

**Stephen Kane** 



- Lecture 1: The Fundamentals of Planetary Habitability
- Lecture 2: Habitability Lessons Learned from our Sister Planet
- Lecture 3: Stars and the Planetary Energy Balance
- Lecture 4: The Habitable Zone and Orbital Dynamics

• Available from IOP Publishing here:



• I have also made it available here:



• Also recommend "Planetary Sciences, Updated Second Edition" by Imke de Pater & Jack Lissauer, "Principles of Planetary Climate" by Raymond Pierrehumbert, and "Atmospheric Evolution on Inhabited and Lifeless Worlds" by David Catling & James Kasting.

AAS | IOP Astronomy

# Planetary Habitability

**Stephen R Kane** 



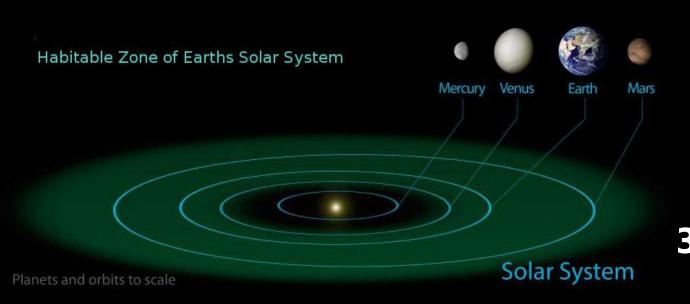


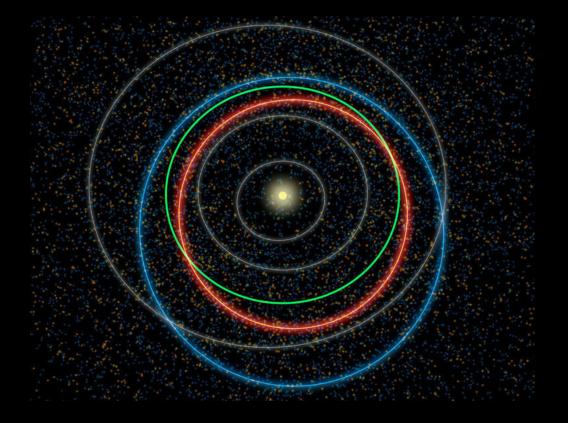
# The Stages of my Planetary Research



#### 1. Discovering planets orbiting other stars

### 2. Studying planetary orbits and atmospheres





3. Habitable Zones and planetary habitability

30% GAS GIANT

The size of Saturn or Jupiter (the largest planet in our solar system), or many times bigger. They can be hotter than some stars!

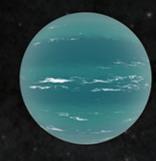
31% SUPER-EARTH

Planets in this size range between Earth and Neptune don't exist in our solar system. Super-Earths, a reference to larger size, might be rocky worlds like Earth, while mini-Neptunes are likely shrouded in puffy atmospheres.



4% TERRESTRIAL

Small, rocky planets. Around the size of our home planet, or a little smaller.



35% NEPTUNE-LIKE

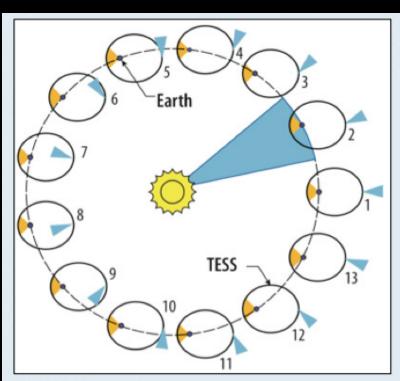
Similar in size to Neptune and Uranus. They can be ice giants, or much warmer. "Warm" Neptunes are more rare.

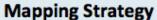
5000+ PLANETS FOUND



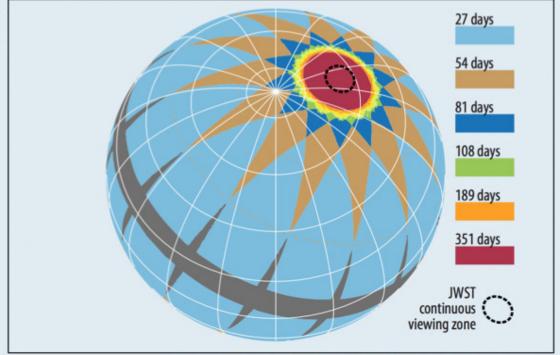
# Transiting Exoplanet Survey Satellite (TESS)

TESS is observing bright stars over the whole sky, enabling detailed follow-up.





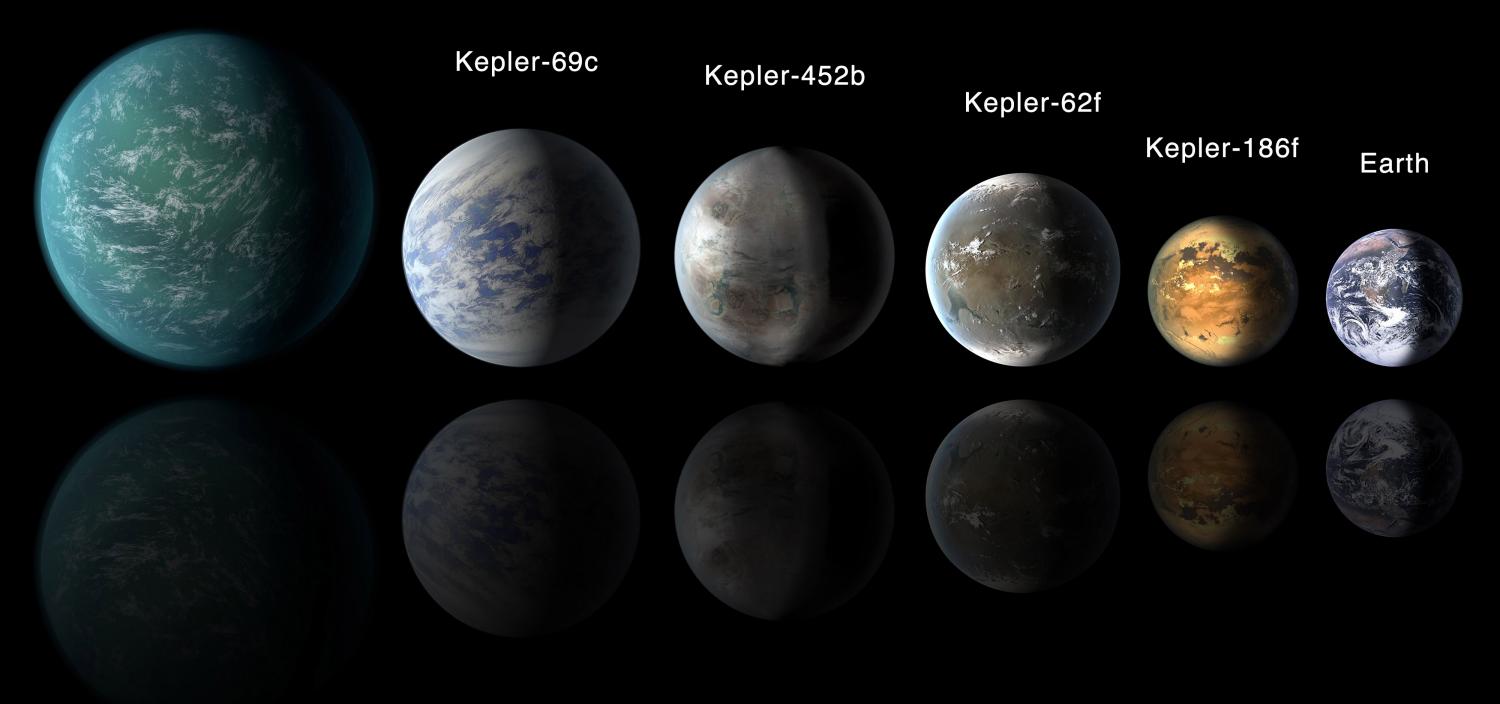
- · Stare and step strategy
- 26 total segments
- 13 per year
- Each segment mapped for 2 orbits ~= 27 days



#### **Survey Coverage**

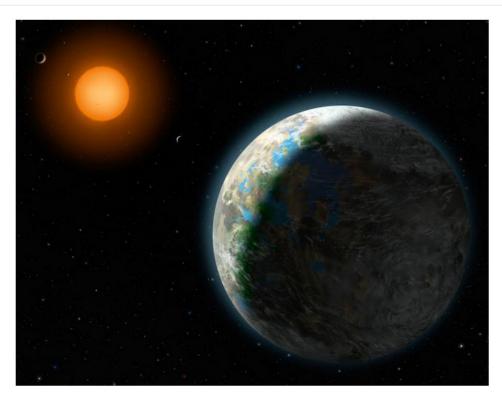
- 200,000 star coverage survey
- 10,000 star concurrent survey covering ecliptic poles

Kepler-22b



The occurrence rate of planets increases to smaller sizes.

#### NATIONAL GEOGRAPHIC



The new planet Gliese 581g bears Earthlike blues and greens in an artist's conception.

ILLUSTRATION COURTESY LYNETTE COOK

# First Truly Habitable Planet Discovered, Experts Say

Earthlike world in elusive "Goldilocks zone."

#### NASA Telescope Reveals Largest Batch of Earth-Size, Habitable-Zone Planets Around Single Star





This illustration shows the possible surface of TRAPPIST-1f, one of the newly discovered planets in the TRAPPIST-1 system. Scientists using the Spitzer Space Telescope and ground-based telescopes have discovered that there are seven Earth-size planets in the system.

Credits: NASA/JPL-Caltech

View this and many more images, as well as several videos, in an extensive multimedia gallery highlighting this discovery.

Academic rigor, journalistic flair

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Have we really discovered other "Earth-like" planets orbiting around other stars? Understanding what we do and do not know about exoplanets is the key to answering this question. ESO/L. Calcada/N

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In 1950, physicist Enrico Fermi famously asked, "Where are they?" as a kind of lament about the lack of observational evidence for alien intelligence in our universe. Today, the question is still asked in the context of the always-hoped-for discovery of other worlds like our own,







#### Earth-Like Planet? Not So Fast — Scientist Says to Watch Your Words

By Leonard David December 13, 2017 Science & Astronomy















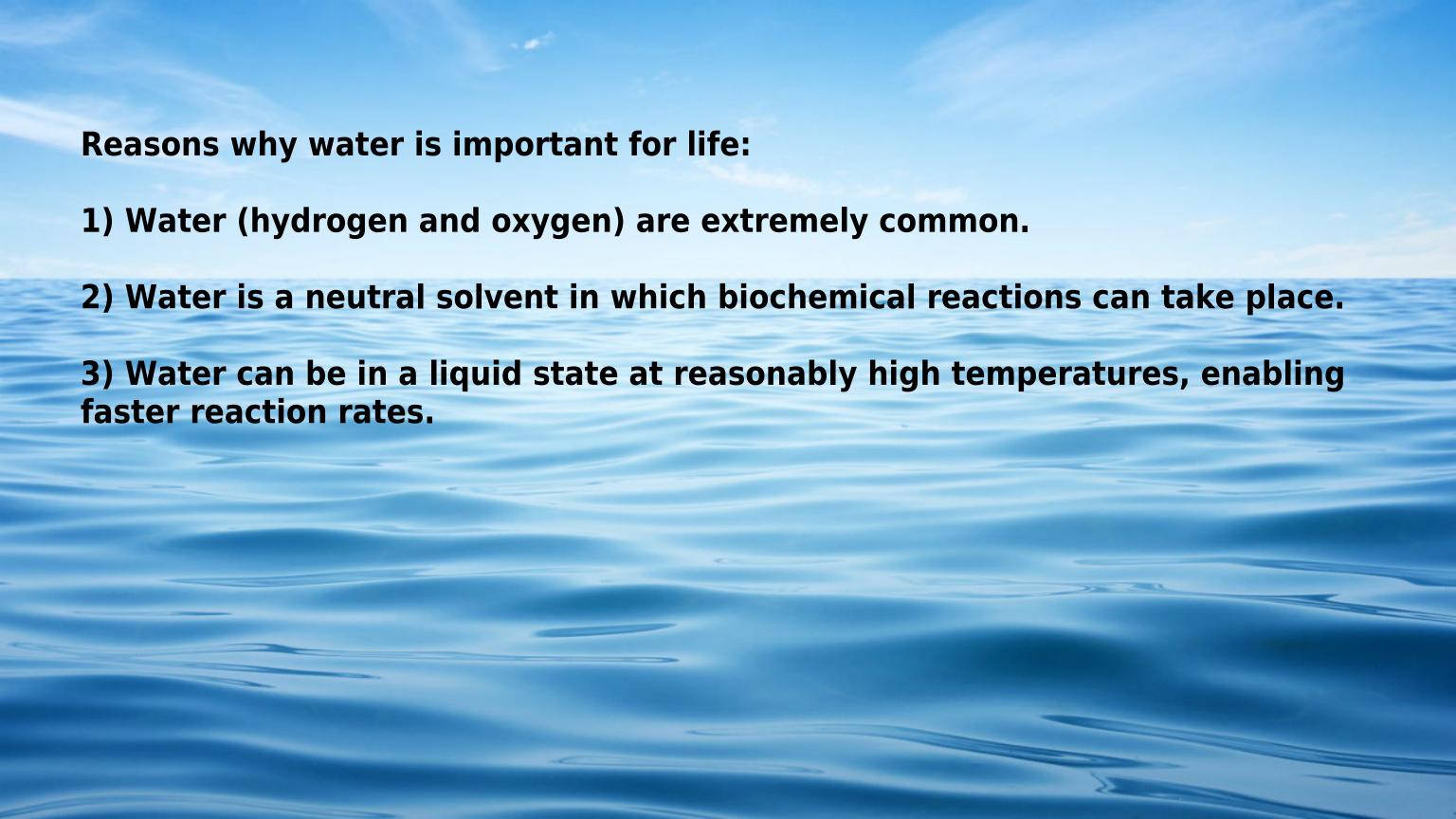
The art of exoplanet detection is on the upswing, and scientists are perhaps at the cusp of a watershed moment — detecting life on other worlds.



# What is planetary habitability?

- Planetary habitability is fundamentally an assessment of the energy balance at the planetary surface.
- What makes a planet habitable? Which factors dominate?
- What measurements do we need to make?
- What can we do with these measurements?
- How can we apply these principles to planets inside and outside of our solar system?
- Anthropic bias and the "anthropic principle".



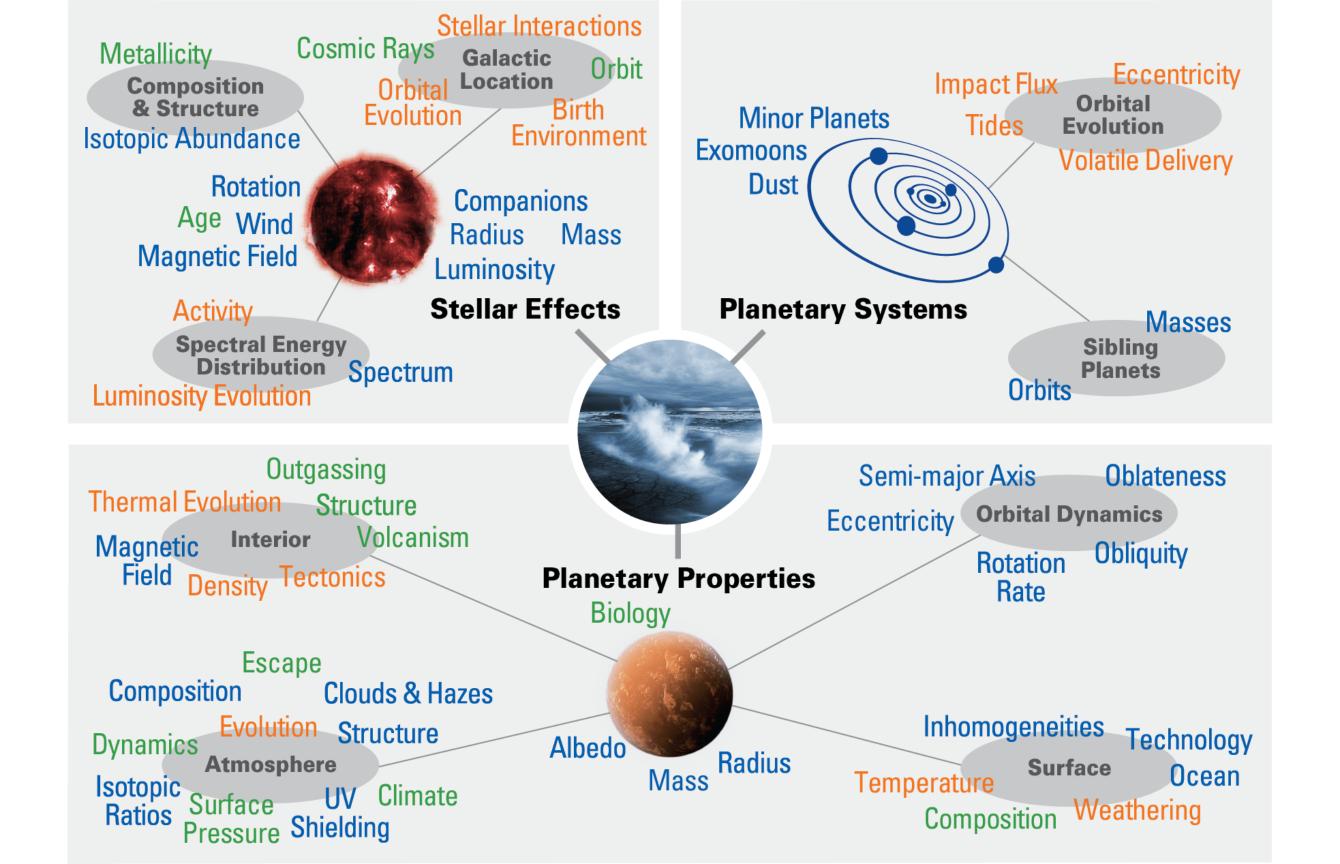


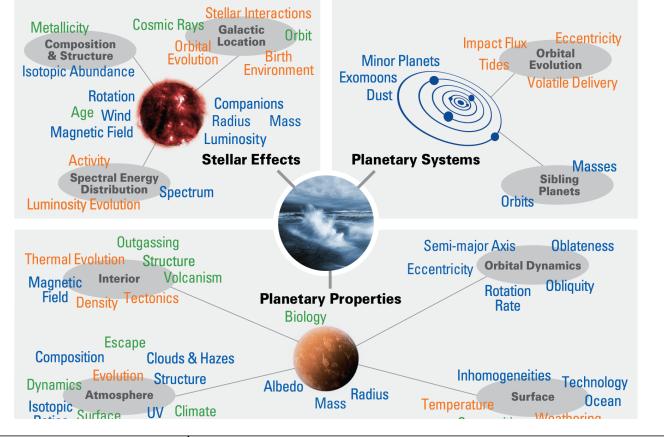
#### Reasons why water is important for life:

- 1) Water (hydrogen and oxygen) are extremely common.
- 2) Water is a neutral solvent in which biochemical reactions can take place.
- 3) Water can be in a liquid state at reasonably high temperatures, enabling faster reaction rates.

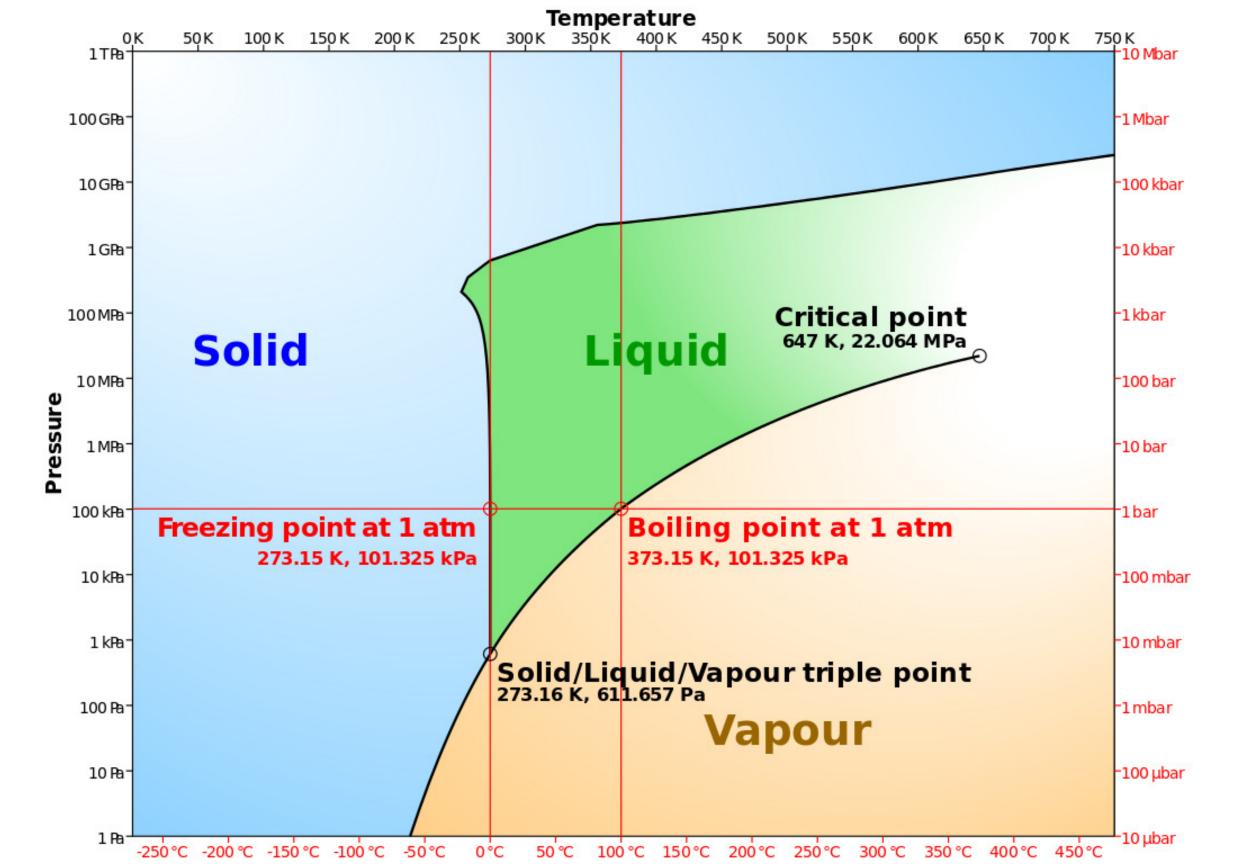
# Planetary habitability: The ability of a planet to retain surface liquid water.

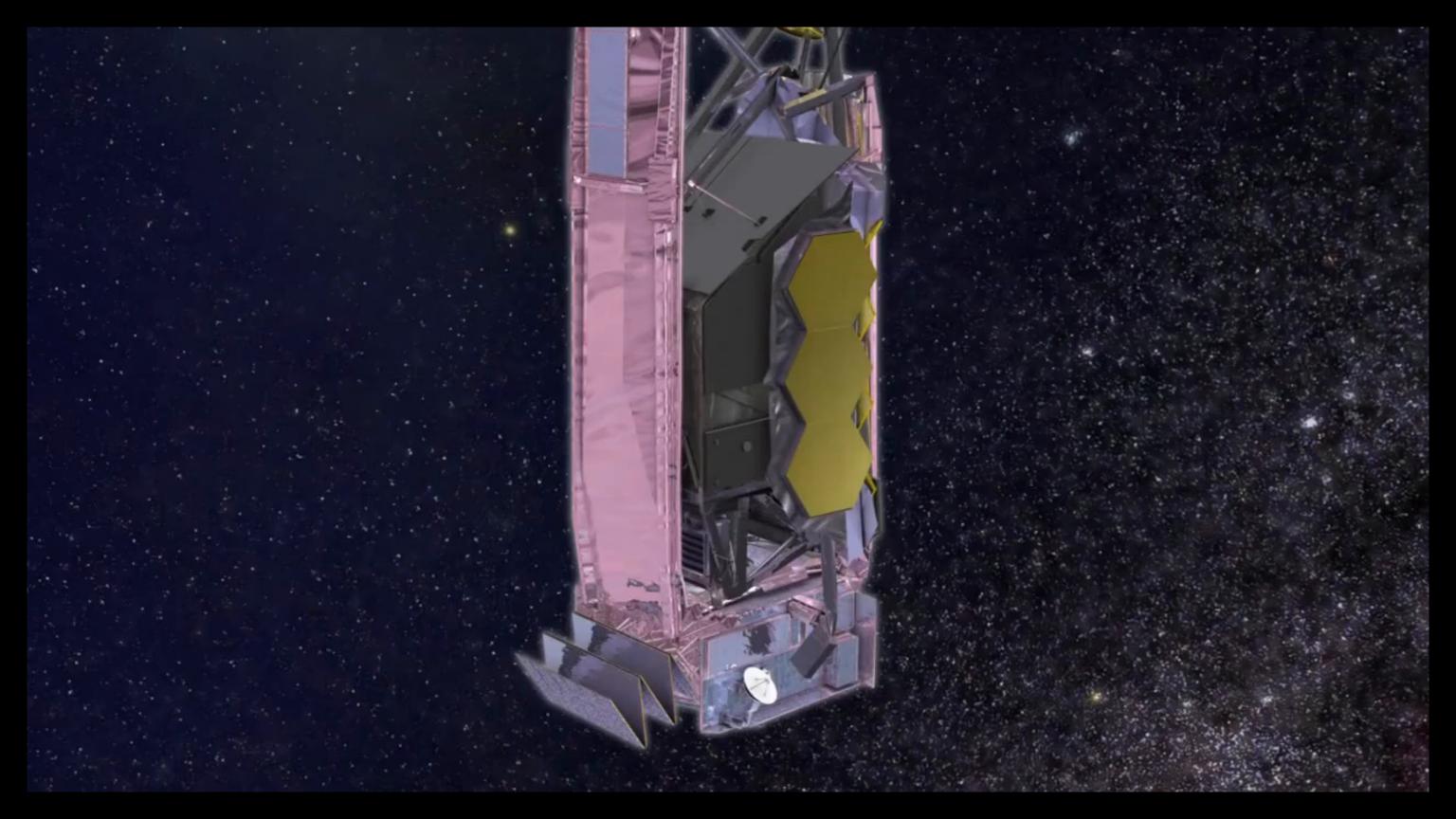
This creates a framework from which to quantify the energy budget of a planet. Importantly, this is applicable to large distances for planets that we will (almost certainly) never visit!





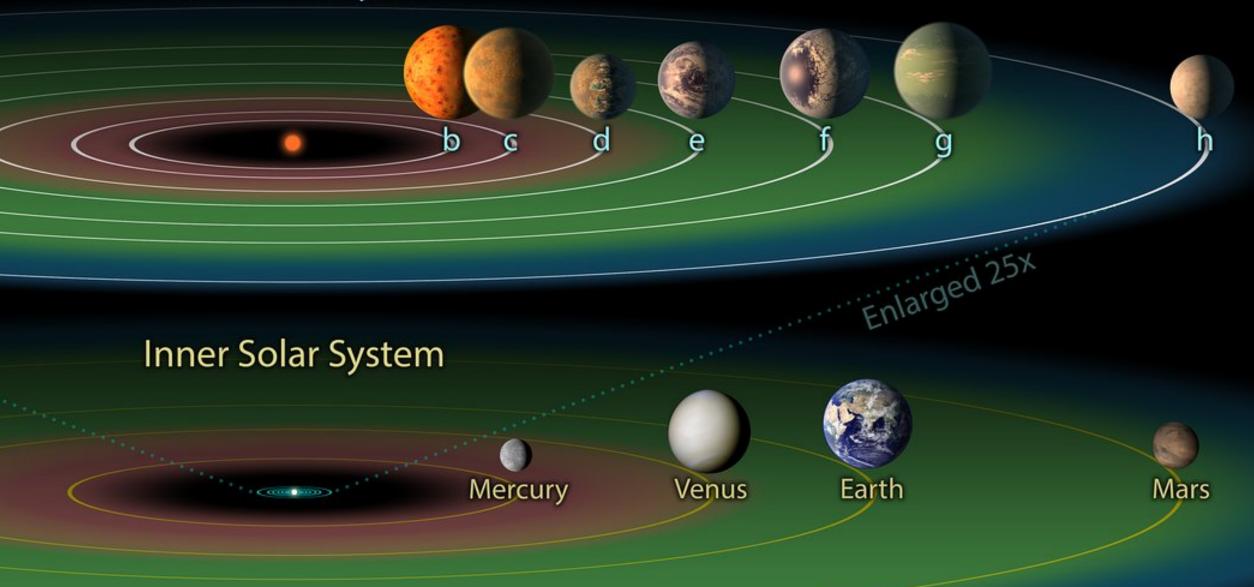
Category	Habitability Factors		
Stellar Astrophysics	Mass, Radius, Effective temperature, Luminosity,		
	Composition, Rotation rate, Activity, Age, Multi-		
	plicity		
Planetary Properties	Mass, Radius, Bulk density, Albedo, Atmo-		
	spheric composition, Atmospheric dynamics, Pressure-		
	temperature profile, <b>Age</b>		
The Planetary System	Multiplicity, Semi-major axis, Eccentricity, Argu-		
	ment of periastron, Orbital inclination, Rotation rate,		
	Spin-axis obliquity, Exomoons, Orbital evolution and		
	stability		





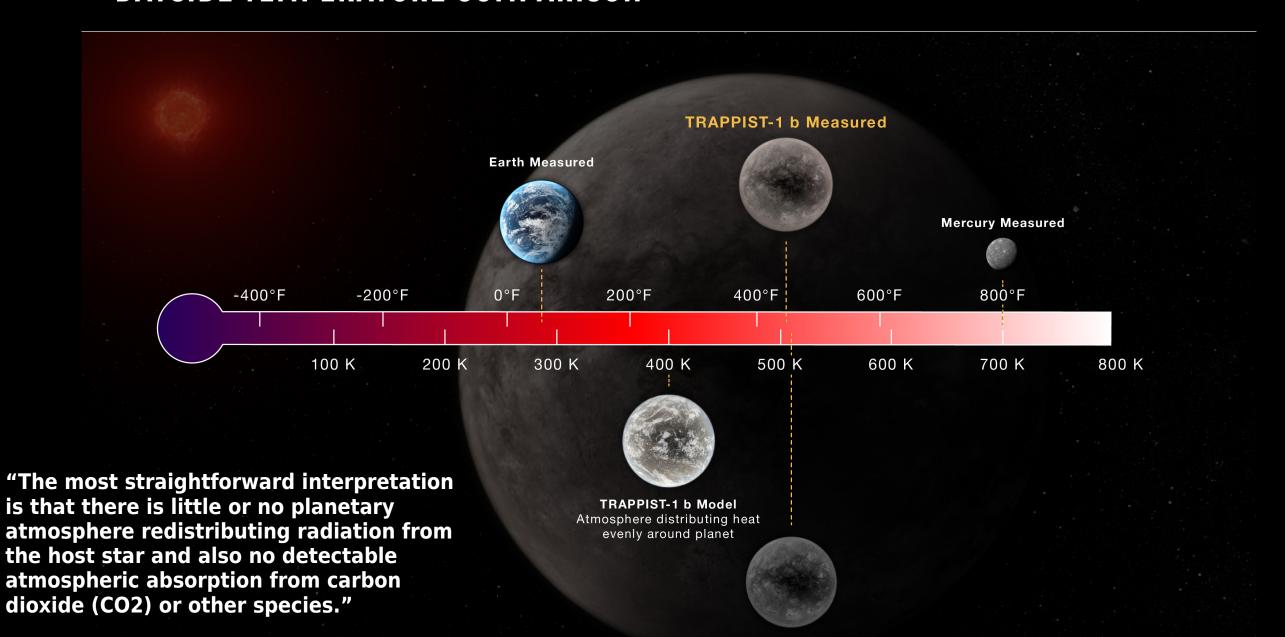


# TRAPPIST-1 System



#### MIRI | F1500W

# DAYSIDE TEMPERATURE COMPARISON

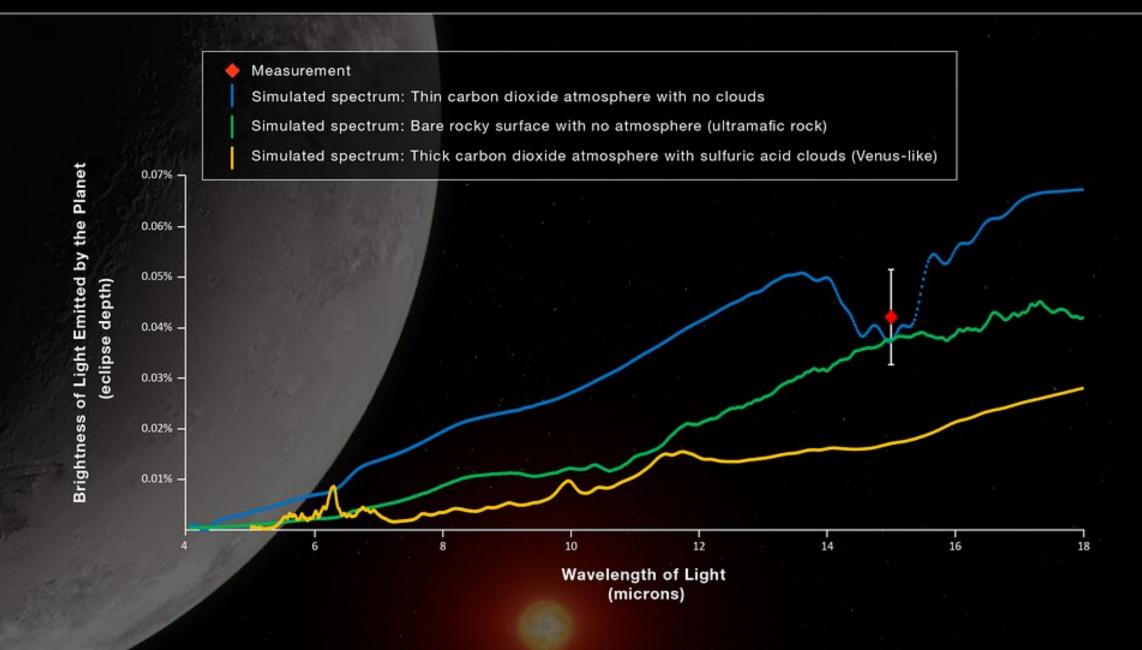


TRAPPIST-1 b Model

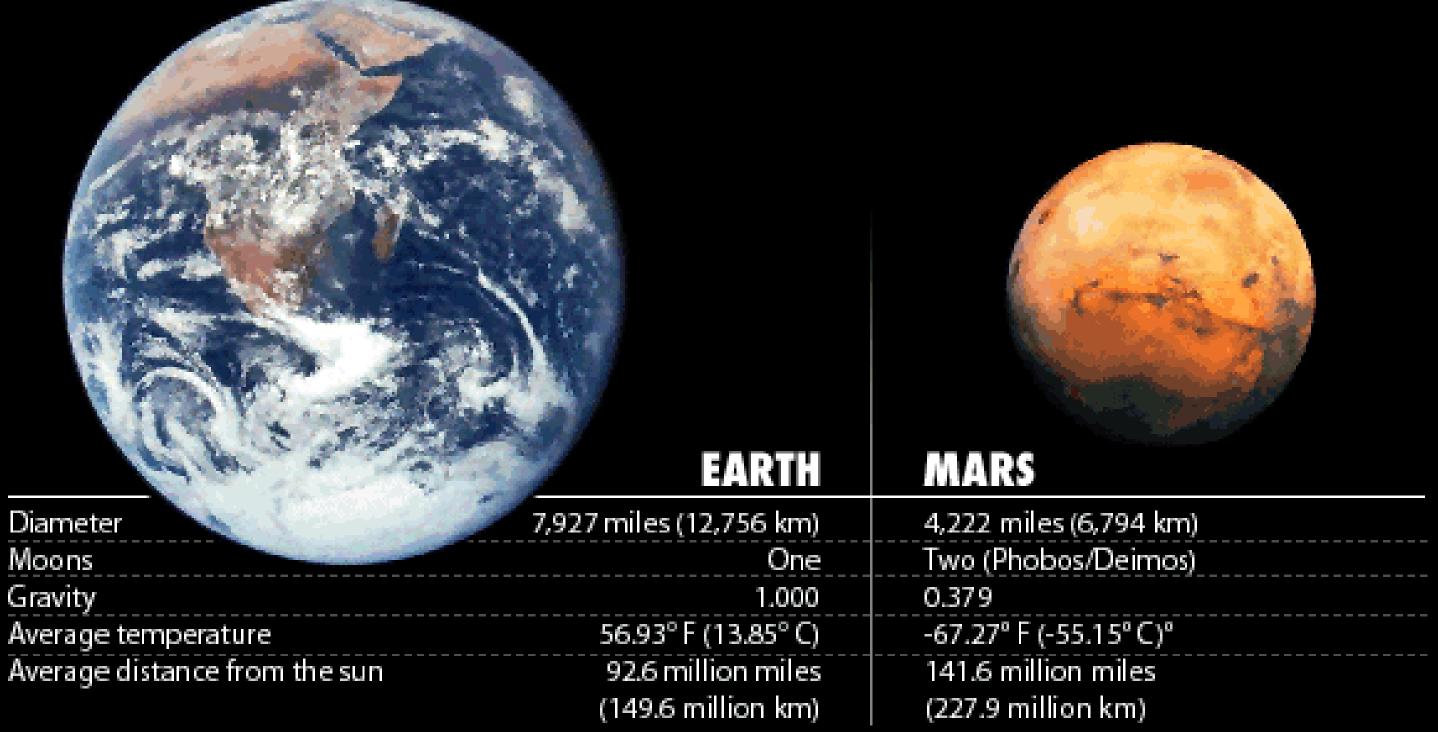
Dark surface, no atmosphere,
no redistribution of heat



# **EMISSION SPECTRA**



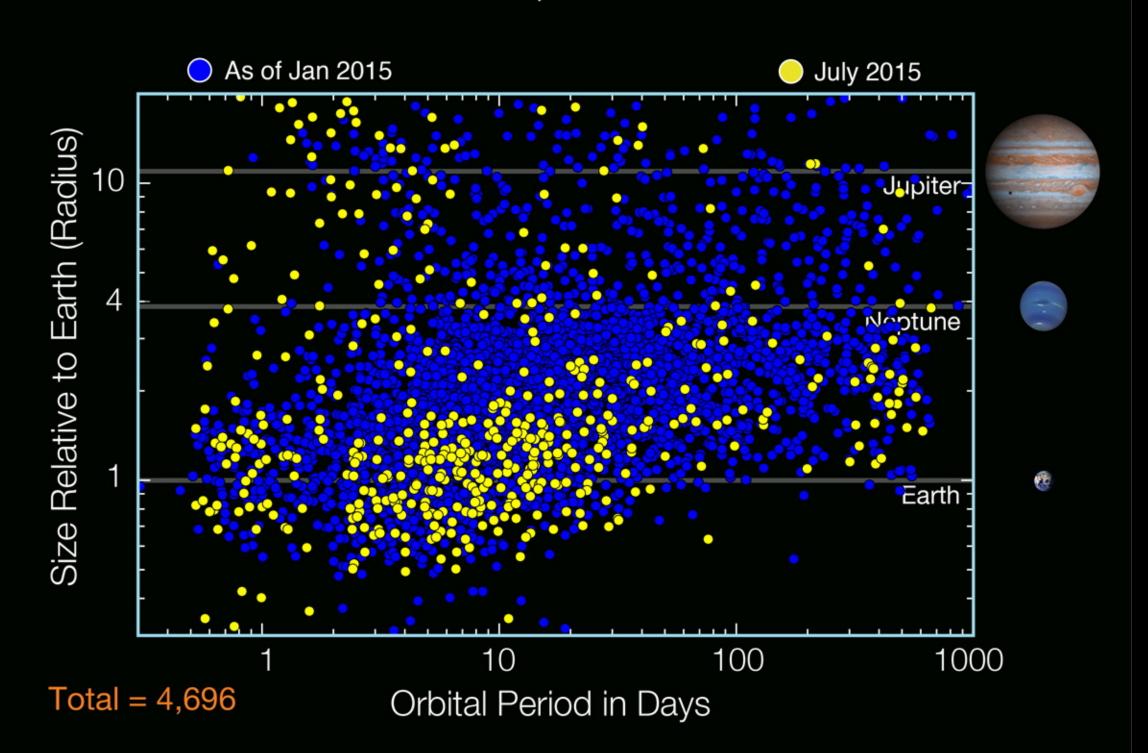




SOURCE: NASA

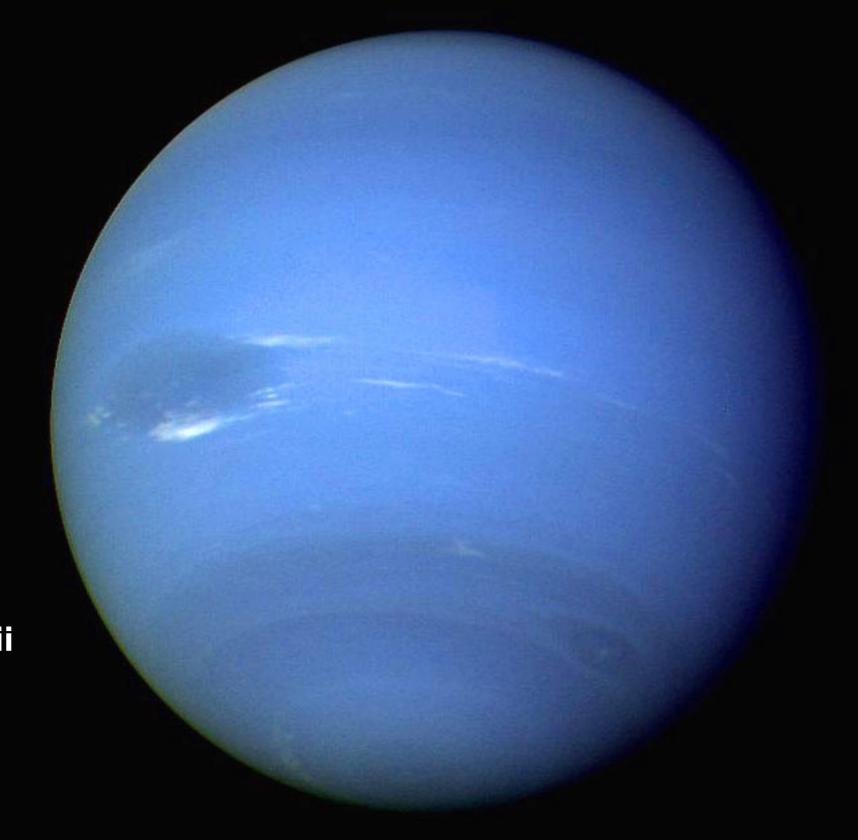
# **New Kepler Planet Candidates**

As of July 23, 2015

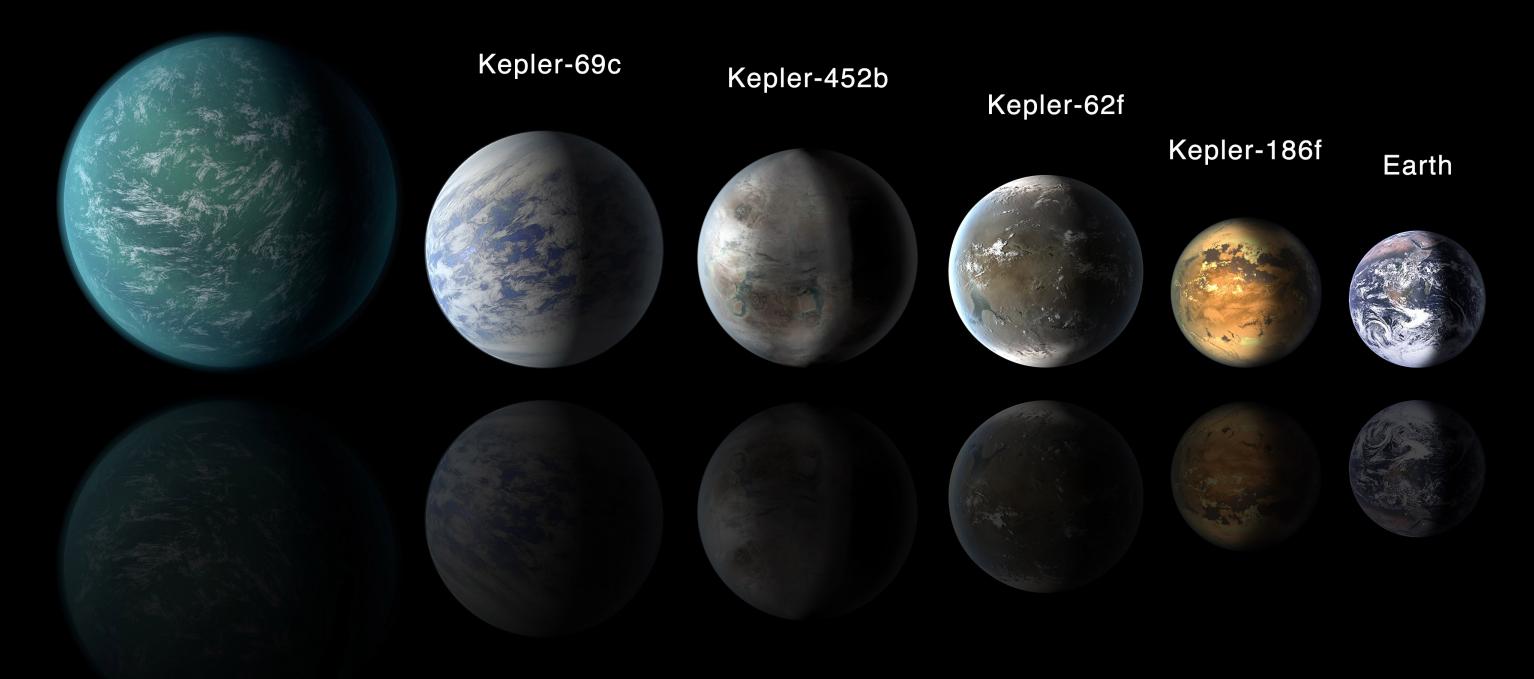




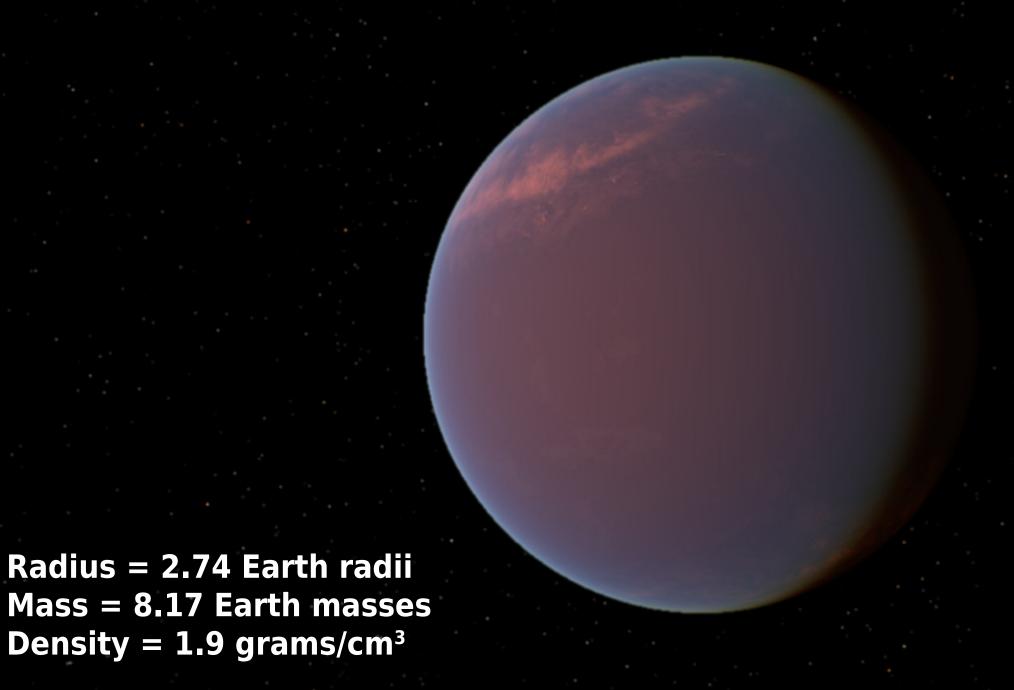
1 Earth radius = 6371 kms 1 Earth diameter = 12742 kms Neptune radius = 3.9 Earth radii



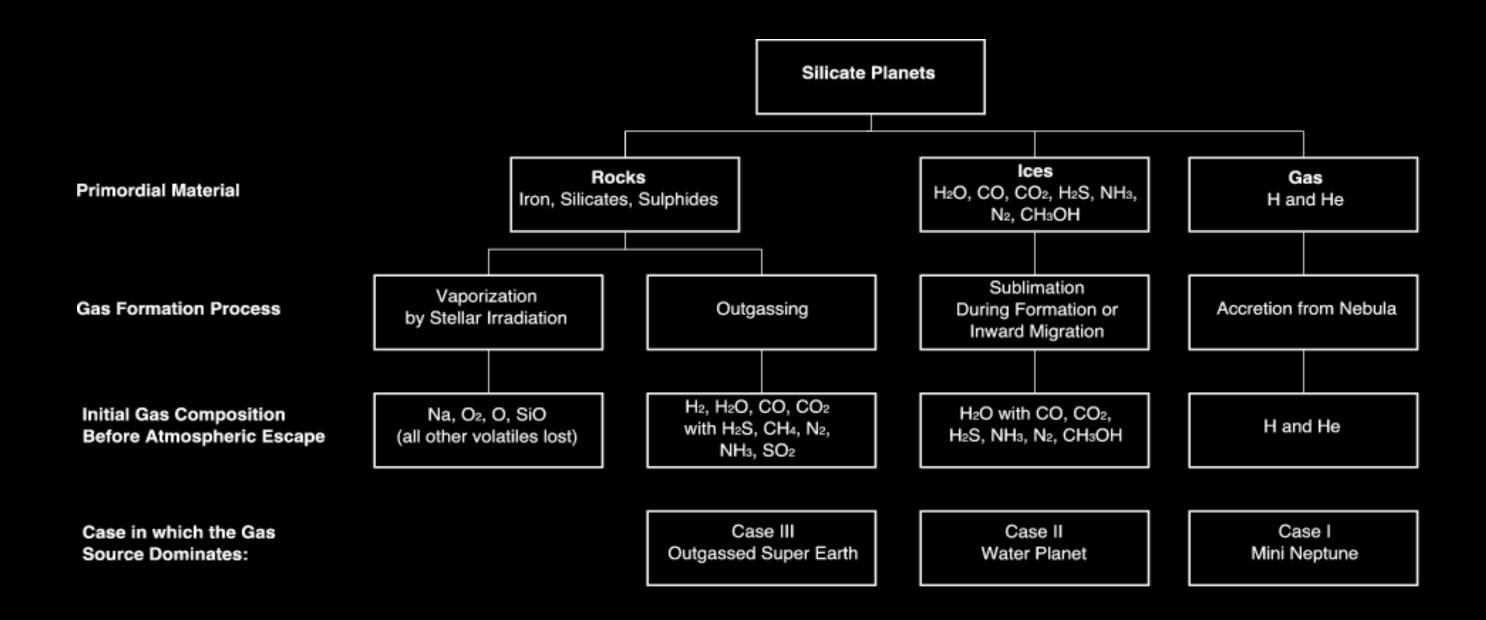
Kepler-22b

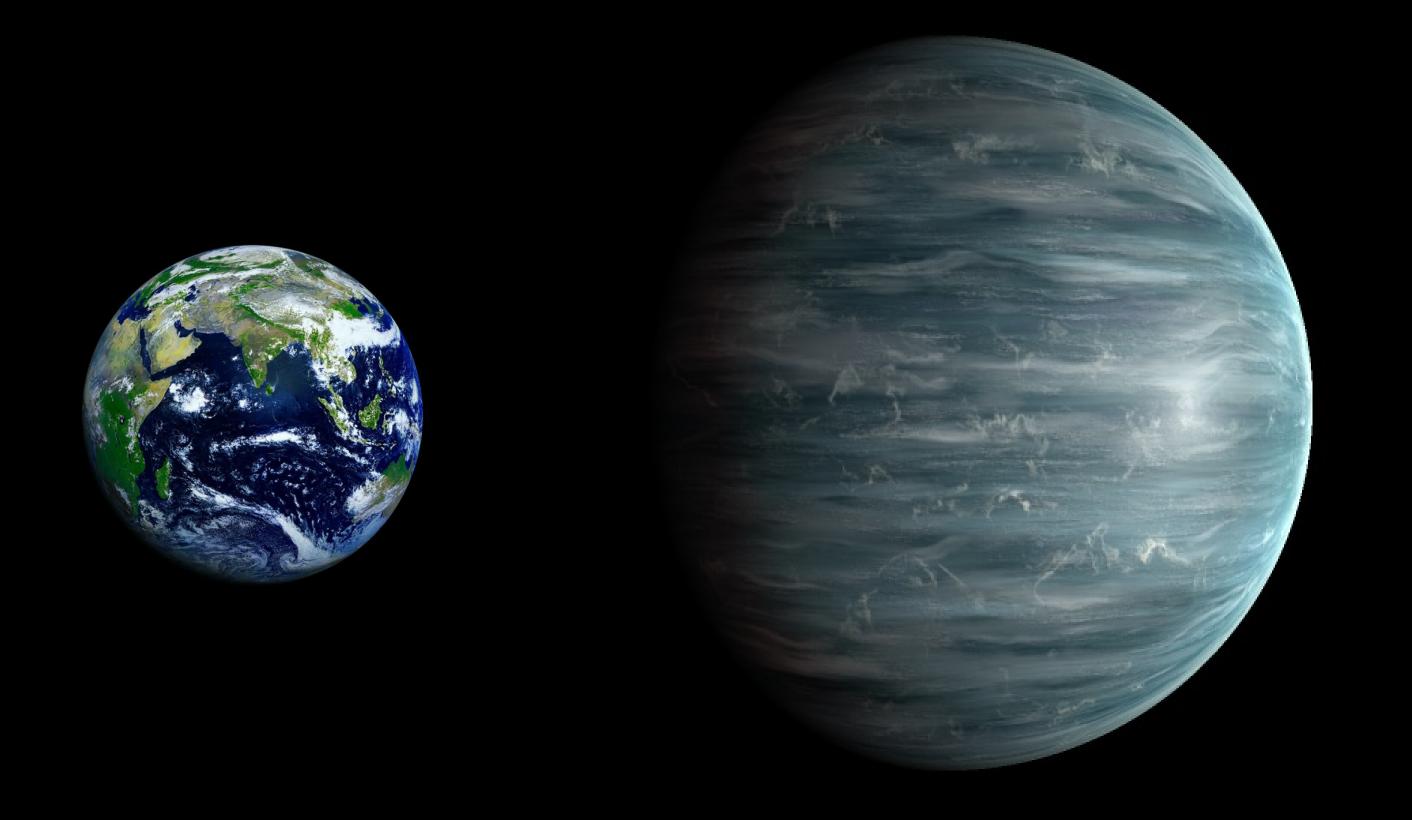


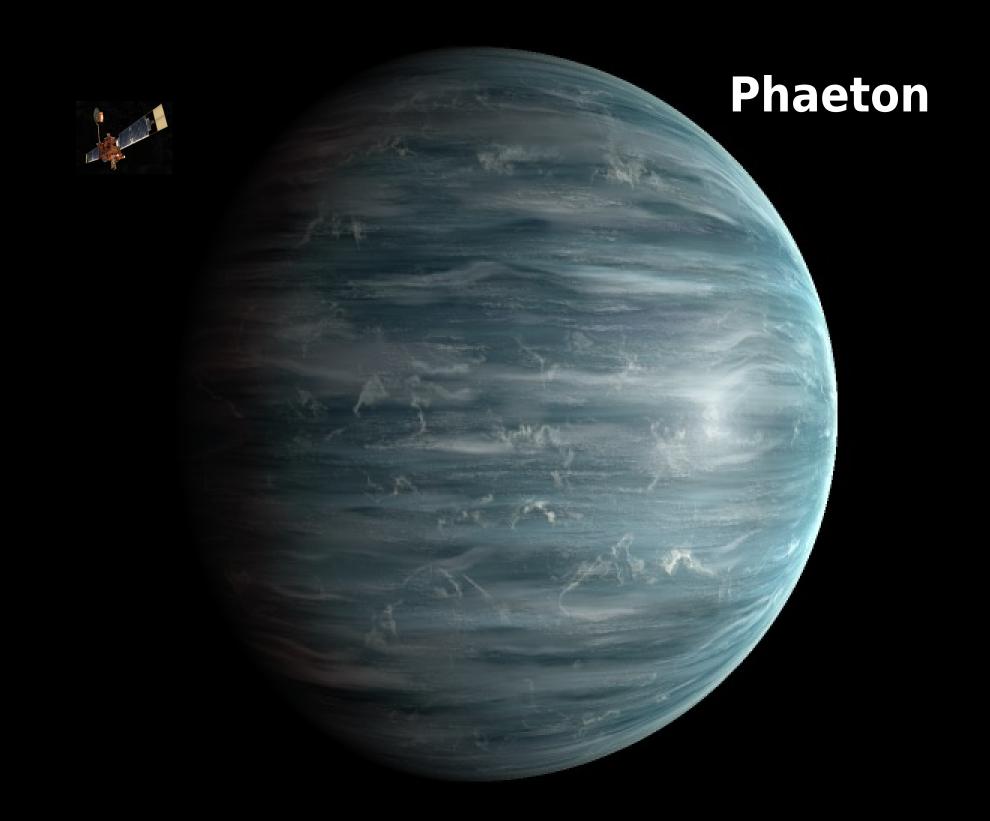
# The Case of GJ 1214 b



## The Case of GJ 1214 b

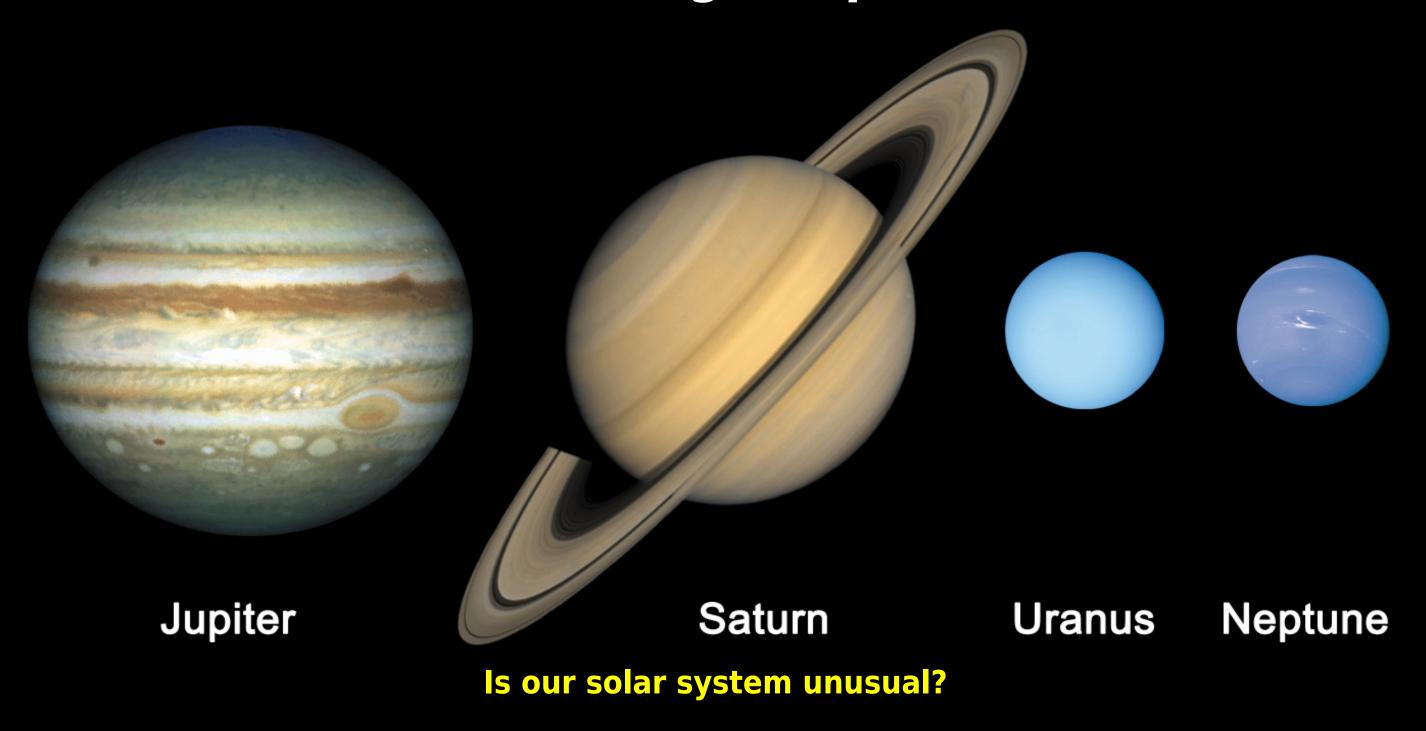








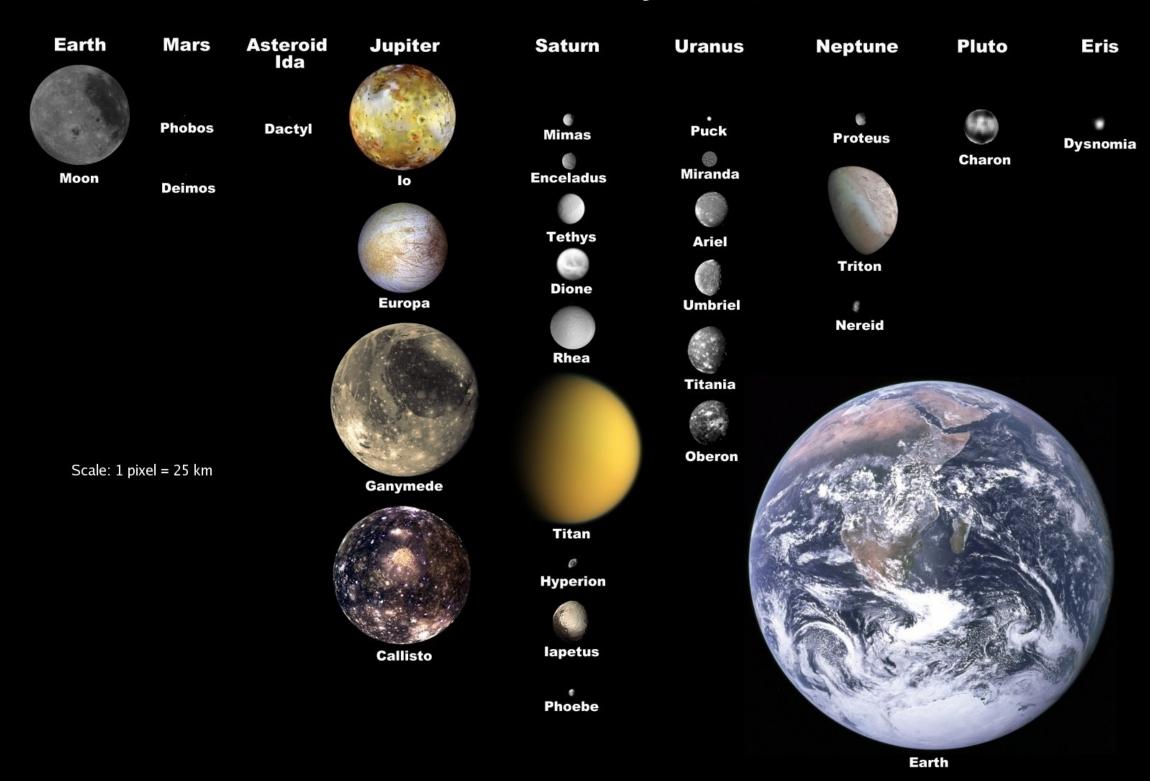
# The role of giant planets



# The Moon and Habitability

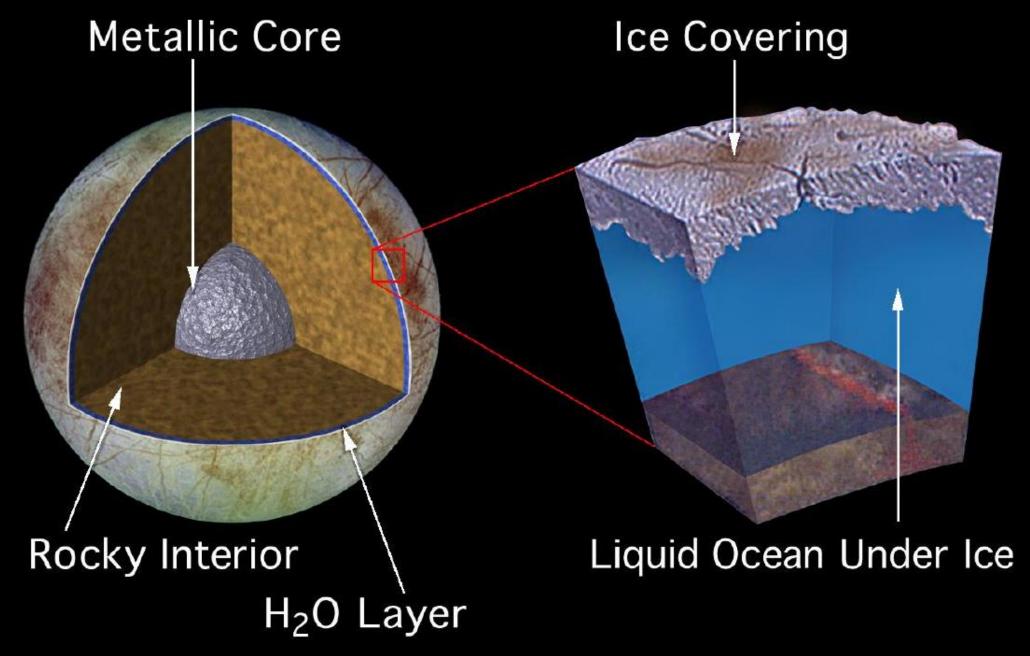


## Selected Moons of the Solar System, with Earth for Scale

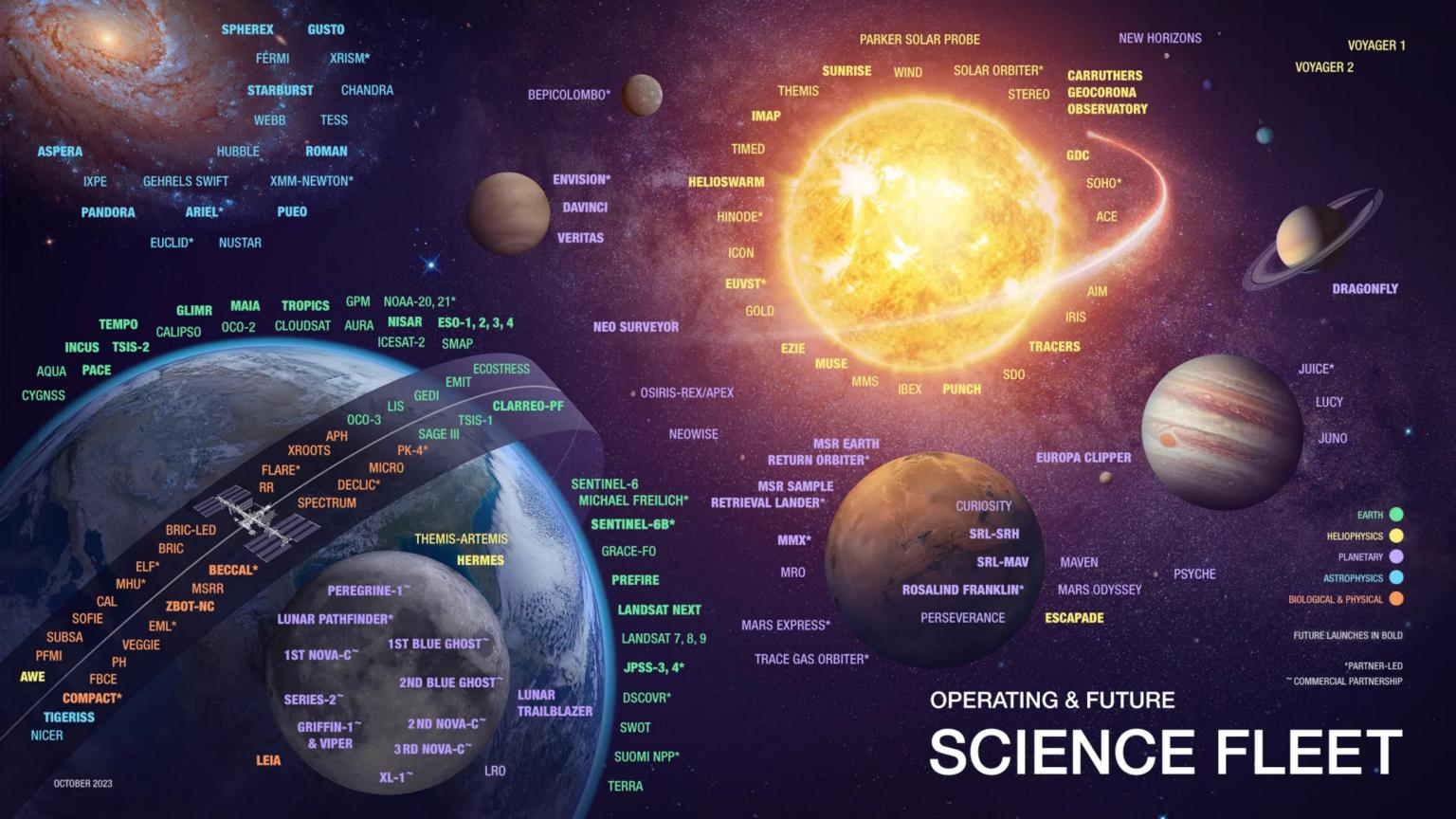


Europa **Enceladus** 

# **Europa: The Water World?**



The center is the metallic core. The top shows the thin wafer like a layer of water ice and beneath that, up to a thickness of about 150 km, there could be liquid water. The radius of Europa is about 3000 km.



# An Incomplete List of Habitability Questions

- How is water delivered?
- When did Mars have surface water?
- When did Venus have surface water?
- Did Venus and Earth have near identical starting conditions?
- How small can a planet be and remain habitable?
- Are plate tectonics crucial for long-term temperate conditions?
- Why don't we have a super-Earth?
- What does the atmospheric profile of a super-Earth look like?
- Does having a giant planet in the system matter?
- Can life survive on planets with highly elliptical orbits?
- How do terrestrial atmospheres respond to changing energy?
- Are planets orbiting more than one star habitable?
- How does atmospheric erosion depend on magnetic field?
- Does a substantial moon create a more habitable world?
- Can life survive in a sub-surface ocean (c.f. Europa)?
- How well do we need to understand the star?
- What observations/measurements do we need to make to test ideas about planetary habitability?