Solar system-exoplanet synergies - general approach and programmatic landscape

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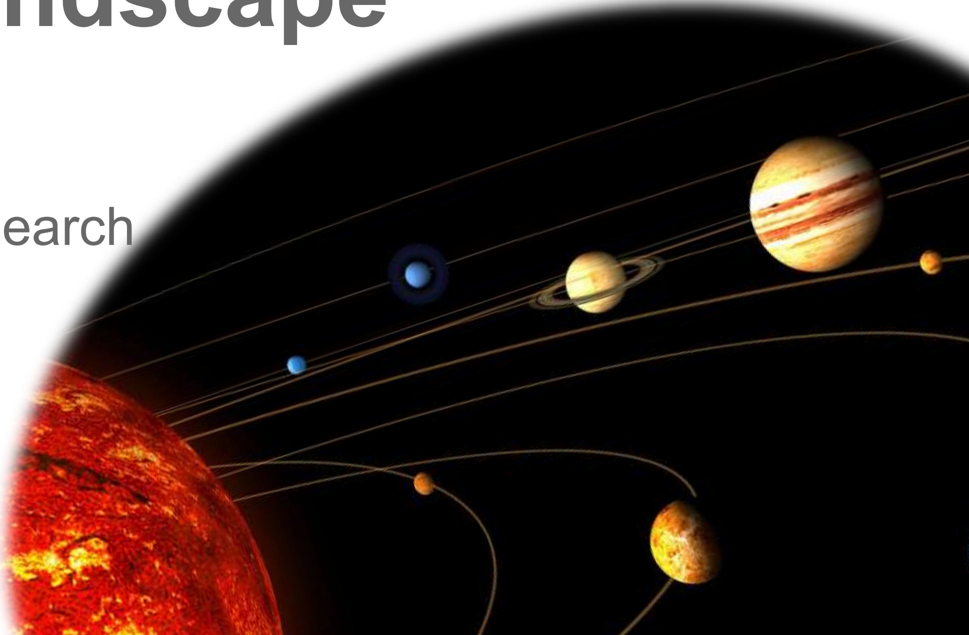
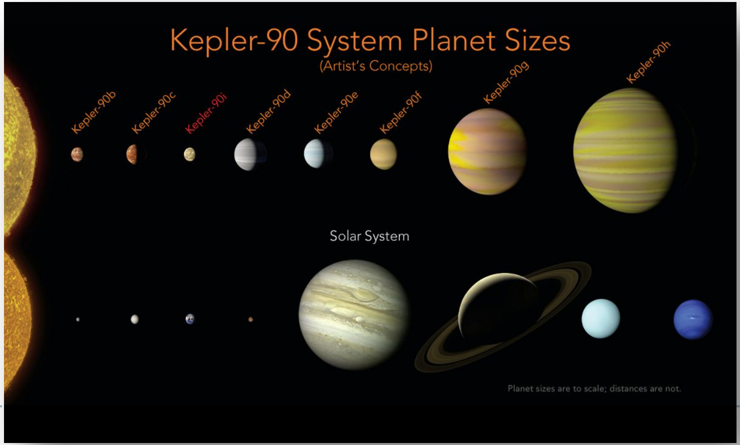
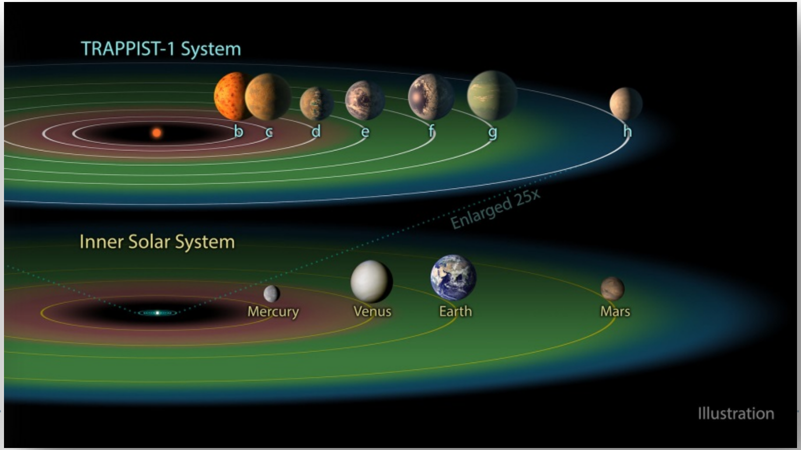


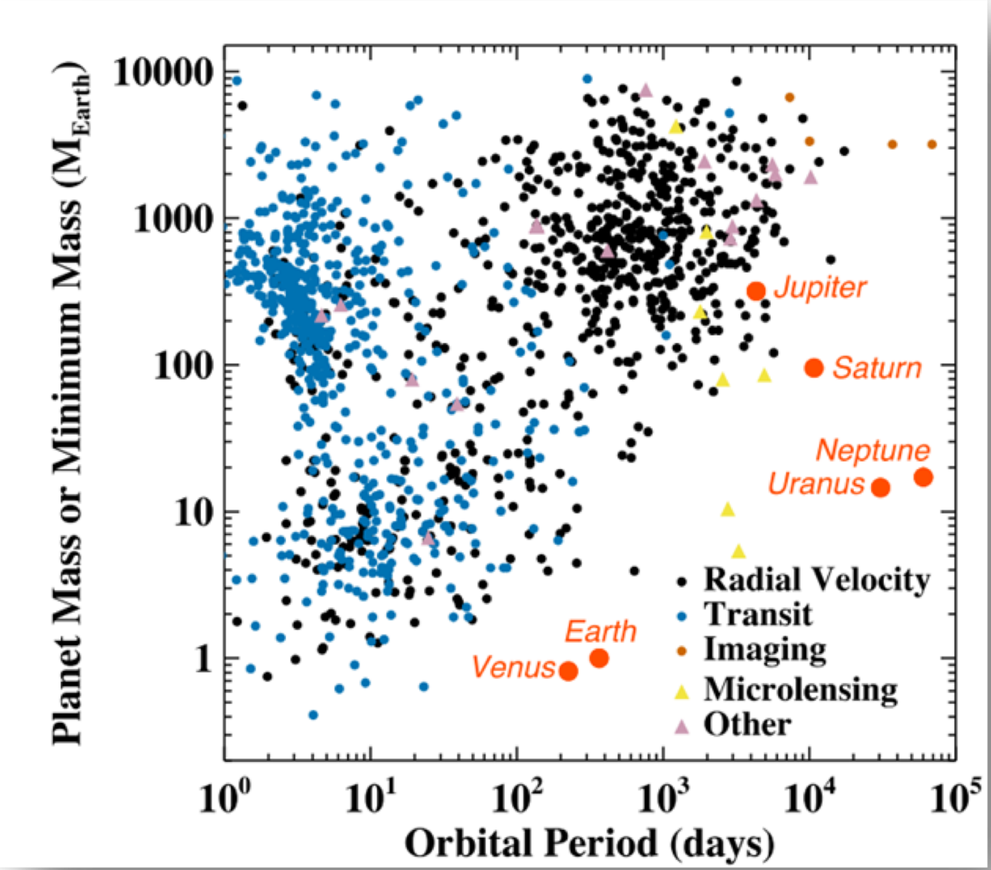
DLR

Overall Science Drivers

- What is the origin of planetary systems?
- How does their formation scenarios produce the diversity of their architectures?
- How well do we understand the diversity of their constituting objects?
- How do planets and planetary systems work?
- Where and under which conditions does their evolution lead to the emergence of potentially habitable worlds?
- How to search for and recognize life in these habitable worlds?







→ The solar system provides `ground-truth` for the study of exoplanets

→ Remote sensing, in situ, sample return

→ Exoplanets provide statistics over a wide parameter range

→ Remote sensing

A hot terrestrial planet in the solar system

Mercury

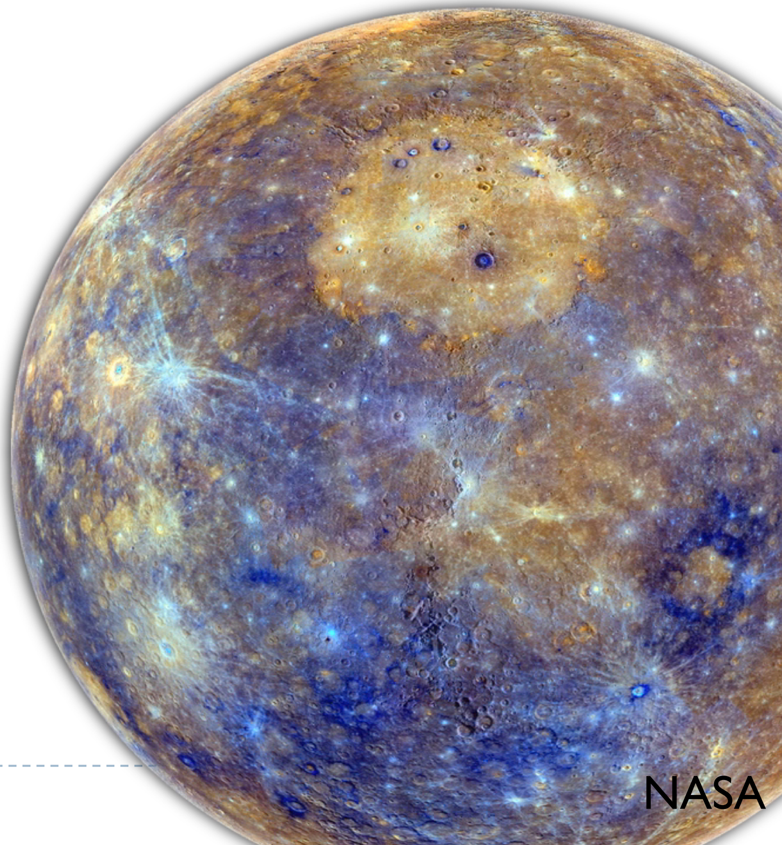
→ The hottest terrestrial planet in the solar system

→ Analogue for hot exoplanets

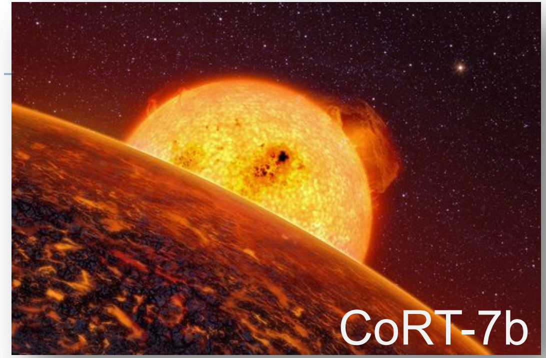
BepiColombo (ESA Cornerstone mission)

Launch: 2018,   Arrival: 2025

- Interior structure and composition
- Surface processes, such as cratering, tectonics, polar deposits and volcanism
- Exosphere
- Magnetosphere



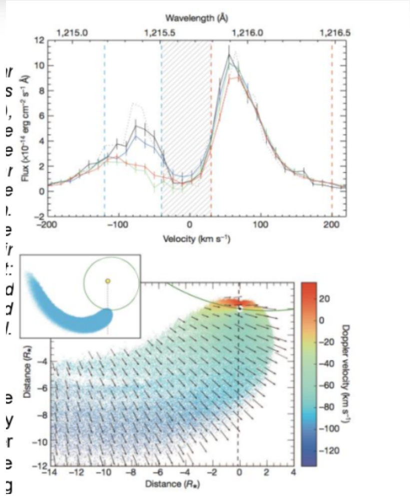
Hot terrestrial planets



Short period planets, including periods < 1 day

Science questions:

- What are their formation processes, e.g. the role of migration? Are they stripped cores of gas planets? The role of collisions?
- What are their bulk compositions, atmospheres and exospheres?
- The role of tides and resonances on their evolution?
- Interactions with the stellar magnetic field and wind?

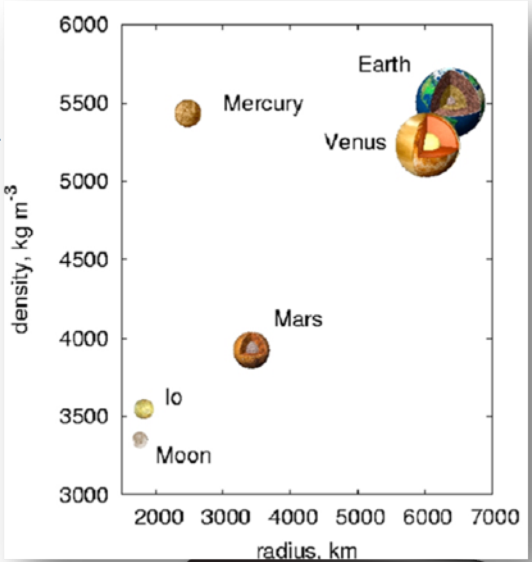


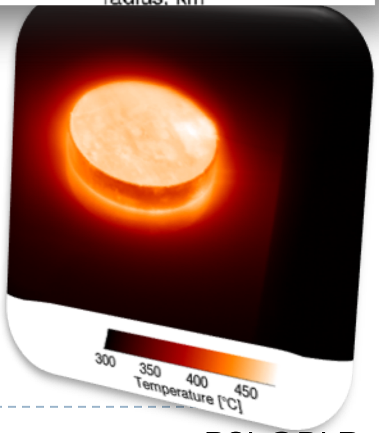
Ehrenreich 2015

Hot terrestrial planets

Future needs:

- Complete exploration of parameter space (orbit, size, mass, densities, ages, host stars):
  TESS, CHEOPS, PLATO, ARIEL, JWST, …
- Characterize composition and internal structure (e.g. Love numbers)
- Characterize outgassing atmospheres
  → atmo(exo)sphere characterization
  → loss processes and planet – star interactions
- Understand high temperature surface processing
  → lab work

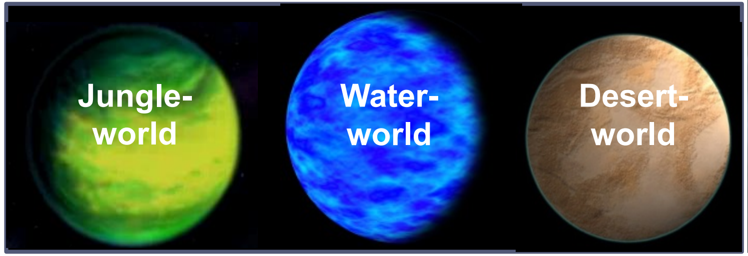


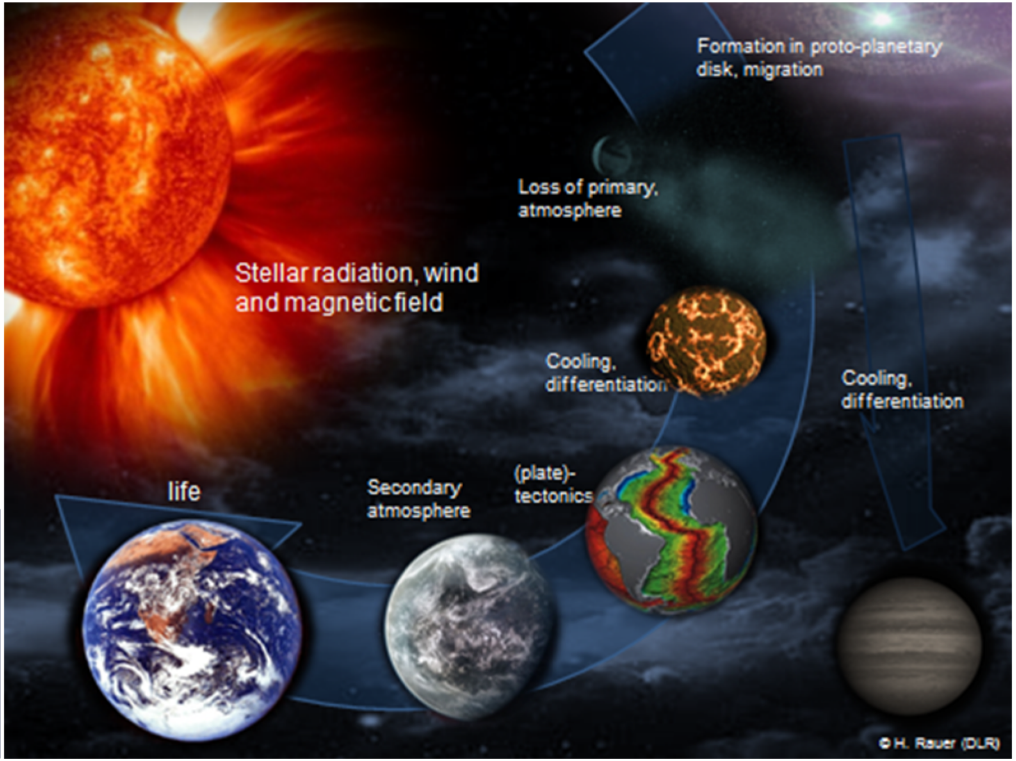


PSL@DLR

A typical habitable planet evolution?

Earth is the only inhabited planet we know.
BUT habitable planets could be very different from Earth, e.g. in their temporal evolution.





Venus

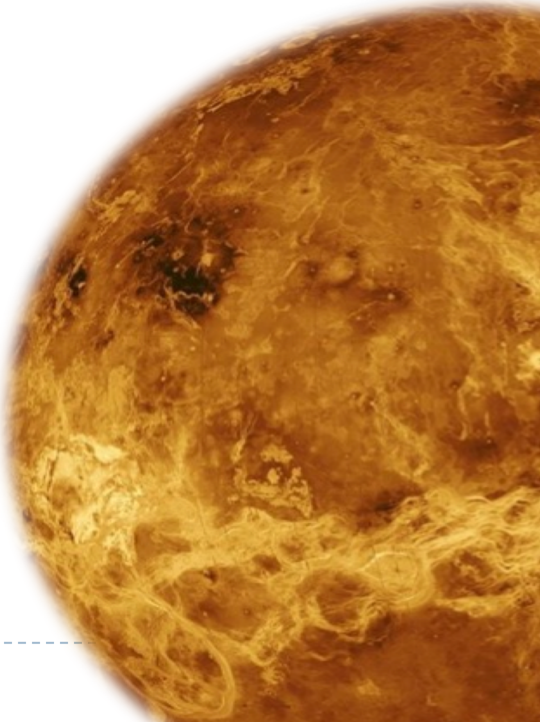
→ **What lessons can be learned for the evolution of Earth?**
→ **Understand similarities to warm terrestrial exoplanets: impact of stellar distance and geophysical effects (runaway greenhouse, no plate tectonics, …)**

Science themes:

- understand Venus' geologic evolution
- find evidence for past water.

Addressed by a number of missions **under study**

- **2025/26** launch: **VERITAS** (NASA Discovery candidate)
  - Venus Emissivity Mapper: surface emissivity
  - Venus Interferometric Synthetic Aperture Radar
- **2025** launch: **Venera D** (Roscosmos, study)
  - Elements: orbiter, lander and balloon
- **2032** launch: **ENVISION** (ESA M5 candidate)
  - S-band radar and a subsurface radar sounder
  - Emissivity mappers (UV to IR)

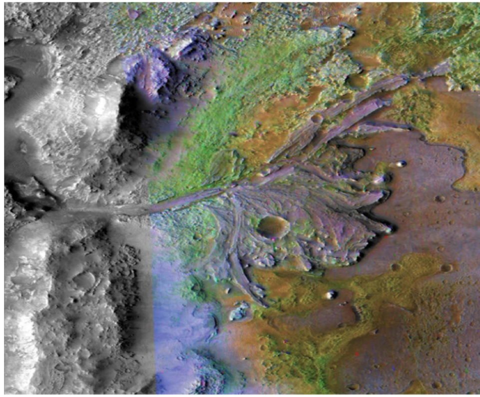


Mars

→ **Planet at the outer edge of the habitable zone**
→ **Potentially habitable at young ages**

- Science goals:
  - biosignatures of past Martian life
  - characterise the water and geochemical subsurface distribution
  - Study surface environment
  - better understand the evolution and habitability of Mars

- Instruments include: exobiology laboratory suite, sub-surface core drills, Raman Laser Spectrometer, Infrared spectrometer, multi-spectral imager, neutron spectrometer,…



NASA/JPL/JHU-APL/MSSS/ Brown University

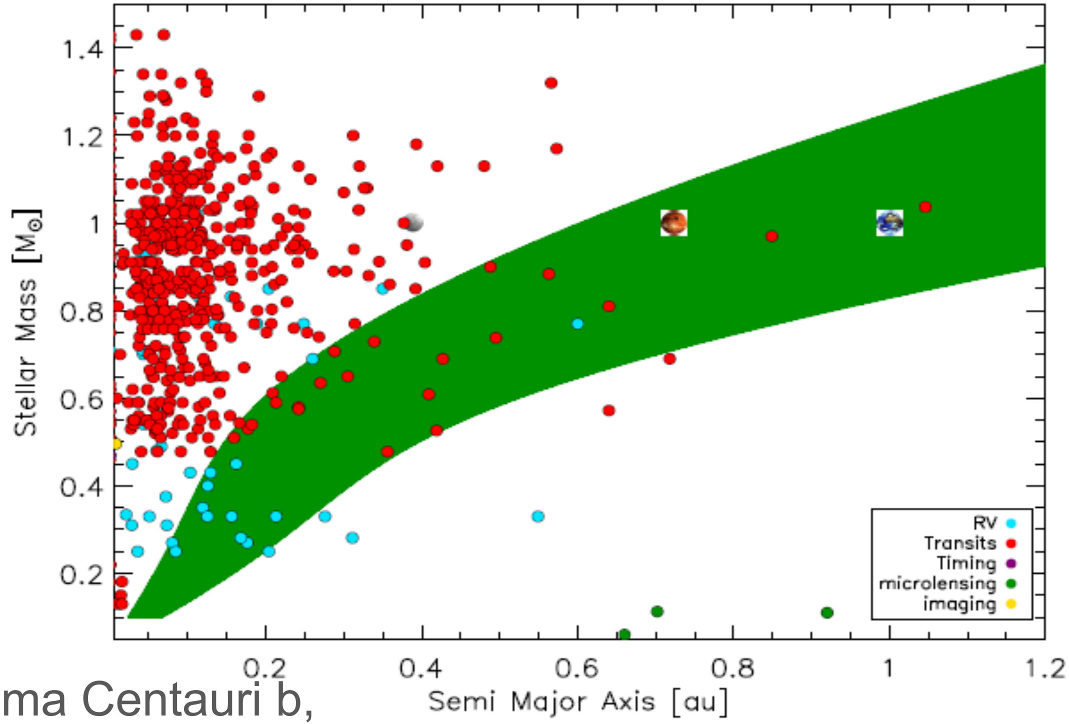
Future plans for Mars and its Moons

2020s

• **Hope Mars Mission** (United Arab Emirates):	study atmospheric loss
• **Mars 2020 Rover** (NASA):	collect samples of rocks, minerals for later return
• **ExoMars Rover** (ESA, Roscosmos):	evidence of past or present life
• **Mars Global Remote Sensing Orbiter, Lander, and Small Rover** (China's National Space Science Center)	orbiter, a lander, and a rover
• **Mars Terahertz Microsatellite** (Japan):	oxygen isotope ratios
• **Mangalyaan 2** (India):	orbiter, maybe lander, rover
• **Martian Moons Exploration** (MMX) (Japan): with CNES/DLR rover	orbiter, Phobos rover and sample return

…→ **manned missions!**

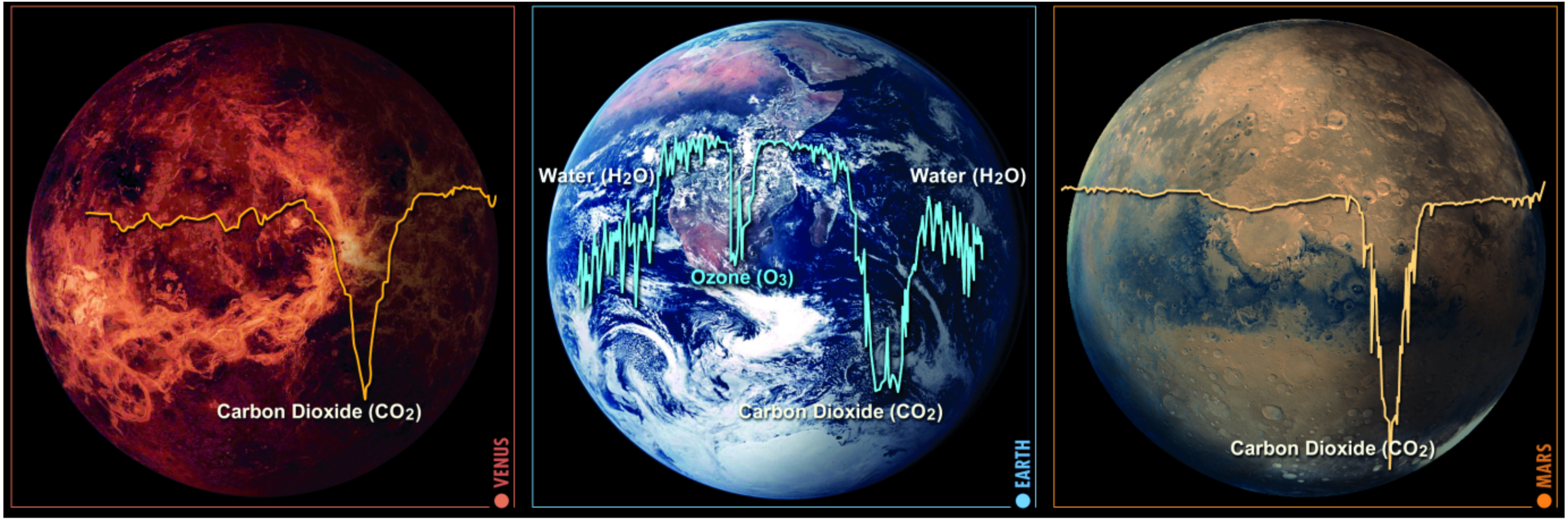
The 2nd Earth?



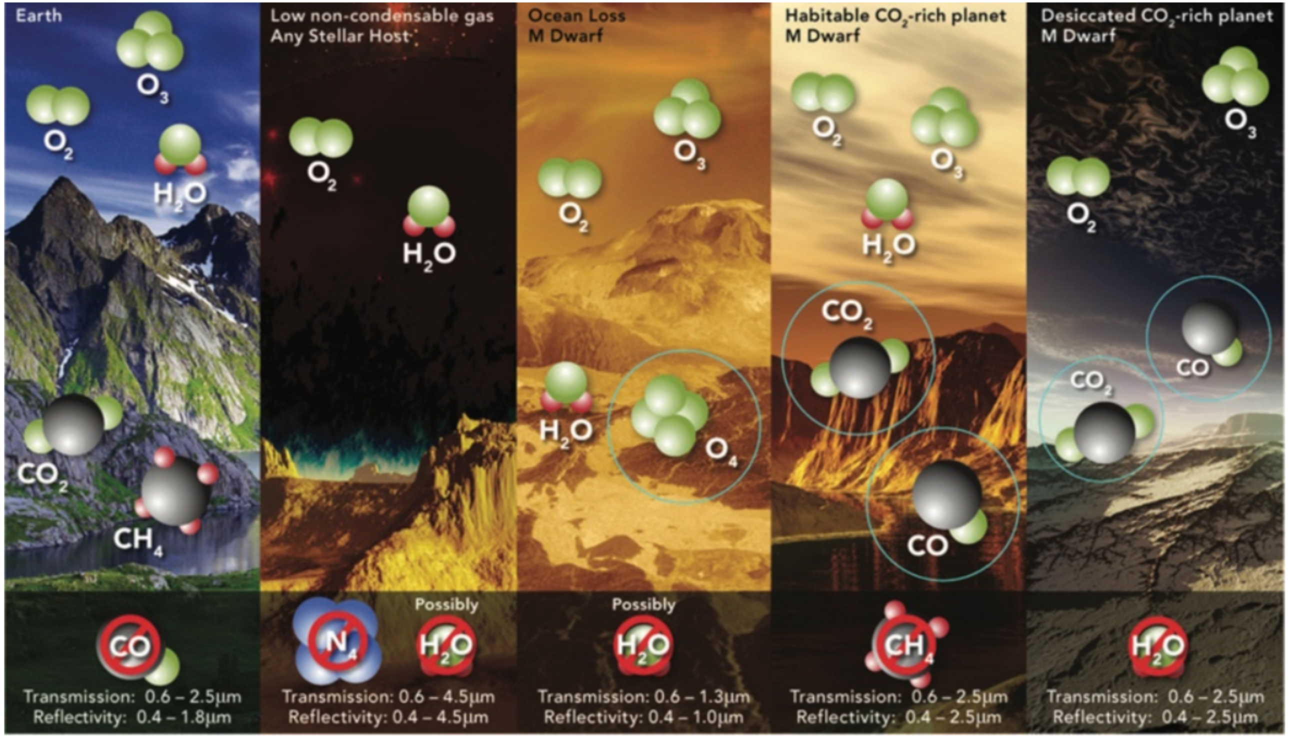
- How many habitable planets around solar-like stars?
- Are there habitable planets around M dwarf stars?
- Do all habitable planets develop in a characteristic way?
- What are good biosignatures?

Proxima Centauri b, TRAPPIST system

Habitability indicators and biosignatures

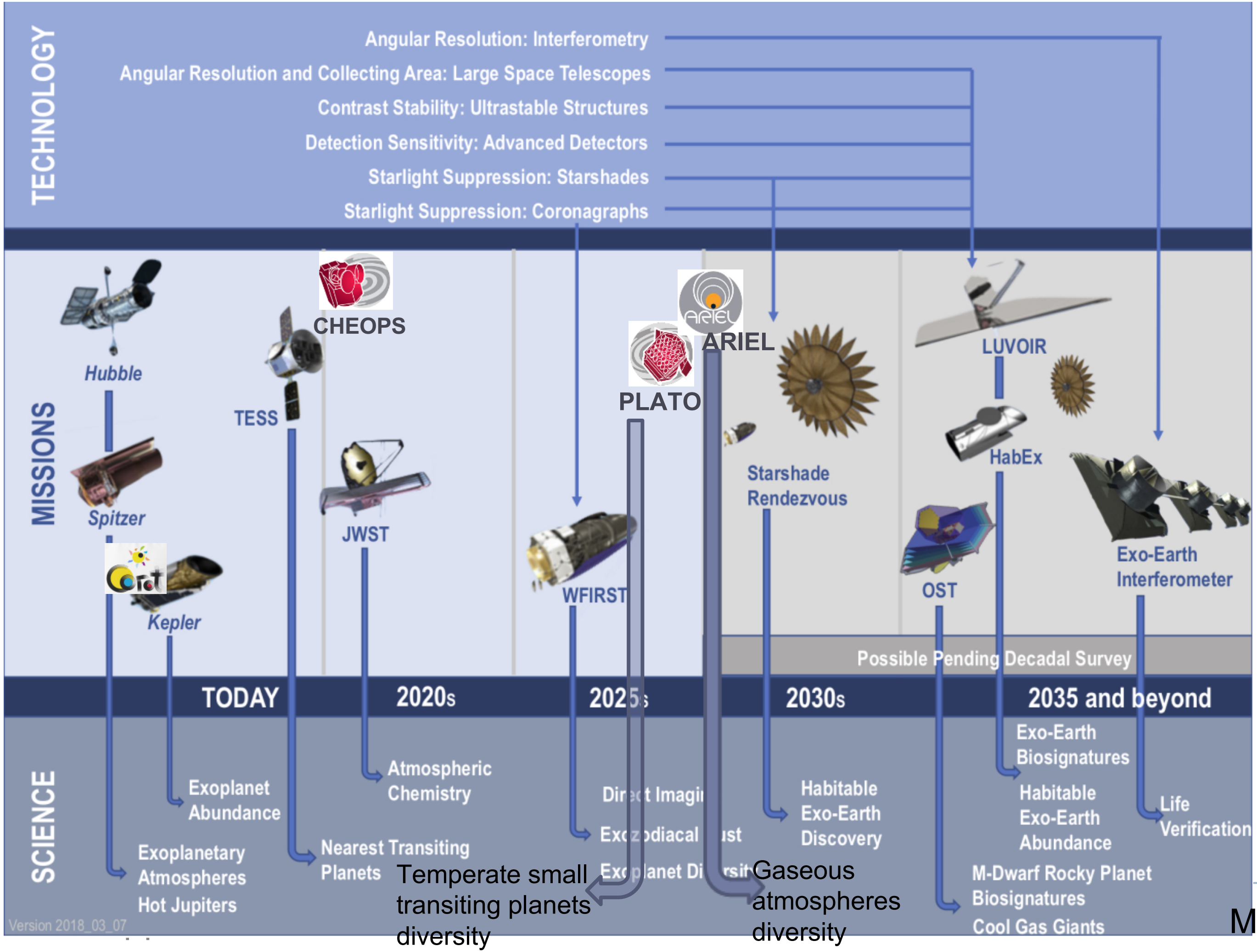


Habitability indicators and biosignatures



Meadows et al., 2018

- Need to separate biotic from abiotic production
- Spectroscopy in optical, near- to mid-IR range



From characterization of basic parameters to atmosheres and biosignatures

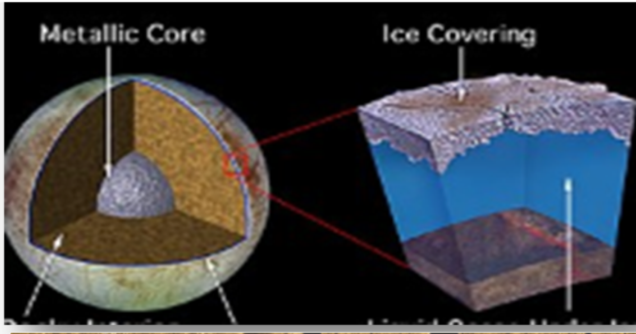
Modified from NASA/JPL/Caltech

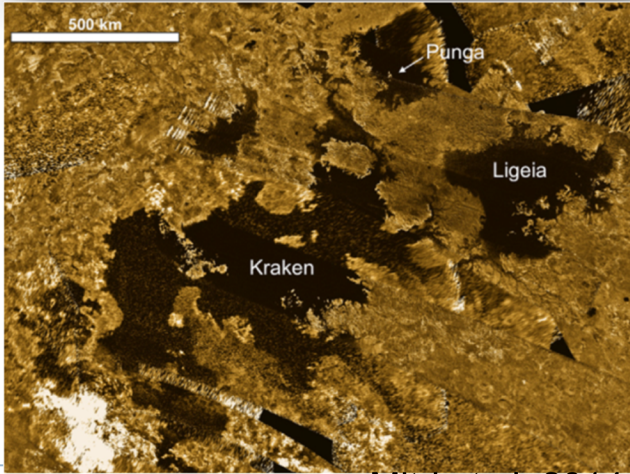
Other habitats: Icy moons and water worlds

- Can we detect organic molecules in sub-surface oceans?
  → determine saltiness, redox state and general composition of oceans
- Characterize the energy source maintaining the ocean, determine duration of oceans (since when and how long)
- Characterize interactions of ocean with surface and with interior
- Detect life

- Sub-surface oceans on icy moons → can sub-surface oceans exist also on an (exo)planet-size scale?

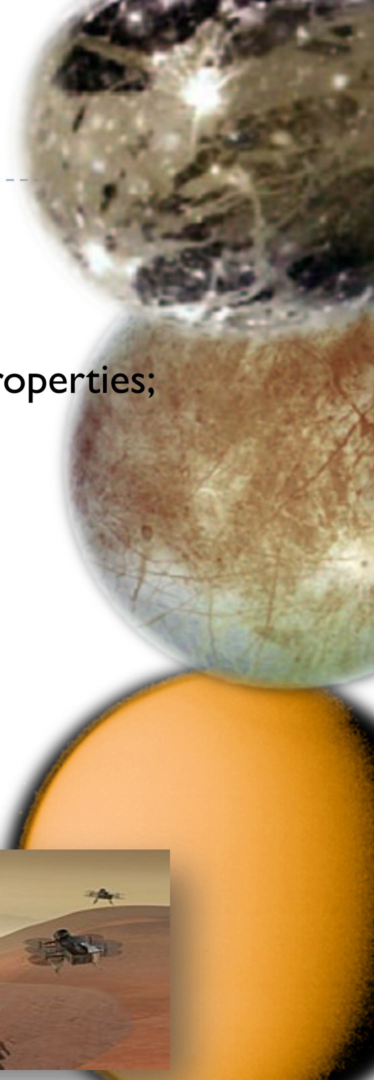
- What characterizes cool icy terrestrial planets?





Mitri et al. 2014

Missions to icy moons



JUICE (ESA), launch 2022, arrival 2029, Ganymed 3032
Ganymed science:

- Characterisation of the ocean layers, detect subsurface water reservoirs;
- Topographical, geological and compositional mapping of the surface, physical properties;
- Internal mass distribution, dynamics and evolution of the interiors;

Europa Clipper (NASA), launch 2023, arrival 2026
Europa science

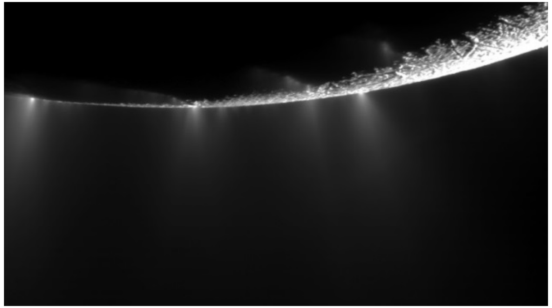
- Ice shell and ocean: Confirm the existence, characterize nature
- Composition and surface geology

Dragonfly mission study (NASA, New Frontiers, launch 2024/25)
Titan science

- mobile robotic rotorcraft landers on Titan
- complex carbon-rich chemistry, and habitability
- liquid water and hydrocarbons on surface

The outer solar system cont.

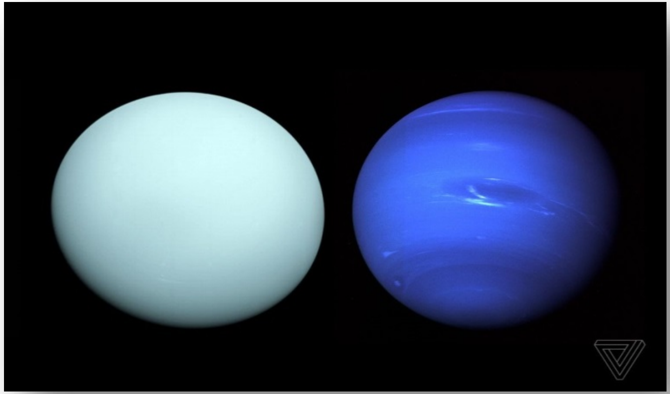
- **Enceladus** Life Finder mission proposal to NASA New Frontiers (not selected)
- Concept: orbit Saturn and fly through Enceladus's geyser-like plumes
- Determine plume composition and indications for sub-surface organics in ocean



Uranus/Neptune?

Potential future targets: ice giants Neptune or Uranus and their moons

- Many exoplanets are in the size range of Neptune and Uranus.
- exploring those planets in our solar system helps understanding how our system developed as well as understanding exoplanet systems



Missions to the Moon under development

2019

- Beresheet: private lander, magnetism
- Chandrayaan-2, lander, rover
- Lunar Scout, private lander
- Chang'e 5: sample-return

2020

- EM-1: orbit + 13 cubesats
- Peregrine, private, lander + 3 rover
- Chang'e 6, sample-return
- ALINA, private, lander, rover
- Korea Pathfinder Lunar Orbiter

2021

- SLIM, lander, rover
- Luna 25, explore natural resources

2022

- Luna 26, explore natural resources

2023

- Luna 27, explore natural resources
- Chang'e 7, south pole lander (study)

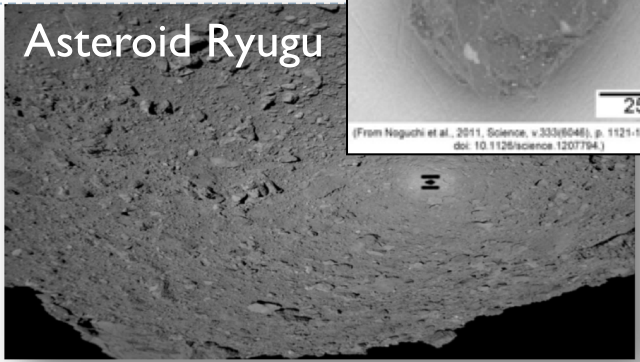
Manned missions…

The beginning: Small Bodies

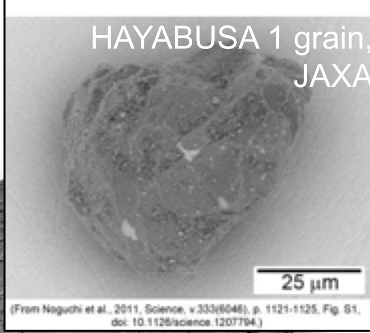
→ „ground-truth“ for the earliest phases of solar system formation

Science themes

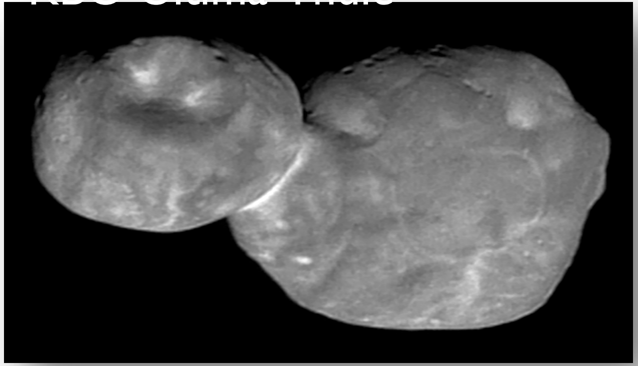
- Proto-planetary material
- Gas/dust ratios
- Isotopic ratios
- Mineralogical, chemical compositions, heterogeneity, mixing of different temperature regimes
- Water and volatile fractionation, and devlivery in the solar system
- Migration and collisional history of planetesimals



JAXA/UTokyo/Kochi U./Rikkyo U./Nagoya U./Chiba Ins. Tech/Meiji U./U. Aizu/AIST



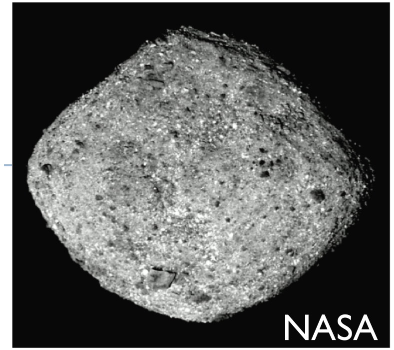
(From Noguchi et al., 2011, Science, v.333(6046), p. 1121-1125, Fig. S1, doi: 10.1126/science.1207794.)



NASA/JHU-APL/Carnegie Inst. of Washington

LUCY and PSYCHE

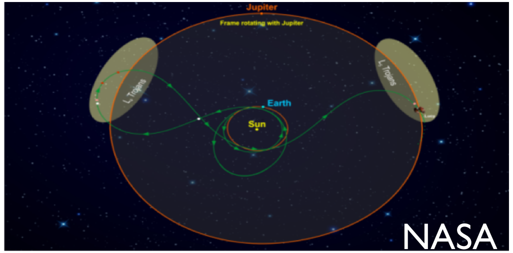
Hayabusa2, JAXA, return asteroid sample in 2020



OSIRIS-Rex, NASA, return asteroid sample in 2023

LUCY, NASA, launch 2021

- Flyby main belt asteroid (52246) Donaldjohanson
- Explore Trojans of Jupiter:
    - Fly-by 4 Trojans in L4 point
    - Explore double-asteroid in L5



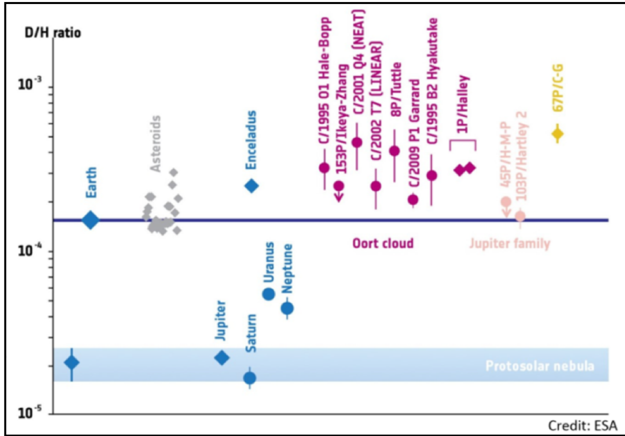
PSYCHE, NASA, launch 2022

- Study M-type asteroid, potential iron core of proto-planet

CometInterceptor, ESA, launch 2028

- Fly-by long-period comet

Future: Comet sample return?



Summary

Leading scientific themes for the future include:

- Characterizing the processes for habitability and detect habitable conditions
- Detect past or present life in the solar system or beyond

Planned solar system missions include:

- orbiters
- Landers
- Rovers
- Drills
- Drones
- Baloons
- In situ analysis labs
- Sample return mechanisms

Exoplanet missions:

- Transiting planets investigations for atmosphere characterisation ongoing
- Direct imaging methods driver for future missions
- Large-scale telescopes
- Star shades, coronagraphy, interferometry
- Cube sats for dedicated applications on bright objects under study

It is difficult to predict the future…

Made in 1900