Characterization of Exoplanets by Synergy with Space and Ground-based Telescopes

LOI-09

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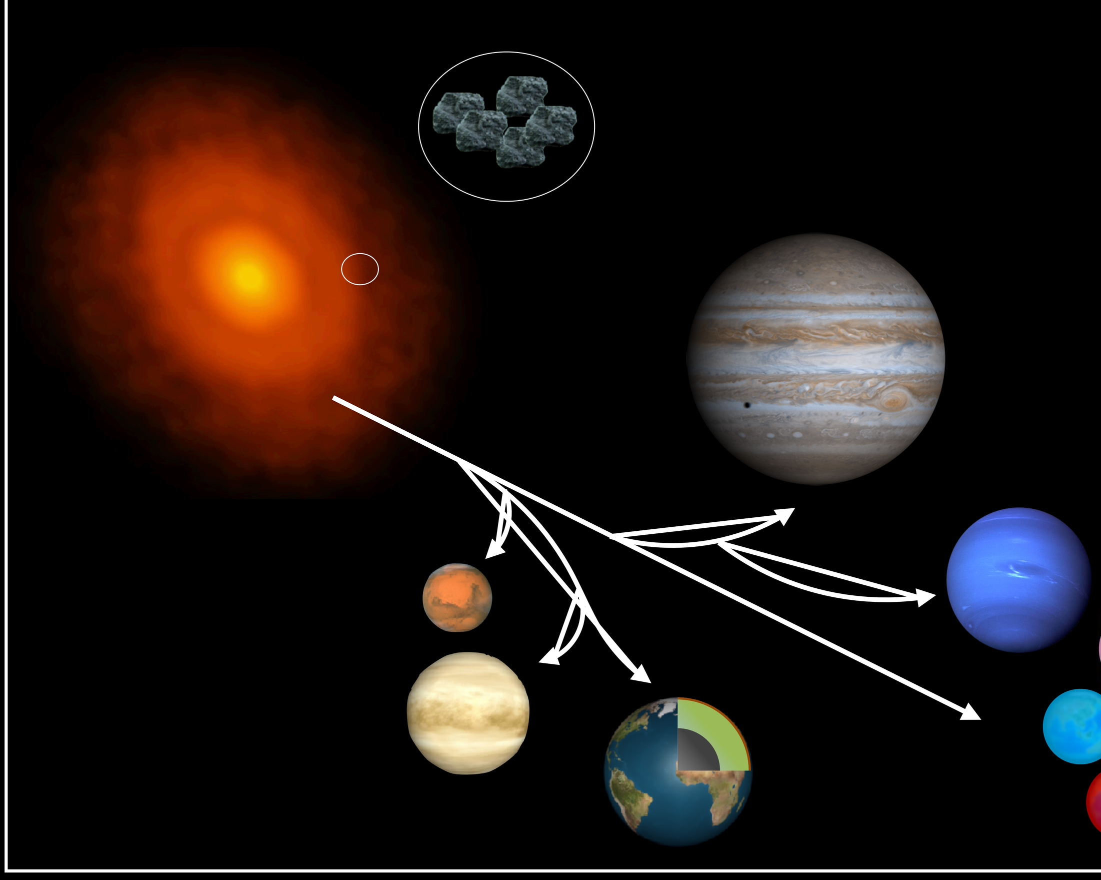
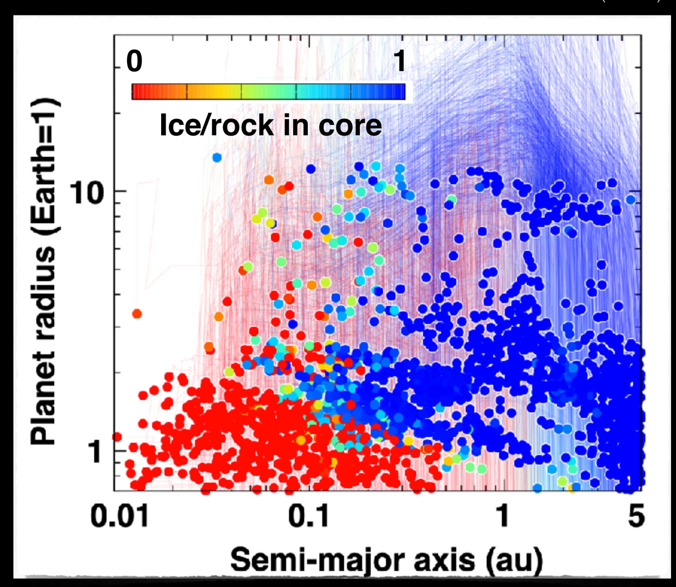
Planet Formation

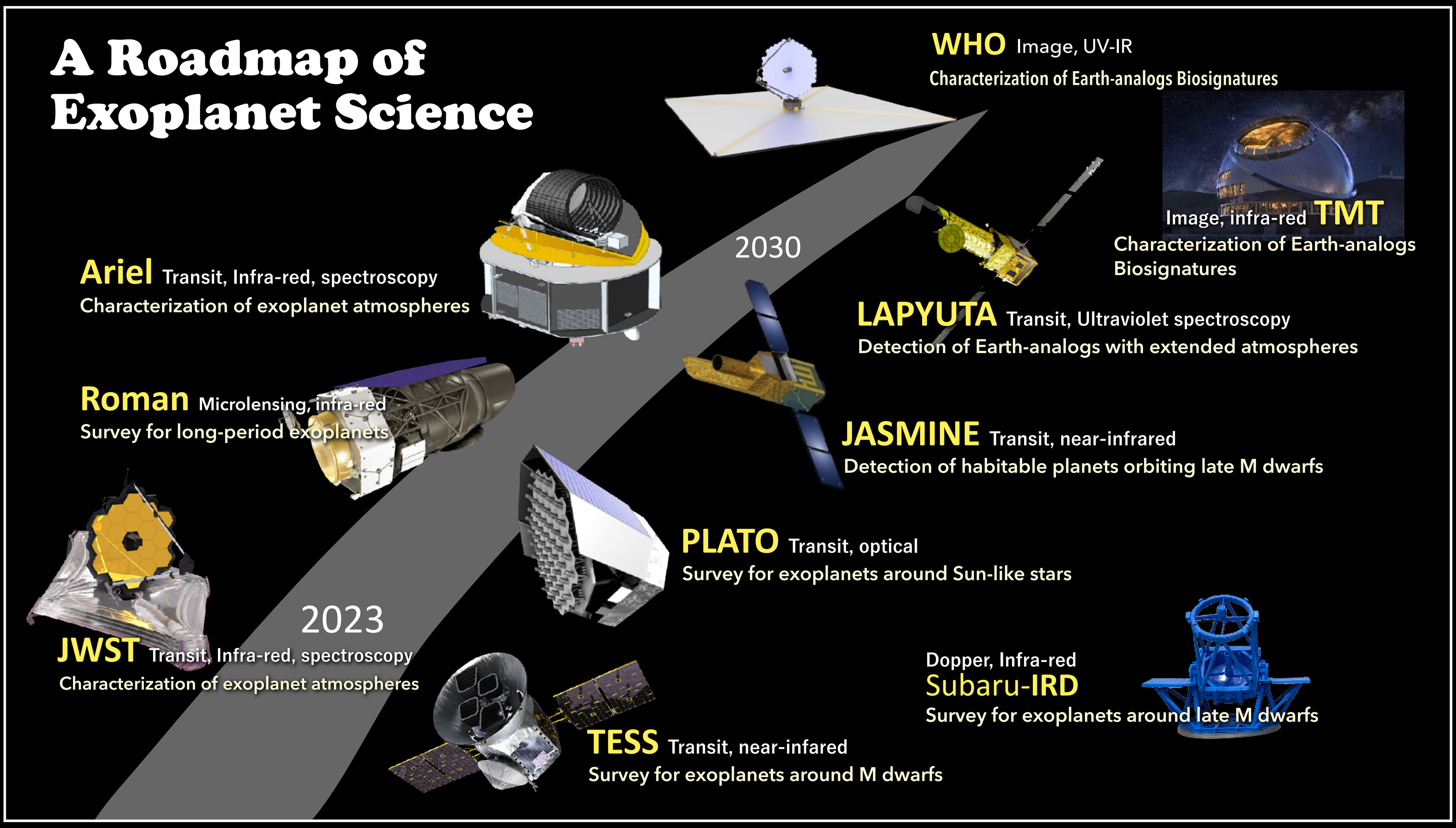


Planet formation model Kimura & Ikoma (2022)



Diverse planets and planetary systems are theoretically predicted.

A Roadmap of Exoplanet Science



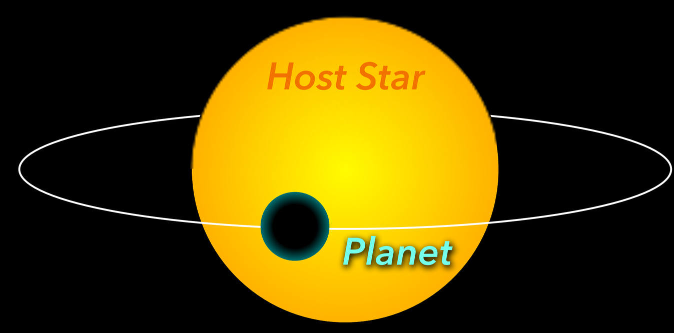
Space Telescope Missions (2028-)

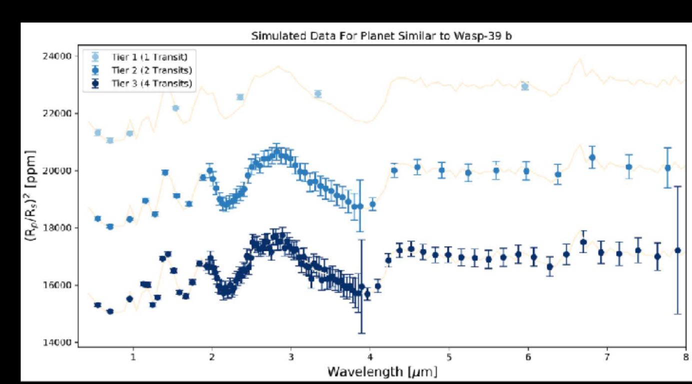
- **JASMINE** scheduled for launch in 2028
  - JAXA S-class mission for high-precision astrometric observation in the near-infrared, which is also used to detect potentially habitable planets orbiting M dwarfs.
  - Exoplanet science is led by H. Kawahara.
- **Ariel** scheduled for launch in 2029
  - ESA space mission dedicated to low-resolution spectroscopic observations (λ=1-8μm, R=30-200) for characterizing a great number of exoplanet atmospheres, scheduled for launch in 2029.
  - Japan participates in the mission as a co-PI nation (Japanese PI: M. Ikoma) and possesses the same data access rights as European nations.
- **LAPYUTA** proposed for launch in 2032
  - Competitive S-class mission proposed to JAXA with the aim of gaining a deep understanding of the diversity of habitable environments in and beyond the solar system and the origin of the universe and matter through UV observations.
  - Exoplanet science is led by M. Ikoma.
- **GREX-PLUS** proposed for launch in the mid-2030s
  - Strategic M-class mission proposed to JAXA with the aim of revolutionizing the understanding of the evolution of galaxies and the formation of planetary systems through high-resolution infrared spectroscopic observations (λ=10-18μm, R=30000).
  - Planetary science is led by H. Nomura.

Ariel

Atmospheric remote-sensing infrared exoplanet large-survey

- Dedicated to infra-red observation of transiting exoplanets -> Large survey for ~1000 exoplanet atmospheres
- ESA-M4: Launch in 2029; Operation 4 + 2 years
- Key scientific questions to be addressed
  - What are the physical processes shaping planetary atmospheres?
  - What are exoplanets made of?
  - How do planets and planetary systems form and evolve?
- Payload
  - 1.1m x 0.7m elliptical mirror
  - Infrared spectrometer (1.1-7.8μm) with R=30-200 & 3 photometric channels (0.5-1.1μm)
  - Photometric precision 10-100 ppm
- Complementary to ground-based high-resolution spectroscopy

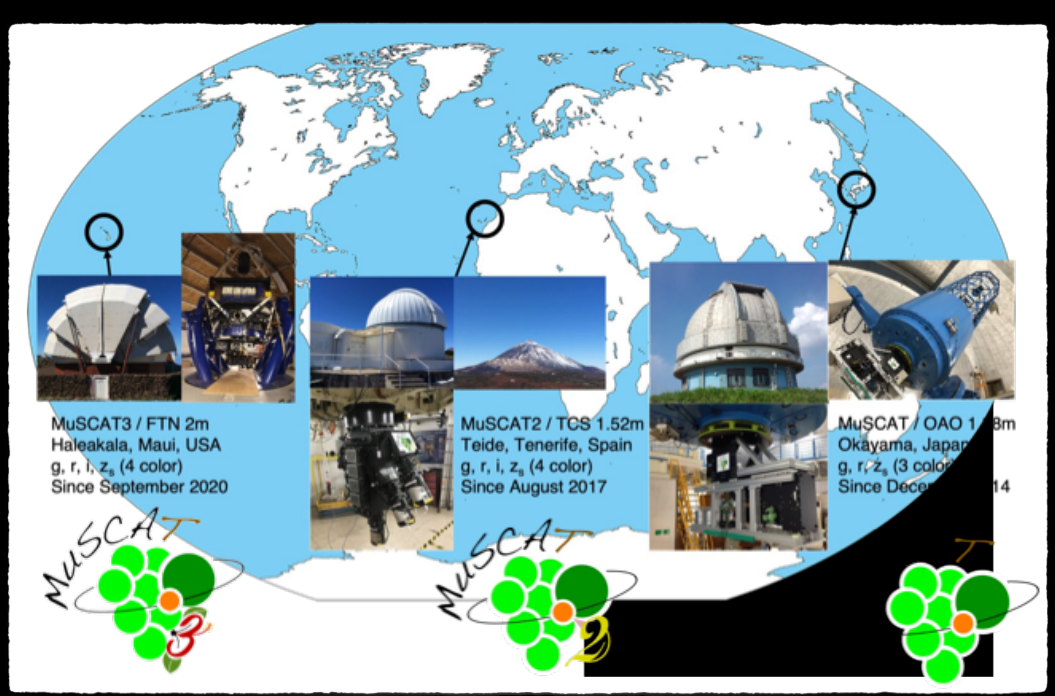




Tinetti+ (2022)

Follow-up from Ground with Photometry

Multicolor Simultaneous Camera for studying Atmospheres of Transiting exoplanets (MuSCAT)

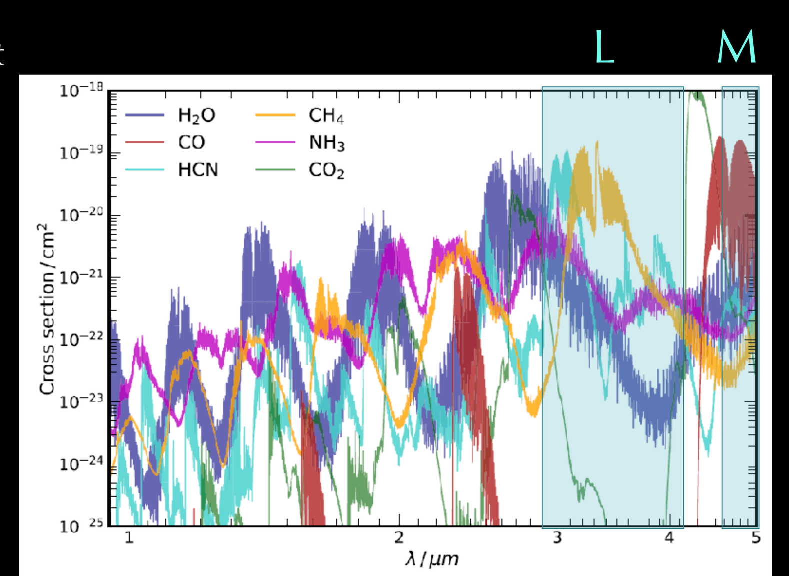


- Three- or four-channel simultaneous imagers in the optical on 1.5 to 2-meter telescopes in three locations in the north hemisphere and one location in the south hemisphere.
- The first MuSCAT was installed on the 1.88cm telescope at Okayama in 2014 and has identified 20+ transiting exoplanets.

Contribute to identifying new exoplanets, measuring planetary masses via TTV, constraining cloudiness, etc.

Need for Thermal Infrared High-res Spectroscopy

- A powerful tool to characterize low-temperature exoplanet atmospheres
- Not well-studied because
  - technically challenging relative to NIR due to the large thermal background and telluric absorption
  - few high-resolution (R > 50000) spectrometers on 8-meter class telescopes
- Complementary to low- to mid-resolution spectroscopy with JWST, Ariel, etc.
- Interesting molecules
  - CH4 … major carbon-bearing molecules at low temperatures < 1000K
  - C_2H_2, HCN … probe photochemistry
  - PH_3, SiH_4, H_3O+ etc. … potential markers for rocky and habitable planets
- Capable of measuring wind and rotation velocities

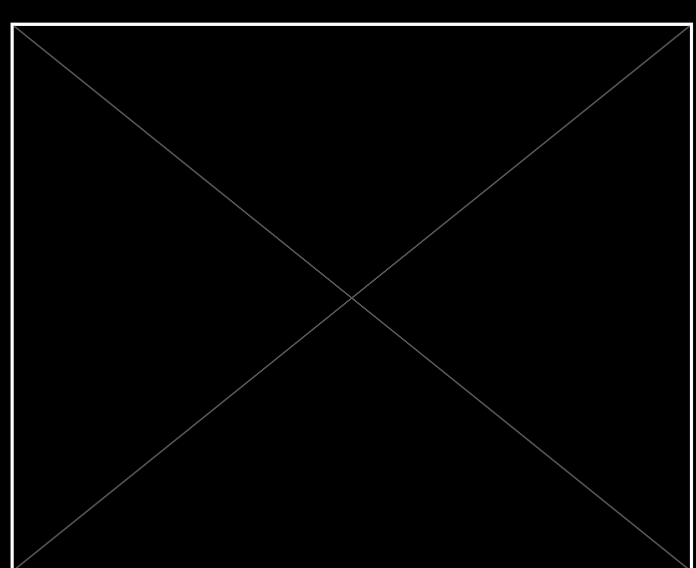


1000K, 0.1 bar, Gandhi+ (2020)

Follow-up from Ground in the Infrared

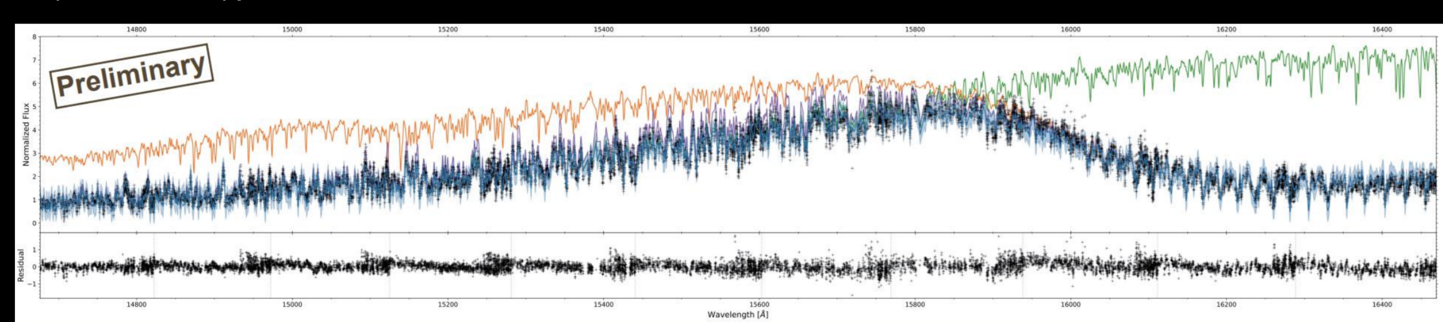
Thermal infrared Spectrometer for HIResolution characTerization (TSHIRT) for Subaru

- Single-mode fiber link, diffraction-limited spectrometer
- Spectral resolution > 70 000
- Spectral coverage: 2.9-4.2 μm (baseline), 1.9-2.4μm, 4.4-5.0 μm
- Simultaneous target + sky observation for precise background subtraction
- Sky background can be reduced thanks to a single-mode fiber
- Detector: 5 μm cut-off H2RG
- High-contrast spectroscopic capability combined with Extreme-AO (AO3000 or SCExAO)
- Cost: ~100MYen
- Operation from 2028 (?)



Synergy with CfCA on GPU Computing for Retrievals

- Bayesian analyses of exoplanet spectra are indispensable in modern exoplanet science.
- High spectral resolution requires powerful GPU environments because of
  - Needs to handle molecules with 10^8-10^9 molecular lines
  - Many (typically 10^5-10^6) samplings of the model spectrum to obtain the posterior distribution of the physical/ chemical parameters
- High quality GPU is (will be) essential for exoplanet characterization, potential synergy with CfCA
  - Latest GPU has 10,000+ CUDA cores and nearly PFLOPS per GPU, 80GB device memory/GPU, but will increase.
  - Easy to use for typical astronomers, unlike HPC.



High resolution retrieval of a subdwarf atmosphere (IRD), Courtesy of Y. Kawashima (ISAS)

Summary

- The space telescopes *JASMINE* and *Ariel*, which are scheduled for launch in 2028-2029, will bring about basic knowledge of the properties of exoplanets (e.g., planet radii, orbits, major atmospheric species, etc.) by discovering new planets and observing planetary atmospheres through the broadband spectroscopy for known planets, respectively.
- Meanwhile, high-dispersion spectroscopic follow-up of those planets in the mid-infrared using ground-based telescopes is needed to reveal more detailed planetary properties, including the detection of minor molecules and the rotation and planetary winds, which are key to understanding the diversity of exoplanets.
- A new infrared high-dispersion spectrometer installed on the Subaru Telescope would enable prompt follow-up observations of planets observed in advance by the space telescopes, maximizing scientific achievement.
- This will enable us to detect key atmospheric molecules, atmospheric winds, and planetary rotation to reveal the nature and dynamics of planetary atmospheres that are unable to be known from space-based observations.
- Such exoplanet characterization will bring significant implications for proposed space missions such as LAPYUTA and GREX-PLUS planned for launch in the 2030s.