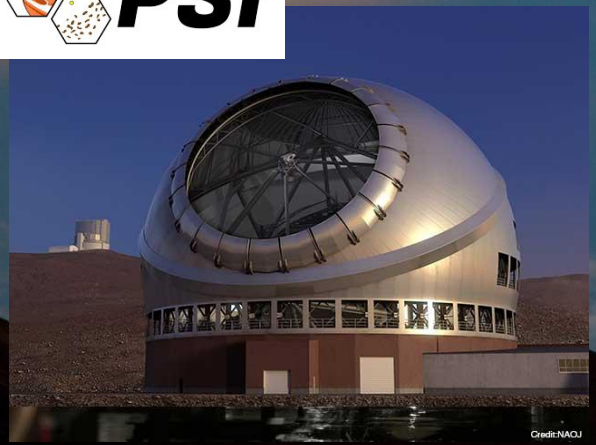
SCExAO
Subaru Coronagraphic Extreme Adaptive Optics
すばるコロナグラフ極限補償光学装置

Exoplanet Imaging and Characterization with Subaru SCExAO & TMT PSI

PSI



Presenter: Olivier Guyon (guyon@naoj.org)

NAOJ & ABC team:
Thayne Currie, Jun Hashimoto,Takayuki Kotani, Tomoyuki Kudo, Masayuki Kuzuhara, Julien Lozi, Toshiyuki Mizuki, Naoshi Murakami, Jun Nishikawa, Motohide Tamura, Taichi Uyama

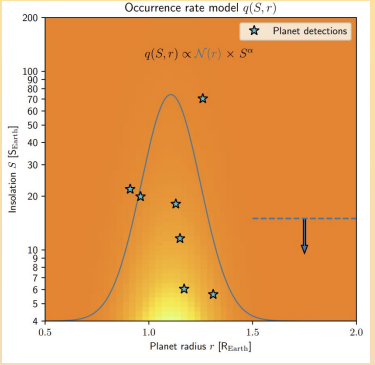
SCExAO and PSI teams

Terrestrial Planets

- Transit and RV surveys have revealed that a **significant fraction (~10-50%) of stars host potentially habitable planets**
- Terrestrial planets appear especially abundant around M-type stars
- Several nearby stars have potentially habitable planets - See Ultra-Doppler presentation

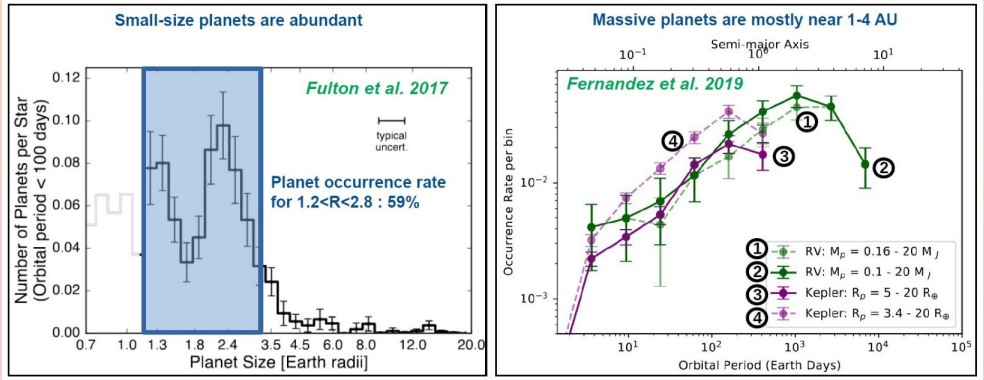
Current limitations:

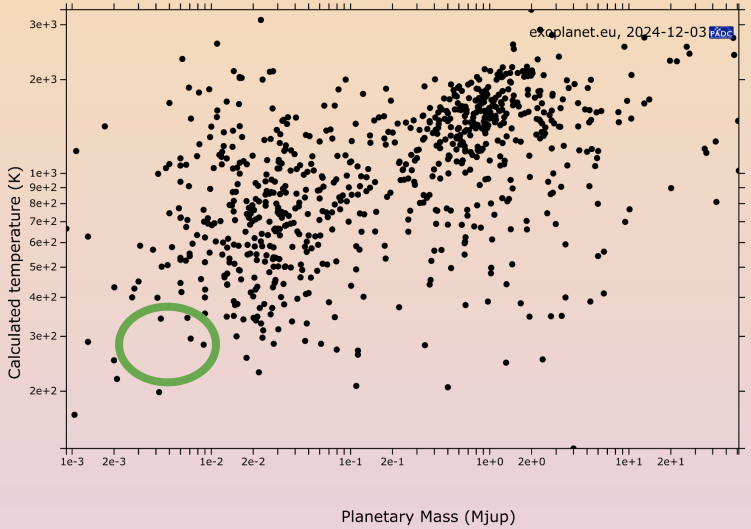
- Most (>90%) nearby planets do not transit
- RV does not provide atmospheric characterization
- Direct imaging (currently) limited to young massive exoplanets



Terrestrial exoplanets population informed from TESS

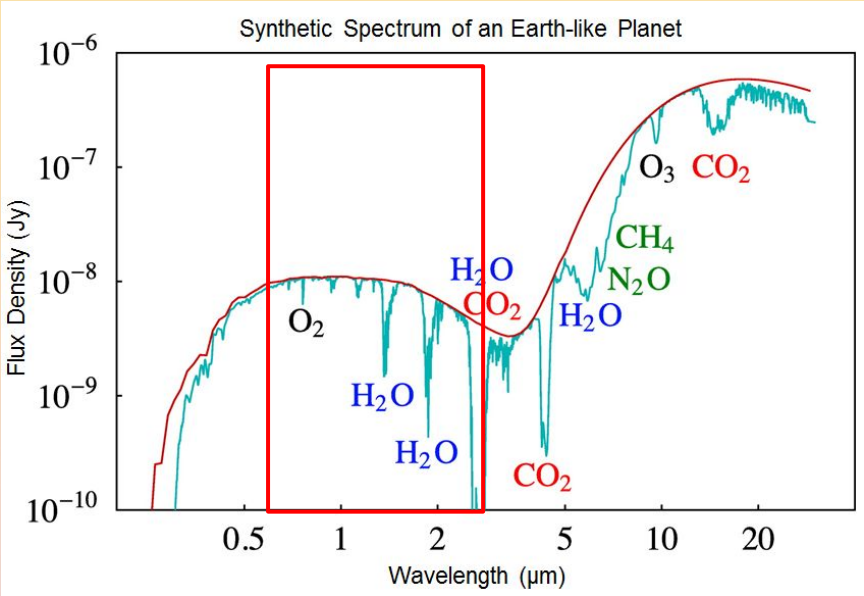
Ment & Charbonneau 2024



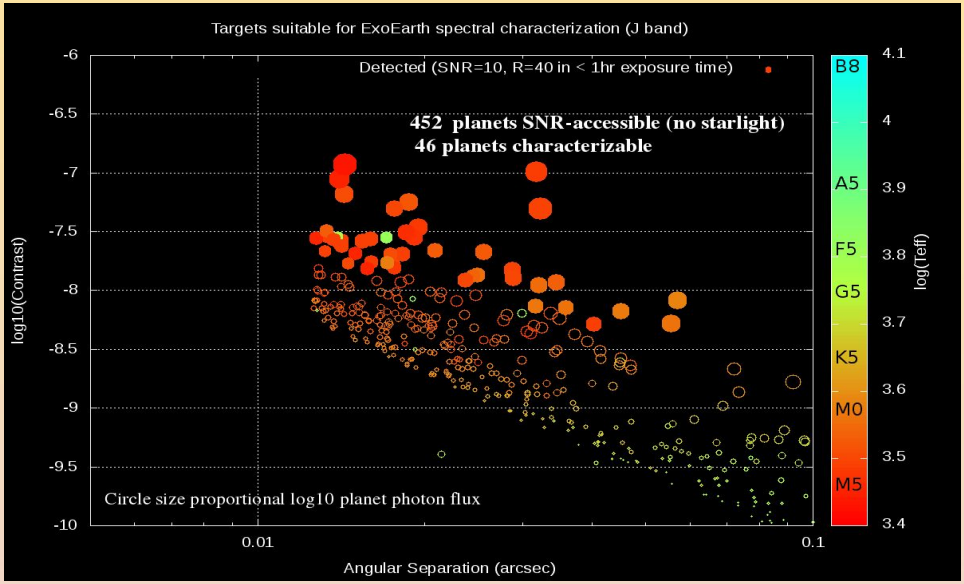


Towards Life Finding with TMT

Spectroscopic characterization in VIS/NIR

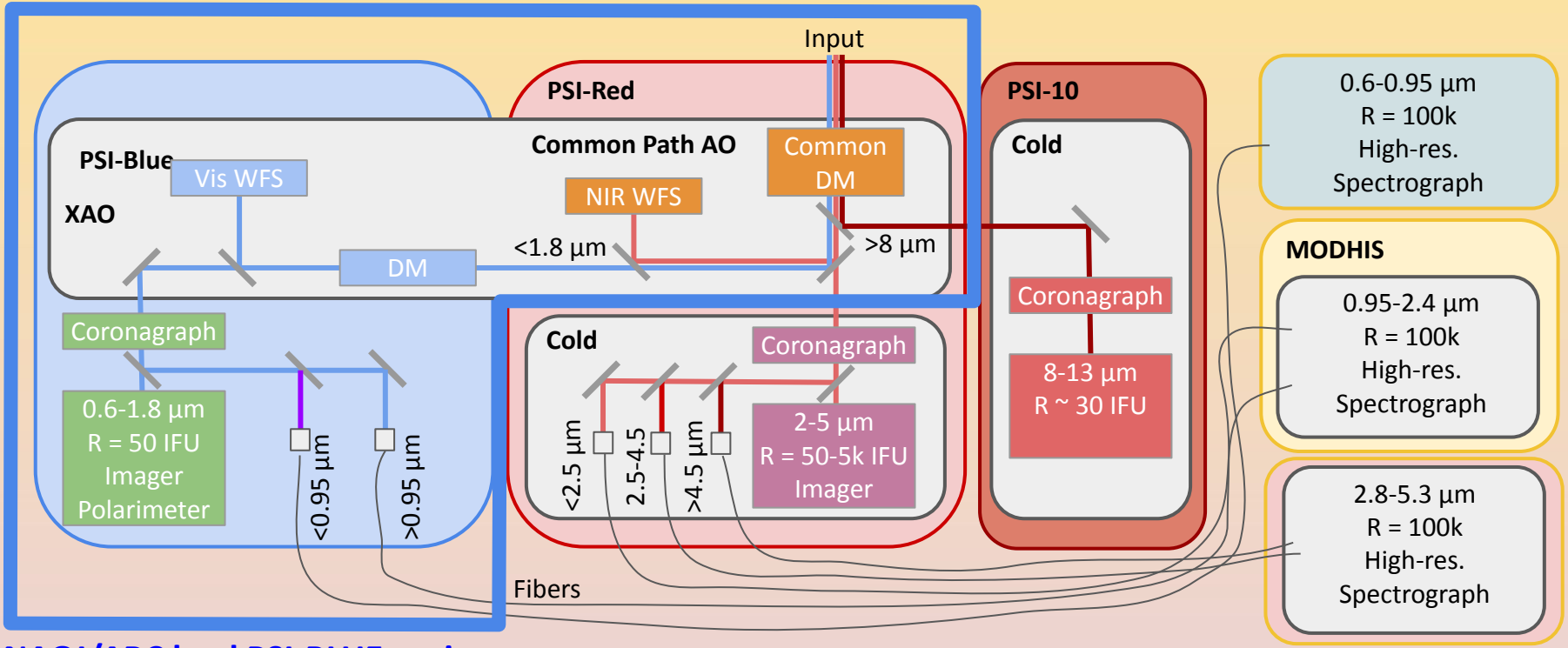


Atmosphere characterization & detection of biomarkers: H2O, O2, CH4, CO2



ExAO system on 30-m telescope can reach habitable planet characterization sensitivity (SNR=10 @ R=40 in 1hr) around 46 nearby stars.

TMT-PSI instrument concept

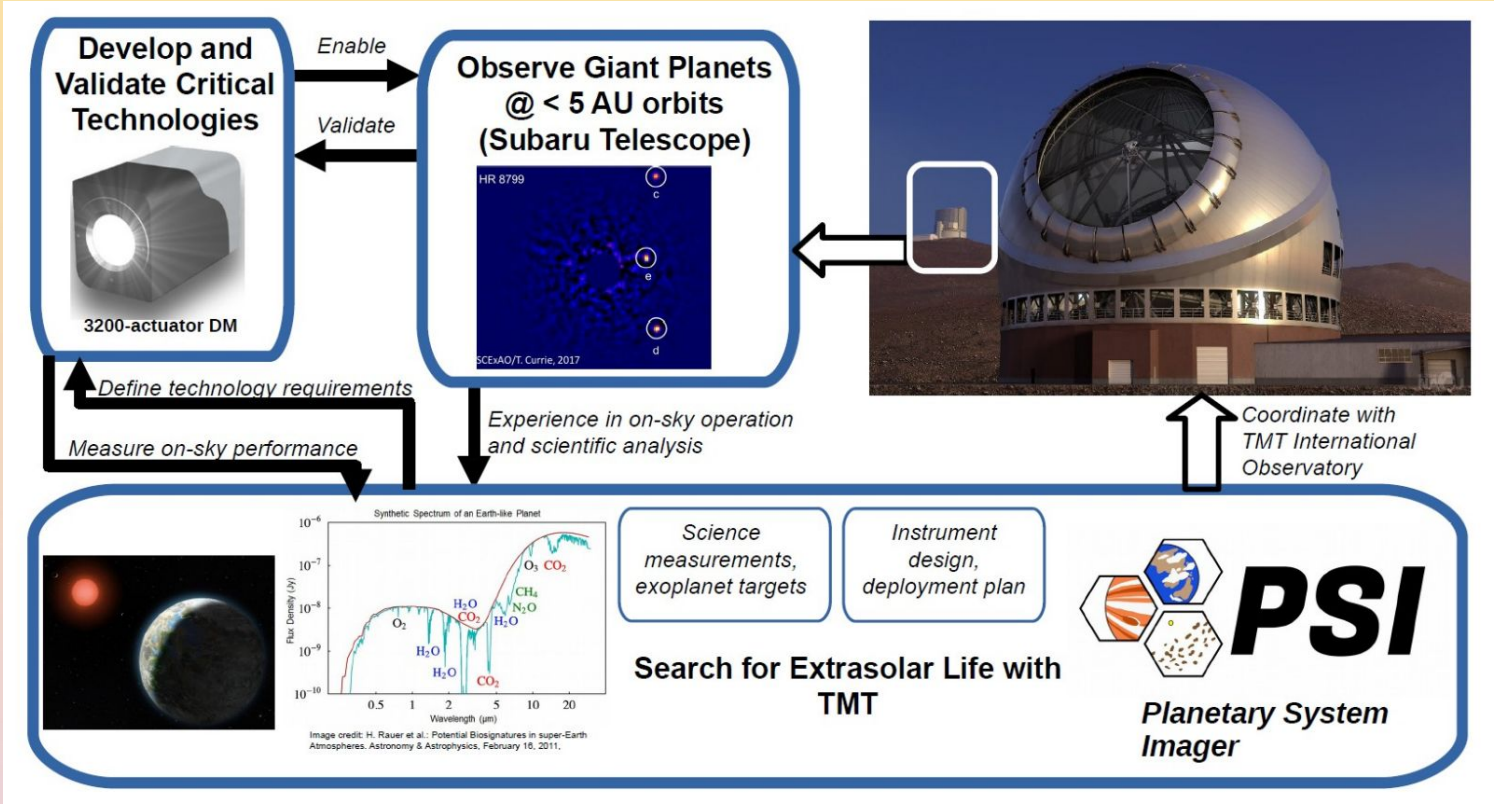


NAOJ/ABC lead PSI-BLUE - prime science goal: habitable exoplanet imaging & spectroscopy

US/Canada leads PSI-RED

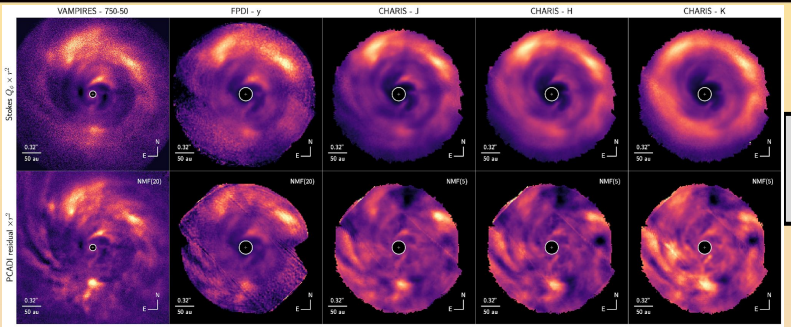
Credit: PSI team

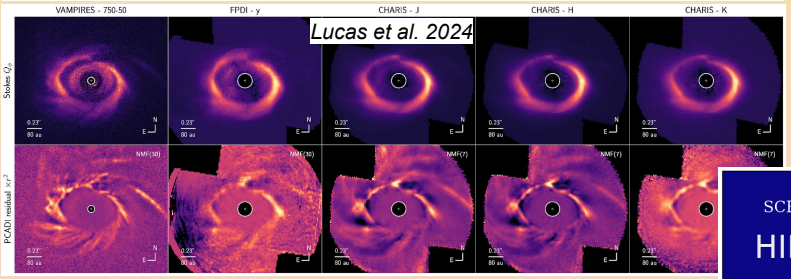
Subaru/SCExAO -> TMT-PSI



We will work closely with the existing Planetary Systems Imager (TMT-PSI) instrument team to develop the *PSI-BLUE* part of the instrument, optimized for habitable planet observations.

SCExAO science



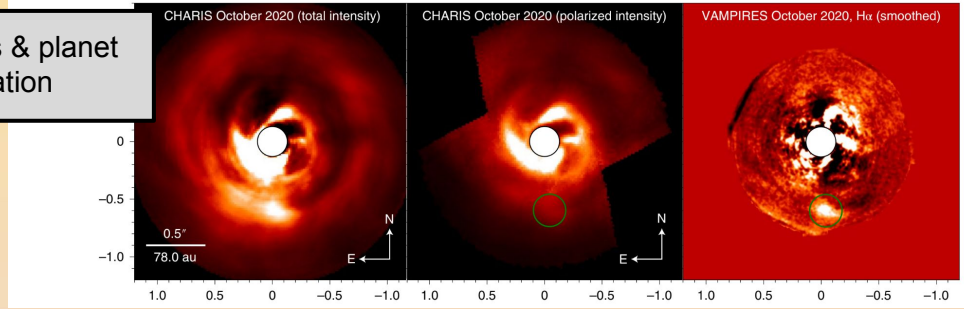


Lucas et al. 2024

"Images of embedded Jovian planet formation at a wide separation around AB Aurigae", *Currie et al. 2022*

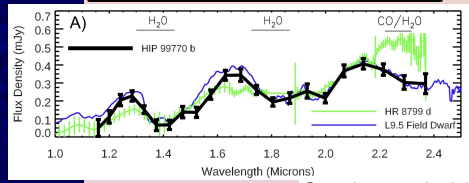
NATURE ASTRONOMY

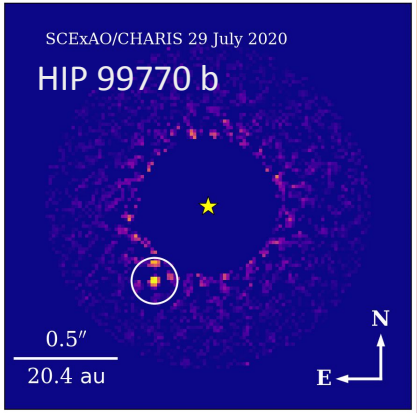
Disks & planet formation



Exoplanet Imaging & Spectroscopy

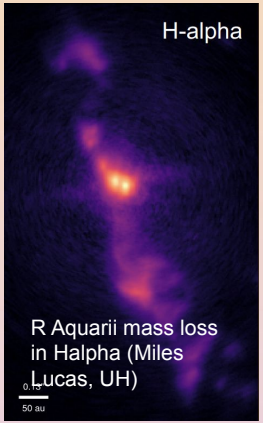
Inner 3 planets in HR8799 system



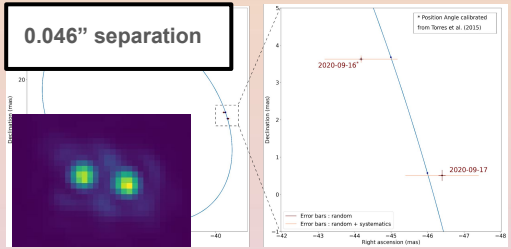


Currie et al. 2023, Science

Stellar Physics



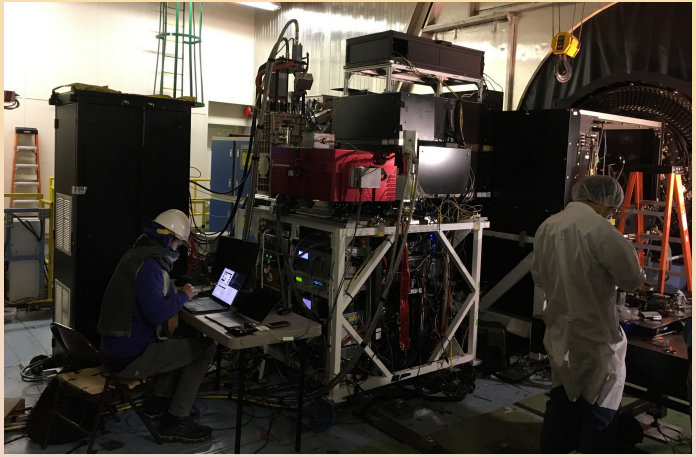
0.046" separation



"Single-aperture spectro-interferometry in the visible at the Subaru telescope with FIRST: First on-sky demonstration on Keho`oea (α Lyrae) and Hokulei (α Aurigae)", *Vievard et al. 2023*

Path to TMT-PSI

Subaru Coronagraphic Extreme Adaptive Optics
すばるコロナグラフ極限補償光学装置



Re-use SCExAO experience, hardware and software to the maximum extent possible for TMT-PSI

Develop and validate on-sky critical technologies and systems @ Subaru:

- High-performance AO correction
- Focal plane wavefront control
- Starlight suppression (coronagraphy, photonic)
- Fast low-noise detectors (CMOS, lmAPD, MKIDS)
- Signal processing
- Exoplanet Spectroscopy

-> Enables new science @ Subaru: mapping inner planetary systems (architecture, evolution, composition)

Existing SCExAO system become prototype for PSI. Early career personnel training (science and technology) to prepare for PSI.

-> **Critical for balancing PSI performance, risk and schedule**

-> Critical to grow the TMT-PSI Japan community

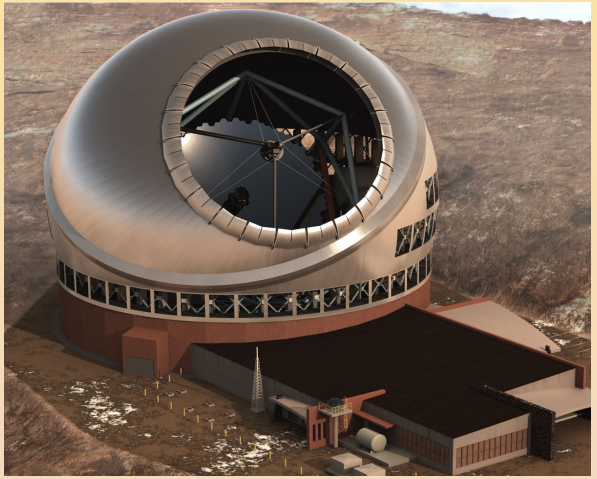
Why NAOJ ? why TMT ?

Why NAOJ & ABC ?

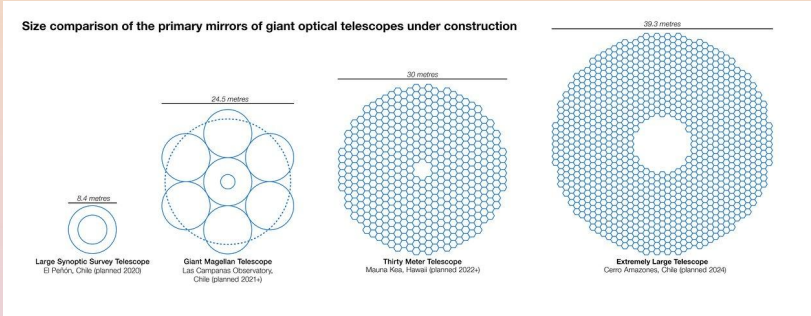
- NAOJ and ABC are **leaders in high contrast imaging & spectroscopy**, leveraging SCExAO, IRD & Japan-based lab R&D
- **Strong exoplanet science research background** with ABC, post-SEEDS, ALMA
- Program needs engagement at the national (Japanese) and international (TMT partners) levels

Why TMT ? (vs. GMT or ELT)

- Maunakea is **better site** than Chilean sites with longer coherence time (no jet stream) and lower telluric absorption of key biomarkers (H2O and O2).
- TMT has **friendly pupil** with low segmentation and small central obstruction, and high-efficiency 3-mirror design



Credit: TMT International Observatory



Credit: ESO

International context, Schedule

International Context:

- GMT planning for first-light instrument (GMagAO-X) with focused capabilities (2030+ ?)
- ESO developing PCS for ELT, currently in technology development phase (2040 ?)
- NASA developing HWO mission (2040+ ?) with complementary capabilities (will probe G-type stars, not M-type stars)

TMT-PSI will the **only habitable exoplanet imaging instrument in the northern hemisphere**
TMT-PSI will likely come online after GMagAO-X, but will be **more capable** (better site, larger telescope, more ambitious instrument).
TMT-PSI can be deployed **before ELT's PCS**, leveraging NAOJ/ABC experience.

We are aiming at developing TMT-PSI for deployment soon after TMT first light (2034 ??).
2025-2030: SCExAO-based R&D program in high contrast imaging/spectroscopy
2026-2030: TMT-PSI instrument design & component prototyping
2029-2033: TMT-PSI-blue build

Funding plan, NAOJ contribution

2025-2030: SCExAO-based R&D program in high contrast imaging/spectroscopy

USD ~$2M per yr: Grants from Japan (JSPS), US (NSF, NASA, private), Australia, Europe & Canada. This is continuation of existing R&D program

2026-2030: TMT-PSI(-blue) instrument design & component prototyping

USD ~$1M per yr: Grants from Japan & TMT-PSI members

2029-2033: TMT-PSI-blue build

USD ~$25M total: Once TMT construction resumed, NAOJ+ABC submit MEXT request (Gaisan Yokyu)

NAOJ contributions:

- 2x FTEs (NAOJ faculty) to assist for SCExAO science operation/use and R&D coordination, proposal preparation, Japan TMT-PSI-blue promotion, team building engaging young researchers. Also needed to help manage possible NAOJ contribution to NASA-led HWO mission.
- Operation support (SCExAO: PI-type -> facility instrument ?)
- Support with software development, data management, computing infrastructure to support science & R&D, provide access & support to Japanese researchers

Subaru exoplanet instrumentation in the 2030s

Before ELT era, SCExAO will remain world-leading exoplanet imaging system with growing capabilities.

During TMT-PSI operation: TMT-PSI performance will ultimately be vastly superior to Subaru/SCExAO for exoplanet imaging and spectroscopy, but TMT observing time will be in high demand, and TMT capabilities will take time to ramp up.

- Subaru/SCExAO should run **survey(s) to identify exoplanets** (giant gas planets) and characterize them (spectroscopy) when possible.
- RV with Subaru/SCExAO + Ultra-Doppler to **identify targets for TMT-PSI & HWO**. This is required to confirm directly imaged planets and **estimate exoplanet masses**.
- Subaru/SCExAO can remain **competitive in short wavelength (optical/blue)**, for which AO becomes extremely challenging on a 30 m aperture.
- Subaru/SCExAO can run **specialized modes** that may not be (initally?) deployed on TMT-PSI to keep the instrument simple: fast PDI (disks), interferometry.

AO3k + LTAO can be evolved to a visible-light MCAO system to provide diffraction-limited (15mas resolution) visible light performance over ~30” field of view.