Science Strategy of NAOJ

国立天文台の科学戦略

Planetary systems and life in the Universe

惑星系と宇宙における生命 (§2.6, §3.1.6)

Yuka Fujii

On behalf of NAOJ Science Roadmap Committee

Planetary systems and life in the Universe

▶ **Ultimate Goal of the Field**

To elucidate the diversity of planets and planetary systems as well as their origins, and to determine the prevalence of environments in the Universe that are capable of supporting life.

▶ **Goals in the Field**

■ Understanding of the **statistical distributions and correlations** of stars and planets

■ Systematic understanding of **planetary properties and diversity**

■ Elucidation of the **formation histories** of diverse planetary systems and the Solar System

■ Elucidation of the conditions for the emergence of **habitable environments**

■ Identification and verification of **biosignatures**

▶ **当該分野の究極的な目的**

惑星および惑星系の多様さとその起源を理解し、生命が存在しうる環境が宇宙においてどの程度の頻度で存在し得るのかを明らかにする。
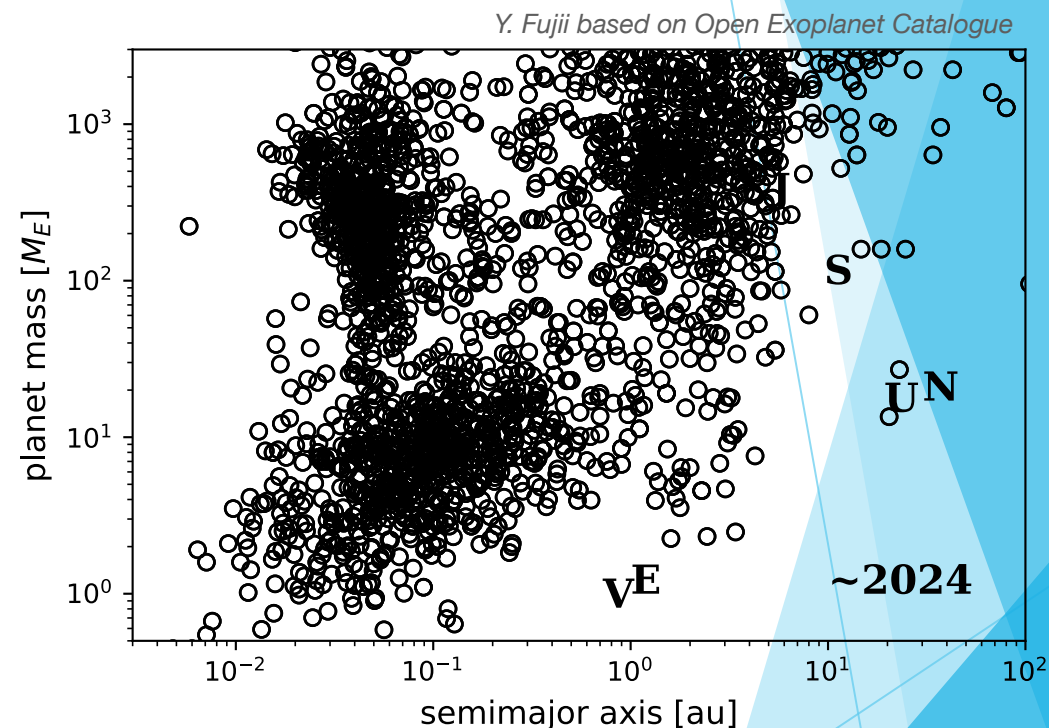
▶ **当該分野の目標**

■ 星惑星系の統計的分布と相関の解明

■ 惑星の性質と多様性の体系的理解

■ 多様な惑星系および太陽系の形成史の解明

■ ハビタブル環境の成立条件の解明

■ 生命兆候の特定と観測的検証

Toward "Understanding of the Statistical Distributions and Correlations of Stars and Planets"

星惑星系の統計的分布と相関の解明

Y. Fujii based on Open Exoplanet Catalogue

Where we are

▶ Occurrence rate of various types of planets

▶ Dependence on stellar properties; e.g.

- Rarer Jupiter-like planets around low-metallicity stars

- Rarer Jupiter-like planets around M-type stars

▶ Sub-structures in demographics of close-in orbits; e.g.

- Deficit of Neptune-sized planets in the proximity of host star ("Neptunian Desert")

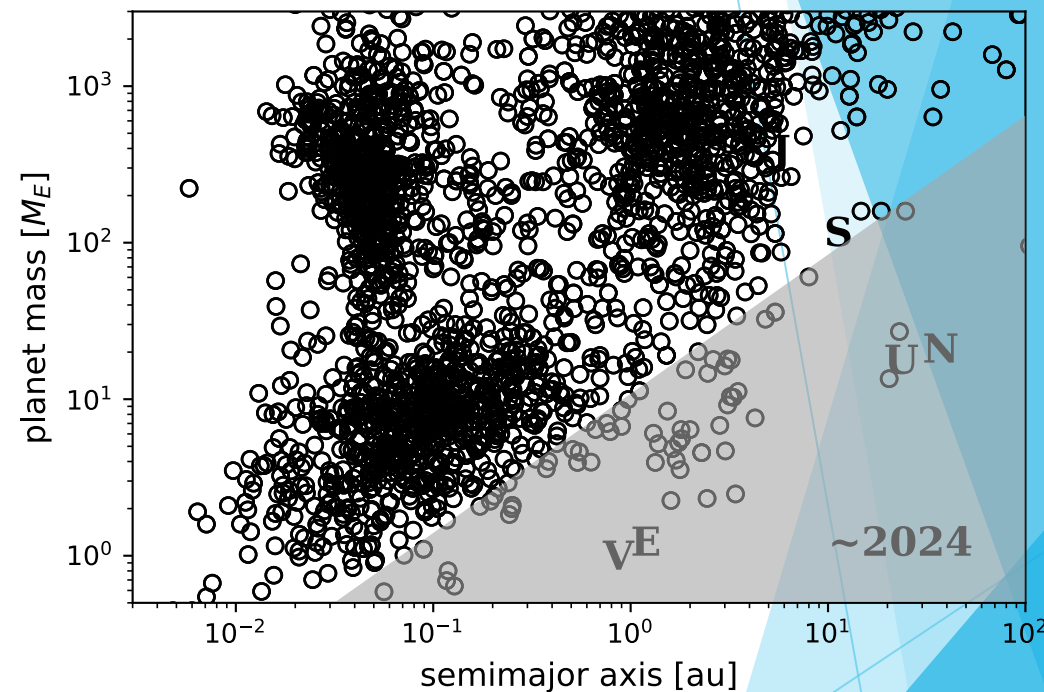- Deficit of planets in 1.5-2 Earth ("Radius Valley")

Toward "Understanding of the Statistical Distributions and Correlations of Stars and Planets"

星惑星系の統計的分布と相関の解明

Directions

▶ Under-explored parameter space

- Small planets in wide orbits (> 100 days)

- …

Toward "Understanding of the Statistical Distributions and Correlations of Stars and Planets"

星惑星系の統計的分布と相関の解明

Directions

Approach ※ Highlighted in red are in NAOJ SRM

▶ Under-explored parameter space

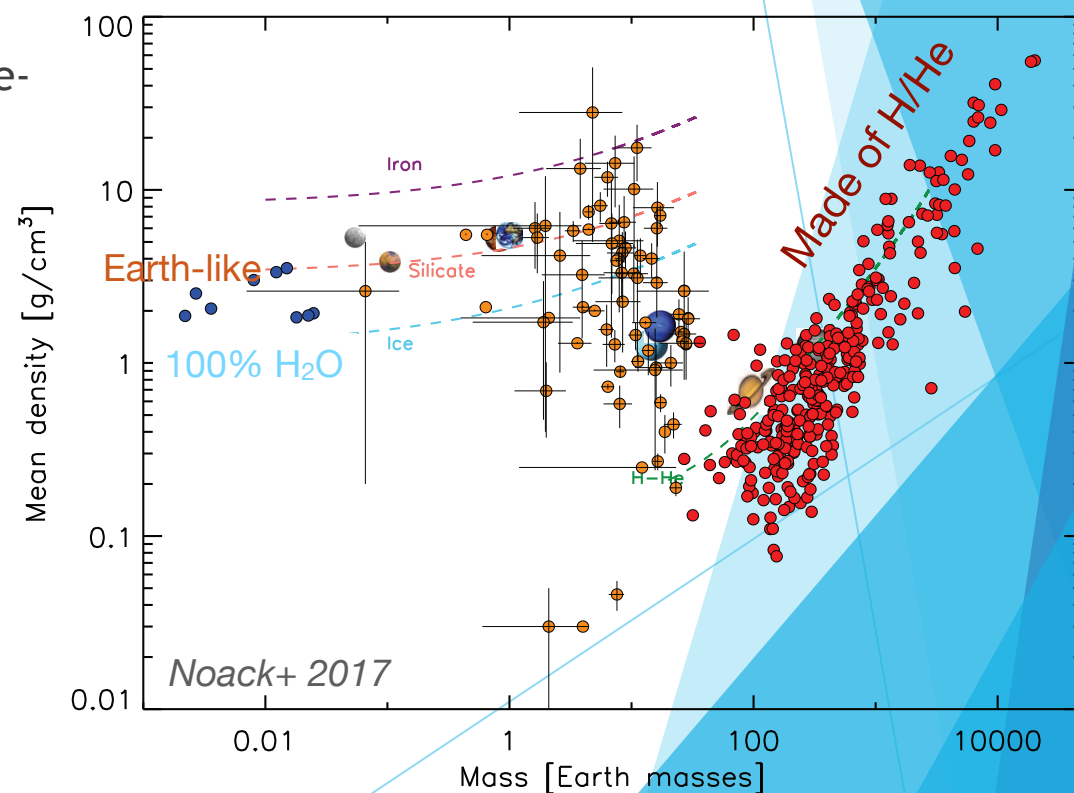| Directions	Approach
• Small planets in wide orbits (> 100 days)	*PLATO* (ESA) *Roman Space Telescope* (NASA)
• …	

Now   2030   2040

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Toward "Systematic understanding of planetary properties and diversity"
惑星の性質と多様性の体系的理解

Where we are

▶ Trends in bulk properties of close-in planets

  • Jupiter-sized planets with thick H_2-rich envelope / Earth-sized rocky planets / volatile-rich intermediate-sized planets

Toward "Systematic understanding of planetary properties and diversity"
惑星の性質と多様性の体系的理解

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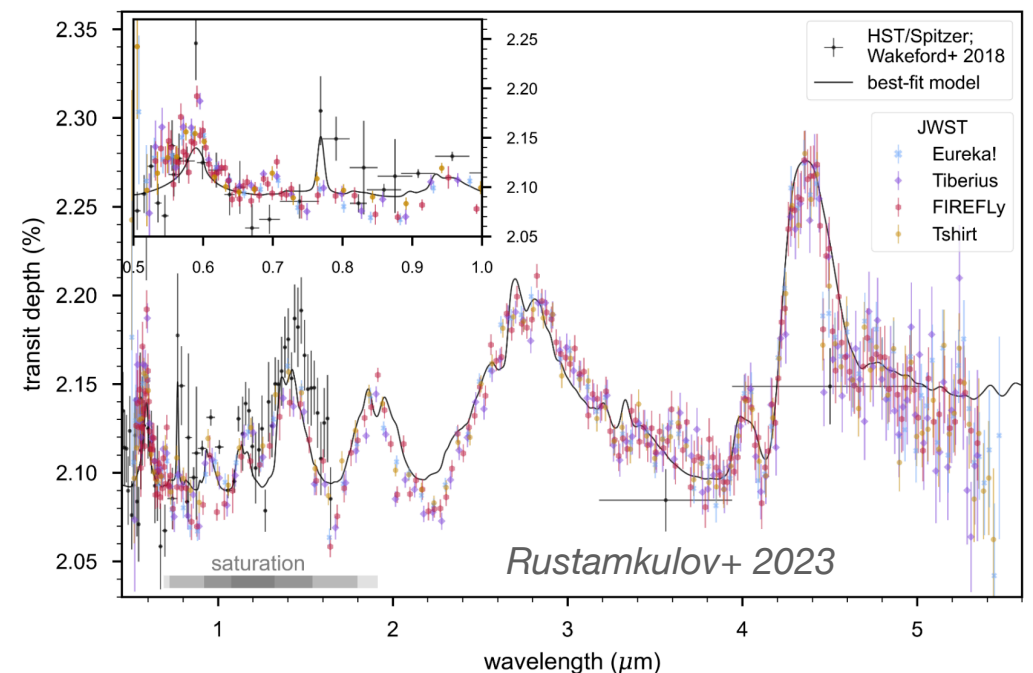
▶ Accumulating data for atmospheric compositions of transiting hot Jupiters/Neptunes/sub-Neptunes
- O/H, C/O, N/H…
- Some emerging trends, e.g. mass-metallicity relation

▶ Evidence of atmospheric processes of these planets
- Photochemistry, aerosols/clouds, atmospheric dynamics
- Atmospheric escape

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Toward "Systematic understanding of planetary properties and diversity"

惑星の性質と多様性の体系的理解

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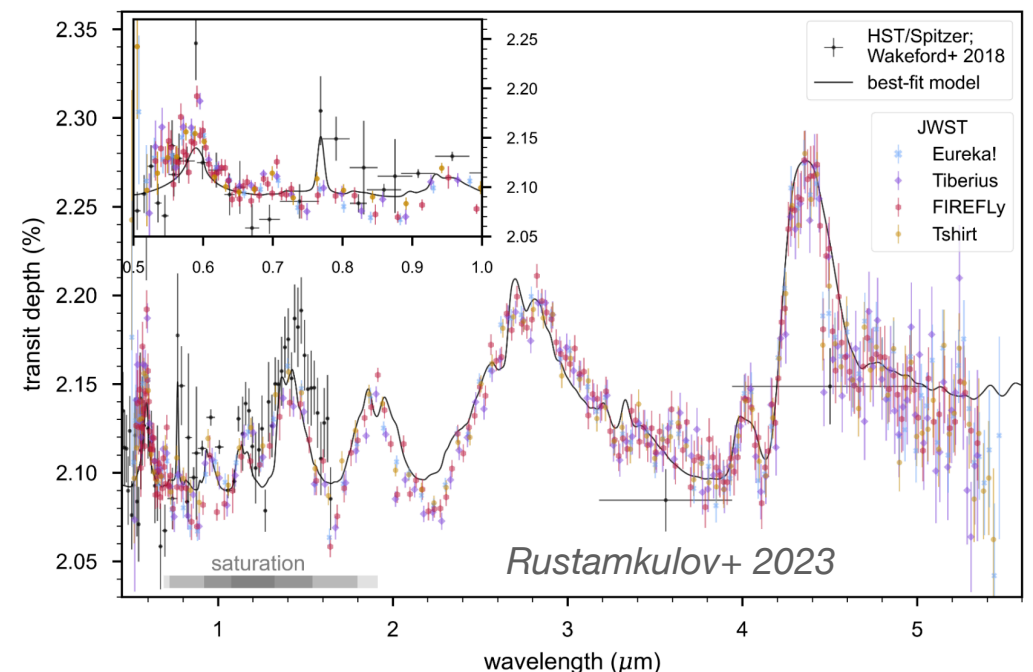- Photochemistry, aerosols/clouds, atmospheric dynamics
- Atmospheric escape

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▶ Development of analysis methods/ pipelines of atmospheric data

▶ Development of atmospheric models

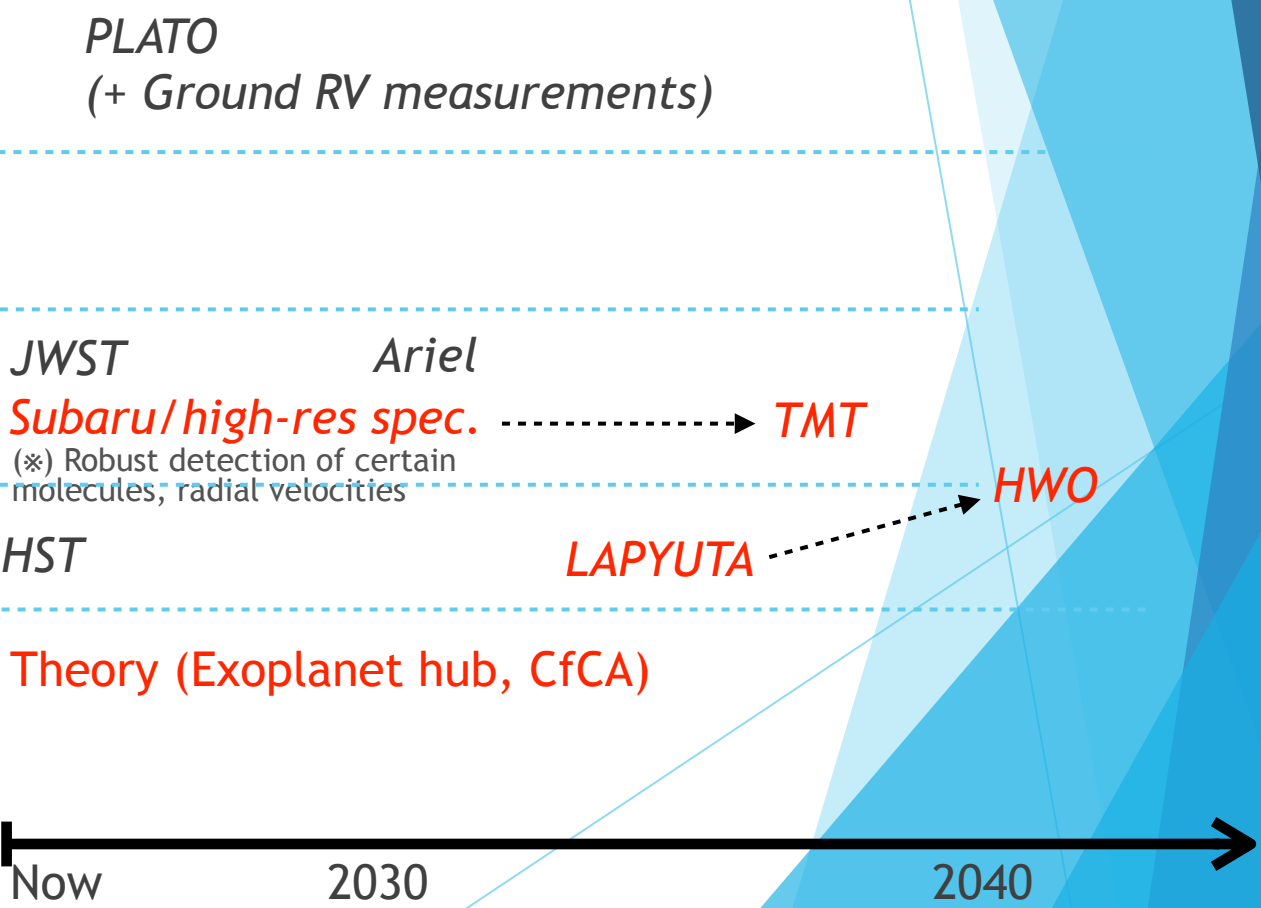- Photochemistry, aerosols/clouds, atmospheric dynamics
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Toward "Systematic understanding of planetary properties and diversity"

惑星の性質と多様性の体系的理解

Directions	Approach ※ Highlighted in red are in NAOJ SRM
▶ Trends in bulk properties of wide-orbit planets	*PLATO (+ Ground RV measurements)*
▶ Diversity and trend in atmospheric properties	
• Atmosphere near photosphere (NIR/MIR)	*JWST Ariel* *Subaru/high-res spec.* ----→ *TMT* (※) Robust detection of certain molecules, radial velocities
• Exosphere	*HST* *LAPYUTA* → *HWO*
▶ Atmospheric models to interpret atmospheres of a wide diversity	Theory (Exoplanet hub, CfCA)

Now   2030   2040

Toward "Elucidation of the formation histories of diverse planetary systems and the Solar System"

多様な惑星系および太陽系の形成史の解明

Where we are

▶ Exotic exoplanet demographics have made us revisit and revise classical planet formation theories ("Kyoto model")

- Orbital migration models to explain hot Jupiters
- Atmospheric loss scenarios to explain "sub-Neptunian desert" and "radius valley"
- Reconsidered in the framework of the emerging paradigm of pebble accretion

▶ Development of statistical planet formation models to compare with observed exoplanet demographics

▶ Quite a few models but no satisfactory consensus yet on major pathways that shaped planetary properties

Toward "Elucidation of the formation histories of diverse planetary systems and the Solar System"

多様な惑星系および太陽系の形成史の解明

Directions

▶ New observational data to test elemental processes of planet formation/evolution

▶ Development of unified theory of planet formation to explain the observed diversity of planetary systems

Toward "Elucidation of the formation histories of diverse planetary systems and the Solar System"

多様な惑星系および太陽系の形成史の解明

Directions	Approach ※ Highlighted in red are in NAOJ SRM
▶ New observational data to test elemental processes of planet formation/evolution	
• Exoplanet properties at birth	*Subaru/SCExAO, high-res* ⟶ *TMT/PSI-Blue* High-contrast *JWST*
• The case of Solar System	*MMX, Hayabusa#2* Geodetic on the origin of Martian Satellites and primordial astroid
▶ Development of unified theory of planet formation to explain the observed diversity of planetary systems	Theory (e.g. Exoplanet hub, CfCA)
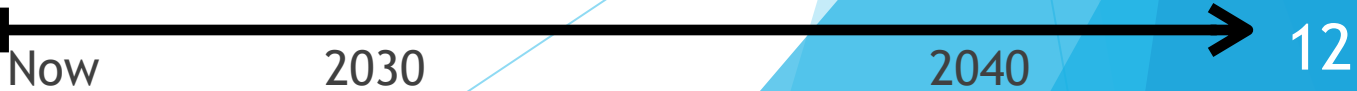
Now　　　　　2030　　　　　2040

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Toward "Elucidation of the conditions for the emergence of habitable environments" and "Identification and verification of biosignatures" ハビタブル環境の成立条件の解明・生命兆候の特定と観測的検証

Where we are

(Observation)

- ▶ Partial constraints on occurrence rate of potentially habitable planets
- ▶ Attempt at atmospheric spectroscopy of potentially habitable planets / Attempts at SETI
- ▶ (Controversial hint at "biosignatures" on sub-Neptunes)

(Theory)

- ▶ Development of climate and evolution models for habitable planets around different spectral types of stars (in particular around M-type stars, which are likely most abundant)
  - Atmospheric circulation of tidally-locked planets
  - Effects of varying irradiation spectra on temperature structure, photochemistry, atmospheric escape
  - Possibility of habitable condition under H_2-rich atmosphere
- ▶ Exploration and organization of various types of "biosignatures"

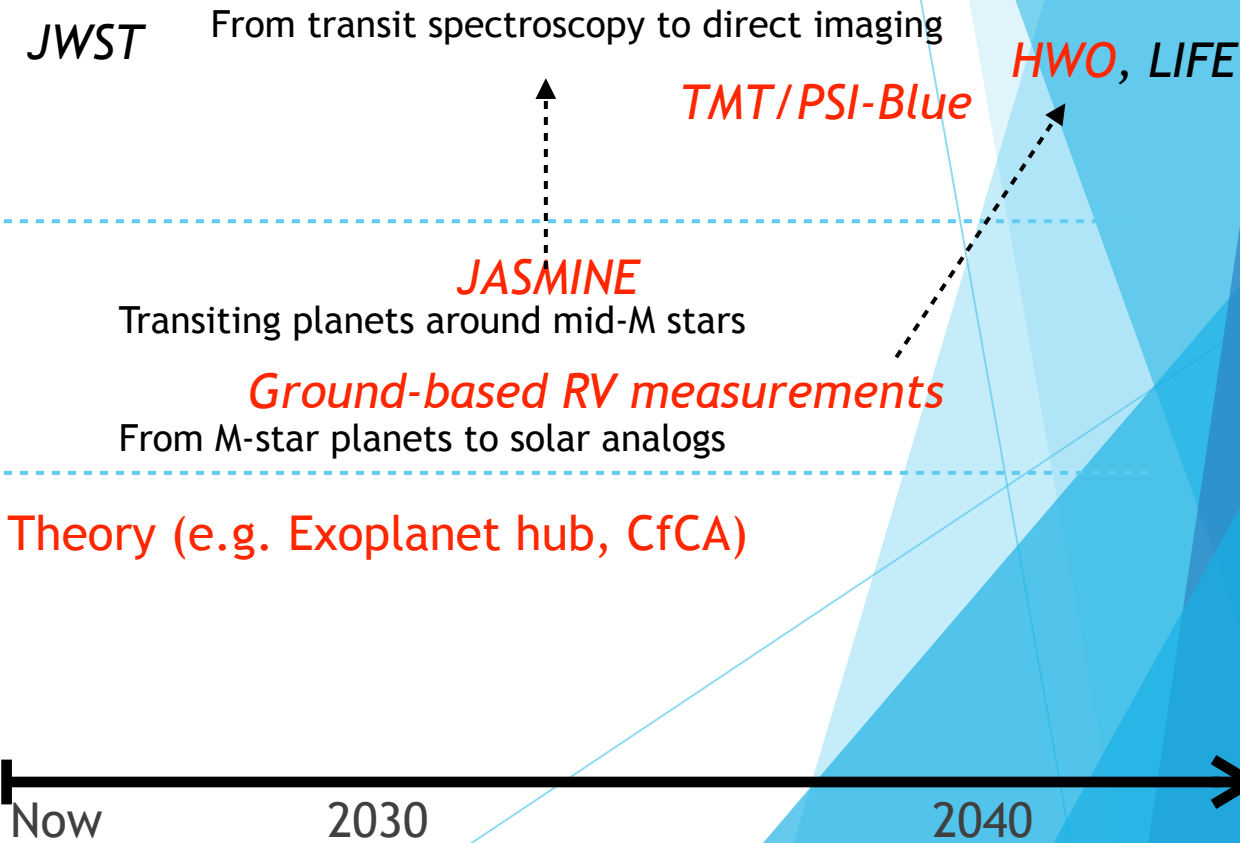# Toward "Elucidation of the conditions for the emergence of habitable environments" and "Identification and verification of biosignatures" ハビタブル環境の成立条件の解明・生命兆候の特定と観測的検証

Directions

Approach ※ Highlighted in red are in NAOJ SRM

▶ Photometric/spectroscopic data of potentially habitable planets

JWST From transit spectroscopy to direct imaging

HWO, *LIFE*

TMT/PSI-Blue

▶ Discovering potentially habitable planets around different types of stars

JASMINE
Transiting planets around mid-M stars

Ground-based RV measurements
From M-star planets to solar analogs

▶ Constraining their surface environment
Atmosphere? Ocean? Signs of life?

Theory (e.g. Exoplanet hub, CfCA)

Now   2030   2040

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Summary

▶ The upcoming years will emphasize multi-facet characterization of diverse exoplanet atmospheres (*JWST*/*Ariel*/*Subaru*/*LAPYUTA*).

▶ Elucidation of planet diversity and their origins requires data-model iterations.

▶ Developing high-contrast (*SCExAO*) and/or *high-spectral-resolution* observations with *Subaru* is a crucial pathway to the *TMT* era.

▶ Detecting potentially habitable planets around mid-M stars (*JASMINE*) and solar-type stars (*Subaru*) can also be a unique contribution of NAOJ to the era of characterizing potentially habitable planets.