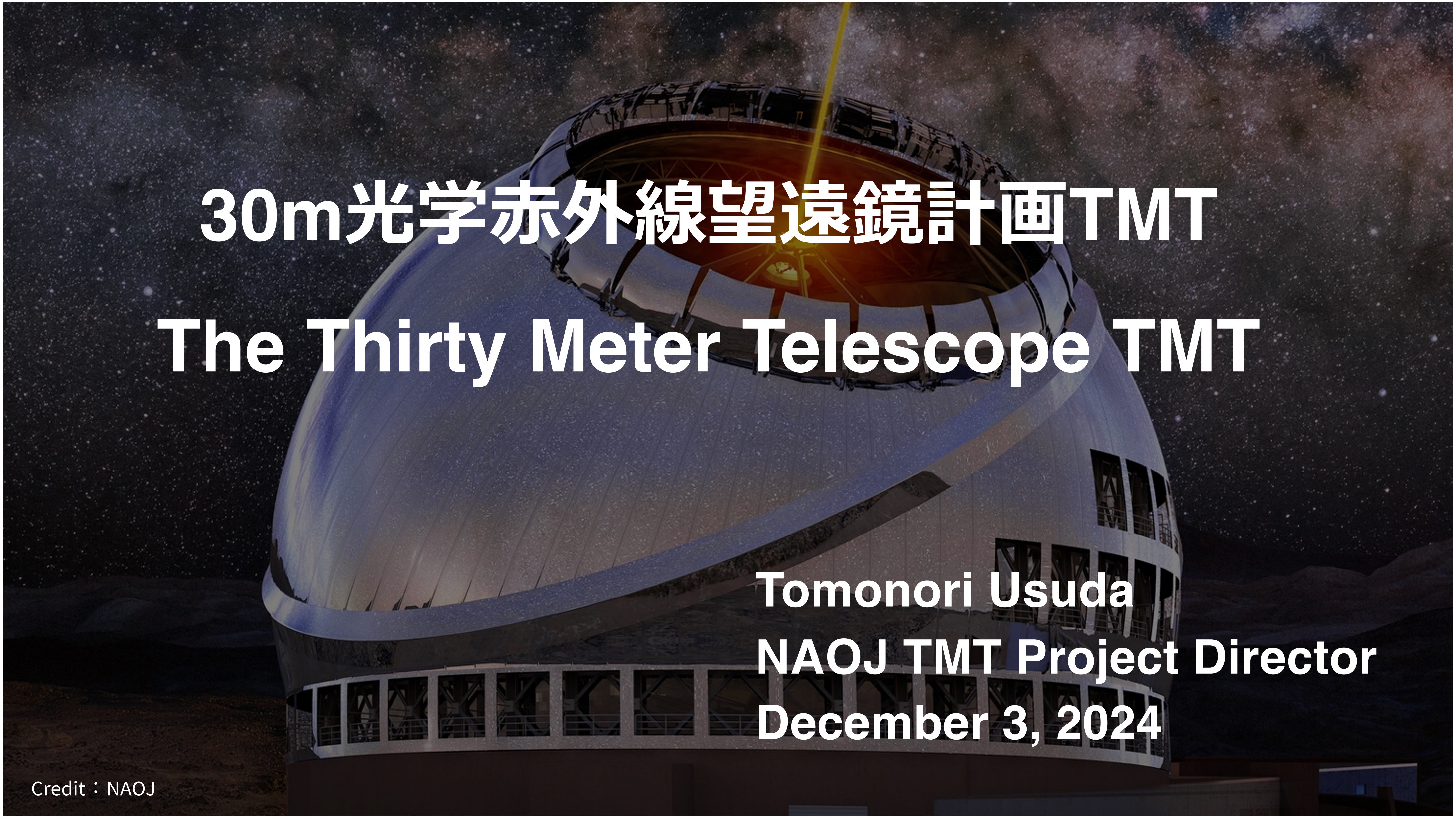

30m光学赤外線望遠鏡計画TMT
The Thirty Meter Telescope TMT
Tomonori Usuda
NAOJ TMT Project Director
December 3, 2024
Credit：NAOJ

Outline

This talk

1. Evaluations of the TMT project in Japan and partners p3-10
2. Science goals and performance p11-12
3. Advantage over JWST, E-ELT/GMT, discovery space p13-18
4. Science objectives and synergies p19-23
5. International collaboration, construction and operation p24-27
6. Current status of Hawai‘i and NSF p28-29
7. Budget plan, project organization p30-34
8. Why NAOJ? Collaboration and spillover effects p34-36

NAOJ Science Roadmap

1. Science Goals
2. Scientific Objectives
3. Science Investigations (until 2033 and beyond 2034)
4. Instruments and data to be returned
5. Originality and international competitiveness
6. Current status
7. Cost assessment, budget line and status
8. Project organization
9. Why NAOJ?
10. Collaboration and spillover effects outside astronomy

Roadmap 2014

Ministry of Education, Culture, Sports, Science and Technology (MEXT)

	Project	Project's overview	Executing institute	Japan's contribution	Schedule	Current Status (Status of securing financial resources)
分野	計画名称	計画概要	中心機関と連携機関	所要経費（億円）	計画期間	進捗状況（主な財源確保の状況）
物理科学・工学	TMT 30m光赤外線望遠鏡（TMT）計画	直径30mの光赤外望遠鏡をハワイに建設し、ダークマター・ダークエネルギーの物理、初期宇宙の銀河形成史、太陽系外惑星特に生命が存在し得る地球型惑星の探査、ブラックホールの物理の解明など、広範な宇宙解明の最前線を開く。	【中心機関】 自然科学研究機構国立天文台 【連携機関】 東京大学、京都大学、東北大学、広島大学、名古屋大学、北海道大学、大阪大学、東京工業大学、愛媛大学、茨城大学、埼玉大学　等	建設費：1500 運用経費：50 /年 （日本は各1/4程度を分担）	H25−H33 ：建設期間 H30−H33 ：部分運用 H34− ：本格運用	・大規模学術フロンティア促進事業により、4,080百万円（平成25年度1,244百万円、平成26年度2,836百万円）及び平成24年度補正予算300百万円が措置され、取組を実施中。 ・日本の役割分担である望遠鏡本体の概念設計/基本設計を平成25年度内に完了し、専門家による国際技術評価に合格。平成26年度は詳細設計を行う。また574枚製作予定の主鏡鏡材のうち60枚を平成25年度に製作完了し、うち12枚の非球面研削加工を完了した。第一期観測装置3台のうち2台の撮像系の製作を分担すべく、基本検討と開発を進めている。 ・カリフォルニア大学、カリフォルニア工科大学、中国、インド、カナダとの合意書策定を完了し、日本，中国、両カリフォルニア大学の署名を得て、5月にTMT国際天文台を米国内に法人登記.設立した。インド、カナダは遅れて署名の見込みだが、建設予定地の地盤調査と建設許可取得は済んでおり、ハワイ大学との転貸借協定を調印後、建設開始を宣言し、平成26年10月に山頂で起工式を行う予定である。

https://www.mext.go.jp/b_menu/shingi/gijyutu/gijyutu4/toushin/1351171.htm

TMT End-term Evaluation Report, Aug. 21, 2023

Working Group on Large Scientific Research Projects, Council for Science and Technology
Ministry of Education, Culture, Sports, Science and Technology (MEXT) (1/2)

► In the annual plan previously submitted, the project was scheduled for start of 9-year-long construction in FY2013 with completion in FY2021. However, **due to unforeseen circumstances for the executing institution, on-site construction have been stalled since April 2015**. Please note that, **based on the understanding that heteronomous factors have delayed the project**, the WG reviewed the executing institute's role and achievement in accordance with criteria defined related to the evaluation of management.

► **Despite delays in the entire project due to a series of unexpected events, NAOJ has steadfastly assumed the responsibilities for its in-kind work to the extent possible**.

► The WG acknowledges that **NAOJ has significantly contributed to the overall project**. NAOJ introduced such measures for improving TIO's operational structure as a shift of the headquarters to Hawai‘i and a reshuffle of its Hawai‘i engagement team. Furthermore, starting with relocation of NAOJ TMT Project Manager and other staff members to Hawai‘i, NAOJ's broad range of activities have helped to gain the local communities' understanding of the project.

TMT End-term Evaluation Report, Aug. 21, 2023

Working Group on Large Scientific Research Projects, Council for Science and Technology
Ministry of Education, Culture, Sports, Science and Technology (MEXT) (2/2)

►The WG recognizes **NAOJ's key role in advancing the project has strengthened the nation's trust and presence.** NAOJ has been fully participating in the project, taking the initiative in strengthening TIO's governance and reorganizing the project management structure, as well as assigning some staff members to Hawai‘i to actively carry out the community engagement activities to deepen trust and to continuously help with the communities' needs.

►Notwithstanding the suspension of on-site construction work, **the TMT project remains academically significant. It is expected to deliver scientific results which will be critical not just for astronomy but also for other areas of physics and Earth and planetary science.**

►**The issues surrounding the construction site in Hawai‘i are not project-specific matters, but has a major impact on consideration of the role of science in the society. The WG hopes lessons learned from this project will be widely shared with other large-scale projects under international collaboration.**

ロードマップ2023　掲載計画概要

※カッコ内は実施主体（中核機関）
※＊はロードマップ2020からの継続掲載（５計画）

BSL-4施設を中核とした感染症研究拠点の形成＊　（長崎大学）

BSL-4施設を中核とした世界トップレベルの感染症研究拠点を形成し、感染症の病態解明、診断・治療法の確立、有効な予防法の構築による国民の安全・安心の確保、WHO 等による国際的な感染症管理体制への貢献を通じ、世界の保健向上に資する。

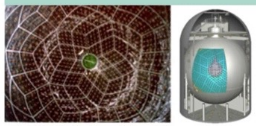
スピントロニクス・量子情報学術研究基盤と連携ネットワーク＊　（東京大学）

将来の量子科学・量子情報技術の中核となる分野である「スピントロニクス」について、卓越した研究機関のネットワークによる国際共同研究拠点を形成・強化し、革新的省エネルギーデバイス、古典・量子情報融合デバイスなどの新しい情報処理技術の実現に向けて不可欠の科学技術基盤を提供する。

多様な知が活躍できるパワーレーザー国際共創プラットフォーム：J-EPoCH計画
（大阪大学レーザー科学研究所）

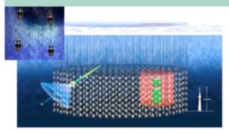
我が国の強みを活かした世界一の高繰り返し大型パワーレーザーによる国際共創プラットフォームをオールジャパン体制で構築し、量子真空の探査（場）、核融合エネルギーの探求（プラズマ）、超高圧新奇量子物質の創生（固体）を通して、エネルギー密度の高い極限的な量子科学の開拓で世界を先導する。

極低放射能環境でのニュートリノ研究　（東北大学ニュートリノ科学研究センター）



神岡地下に建設したカムランド実験装置の高性能化により、素粒子原子核研究の最重要課題に挙げられる二重ベータ崩壊研究や、地球内部の組成や活動様式解明に挑む地球ニュートリノ観測、特徴的な低エネルギーニュートリノ天文学等を展開する。

IceCube-Gen2 国際ニュートリノ天文台による高エネルギーニュートリノ天文学・物理学研究　（千葉大学ハドロン宇宙国際研究センター）



南極点直下に設置したIceCube検出器を世界15か国の連携により高度化し、世界最大のニュートリノ観測装置により高エネルギー宇宙ニュートリノの高感度観測を行う。電波からガンマ線まで分布する電磁波及び重力波との統合観測によるマルチメッセンジャー天文学を展開し、宇宙線の統合的理解、遠方宇宙や天体内部の探求に貢献する。

CTA国際宇宙ガンマ線天文台　（東京大学宇宙線研究所）

次世代の国際宇宙ガンマ線天文台CTAにより、超高エネルギーガンマ線領域の世界唯一の天文大型施設として、極限宇宙の姿を捉え、ブラックホール、宇宙線の起源、暗黒物質などの解明を目指す。さらに、従来の電磁波・宇宙線観測に加え、重力波やニュートリノ観測と連携し、マルチメッセンジャー天文学の重要な一つの柱となる。

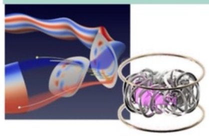
強磁場コラボラトリー：統合された次世代全日本強磁場施設の形成＊
（東京大学物性研究所）

全日本的な強磁場施設の連携の下で世界最高性能の設備を組み合わせた独創的な戦略により、我が国が強みを持つ物質・材料科学-とりわけ、半導体、磁石、超伝導材料などの研究で世界を先導する。情報、エネルギー、医療等の課題解決に貢献するとともに、1200テスラ超強磁場下の学際的研究により宇宙、生命、化学などにおける未知現象を発見する。

30m光学赤外線望遠鏡計画TMT　（自然科学研究機構国立天文台）

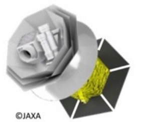
ハワイ島マウナケア山頂域に口径30m光学赤外線望遠鏡TMTを建設し、すばる望遠鏡の広域探査と連携して地球型系外惑星や宇宙の初代星等の観測を行う。膨張宇宙における星、銀河、元素生成等の全貌を理解し、惑星の形成や生命誕生という人類究極の課題に挑む。

超高温プラズマの「ミクロ集団現象」と核融合科学
（自然科学研究機構核融合科学研究所）



超高温プラズマを高精度で制御・操作し、世界最高の分解能で計測する実験システムを構築することで、核融合炉のみならず宇宙・天体にも共通するプラズマに独特な揺らぎの発生原因とその影響を解明する。計測と理論・シミュレーションを連携し、核融合イノベーションを駆動する科学的指導原理の構築を目指す。

LiteBIRD－熱いビッグバン以前の宇宙を探索する宇宙マイクロ波背景放射偏光観測衛星＊　（宇宙航空研究開発機構）

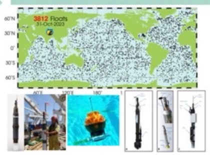


熱いビッグバン以前の宇宙に関する最有力仮説である「インフレーション宇宙理論」を検証するため、LiteBIRD衛星による宇宙マイクロ波背景放射の全天偏光観測から原始重力波を探索する。代表的インフレーション宇宙理論を検証することで、宇宙創生の謎に挑む。

アト秒レーザー科学研究施設＊　（東京大学）

我が国で長年にわたって培われてきた先端レーザー技術と自由電子レーザー技術を集約し、アト秒レーザー科学研究施設を建設する。物質中の電子の動きを実時間で捉えることにより、物理学、化学、生物学、工学、薬学、医学等の幅広い分野でイノベーション創出を目指す。

統合全球海洋観測システムOneArgoの構築と海洋融合研究の推進　（東北大学）



全球海洋の深度2000mまでの水温・塩分を常時計測する現行のArgoフロート観測網を、海底まで、かつ、生物地球化学変数の計測にまで拡張する統合全球海洋観測システムOneArgoを構築する。海洋全層における気候変動シグナルの検出や、海洋酸性化・貧酸素化の実態把握と生態系の応答の解明等により、海洋融合研究を推進する。

Roadmap 2023 of Ministry of Education, Culture, Sports, Science and Technology (MEXT)

TMT Project

MEXT's WG conducted hearings for 18 projects out of 47 projects after its document screening. As a result,12 projects are listed on MEXT's Roadmap 2023.

https://www.mext.go.jp/content/20231222-mxt_gakkikan-000033259_1.pdf

Roadmap 2023

Ministry of Education, Culture, Sports, Science and Technology(MEXT)

National Astronomical Observatory of Japan

研究分野	計画名称	計画概要	実施主体		所要経費(百万円)	計画期間	主な優れている点	主な課題・留意点等	備考
	Project	Project's overview	Executing institute	Partners	Japan's contribution	Schedule	Excellent points	Issues & points	
			中核機関	連携機関					
物理学	TMT 30m光学赤外線望遠鏡計画 TMT	ビッグバンで始まり膨張を続ける宇宙における星、銀河、大規模構造の形成や元素生成の全貌を理解し、惑星の形成と生命誕生を探ることは人類の究極の課題である。これに挑む基幹観測装置として口径 30m 光学赤外線望遠鏡 TMT を地上観測の最適地であるハワイ島マウナケアに建設して大学共同利用に供し、すばる望遠鏡の広域探査と連携して地球型系外惑星や宇宙の初代星、宇宙膨張史等の理解を一新する研究を推進する。国際協力による建設において日本は枢要部分である望遠鏡本体と制御系、主鏡分割鏡、観測装置の主要部分を担当する。	自然科学研究機構国立天文台	TMT 国際天文台(TIO)、カリフォルニア工科大学、カリフォルニア大学、カナダ国立研究機関、インド科学技術庁、米国天文学大学連合(AURA)、(米国国立科学財団(NSF))	総額(日本負担分):42,684 施設・設備費:37,304 共同利用準備(建設期):1,340 人件費:1,100 旅費:240 TIO 分担金(建設期):2,700	【建設期間】 1年目:望遠鏡本体構造のTIO審査対応、主鏡(分割鏡)の試作・製造準備、観測装置の詳細設計、科学運用の検討・共同利用運用準備 2-10 年目:望遠鏡本体構造の製造・輸送・現地据付調整、主鏡(分割鏡)の製造、観測装置の製造・組立・総合試験、科学運用の検討・共同利用運用準備 【運用期間】 10 年目:初期科学運用	次世代の光学赤外線望遠鏡として世界最高性能を持つ基幹観測装置であり、地球型系外惑星の直接撮像と生命関連物質の探査、初代星の検出など、天文学にとって大きな学術的成果が期待できる。また、一部の地元住民の反対運動による計画の遅れに対し、実施主体が長期にわたって真摯に解決に向けた取組を進めてきたことは評価できる。	ハワイ現地の状況は改善がみられる点がある一方で、米国NSFの参画や現地住民との合意等について現時点で明確でない部分もあり、更なる計画遅延や変更のリスクを有している。計画の推進や国の支援にあたっては、それらの状況を注視し、慎重かつ適切な対応が求められる。	

https://www.mext.go.jp/content/20231222-mxt_gakkikan-000033259_1.pdf

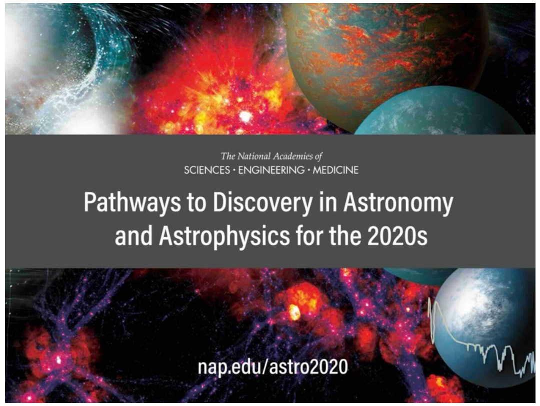
US Decadal Survey - Astro 2020 -

TMT is selected as top priory in Astro2020

US-Extremely Large Telescope(ELT) Program, which includes TMT, was selected as **the top priority** among all ground-based telescope projects.

The survey highly evaluated TMT's unparalleled capabilities across a wide range of fields in astronomy and astrophysics, along with its level of technical maturity.

All projects previously ranked as the top priority in past Decadal Surveys—such as ALMA, James Webb Space (JWST), and the Vera C. Rubin Observatory—have proceeded to construction and now in successful operation.



US-ELT Program

Recommendation: The NSF should achieve a federal investment equal to at least 50 percent time for the U.S. community in at least one and ideally both of the two extremely large telescope projects – the Giant Magellan Telescope and the Thirty Meter Telescope, with a target level of at least 25% of the time on each telescope. If both projects are viable, then that time should be distributed across the two proposed telescopes. If only one project proves to be viable, the NSF should aim to achieve a larger fraction of the time, in proportion to its share of the costs and up to a maximum of 50 percent

Participation in both projects is the optimal outcome

- full-sky access
- maximizes public nights available (~180/yr total)
- exploit complementary instrumentation

If circumstances preclude participation of one observatory (financial, site availability) goal should be to obtain as large a share on the other as available

This is the survey's top priority MREFC recommendation due to the timeliness and transformative potential

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

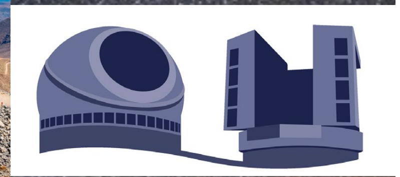
How We Got Here – NSF Large Facilities Over the Decades

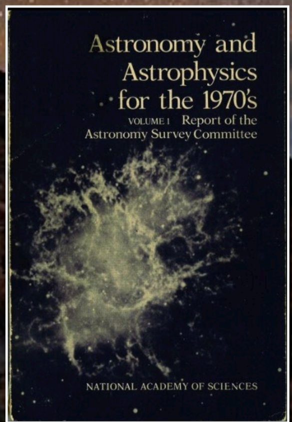
Ms. Jean Toal Eisen (AURA) for Committee on Astronomy and Astrophysics Fall Meeting, Nov. 8, 2024

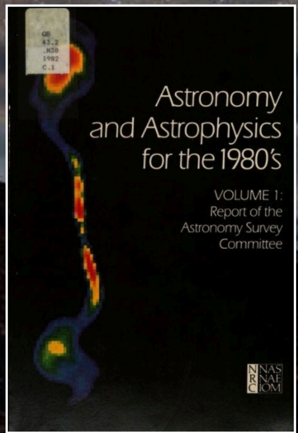
Very Large Array	VLBA	Gemini	ALMA	Rubin	US ELT

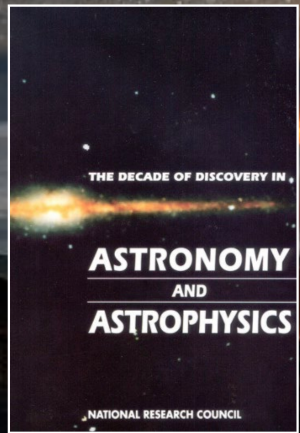


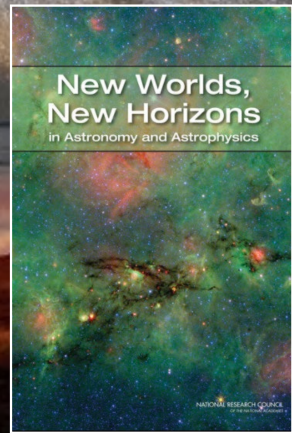


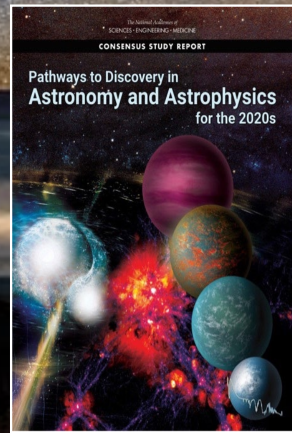









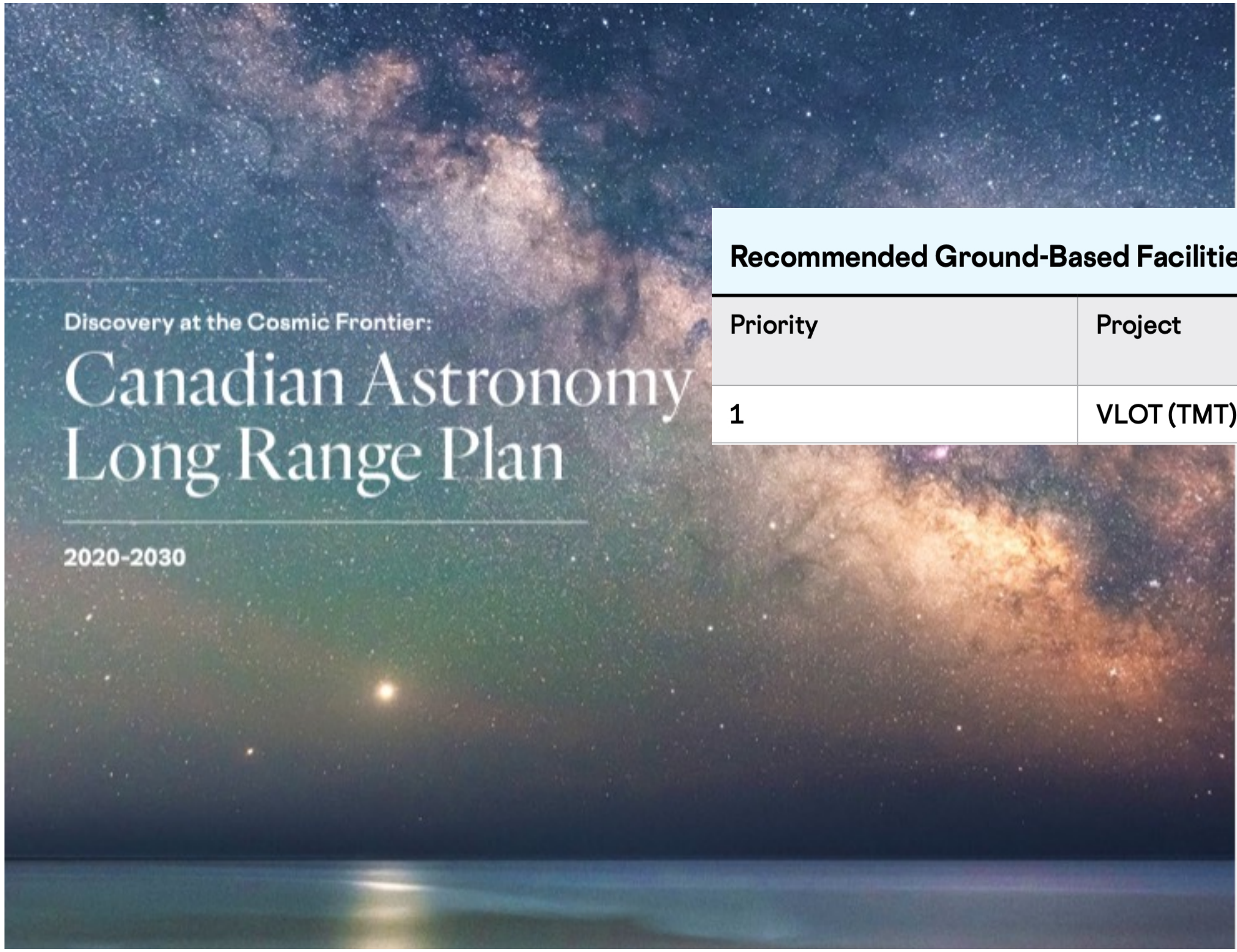




Decadal	1972	1982	1991	2001	2011	2021
Operational	*1980*	*1993*	*1999, 2001*	*2011*	*2025*	*???*

Photo Credits: Background: International Gemini Observatory/NOIRLab/NSF/AURA/J. Chu; VLA: W. Grammer, NRAO/AUI/NSF; VLBA: NRAO/AUI/NSF; Gemini: Gemini/NSF/AURA; ALMA:C. Padilla, NRAO/AUI/NSF; Rubin:RubinObs/NOIRLab/SLAC/NSF/DOE/AURA

Canada Long Range Plan 2020



Supported by Canada
response to **the recommendation by the Canadian Astronomy Long Range Plan** of the Canadian Astronomical Society (2000, 2010, 2020)

Recommended Ground-Based Facilities: Large (>$30M) Investments In Near-Term Projects

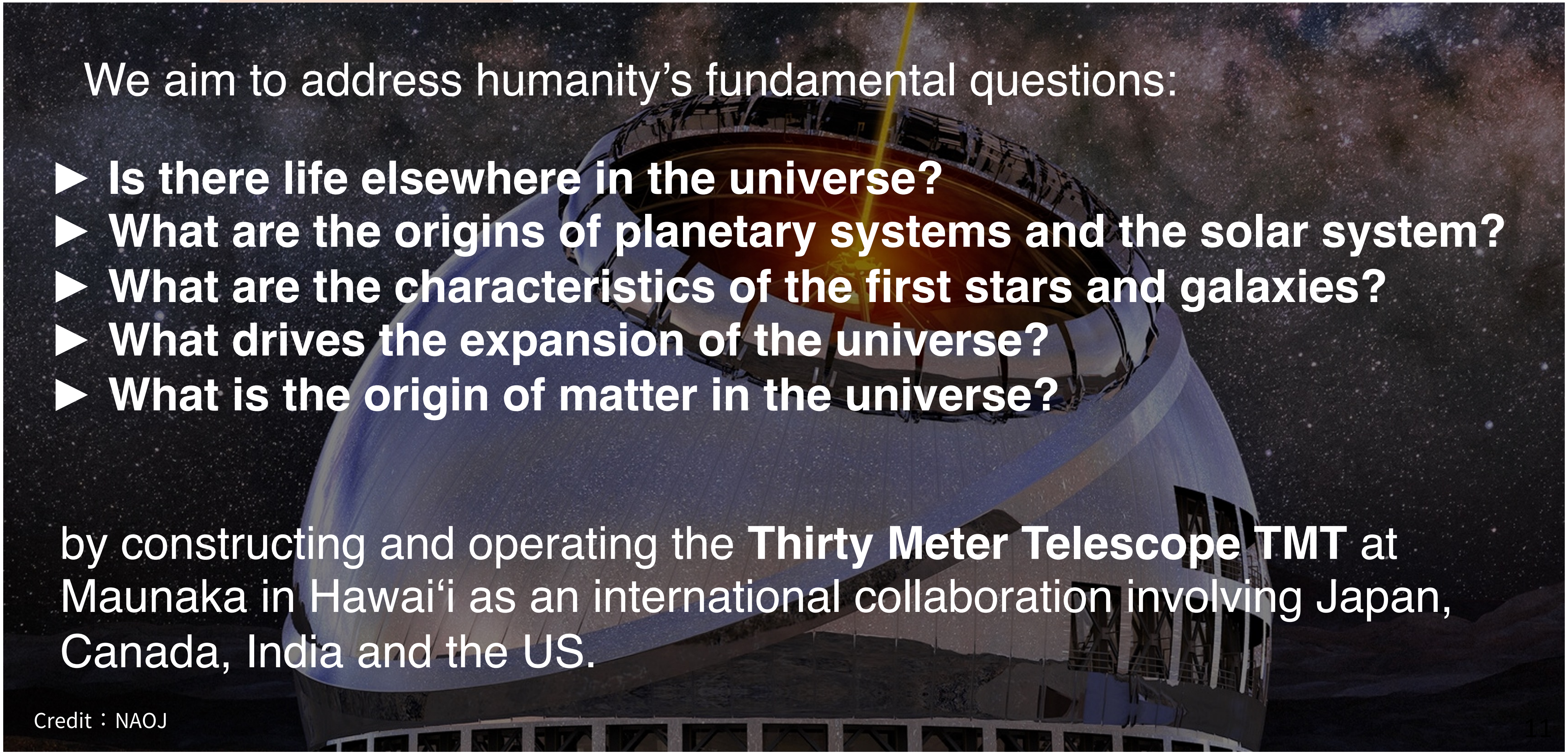
Priority	Project	Anticipated Cost to Canada (New Construction/Operations)	Estimated Operational Date
1	VLOT (TMT)[13]	TBD[14] / US$7M[15] per year	2033 or later

VLOT: Very Large Optical Telescope

https://casca.ca/wp-content/uploads/2021/05/LRP2020_final_EN.pdf

Thirty Meter Telescope

1. Top-level science goals



We aim to address humanity's fundamental questions:

- ▶ **Is there life elsewhere in the universe?**
- ▶ **What are the origins of planetary systems and the solar system?**
- ▶ **What are the characteristics of the first stars and galaxies?**
- ▶ **What drives the expansion of the universe?**
- ▶ **What is the origin of matter in the universe?**

by constructing and operating the **Thirty Meter Telescope TMT** at Maunaka in Hawai'i as an international collaboration involving Japan, Canada, India and the US.

Credit：NAOJ

The 30-meter optical-infrared telescope TMT

Location: Summit of Maunakea, Hawai‘i (ideal for ground-based observation)
Members: Japan/NINS, Caltech, University of California, Canada/NRC, India/DST, (NSF/AURA)
Japan’s Responsibilities: Telescope structure, primary mirror, science instruments

TMT offers exceptional clarity

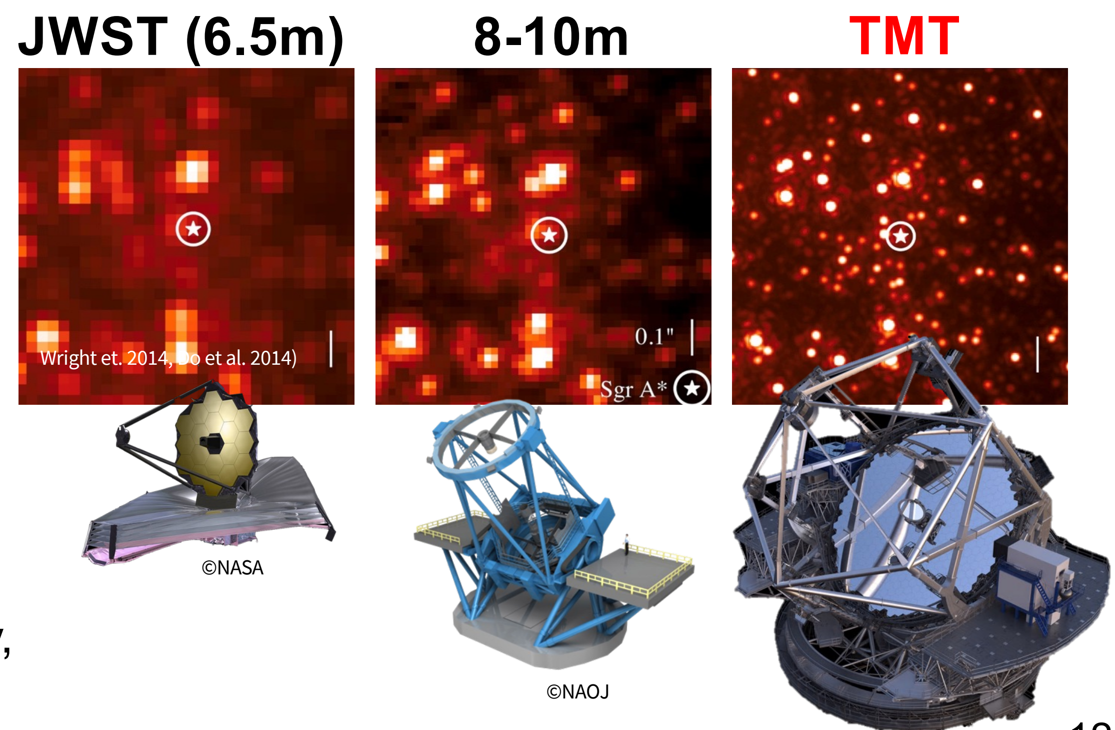
- ► 5x sharper than JWST
- ► 3x sharper than 8-10m class telescopes

TMT is extremely sensitive

- ►20x more sensitive than JWST
- ►100x more sensitive than 8-10m telescopes

e.g.,

- ➢ TMT completes a 10-hours Subaru Telescope observation in just 3 minutes.
- ➢ TMT can observe ten explosive events annually, compared to JWST's once per decade.



Courtesy TMT International Observatory

TMT's Uniqueness over JWST

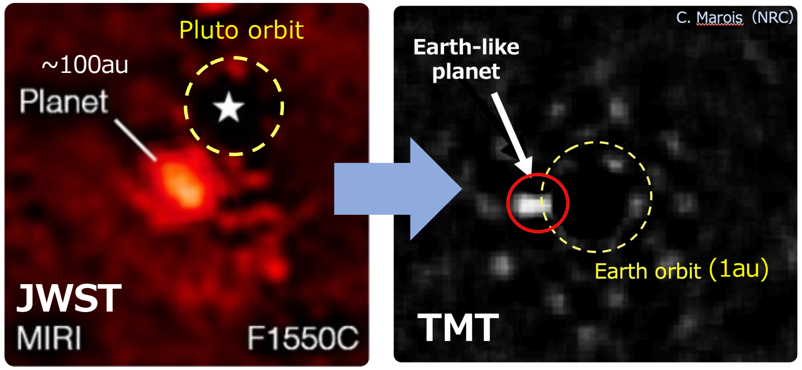
THIRTY METER TELESCOPE

5. Originality and International Competitiveness

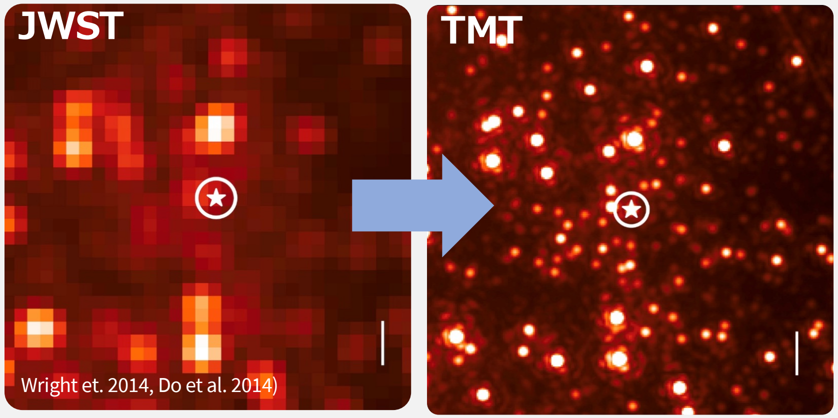
National Astronomical Observatory of Japan

MIRI/F1550C image: NASA/ESA/CSA, A Carter (UCSC), the ERS 1386 team, and A. Pagan (STScI).

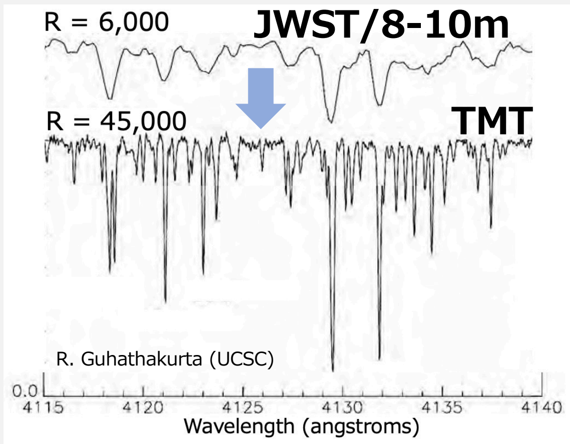
- ▶ **JWST** will continue to play an important role in capturing gaseous planets relatively far from the central star.
- ▶ **TMT**, with its high spatial & spectral resolution capabilities, will directly image and study the atmospheric composition of rocky earth-orbit planets close to the central star.



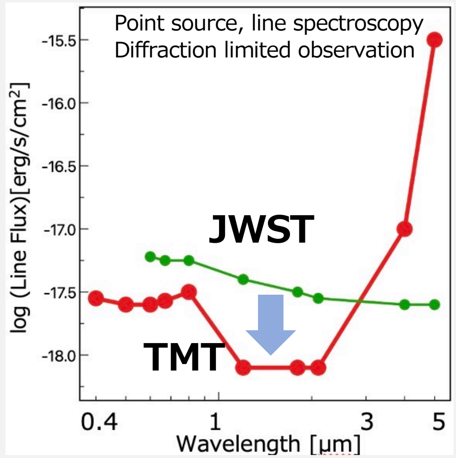
▶ Higher Angular Resolution



▶ Higher Spectral Resolution



▶ Higher Sensitivity in NIR



TMT Provides High Spectral Resolution

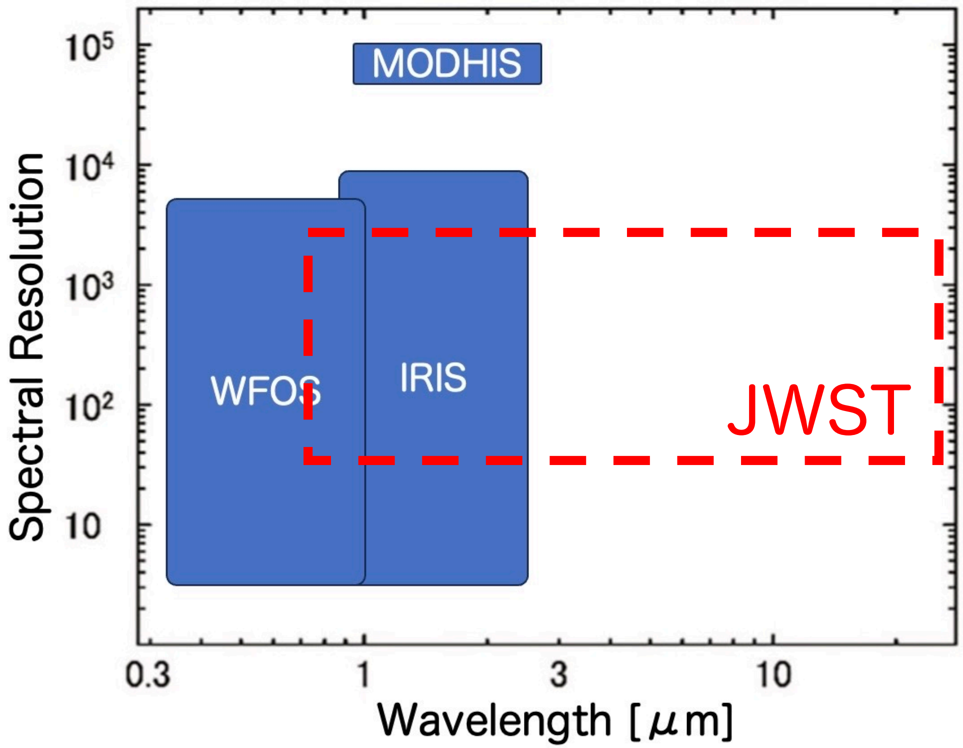
TMT THIRTY METER TELESCOPE

4. Instruments and Data to be Returned | 5. Originality and International Competitiveness

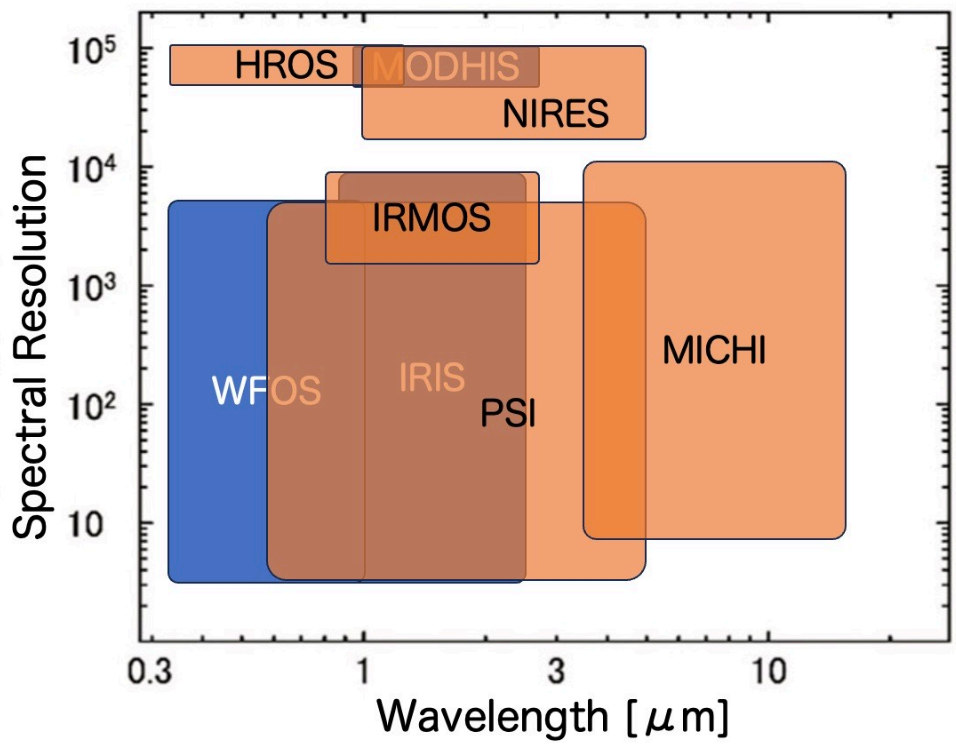
国立天文台 NAOJ National Astronomical Observatory of Japan

TMT instruments are equipped with a wide range of spectral resolution, as high as R~10^5, allowing observations of a wide range of astronomical targets.

First light instruments



Second generation instruments



TMT's Uniqueness over E-ELT/GMT

- **The only ELT in the northern hemisphere**
  - Critical for follow-up observations of transients discovered by Subaru wide-field imaging
  - TMT with E-ELT/GMT can follow a target for many hours because they are at different longitudes
  - Local group, Virgo cluster, and the Andromeda galaxy are in the North
- **Widest FOV** (9x than E-ELT) and **highest efficiency** (~1.2x than E-ELT), wide-field MCAO system, and wide-field visible MOS.
- **Quick instrument switching time (<10 min),** which is **a significant advantage** for rapidly decaying **ToO sources such as neutron star mergers, initial phases of supernovae explosion**
- AO-assisted at 1st light, providing diffraction limited resolution from early science

	TMT	GMT	E-ELT
M1	30m f/1	24.5m	39m f/0.87
M2	3.1m	1.1m x 7	4.1m
# of mirrors	3	2-3	5
Efficiency	0.92	0.92-0.95	0.79
FOV	20' (15' unvignetted)	20'	10' (5' unvignetted)

GMT：Giant Magellan Telescope, E-ELT：European Extremely Large Telescope

TMT has the best site conditions

5. Originality and International Competitiveness

► **High altitude of Maunakea**

→ advantage in UV and IR observations

► **Large isoplanatic angle and coherence time**

→ preferable conditions for AO observations

Red: best among the three sites

Site characteristics	Maunakea (TMT)	Armazones (E-ELT)	Las Campanas (GMT)
Altitude (m)	4050	3064	2415
Seeing at 60m above ground (arcsec)	0.50	0.50	0.50
Isoplanatic angle (arcsec)	2.55	2.05	2.05
Atmospheric coherence time (ms)	7.3	5.0	5.0
Precipitable Water Vapor (PWV) (% time < 2mm)	54	50	23
Mean nighttime temp (deg)	2.3	7.5	13
Fraction of Clear night	0.72	0.86	0.75

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

Top-level Science Objectives

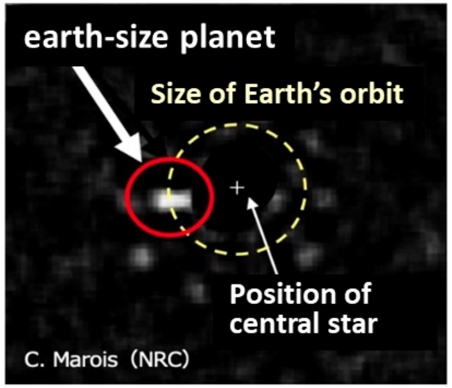
1. Search for signature of life in exoplanets

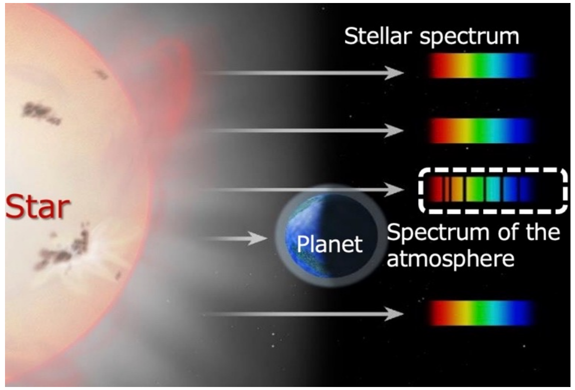
Direct imaging of habitable zone rocky planets

- ▶ Targets: Earth sized planets around low-mass stars (M dwarfs). Expect 1-20 sources.

Investigate molecules related to life (e.g., O_2, O_3, CH_4) in earth-like exoplanets through spectroscopy.

- ▶ Requires > 20 transits (need a few yrs for a detection)
- ▶ High R is required to separate telluric absorption

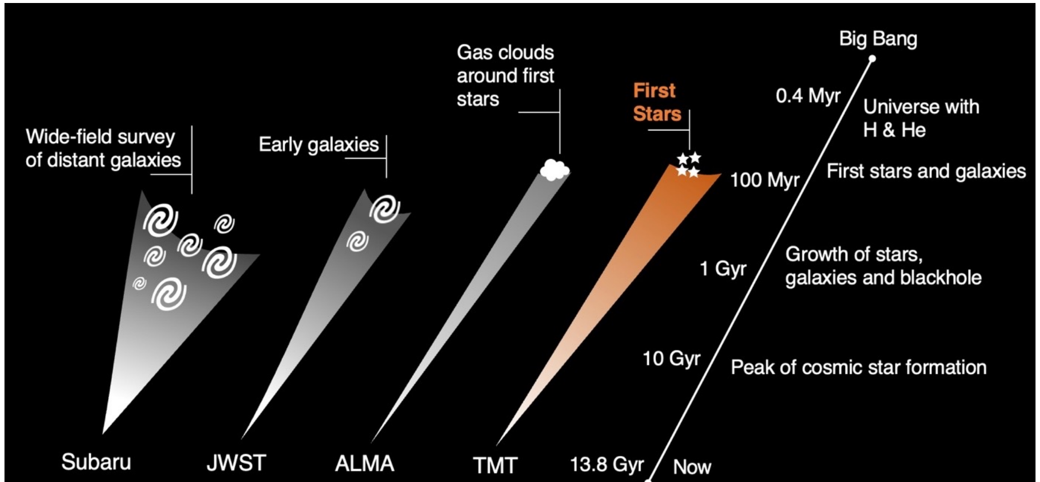




2. Detection of light from the first stars

Detect Helium II (1640 A) from first stars and constrain the formation, their nature, and role in galaxy formation.

- ▶ JWST/NIRSpec has tentatively detected HeII from the halo of an exceptionally luminous galaxy at z=10.6 (Maiolino et al. 2024).
- ▶ Assuming top-heavy IMF, TMT will detect HeII (S/N~ 5: ~10 hours) in compact primordial galaxies up to z~14.



Top-level Science Objectives

TMT THIRTY METER TELESCOPE

2. Science Objectives

National Astronomical Observatory of Japan

3. Constraining the nature of dark energy

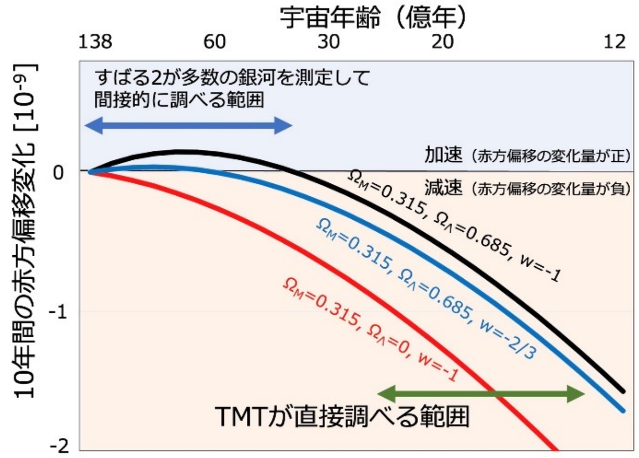
Directly measure the expansion of universe by the redshift drift of intergalactic matter and constrain the nature of dark energy.

- ► Expected redshift drift at z~2 is ~3 cm s[-1] in 10 years.

$$\Delta v = 3.5\ cm\ s^{-1} \left(\frac{S/N}{3350}\right)^{-1} \left(\frac{N_{QSO}}{30}\right)^{-1/2} \left(\frac{1+z_{QSO}}{3}\right)^{-1.7}$$

Liske et al. (2008)

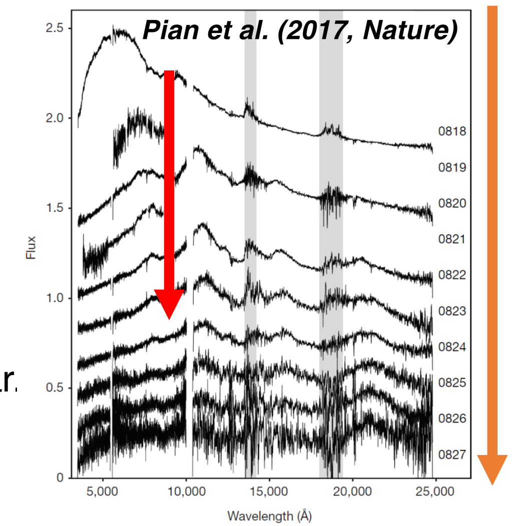
- ► Stack many QSO absorption lines to gain S/N.
- ► Requires a stable high-dispersion spectrograph with R~100,000 (i.e., HROS)



4. Multi-messenger astronomy

Obtain optical-infrared spectroscopy toward gravitational wave or neutrino events, and explore physics in extreme environments and origins of heavy elements.

- ► In the TMT era, GW telescopes will be more sensitive and will reach up to D ~ 200 Mpc. Number of binary neutron star merger events will increase to ~10/year.
- ► Subaru/HSC, LSST, Roman will follow-up and search for optical counterpart.
- ► TMT (WFOS/IRIS) will study the spectral evolution.



Spectrum decays in the order of 10 days. Prompt optical/NIR follow-up by TMT is essential.

TMT + Subaru 2-3: A Powerful Partnership at Maunakea

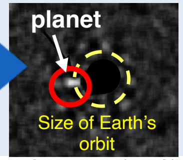
Subaru 2-3 — Ultra wide-field surveys | TMT — High sensitivity and resolution

Exoplanet

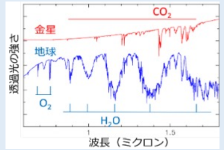
Subaru 2-3: Search for Earth-like exoplanets by indirect method

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

TMT: Direct imaging/spectroscopy of Earth-like exoplanets



C. Marois (NRC)



Virtual Planet Laboratory（VPL）simulation

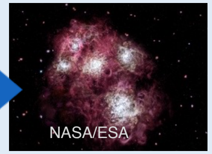
Search for molecules related to life by transmission spectroscopy

Galaxy formation

Subaru 2-3: Search 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.

TMT: 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

Subaru 2-3: 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.

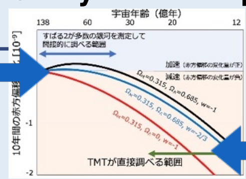
TMT: Spectroscopy of counterparts of GW/neutrino sources

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

Dark matter Dark energy

Subaru 2-3: Indirect measurement of the Universe's expansion by wide-field surveys

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



TMT: Direct measurement of Universe's expansion

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

Strong Synergies with ALMA 2-3

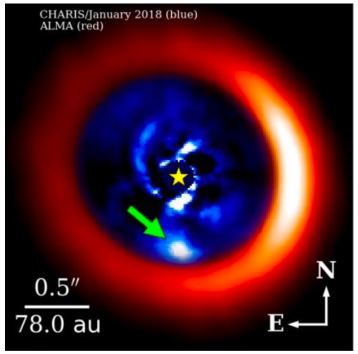
2. Science Objectives, 3. Science Investigations

Both TMT (in NIR) and ALMA (in submm) achieve 0.01” resolution

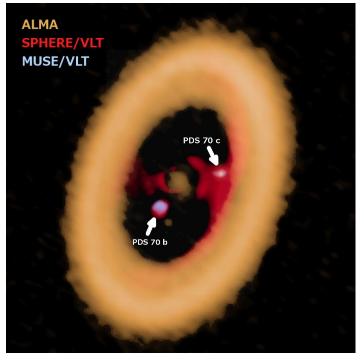
Exo-planets and planet formation

ALMA and TMT (Forming planets): observe multiple emission lines and dust continuum in proto-planetary and circum-planetary disks at high angular resolution.

TMT (Mature Earth-like planets) : directly image Earth-like planets and study their atmospheres through sensitive high-resolution spectroscopy.



Currie et al. (2022)

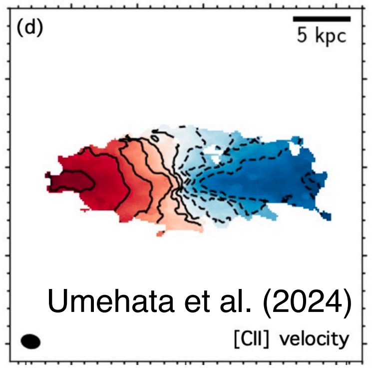


Credit: ALMA (ESO/NAOJ/NRAO) A. Isella

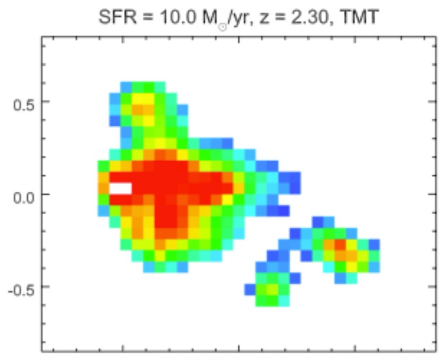
Distant Universe

ALMA (relatively early star-forming galaxies) : resolved structure and detection of gas emission lines and dust continuum from forming young galaxies

TMT (first galaxies and source of reionization) : resolved structure of rest-frame UV to optical lines in first/young galaxies unobscured by dust



ALMA [CII] from a z=3.1 massive galaxy



A simulated z=2.3 galaxy, with Hα redshifted into TMT K-band (from DSC2024, Wright et al. 2014)

Synergies with the Habitable World Observatory

2. Science Objectives, 3. Science Investigations

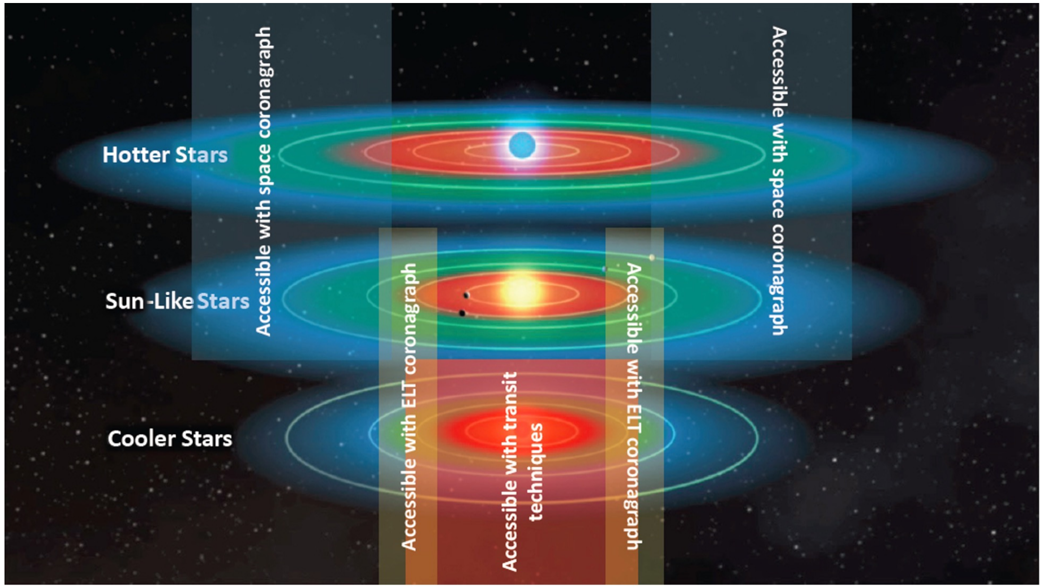
TMT and HWO share a common goal -- "detecting exoplanets"

TMT's role

Image exoplanets in the habitable zones of abundant **low-mass stars (M-type stars)**, which are relatively faint in visible but bright in infrared. Observations with ground –based ELT are necessary steps for HWO.

HWO's role

Image terrestrial planets in the habitable zones of the nearest **Sun-like stars** (around 100 targets) through reflected light and perform spectral characterization of their atmospheres.



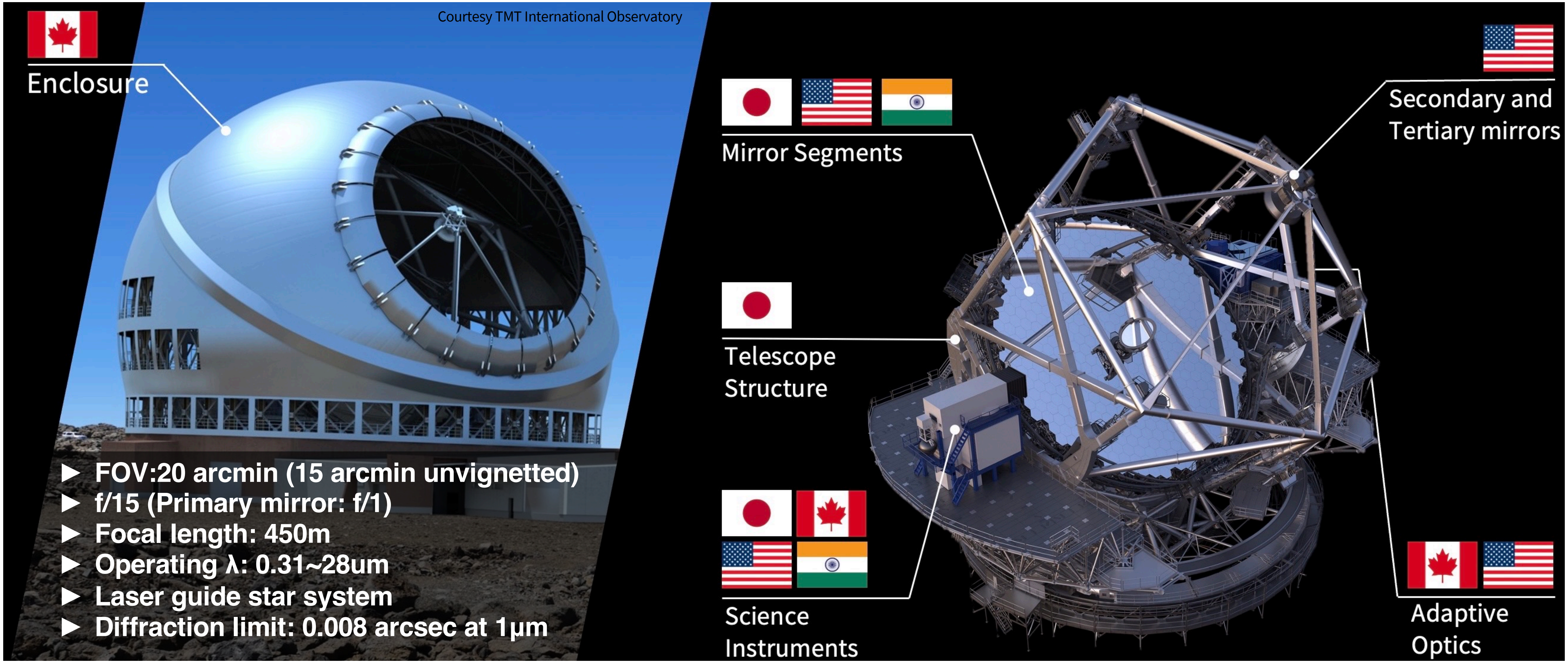
From Pathways to Discovery in Astronomy and Astrophysics for the 2020s

THIRTY METER TELESCOPE

TMT is an international collaboration

National Astronomical Observatory of Japan

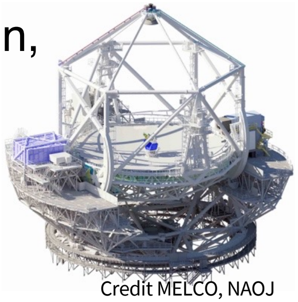
TMT International Observatory (TIO) was established in 2014 for TMT's construction and operation. Member countries are responsible for manufacturing assigned components and/or paying their share.



Japan's in-kind contribution and schedule

1. Telescope structure

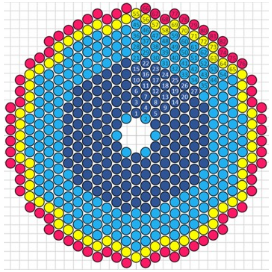
Responsible for design, development and installation.



Credit MELCO, NAOJ

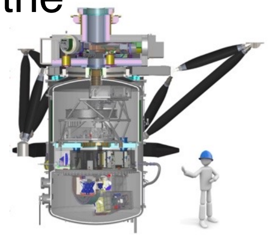
2. Primary mirror

Responsible for all 574 mirror blanks and 175 polishing.



3. Science instruments

Responsible for the IRIS imager.



NAOJ

~FY2026
- Resume onsite construction
- Design and development of science instruments

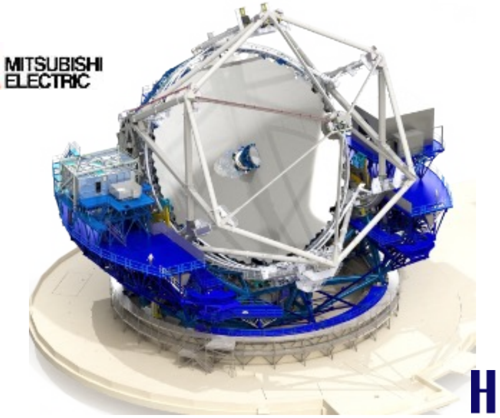
FY2028-2033
第5期中期計画
- Fabrication of mirrors, telescope structure, and instruments
- Telescope assembly in Hawai‘i
- Test observations with 40 segments
- Complete installation of all segments
- Installation of 1st light instruments

FY2034~
- Start science operations (open use)
- Operate TMT for 50 years, updating science instruments.

Japan's In-kind Contributions to TMT

6. Current Status

Telescope Structure (STR)

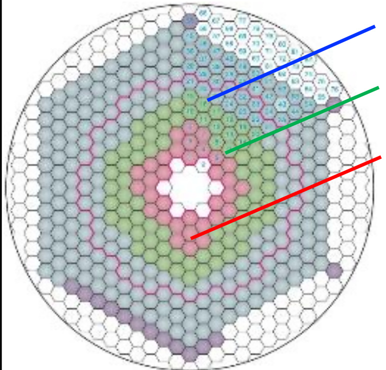


Ready for Fabrication
- Passed FDR on Nov. 2019
- Passed three Production Readiness Reviews (PRR) in Mar. 2020 and Feb 2023
- Reduced manufacturing risk through


Robotic segment mirror handling system


7 dummy M1 on a mirror cell

Primary Mirrors (M1)

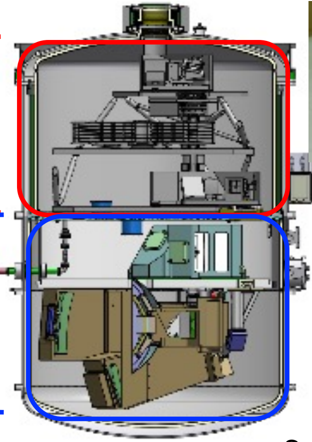


Fabrication started and ready to resume mass production
- 356 Blanks (62%) Delivered
- 33 Aspheric Polishing (19%)
- Fabrication Readiness for Hexing & SSA mounting


Mirror Blanks @Ohara

1st Light Science Instruments

IRIS




Cold Stop Stage


Surface quality (~6nm) Off-axis Aspheric Mirror

Ready for Fabrication
- Passed FDR1 in June 2021
- Reduced risks through extensive analysis, modeling, prototyping

WFOS & MODHIS
- In-kind contributions of Optical, Mechanical, Control system design works and managements
- MODHIS PM is a NAOJ faculty member.

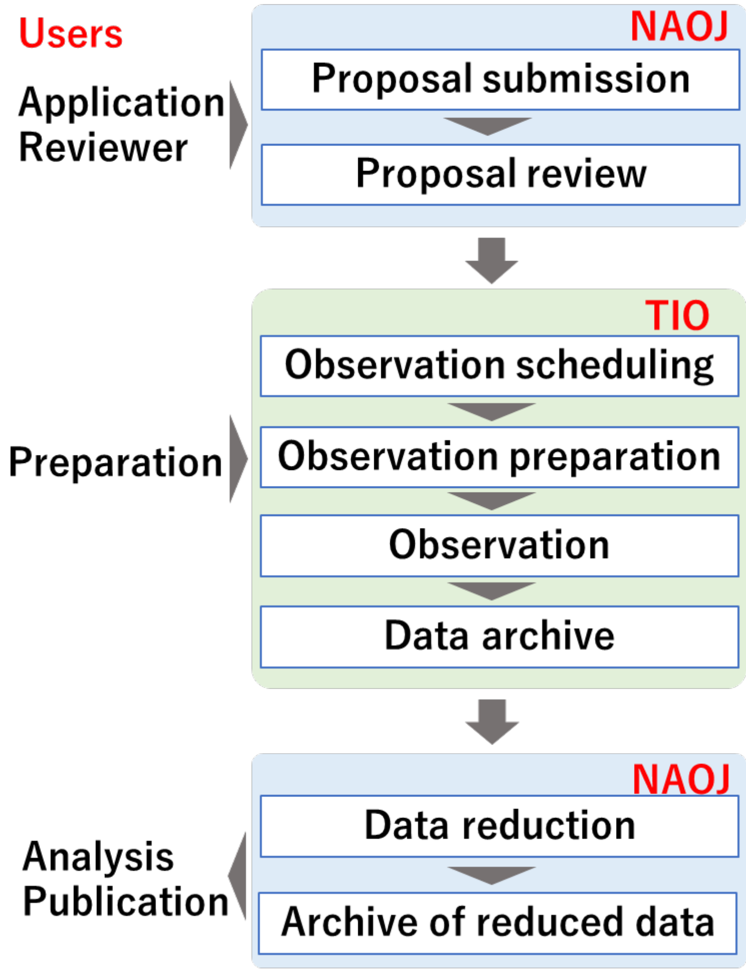
TMT Operation Plan

Once operations begin, the TMT Observing time will become available to all members of the Japanese science community.

► TIO is responsible for the telescope operation, scheduling, observations, and archive of raw data. The archived data will become available to the world after a certain proprietary period.

► TMT partners are responsible for processing proposals and science data reduction and archive. Tools and software developed for the US-ELTP will be available to partners.

► NAOJ will operate and manage the open use of the Japanese time. The idea is to operate TMT and Subaru under a common system for proposal management, data analysis support and archive, facilitating unique science with the two telescopes and increasing the operation efficiency at the NAOJ.



Significant Progress Achieved in Hawai‘i

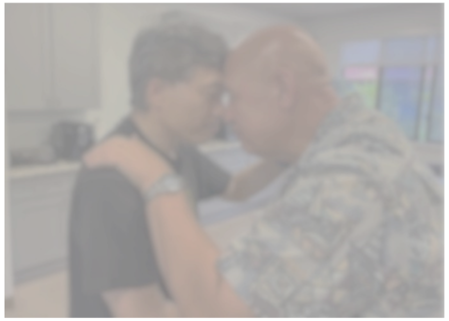
TMT THIRTY METER TELESCOPE

6. Current Status

National Astronomical Observatory of Japan

Building trust for Maunakea Astronomy and TMT

- ► TIO reviewed problems of the activities in Hawai‘i leading up to the protest in 2019. Reorganized the engagement team.
- ► NAOJ Project Director, TIO PM and the TIO team engaged in direct dialogues with the (then) protestors and education activities in the local community.
- ► **Significant improvement in the local atmosphere**



New authority to reflect opinions of the local community including Native Hawaiians on Maunakea management

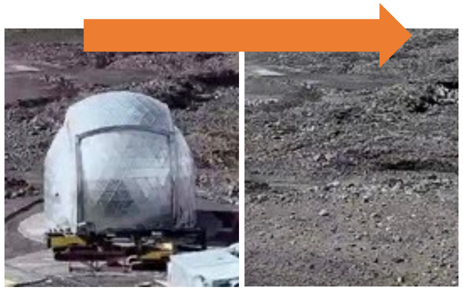
- ► Establishment of the Maunakea management organization MKSOA involving Native Hawaiians
- ► Currently in transition period and co-management with UH. Transition will complete in 2028.
- ► Online meetings are being held every month.
- ► MKSOA is welcomed by the Native Hawaiians as it provides opportunities to discuss issues.
- ► Astronomy community in the US also expressed interest.

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.

Consensus Building in Hawai‘I / NSF Process Underway

Decommission of Aging Maunakea telescopes

- ▶ Long-standing issue: reduce the number of telescopes on Maunakea
- ▶ Two aging telescopes (CSO, Hōkū Ke‘a) have been removed and site has been restored



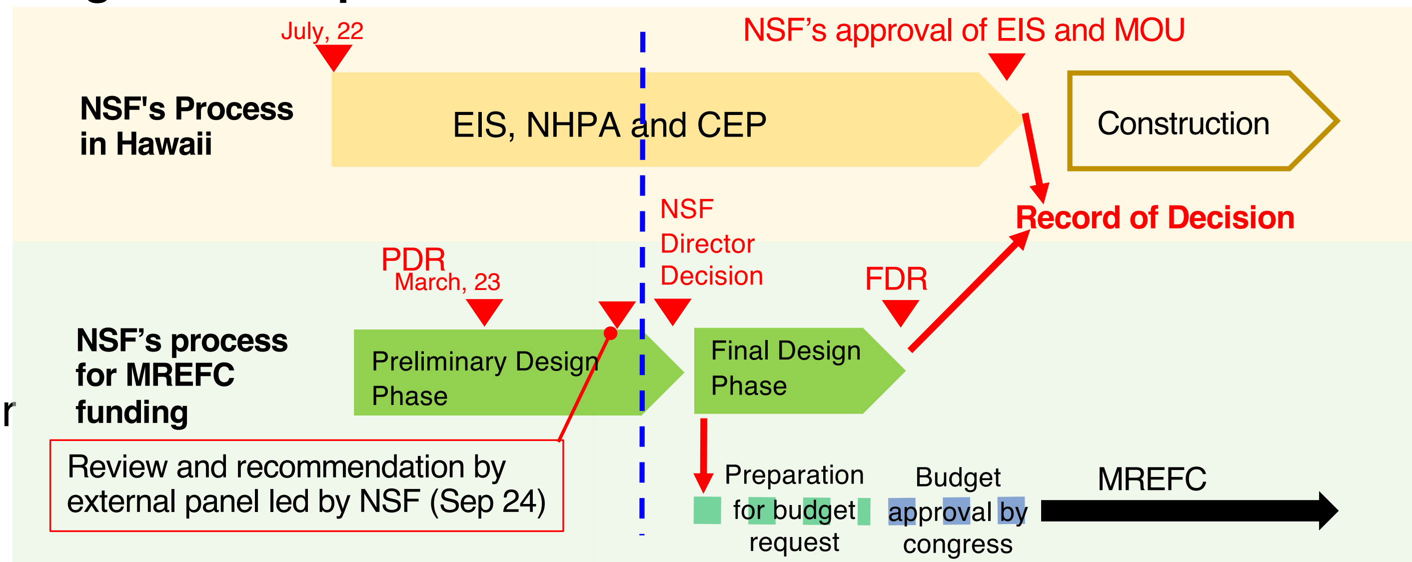
CSO

Hōkū Ke‘a

Prospects to obtain consensus through the NSF process

- ▶ Environment Impact Statement (EIS)
- ▶ National Historic Preservation Act (NHPA) section 106
- ▶ Community Engagement Plan (CEP)
- ▶ Completed by 2026

Approval of MKSOA is necessary for TMT construction.



Collaboration with the industry & community is essential

TMT THIRTY METER TELESCOPE

8. Project organization

National Astronomical Observatory of Japan

NAOJ oversees the implementation of Japan's in-kind contributions, collaborating with domestic companies to manufacture the telescope's main structure and primary mirror.

国立天文台 NAOJ National Astronomical Observatory of Japan

Project lead：TMT Project/ATC

Collaboration: Hawaii Observatory, ALMA Project, ADC

The development, design, and technological advancement of the second-generation observational instruments are being carried out in collaboration with domestic and international universities.

Collaboration

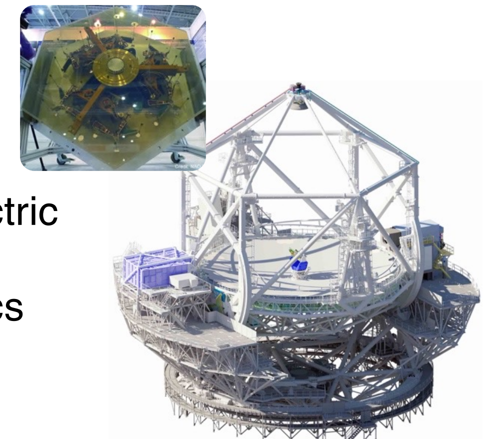
Telescope structure/Mirrors

Joint Research

Second Generation Instruments

Industry

Canon
Kanadevia
Mitsubishi Electric
Ohara
Okamoto Optics



Credit MELCO, NAOJ

The first-light instruments are being developed by the NAOJ ATC.

After completion, the NAOJ TMT project in collaboration with the Hawaii Observatory (Subaru) will operate TMT and Subaru under a unified scheme.

Universities

Hokkaido University
Kyoto Sangyo University
Kyoto University
Okayama University of Science
RIKEN
Tohoku University
University of Texas at Austin
University of Tokyo

Collaboration with the industry & community is essential

TMT THIRTY METER TELESCOPE

8. Project organization

National Astronomical Observatory of Japan

	NAOJ		Community	
Construction	34 FTE	• Currently 18FTE • Need 34FTE once construction in Japan resumes • Need >40FTE once on-site construction resumes	90 scientists and engineers	• Development of science/operation plan • Science advisory committee • Working groups • Engineering collaborations
Operation	67 FTE	• Open-use (partially including Subaru open-use): Astronomers including post-docs　27 • Research Administrators 5 • Administration 25 • Support for TIO operation (incl. in-kind contribution): Engineers & Technicians 10	120 scientists and engineers	• Scientific research through open-use • Instrument development • Proposal evaluation • Development of science/operation plan • Science advisory committee • Engineering collaborations

We plan to develop a common system for the operation of TMT (Japanese time) and Subaru, including proposal management, data analysis support and archive.

TMT Promotes Young Scientists & Engineers

► **Workshop organized by young scientists and engineers:**

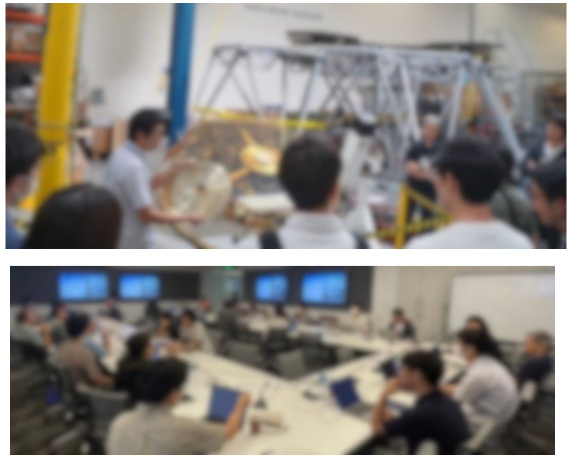
TMT ACCESS: TMT eArly Career Centered, Engineers-Scientists Synergy: a workshop organized by young scientists and engineers (Sept, 2023 in Pasadena, June 2024 in Sendai).

► **TIO's workshop: TMT Early Career Initiative (TECI)**

TIO held three international workshops so far to educate young scientists and engineers. 22 students postdocs and engineers participated from Japan.

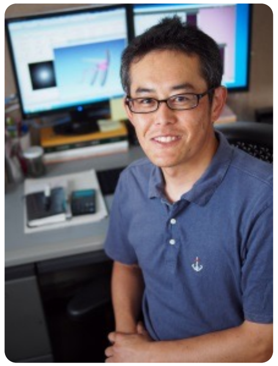
► **Development at universities**

Enhancing young generations' activities and skills through instrument development by international collaborations.



TMT ACCESS (Sept. 2023, June 2024)

Toshihiro Tsuzuki



Ryuji Suzuki

- The Optical Society of Japan, Optics Design Award (2018)
  Toshihiro Tsuzuki (NAOJ)
- The Laser Society of Japan, Encouragement Award (2019)
  Ryuji Suzuki (NAOJ)

TECI (2018, Pasadena)

TMT is Built on the Strength of Community Support

9. Why NAOJ?

- ► The need for an **extremely large telescope in the northern hemisphere has been expressed repeatedly** by the **Japanese optical-infrared astronomy community (GOPIRA)**.
- ► **Strong recommendation** for TMT from the **Japanese society for planetary sciences**, and the **Astronomical Society of Japan**.
- ► Construction/operation of TMT is **fully aligned with NAOJ's Mission Statement.**

Our Mission:

https://www.nao.ac.jp/en/about-naoj/organization/philosophy.html

- To develop and construct large-scale cutting-edge astronomical research facilities and promote their open access aiming to expand our intellectual horizons.
- To contribute to the development of astronomy as a world leading research institute by making the best use of a wide variety of large-scale facilities.
- To bring benefits to society through astronomy public outreach.

International Collaboration, Industrial Growth, and Fostering Young Talent

10. Collaboration and spillover effects outside astronomy

Advancing International Collaboration with Cutting-Edge Technology

- ► TMT is realized through **strong international collaboration**, uniting the cutting-edge technologies of participating countries.
- ► Japan **leverages its experience of building advanced telescopes like Subaru and ALMA.**

NINS, Caltech, University of California, NRC/Canada, DST/India, AURA

Driving Scientific Research and Industrial Growth

NAOJ

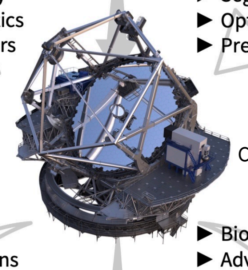
Academia

Industry

Canon
Hitachi Zosen
Mitsubishi Electric
Ohara
Okamoto Optics

- ► Telescope system technology
- ► High-resolution adaptive optics
- ► Primary mirror control sensors

- ► Segment exchange system
- ► Optical system manufacturing
- ► Precision processing and vibration control



Courtesy TMT International Observatory

- ► Robotics
- ► Space optical communications
- ► JAXA's large-scale deep-space antennas

- ► Biomedical microscopes
- ► Advanced precision manufacturing
- ► Ultra—precise pharmaceutical measurements

Broad basic science fields and Japan's industrial foundation

Fostering Globally Active Talent through Technology

- ► Participation as a major partner provides an excellent opportunity for Japan's young researchers and engineers **to learn from and collaborate with leading global scientists, engineers, and project managers**.
- ► NAOJ supports the active participation of young university researchers and graduate students in **developing next-generation instrument components**.

Collaboration with Tohoku University

Hokkaido University
Institute of Science Tokyo
Kanagawa University
Kurume University
Kyoto Sangyo University
Kyoto University
Osaka Electro-Communication University
Okayama University of Science
RIKEN
Tohoku University
University of Texas at Austin
University of Tokyo

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