

- **Angular resolution ∝ *D*[1]→4.6 times higher (with AO)**
- **Light collecting power ∝ *D*[2] →20 times larger**

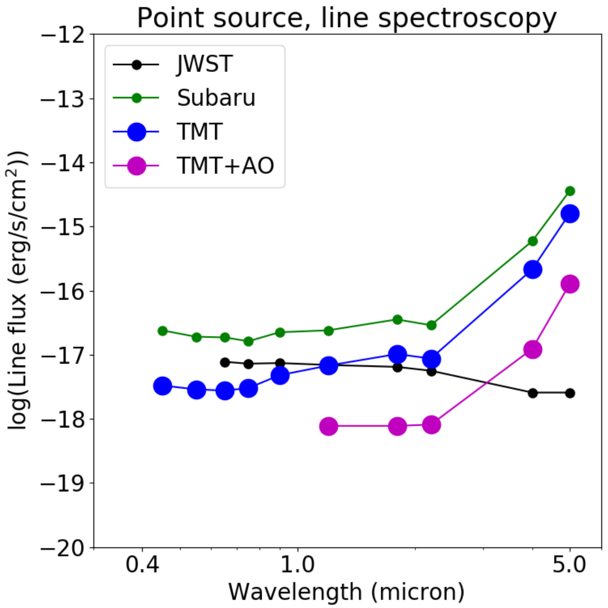
  The volume covered by TMT for objects with the same brightness is 100 times larger than that by JWST
  ex: rare events are observable 100 times more frequently



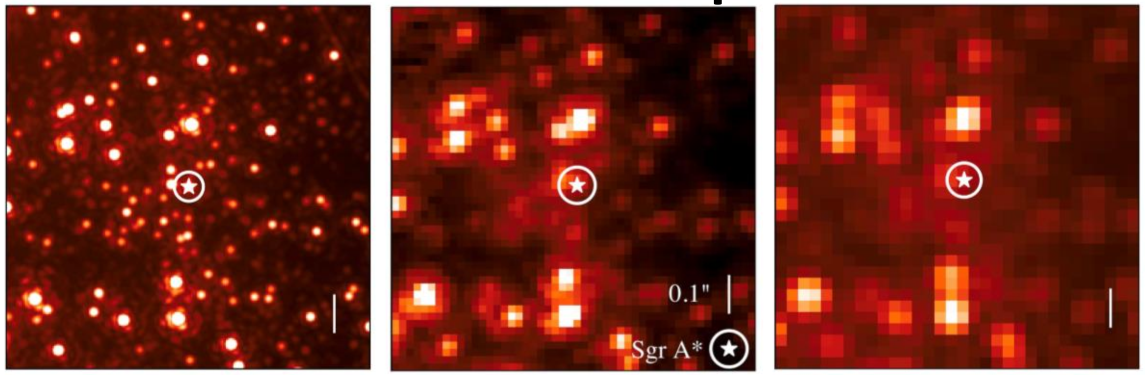
Comparison with ground-based telescope

background noise ∝ image size for a point source (a star) ∝ D^{-2}
→**The sensitivity for faint point sources ∝ D^4**
→ >100 times higher sensitivity

ex. 10-hour observation with Subaru
→ 3 minutes observation with TMT



TMT **10m ground-based telescope** **JWST**



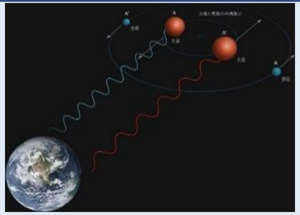
Synergy with the Subaru 2.0

Subaru 2
Ultra wide-field surveys

TMT
High sensitivity

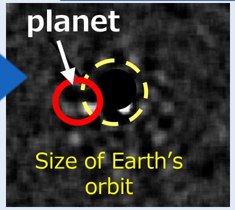
Exoplanet

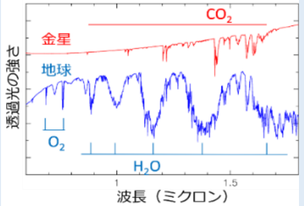
Searches for Earth-like exoplanets by indirect method



Identifying and characterizing a variety of Earth-like exoplanets. Providing candidates for direct imaging.

Direct imaging of Earth-like exoplanets and spectroscopy of planet atmosphere

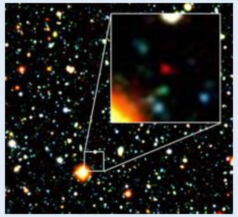




Searches for molecules related to life by transmission spectroscopy

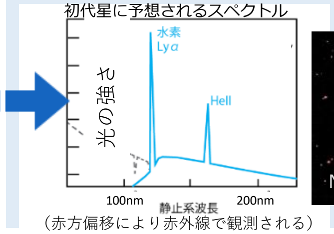
Galaxy formation

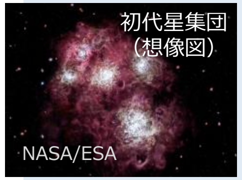
Searches for first galaxy candidates by wide-field survey



Exploring the era of rapid evolution of galaxies about 10 billion years ago. Infrared survey of early galaxies with ULTIMATE that is impossible by optical instruments.

Detection of light from first stars





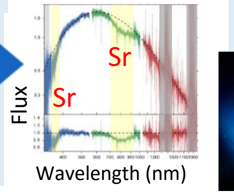
Detecting the light from first stars (helium emission) to constrain the timescale of first star formation and their nature.

Multi-messenger astronomy

Identifying optical/infrared counterpart of gravitational wave/neutrino sources by quick wide-field survey

Following up a variety of gravitational wave sources to investigate synthesis of heavy elements. Identifying origins of high-energy events including neutrino sources.

Spectroscopy of counterparts of gravitational wave/ neutrino sources

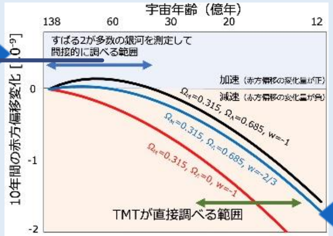


Exploring the explosion mechanisms and synthesis of elements in the Universe by spectroscopy for objects identified with Subaru etc.

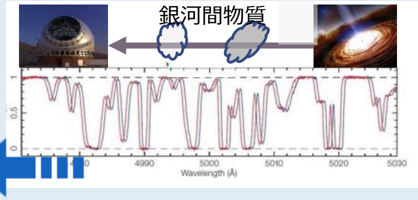
Dark matter Dark energy

Indirect measurement of Universe's expansion by wide-field surveys

Constraining the nature of dark matter and dark energy. Determining the mass of neutrino.



Direct measurement of Universe's expansion



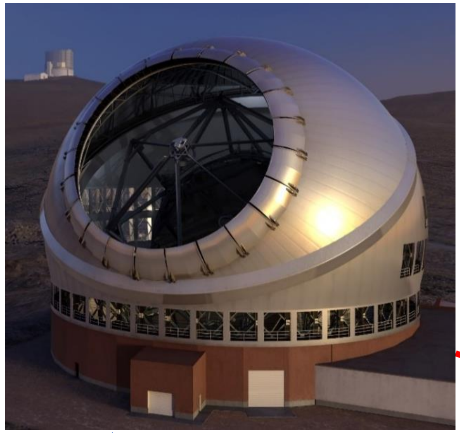
Constraining the nature of dark energy that causes expansion of the Universe by a fully new approach.

Extremely Large Telescopes under construction

- TMT in Hawaiʻi covers northern sky (see next page for site conditions).
- TMT has wider field of view and better efficiency by smaller number of reflections than E-ELT.

	TMT	GMT	E-ELT
Primary mirror	30m	24.5m (8.4m X 7)	39m
Site(altitude)	Hawaiʻi (4012m)	Chile (2500m)	Chile (3064m)
FoV (no vignetting)	20 arcmin (15 arcmin)	20 arcmin	10 arcmin (5 arcmin)
Number of reflections	3	3	5

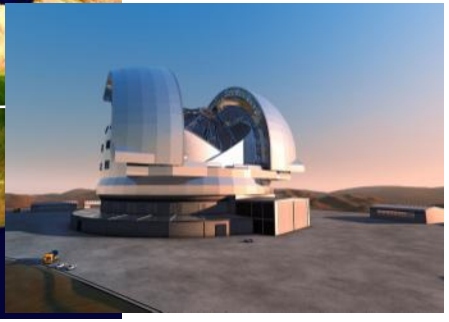
TMT (Maunakea)



US-ELT program

GMT (Las Campanas)

Spain (La Palma)



E-ELT (Armazones)

Site comparisons

- **High altitude of Maunakea → advantage in UV and IR observation**
- **Large Isoplanatic angle and coherence time → preferable conditions for AO observations.**

Site characteristics	Maunakea (MK-13N)	La Palma (TMT-3)	Armazones (E-ELT site)	Ref.
altitude (m)	4050	2250	3064	1,4
Seeing at 60m above ground (arcsec)	0.50	0.55	0.50	1,3
Isoplanatic angle (arcsec)	2.55	2.33	2.05	1,3
Atmospheric coherence time (ms)	7.3	6.0	5.0	1,3
Precipitable Water Vapor (PWV) (mm)	1.86	7.3	2.87	2
Mean UV transmission (0.30-0.38μm)	0.47	0.41	0.43	2
Fraction of Clear night	0.72	0.73	0.86	1

Red: best site among the three

Ref. (1) CATAC report Apr. 16, 2017 (draft), (2) TMT.PSC.TEC.16.008.DRF01, (3) https://www.tmt.org/page/site, (4) Schöck et al. 2009, PASP 121, 384

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TMT Science Instruments

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National Astronomical Observatory of Japan

First Light Instrument
First Decade Instrument

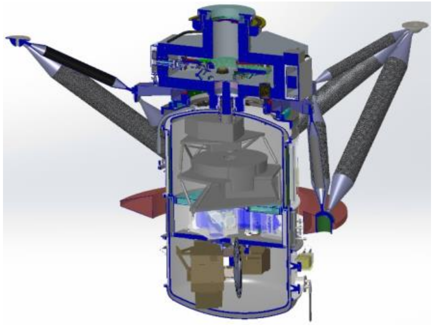
MODHIS

Multi-objective Diffraction-limited High-resolution Infrared Spectrograph

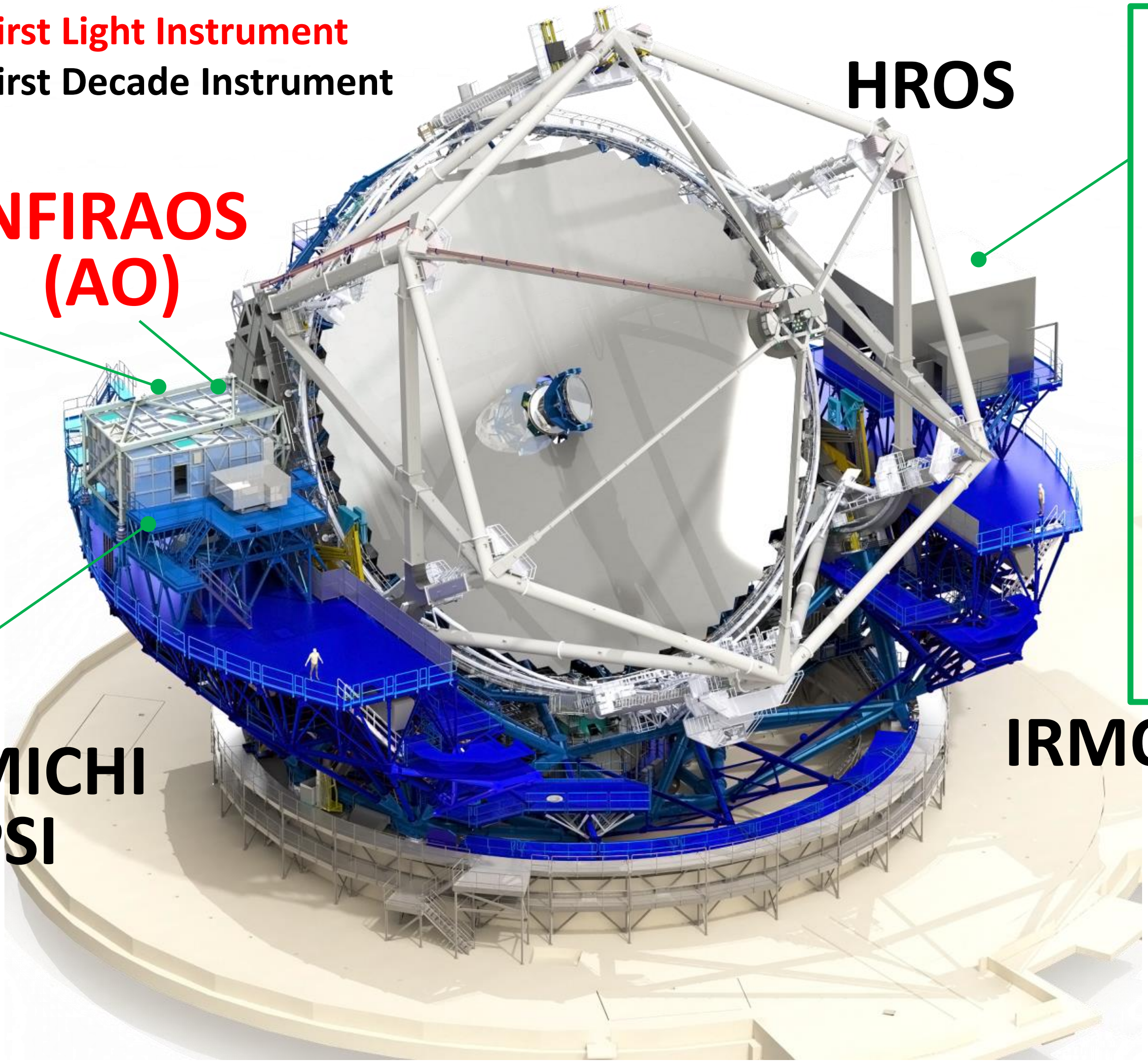
Japan is contributing to management and science.

IRIS

InfraRed Imaging Spectrograph

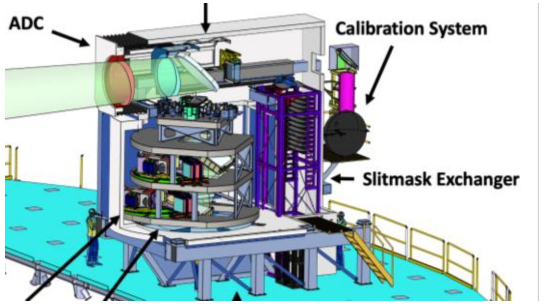


Japan is responsible for the Imager part.



WFOS

Wide-field Optical Spectrometer

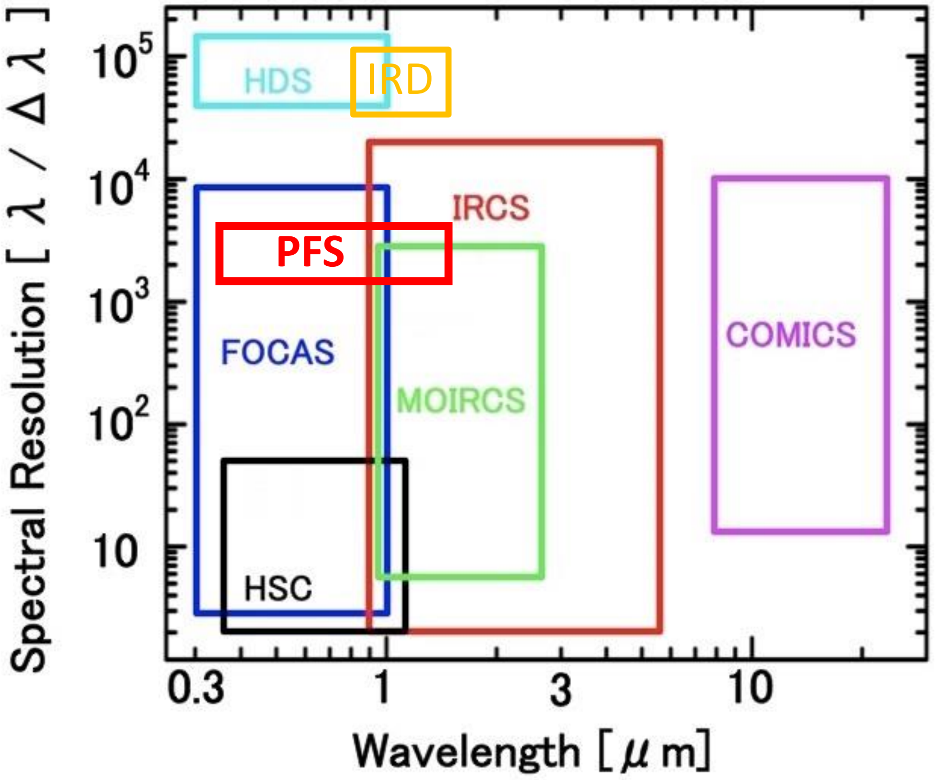


Japan contributed design studies of slitmask exchanger, integral field unit, etc.

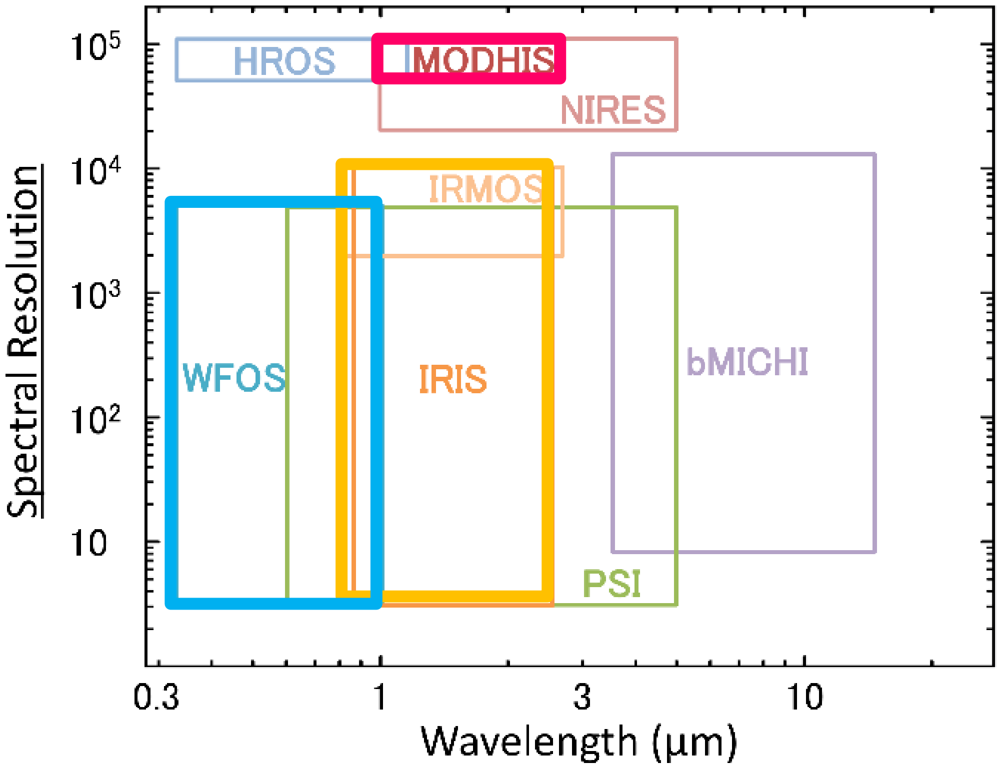
TMT Science Instruments

Instrument lineup covering optical/near- and mid- infrared and imaging/low- and high-resolution spectroscopy

The Subaru Telescope



TMT planned



Instrument plan

TMT

	First light inst.	2nd generation inst.	Targets of the 4 science goals
Optical	WFOS (Wide Field Spect.)		Galaxies, Multimessenger
		HROS (High-res spect.)	Exoplanet, Cosmology
Near Infrared	IRIS (Imager/Spect.)		Galaxies, Multimessengr
	MODHIS (High-res spect.)		Exoplanet
		PSI (High contrast)	Exoplanet (direct imaging)
Mid Infrared		MICHI (Imager/Spect.)	Exoplanet

E-ELT

	First light inst.	2nd generation inst.
Optical		MOSAIC (Wide Field Spect.)
		ANDES (Opt-NIR High-res spect.)
Near Infrared	HARMONI (Imager/Spect.)	
	MICAD (Imager/Spect.)	
		PCS (High contrast)
Mid Infrared	METIS (Imager/Spect.)	

GMT

Optical	GMACS (Wide Field Spect.)
	G-CLEF (High-res Spect.)
Near Infrared	GMTIFS (IFS Spect.)
	GMTNIRS (High-res Spect.)
Mid Infrared	

Searches for molecular oxygen in Earth-like planets: transmission spectroscopy

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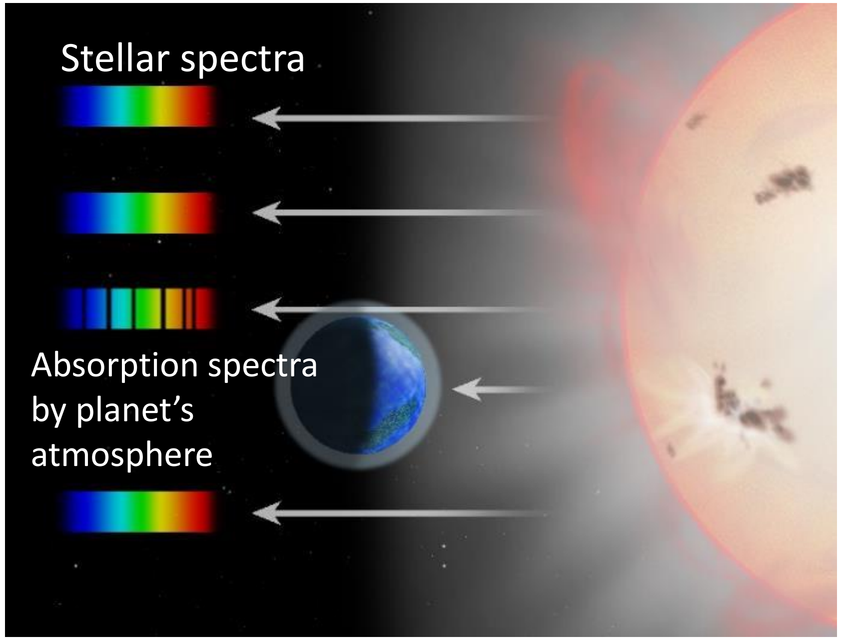
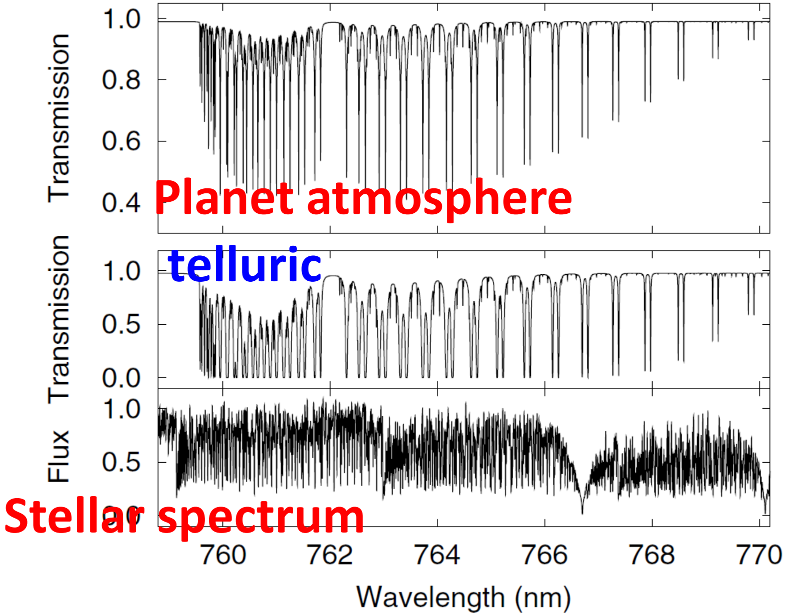
National Astronomical Observatory of Japan

High-sensitivity spectroscopy of stellar light during transit is used to search for signature of life including O_2.

- Targets are nearby (<10pc) M dwarfs: orbital periods of planets in habitable zone are ~10 days.
- Observations for more than 20 transits are required ➡ it takes a few years to detect signatures
- High spectral resolution is required to separate telluric absorption

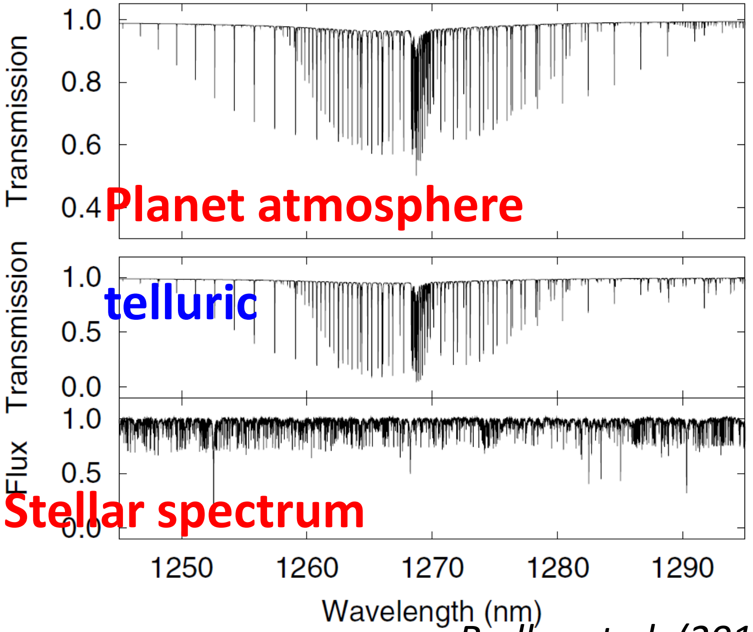


O_2 "A band" at 760nm with HROS



→early M dwarfs (M1-5)

NIR band at 1260nm with MODHIS



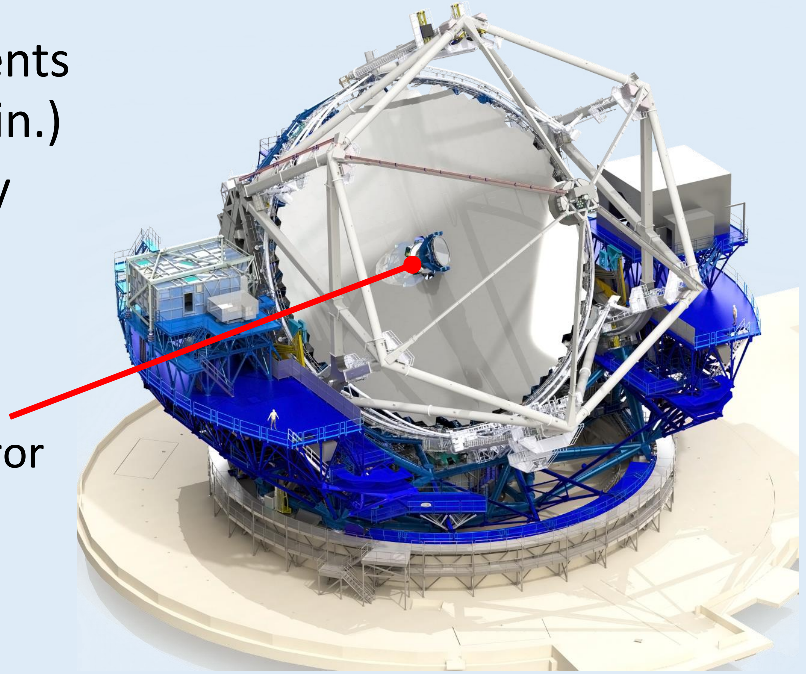
Rodler et al. (2014)

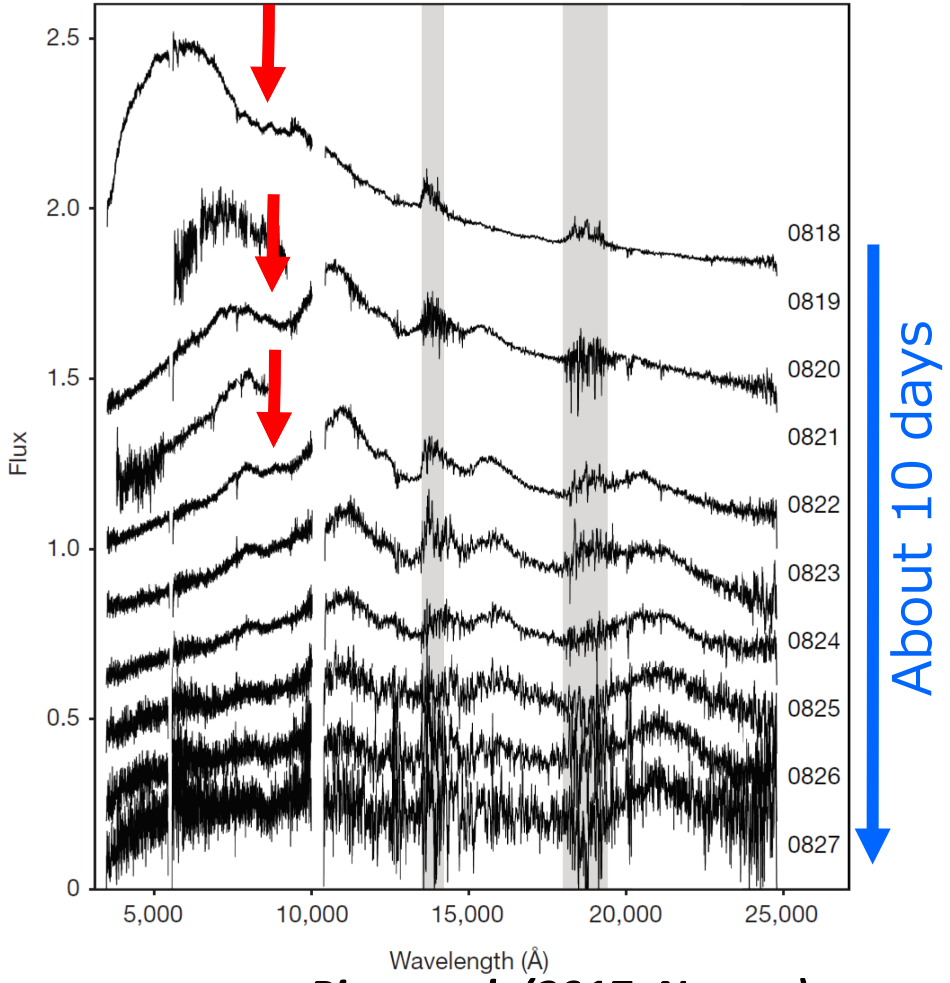
→mid or late M dwarfs (M6-9)

Multimessenger astronomy: follow-up spectroscopy for gravitational wave sources

- Successful observations for GW170817 demonstrated the possibility to directly measure r-process by mergers of binary neutron stars.
- High sensitivity in optical and near-infrared spectroscopy is required. Follow-up observations with WFOS and IRIS is possible from the first light.

TMT's science instruments can be quickly (～10 min.) switched by the tertiary mirror.





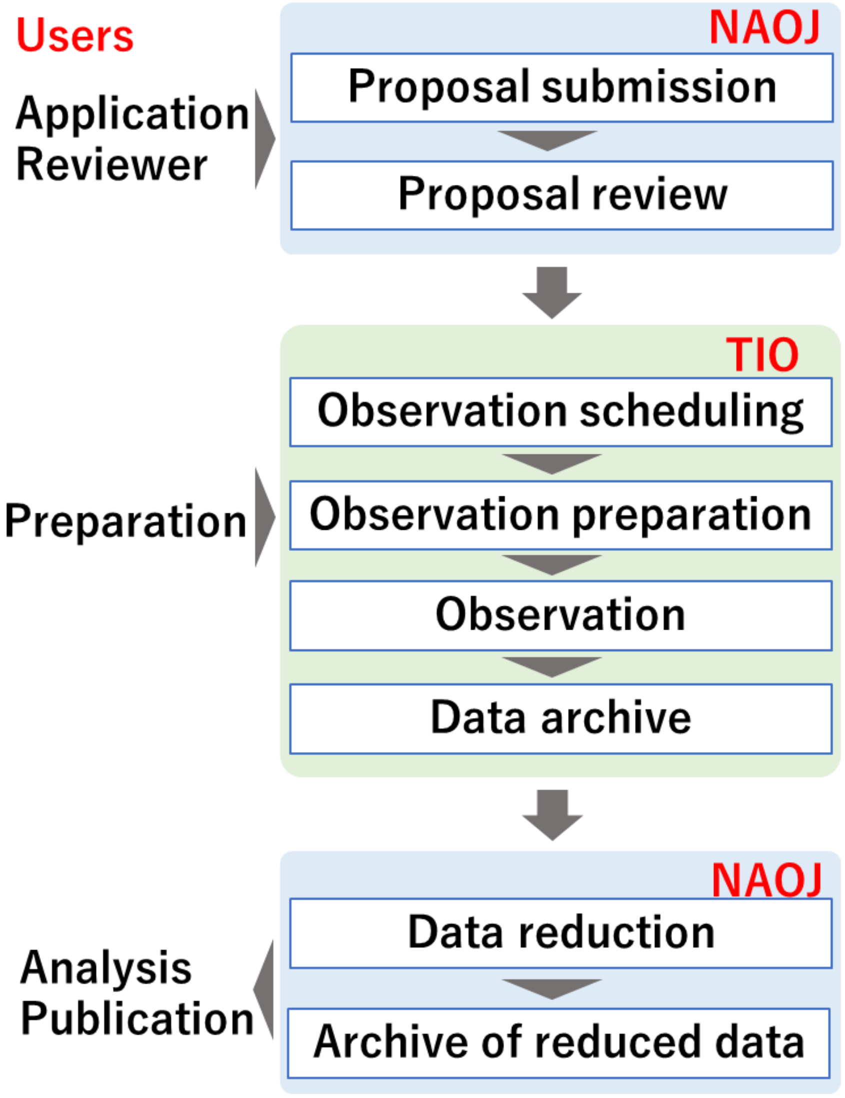
Pian et al. (2017, Nature)

TMT operation plan

TMT Observing time for Japan is opened for community of Japan as the open use of the Subaru Telescope and ALMA.

- TIO is responsible for the telescope operation, including scheduling, observations and archive of raw data. TMT partners are responsible for processing proposals and science data reduction and archive. Tools and software developed by US-ELTP will be available for partners.

- NAOJ will operate open use of the TMT Japan time and the Subaru Telescope time with a common system for proposal management, data analysis support and archive to promote unique science with the two telescopes and to increase the operation efficiency.



Discussion items on TMT operation

TMT operation plan has been discussed in TMT-Japan Science Advisory Committee corresponding to the update of the plan by TIO for NSF PDR in 2022 Dec and 2023 Feb.

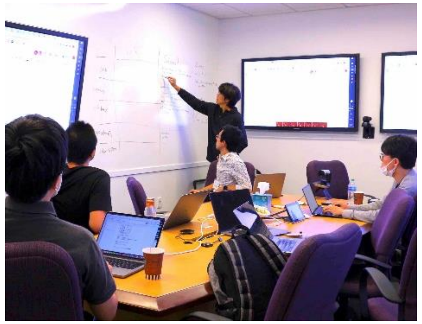
- **Proposal management and selection**
  Time allocation committees will be independently organized by individual partners. Duplication of programs needs to be solved. A common system to treat proposals for TMT-Japan time and Subaru will be useful.
- **Observing mode and ToO**
  Queue mode and visitor mode are assumed. Quick instrument switching is an advantage of TMT for Target of Opportunity (ToO) observations. The TMT operation plan needs to be designed as ToO observations to be effective even in visitor mode observations.
- **Large programs (Key science program)**
  More than one partners may share some observing time for joint programs. We need to consider possible collaborations with key science programs that will be designed by US-ELTP.

Ongoing science activities

Science activities, including update of science cases and workshops, are enhanced toward NSF Final Design Review. Japan's activities are led by the NAOJ's TMT Science Advisory Committee.

- **Science cases**
  - TIO's International Science Developing Teams (ISDTs) are working to update the Detailed Science Cases (DSC).
  - A series of workshops (WS) are planned to promote discussion about the synergy with JWST and other telescopes. First WS will be opened at UCLA in Dec. 2023, and 2nd WS is planned at Tohoku University in June 2024.
  - TMT ACCESS: TMT eArly Career Centered, Engineers-Scientists Synergy: a WS organized by Japanese young scientists and engineers held in September in Pasadena in Sep. 2023. Next WS is planned in June 2024.
- **Second generation instruments**
  - Discussion on future instruments based on "Roadmap for the realization of the next TMT instrument" published in 2022.
  - R&D in universities including students are promoted by NAOJ TMT Project's support.
- **Science operation**
  - Discussion on the TMT operation plan is ongoing focusing on merged operations of TMT and the Subaru Telescope in Japan.

Workshop "ELT Science in Era of JWST"



TMT-ACCESS (Sep. 2023)

Instrument development in universities

Project Status and prospects

Construction of TMT by International Collaboration

TMT is an international project to complete the telescope in 2030s. Japan is responsible for the telescope structure, primary mirror and a part of science instruments.

① Telescope structure

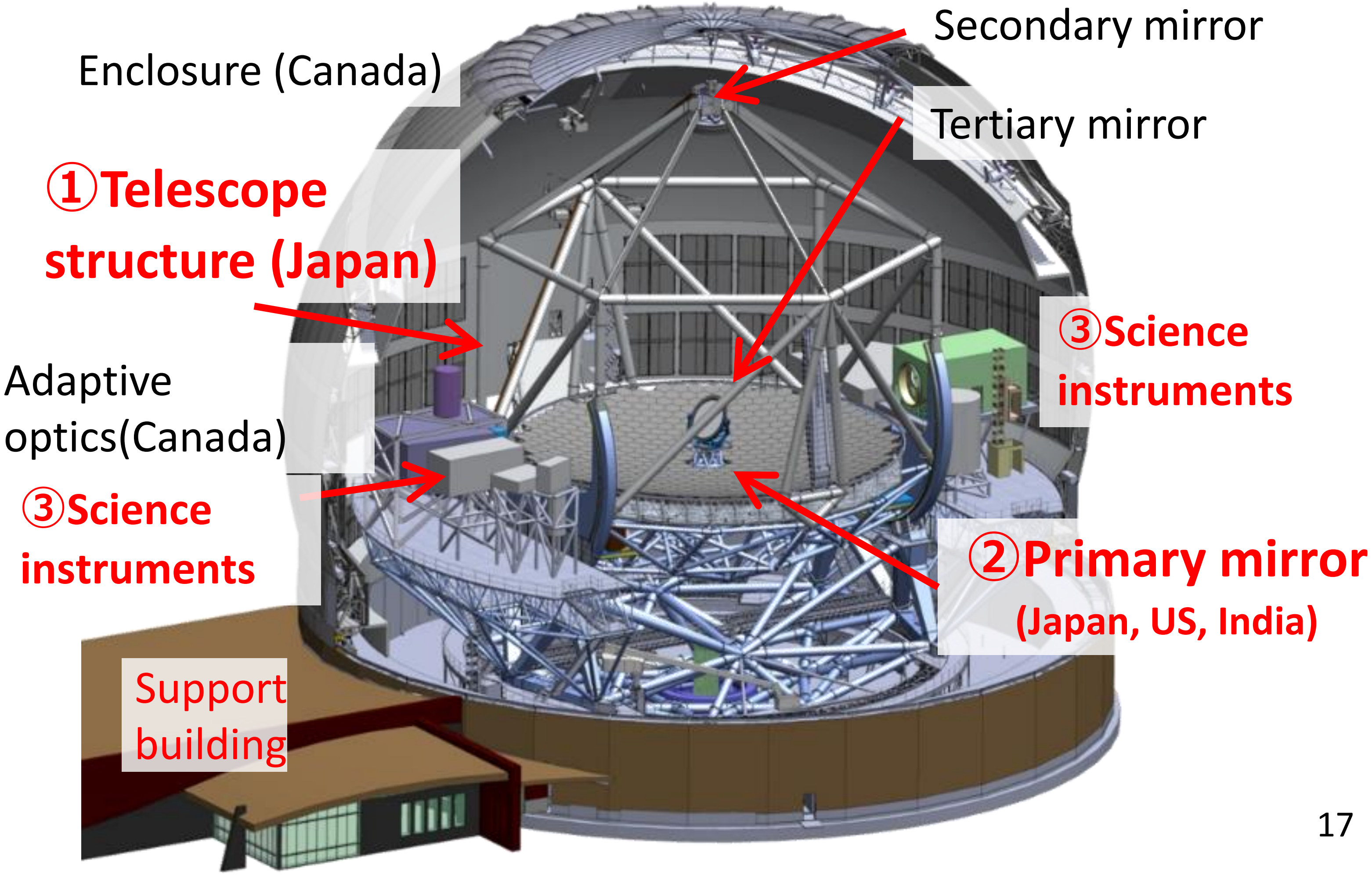
The main structure points the optics to a target and track it with guiding error of less than 0.015 arcsec. The weight of the structure is about 2600t, just 5 times larger than the weight of the 8.2m Subaru Telescope.

② Primary mirror (M1)

M1 is composed of 492 segment mirrors with hexagonal shape. Total 574 segments including 82 for exchange will be produced, polished and coated.

③ Science instruments

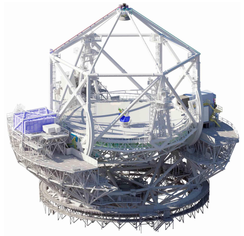
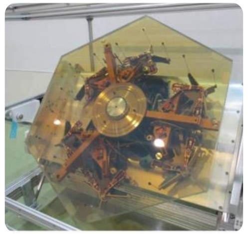
Three first-light instruments are identified and in designing phase.



Progress of TMT construction in Japan

- Final design review and production readiness review were completed for the Telescope Structure.
- Production of segment mirror blanks and polishing started, and will be resumed corresponding to the construction master schedule.

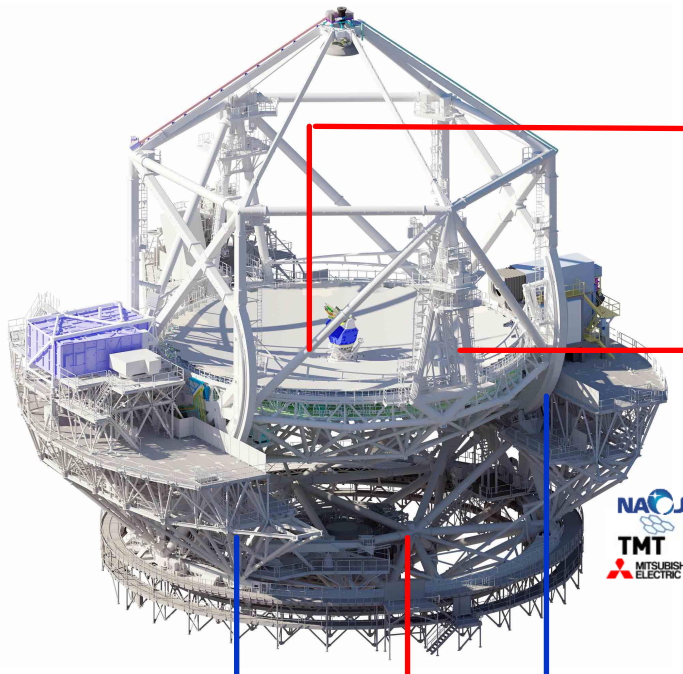
Completed | On going | Plan

Telescope Structure		Preliminary Design Final Design Production Preparation Fabrication Shipping to Hawaiʻi Onsite assembly
Segment Mirrors		Segment mirror blank Aspherical polishing Aspherical polishing (US and India) Hex. Cutting, mounting on SSA etc. Hex. Cutting mounting on SSA etc. (US and India) Ion beam figuring (US)
Science instrument IRIS	Imager (Japan)	Preliminary Design Final Design Fabrication Assembly and test
	Spectrometer (US) Wavefront sensor (Canada)	Preliminary Design Final Design Fabrication Assembly and test

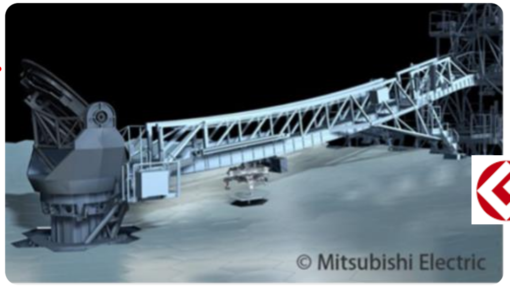
Japan's In-Kind Contribution to TMT: Telescope Structure (STR)

The final design of the telescope structure and its control system are completed.

- Substantially reduced manufacturing risk through extensive analysis, modeling, and prototyping by Mitsubishi Electric (MELCO), Hitachi Zosen (Hitz) and NAOJ.
- Passed three production readiness reviews (PRRs) of the main components (Azimuth, Elevation and Nasmyth structures) in March 2020 and Feb 2023, followed by the completion of all 10 international design & readiness reviews.
- PRRs of the control system, segment mirror handling system, Elevator, M1 CO_2 cleaning arm etc. will be held in 2024.



Prototype of the primary mirror cell



GOOD DESIGN

Segment-Handling Robot, equipped with an image recognition system and force sensors. Winner of the 2016 Good Design Award.

Prototype of welded joint of multiple branch pipe supporting telescope structure.

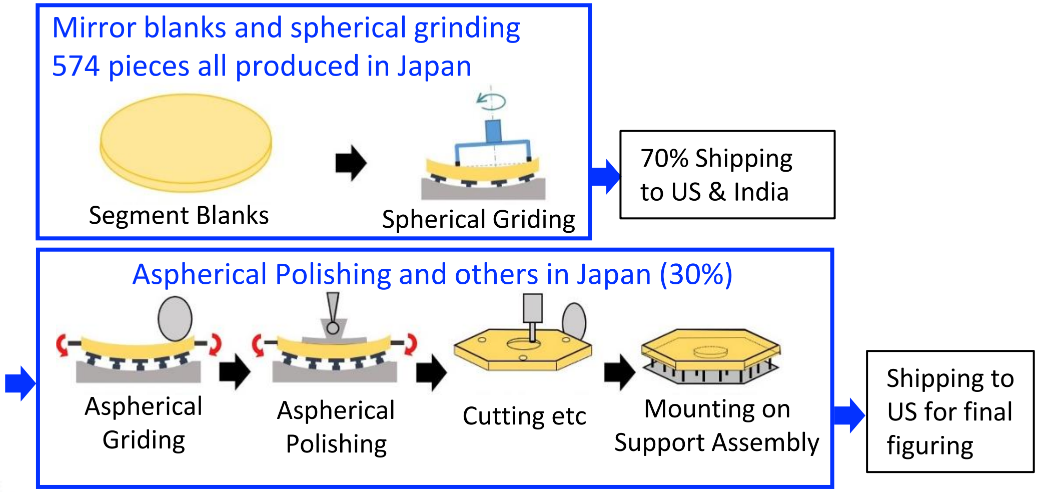
Cable winder for the Elevation axis. The cableveyor connection structure allows for a smooth operation.

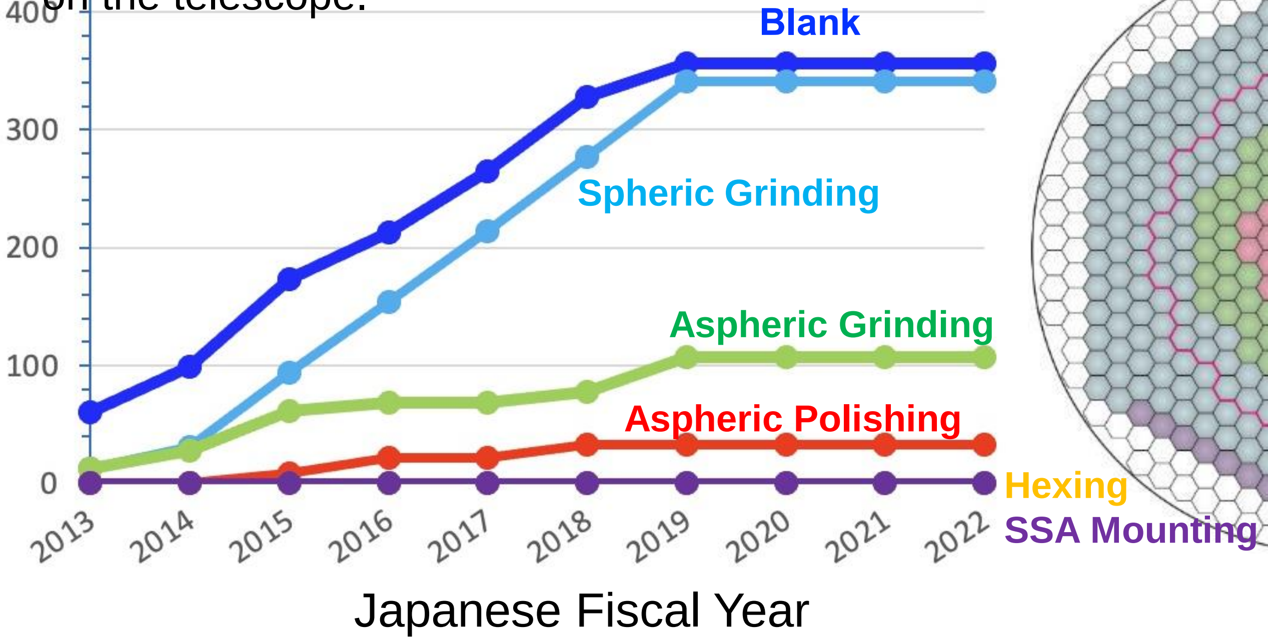
A unique seismic isolation mechanism that combines seismic isolation damper and locking functions.

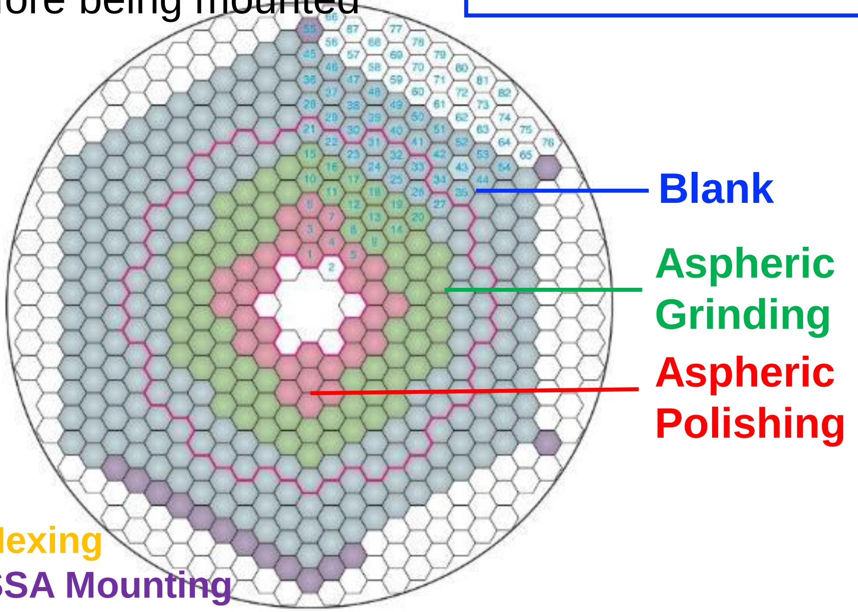
Japan’s In-Kind Contribution to TMT: Primary Mirror (M1)

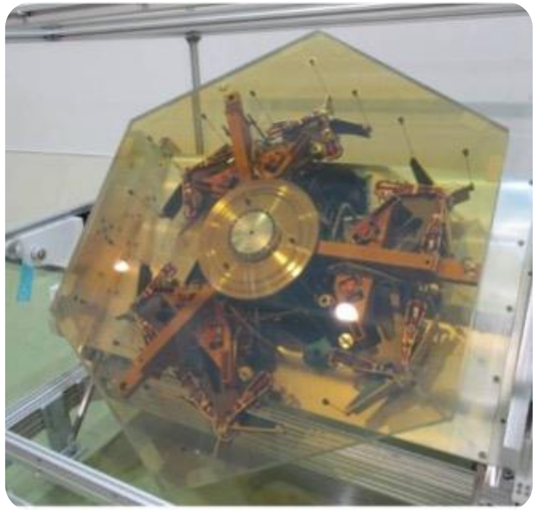
Mass production for Blanks and aspherical polishing were carried out until FY2019. Production and polishing will be resumed corresponding to the TIO master schedule.

- Japan will manufacture and perform spherical grinding for all 574 Blanks. 356 blanks and 341 spherical grinding have been manufactured already.
- 175 (30%) will be polished in Japan, and the remaining 399 will be sent to the United States (TIO) and India for the remaining processes. After hexing and Segment Support Assembly mounting , all mirrors will be shipped to the U.S. for IBF polishing and coating before being mounted on the telescope.





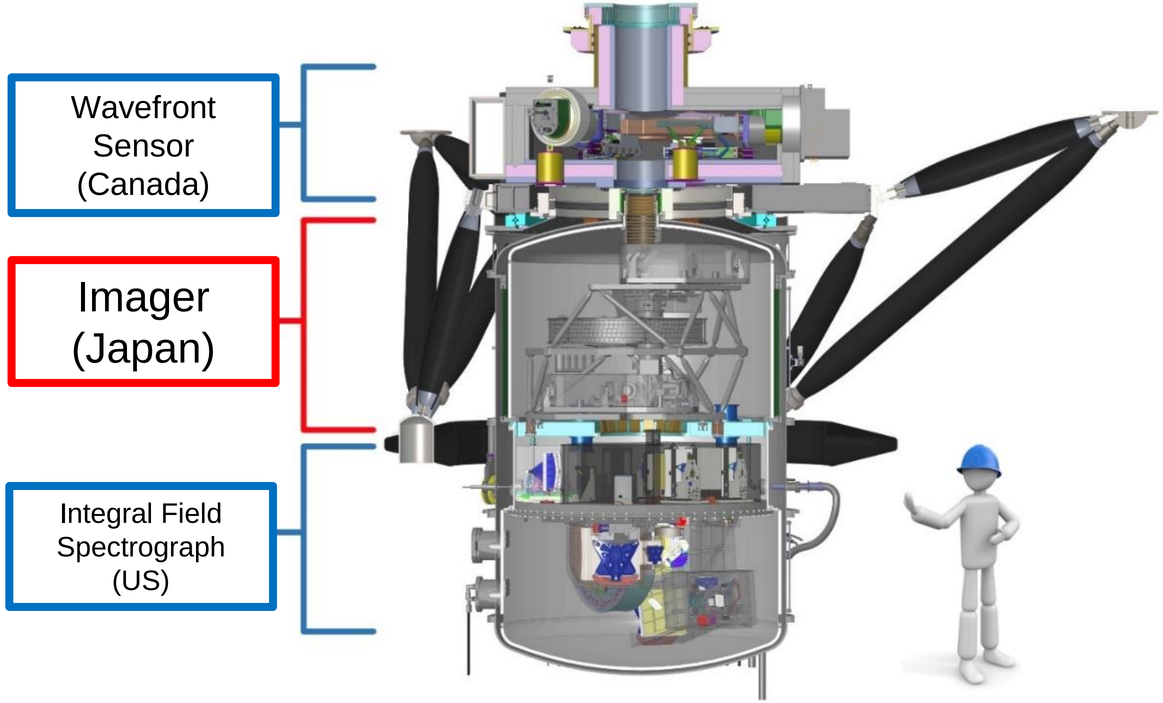


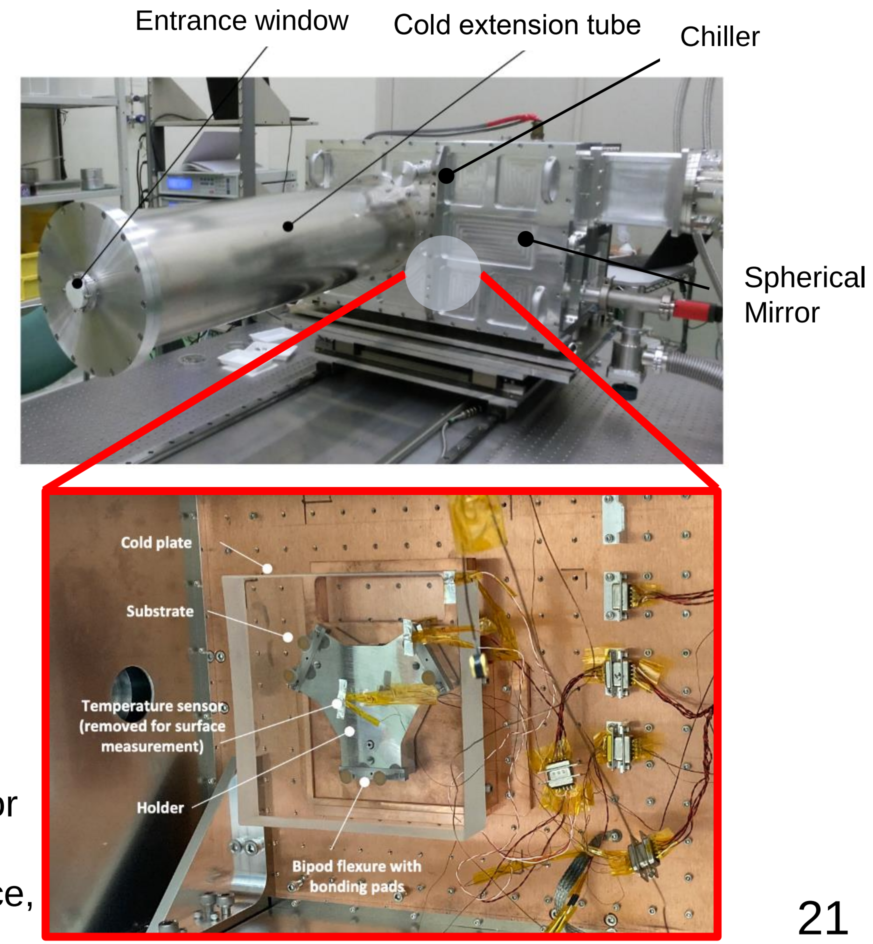


Protptype mirror after hexing and SSA mounting.

Japan’s In-Kind Contribution to US-ELT/TMT: InfraRed Imaging Spectrograph (IRIS)

The near-infrared imager/spectrometer IRIS is one of the first instruments to be installed on TMT. Used together with adaptive optics, IRIS will achieve an angular resolution of 0.01 arcseconds. The Preliminary Design Review was completed in 2017. Design and development toward Final Design Review (2024) is on going at NAOJ Advanced Technology Center.





NAOJ has

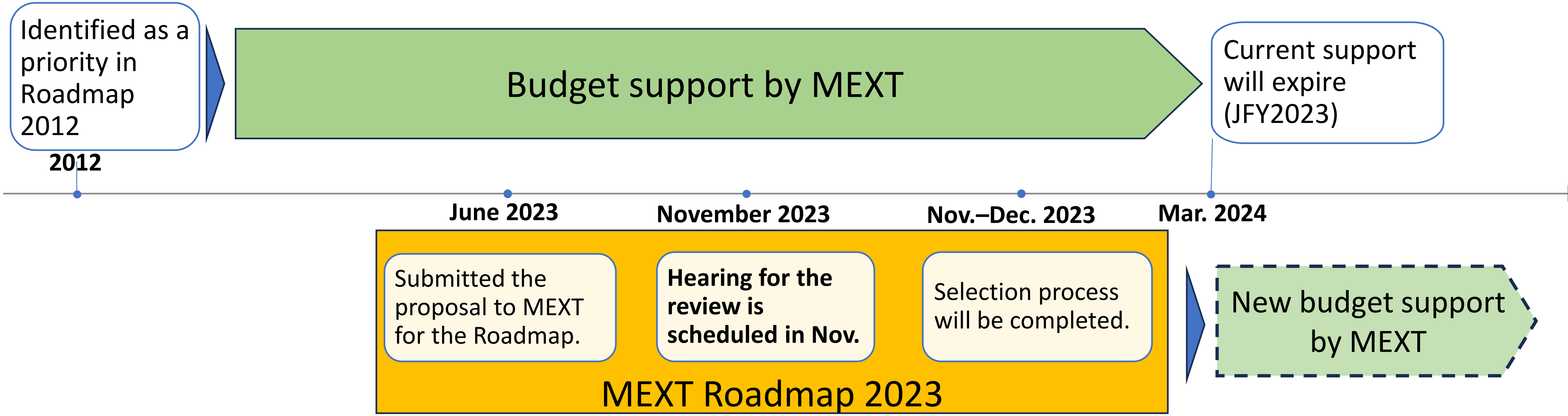
(1) established an evaluation procedure for a cooled optical system that achieves a wavefront error of 40 nm under liquid nitrogen temperature,

(2) demonstrated a cooled drive system that continues to operate for 10 years without maintenance,

(3) shown that optical distortion can be corrected with an accuracy of 0.01 arcsec or less.

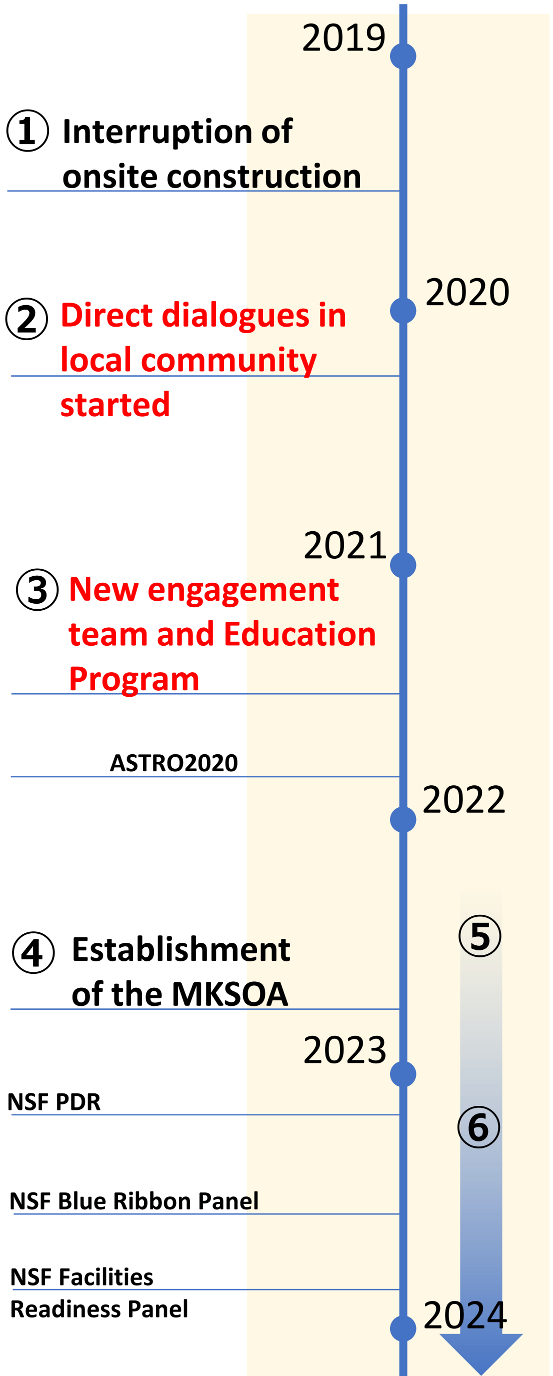
MEXT Roadmap

- TMT Project was selected in the “**MEXT Roadmap* 2012**” and the construction budget was supported from FY2013. The term-end review was successfully done in June 2023.
- NAOJ/NINS submitted a proposal to “**MEXT Roadmap 2023**” in order to continue the project after JFY2024 and beyond, and to cover the increased construction costs to complete Japan's contribution.



* Fundamental Concepts for Promoting Large Scientific Research Projects – MEXT Roadmap is formulated by the Working Group** under MEXT every three years to identify the nation’s priorities for large projects and provide grants.
Both Subaru Telescope and ALMA Project were re-selected in the MEXT Roadmap 2020 as Subaru2 (Super Wide Field Large Optical-IR Telescope) and ALMA2 (A Giant Millimeter/submillimeter Telescope in Search of our Cosmic Origins).
** The Working Group on Large Scientific Research Projects, Research Environment Infrastructure Subcommittee, Science Committee, Council for Science and Technology
cf) https://www.mext.go.jp/content/20210511-mxt_gakkikan1388523_2.pdf

Progress in Hawai‘i situation



①interruption of onsite construction（2019）

- Efforts to restart construction stalls

②Direct dialogues in local community started（2020）

- Recognized that TIO's understanding of the background of the opposition was insufficient
- Changed TIO's perspective on Hawai‘i engagement, focusing on activities based on local communities. Started phased relocation of TIO headquarters to Hilo.

③New engagement team and Education Program started（2021）

- TIO project manager and TMT-J project manager relocated to Hilo
- Direct dialogue with more than 400 in the local community including headline opposition leaders since 2021. Educational assistance and workforce development started based on demand of local community.

④Establishment of MaunaKea Stewardship Oversight Authority（MKSOA）（2022）

- There has been strong criticism against the Maunakea Management that has not reflected opinions of Native Hawaiians and has no benefit for local community from the land lease.
- New authority was established for Maunakea Management (MKSOA) that involves Native Hawai‘ians. MKSOA now co-manages the designated area on Maunakea with University of Hawai‘i (UH).

⑤NSF's process in Hawai‘i started (2022)

- NSF started the process on Environment Impact Statement (EIS), National Historic Preservation Act (NHPA) section 106, and Community Engagement Plan (CEP).

⑥Decommissions of telescopes started（2023）

- Reducing telescopes is a key issue for Maunakea astronomy.
- Decommission of CSO is on going. Hoku Kea, a UH telescope for education, will be

Prospects to obtain consensus on construction

- **Building trust for Maunakea Astronomy and TMT**
  - TIO reviewed problems of the activities in Hawaiʻi until 2019 and reshuffled the engagement team.
  - The change of TIO has been being recognized by direct dialogues and education activities in local community.
  - Decommissions of telescopes have started.

Decommission of CSO is ongoing and featured in local media.(Sep. 2023)

Maunakea visit by Gov. Green and MKSOA members (Aug. 2023). A native Hawaiʻian member commented that he welcomes the opportunities to talk many people by the MKSOA.

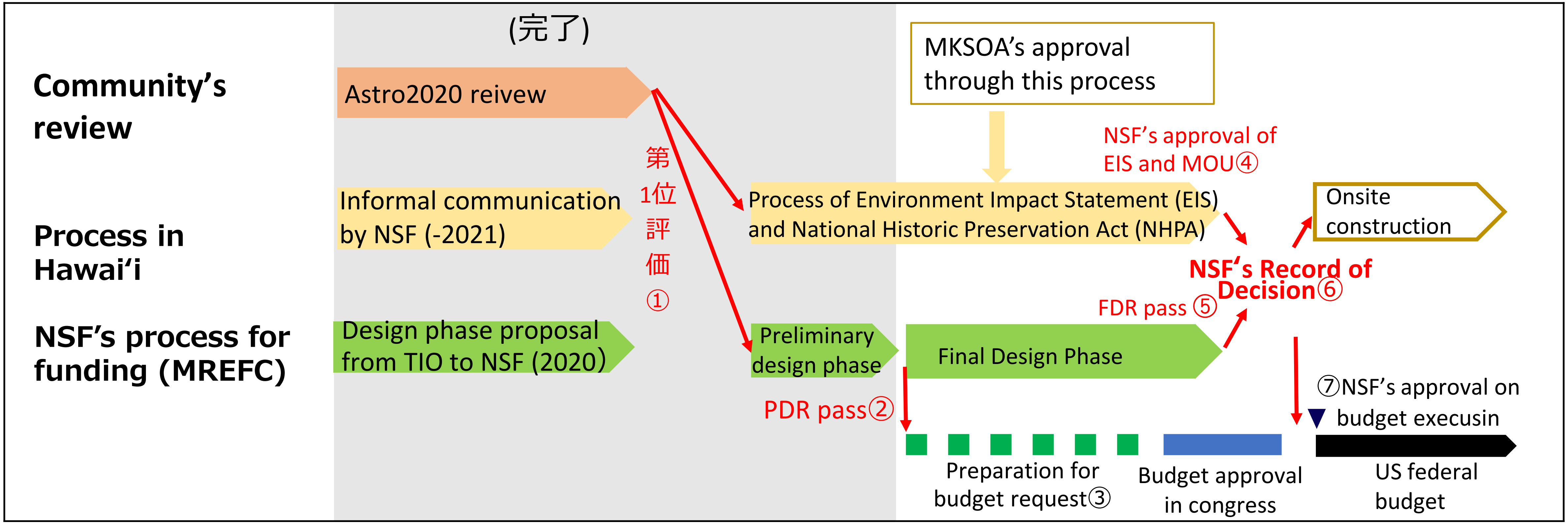
- **New authority to reflect opinions of the local community including native Hawaiʻians on Maunakea management**
  - The new Maunakea management organization MKSOA involving native Hawaiʻians formally started the transition period and co-management with UH.
  - MKSOA is expected by native Hawaiʻians as it provides opportunities to discuss issues.
  - Astronomy community in US also exhibits interest in and expectation for MKSOA.

Panel discussion by MKSOA members in the AAS meeting (Jan. 2023). The MKSOA members received a standing ovation from more than 700 participants for their experience of building trust and understanding each other's stance.

- **Prospects to obtain consensus through the NSF process**
  - NSF started the process on Environment Impact Statement (EIS) and National Historic Preservation Act (NHPA) section 106, and Community Engagement Plan (CEP).
  - NSF started communication with MKSOA, stating that approval of MKSOA is particularly important for TMT construction
  ➡EIS and MOU based on the NHPA will be made with agreement with the MKSOA

NSF's process toward US federal funding

- Following Astro2020 ①, NSF started the process in Hawai'i, including EIS and NHPA Section 106 process, and procedure for Preliminary Design Review (PDR).
- Following the PDR ②, the project moves to the Final Design Phase and NSF starts preparation of budget request to congress ③. NSF approves the EIS and MOU of the NHPA process ④. Following the Final Design Review (FDR), NSF makes Record of Decision ⑥ and approves execution of the budget.

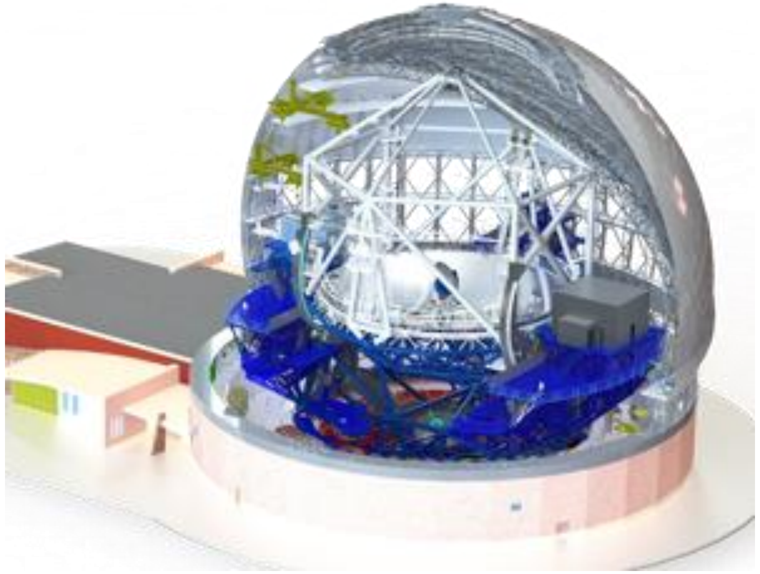


Construction schedule

TIO and partners are cooperating the state of Hawai‘i and others for resuming the onsite construction in FY2025. The completion is expected in FY2034.

- Construction milestones:

2025	Resuming onsite construction
2029	Starting telescope assembly in Hawai‘i
2033	Test observations with 40 segments Completion of installing all segments.
2035	Starting science operation (open use)



- Operation:

  Japan’s observing time is provided with for open-use. The telescope is expected to be operated 50 years, updating science instruments.

Summary: TMT Science and project status/prospects

- TMT is an extremely large telescope necessary for optical/infrared astronomy and related sciences in 2030s (and more future).

- Studies of science cases are getting active including the results with JWST and other recent facilities. Synergy with Subaru 2.0 is key to developing unique science.

- Development of technology for second generation instruments and of the operation plan are also ongoing.

- The prospect of the project is getting clear by the steady progress in Hawai‘i and NSF process for US federal funding.