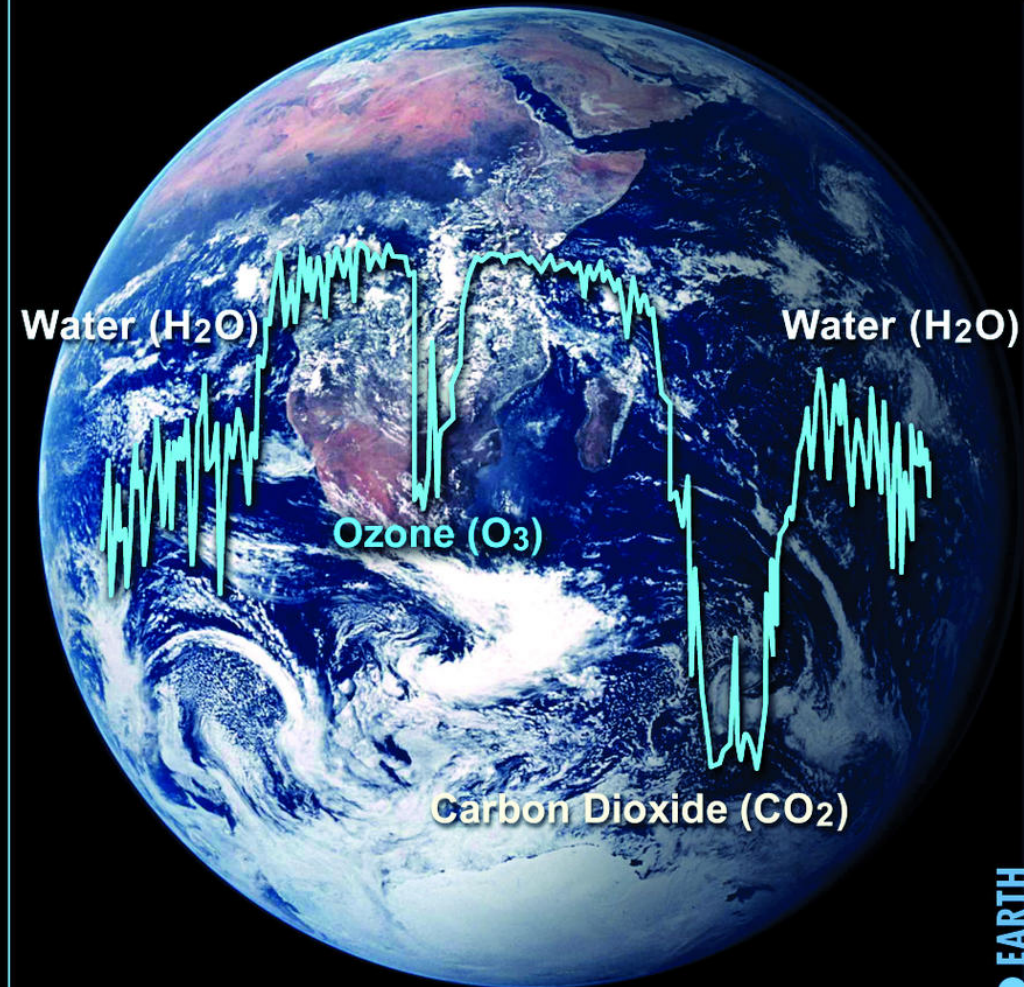
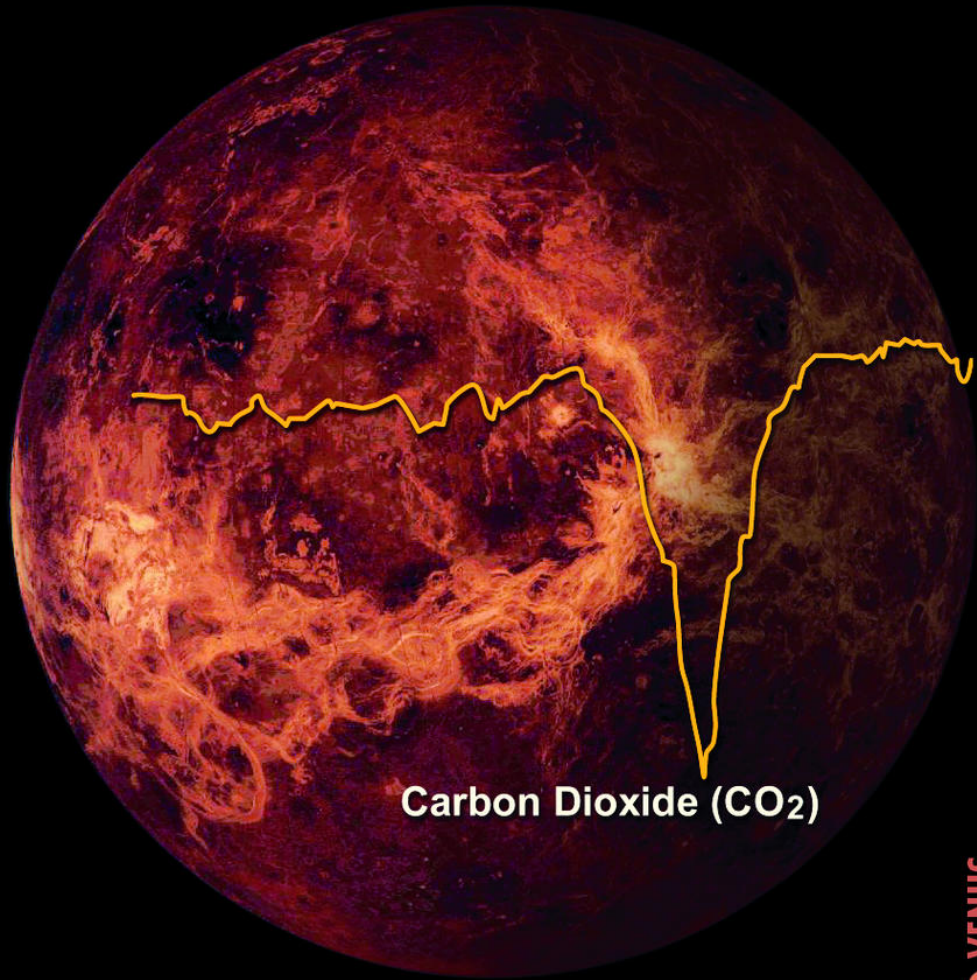


# Planetary Habitability



Stephen Kane

# Planetary Habitability

- **Please do not use laptops, tablets, cell phones in class.**
- **My office hours are every Wednesday 1pm-3pm in Pierce Hall 2360.**
- **The class web page is live:  
<http://stephenkane.net/teaching/g280>**
- **The course syllabus is available from the web site.**

<http://stephenkane.net/teaching/q280>

# PLANETARY HABITABILITY

Welcome to the course webpage for GEO 280: Planetary Habitability

## Class Announcements:

2023-01-16: Interesting review paper on "[The Inner Solar System's Habitability Through Time](#)".

2023-01-05: Class announcements will appear here periodically.

## Contact details:

- Instructor: Stephen Kane
- Office: Pierce Hall 2360
- Office hours: Wednesdays, 1:00pm-3:00pm
- Phone: 951-827-6593
- Email: [skane@ucr.edu](mailto:skane@ucr.edu)

Download the class syllabus [here](#).

## Useful Links:

- [The NASA Astrophysics Data System](#)
- [astro-ph preprint server](#)
- [The Habitable Zone Gallery](#)
- [The NASA Exoplanet Archive](#)
- [The Exoplanet Data Explorer](#)
- [The Exoplanet Characterization Toolkit](#)
- [The Systemic Console](#)
- [Planetary Spectrum Generator](#)

## Lectures:

- [Lecture 1](#) - Introduction

## Class times:

- Tuesday, 12:30am-1:50am Pierce Hall 2330
- Thursday, 12:30am-1:50am Pierce Hall 2330

## Text:

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

## Assessment:

- **Homework (30%):** There will be three homeworks during the quarter. Most problems will require analytic solutions, however there will usually be one problem per assignment that will involve graphing and numerical solution with computer software such as Mathematica, MATLAB, or any programming language.
- **Paper Discussion (30%):** Students will choose a refereed paper to discuss in front of the class, answering questions as they arise. The paper may be from planetary science, exoplanets, biology, geophysics, etc. but must discuss planetary

# Class Assessment

- **Assessment: Homeworks - 30%**  
**Paper Presentation - 30%**  
**Data Project - 40%**

# Class Assessment

- **Assessment: Homeworks - 30%**
  - Paper Presentation - 30%**
  - Data Project - 40%**
- **Homeworks will be due Thursdays in class. Times between issue and due dates will vary.**
- **Programming will be required (IDL, python, MATLAB).**
- **First homework will be handed out next Thursday.**

# Class Assessment

- **Assessment: Homeworks - 30%**
  - Paper Presentation - 30%**
  - Data Project - 40%**
- **Working in groups is encouraged, but must hand in your own work.**
- **Late homeworks are 50% off until following Monday and 100% off after that.**

# **Class Assessment**

- **Assessment: Homeworks - 30%**
  - Paper Presentation - 30%**
  - Data Project - 40%**
- **Select a paper that has appeared in a refereed journal regarding habitability.**
- **Topics can be very broad, including solar system, exoplanets, biology, etc.**
- **Sign up for a discussion section in which to present the paper, indicating the title of the paper and link to the article.**
- **You will lead a discussion of the paper, answering questions from the audience.**

# **Class Assessment**

- **Assessment: Homeworks - 30%**  
**Paper Presentation - 30%**  
**Data Project - 40%**
- **Choose a terrestrial exoplanet within the Habitable Zone of the host star.**
- **Write a 6-page analysis of the planet, intrinsic properties, effects of the star and other planets, potential habitability, and follow-up prospects.**
- **Topic/abstract due Thursday in Week 5.**
- **Final project due on Thursday in Week 10.**

# **Class Assessment**

- **Assessment: Homeworks - 30%**  
**Paper Presentation - 30%**  
**Data Project - 40%**
- **For homeworks and data project, hard copies are required. No email submissions!**
- **Do not miss homeworks/exams. There are no make-ups or extra credit!**
- **Extensions always require documentation!**

# **Textbook/Lectures**

- **Textbook: “Planetary Habitability” by Stephen Kane. 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.**
- **Lectures will (mostly) be available on the class website but some things covered in class won't be.**
- **Discussion of peer-reviewed papers.**
- **Guest speakers.**

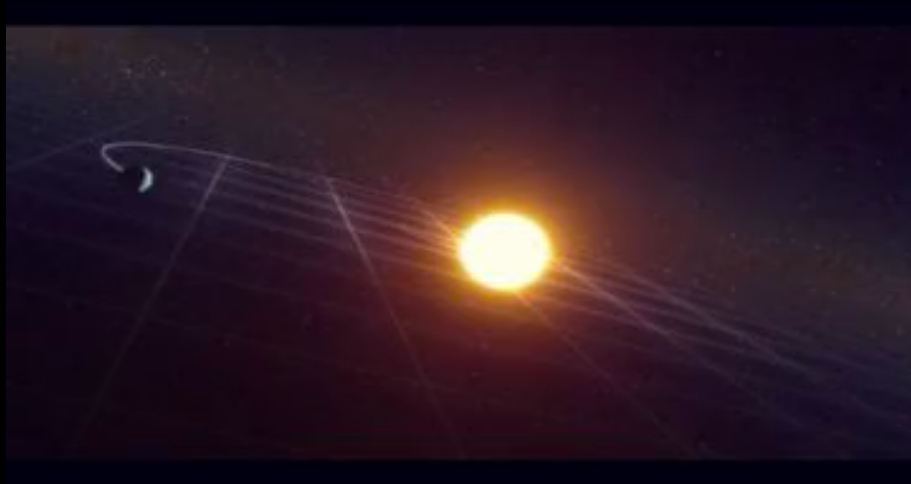
# **Useful Links**

- **The NASA Exoplanet Archive**
- **The Exoplanet Data Explorer**
- **The Habitable Zone Gallery**
- **The Systemic Console**
- **The Exoplanet Characterization Toolkit**
- **Planetary Spectrum Generator**
- **LAPS: Online 1-D climate model**
- **REBOUND: N-body integrator**
- **NASA/ADS**
- **ArXiv preprint server (astro-ph)**

# Topics

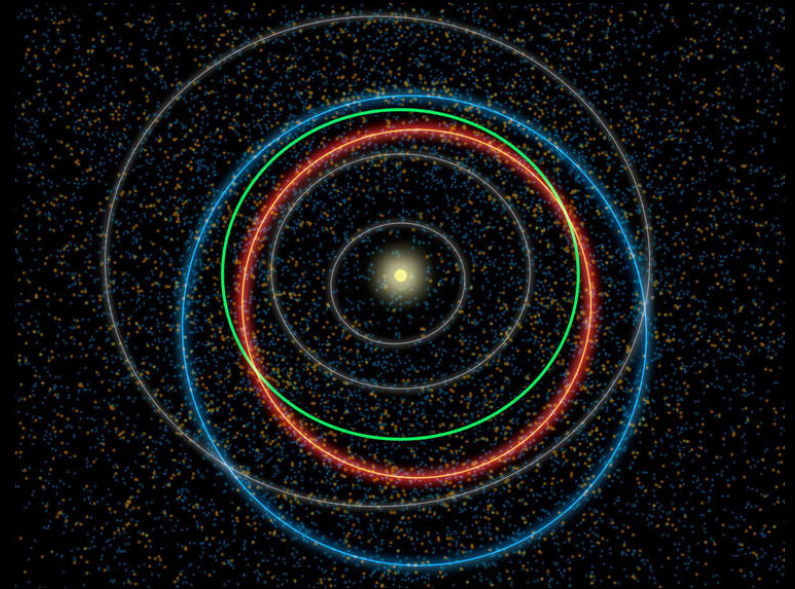
- **Lecture 1 - Introduction**
- **Lecture 2 - Habitability Factors**
- **Lecture 3 - Stars**
- **Lecture 4 - Planetary Atmospheres**
- **Lecture 5 - Planetary Interiors**
- **Lecture 6 - Planetary Energy Balance**
- **Lecture 7 - Habitable Zone I**
- **Lecture 8 - Habitable Zone II**
- **Lecture 9 - Earth as a Living Planet**
- **Lecture 10 - Mars**
- **Lecture 11 - Icy Moons**
- **Lecture 12 - Venus**
- **Lecture 13 - Mercury & the Moon**
- **Lecture 14 - The Role of Giant Planets**
- **Lecture 15 - Stellar Influences**
- **Lecture 16 - Magnetic Fields**
- **Lecture 17 - Milankovitch Cycles**
- **Lecture 18 - Geological Cycles**
- **Lecture 19 - The Next Steps**
- **Lecture 20 - Summary/Discussion**

# The Stages of my Planetary Research



**1. Planet hunting using transits, microlensing, radial velocities, and imaging**

**2. Studying planetary orbits and atmospheres**



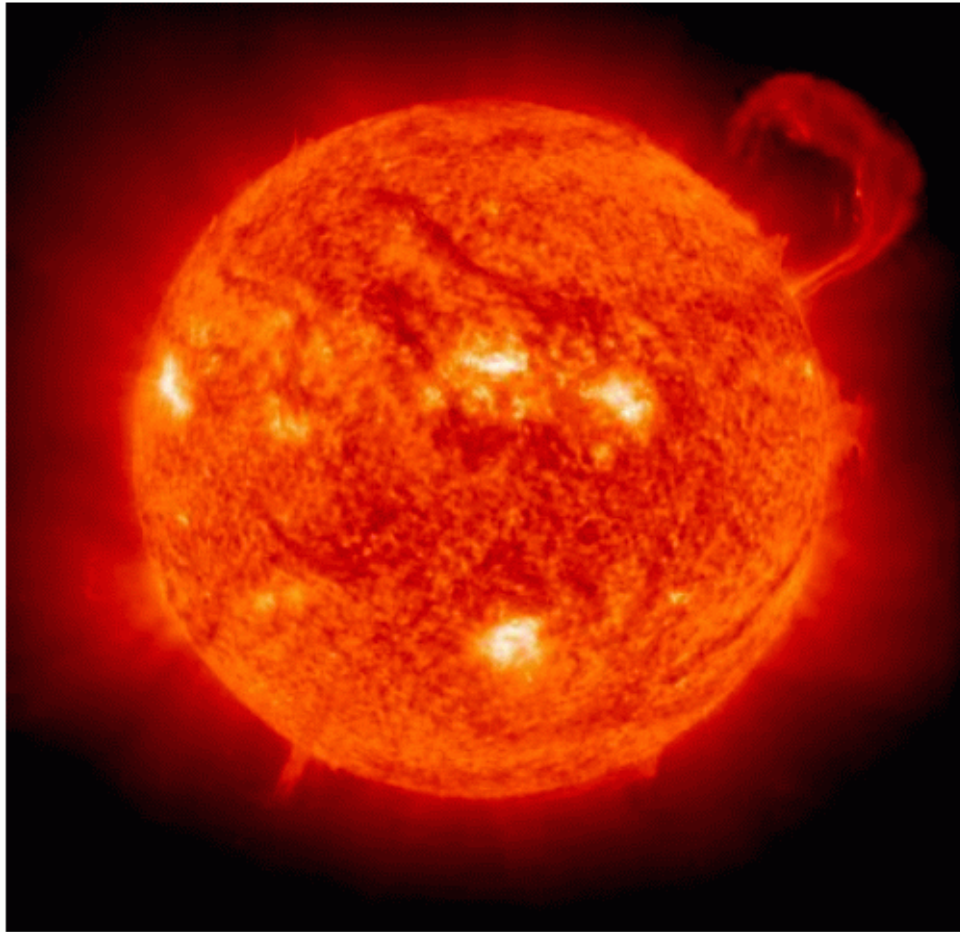
Habitable Zone of Earths Solar System



Mercury Venus Earth Mars

**3. Habitable Zones and planetary habitability**

# Numbers you should know: The Sun



source: SOHO/EIT

Mass  $\approx 2 \times 10^{30}$  kg =  $1 M_{\odot}$

Radius  $\approx 7 \times 10^8$  m =  $1 R_{\odot}$

Distance =  $1.5 \times 10^{11}$  m = 1 AU

Luminosity =  $4 \times 10^{26}$  W =  $1 L_{\odot}$

Surface temperature = 5800 K

age  $\approx 4.5$  Gyr

spectral type = G2 V

All other stars are scaled to these parameters for convenience.

# Numbers you should know: planets

- **Mass:** Sun, Jupiter, Earth are units of measurement
- **Radius:** Sun, Jupiter, Neptune, Earth are units of measurement

**What is planetary  
habitability?**



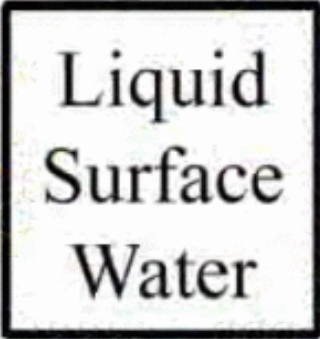
## **Reasons why water is important for life:**

**1) Water (hydrogen and oxygen) are extremely common.**

**2) Water is a neutral solvent in which biochemical reactions can take place.**

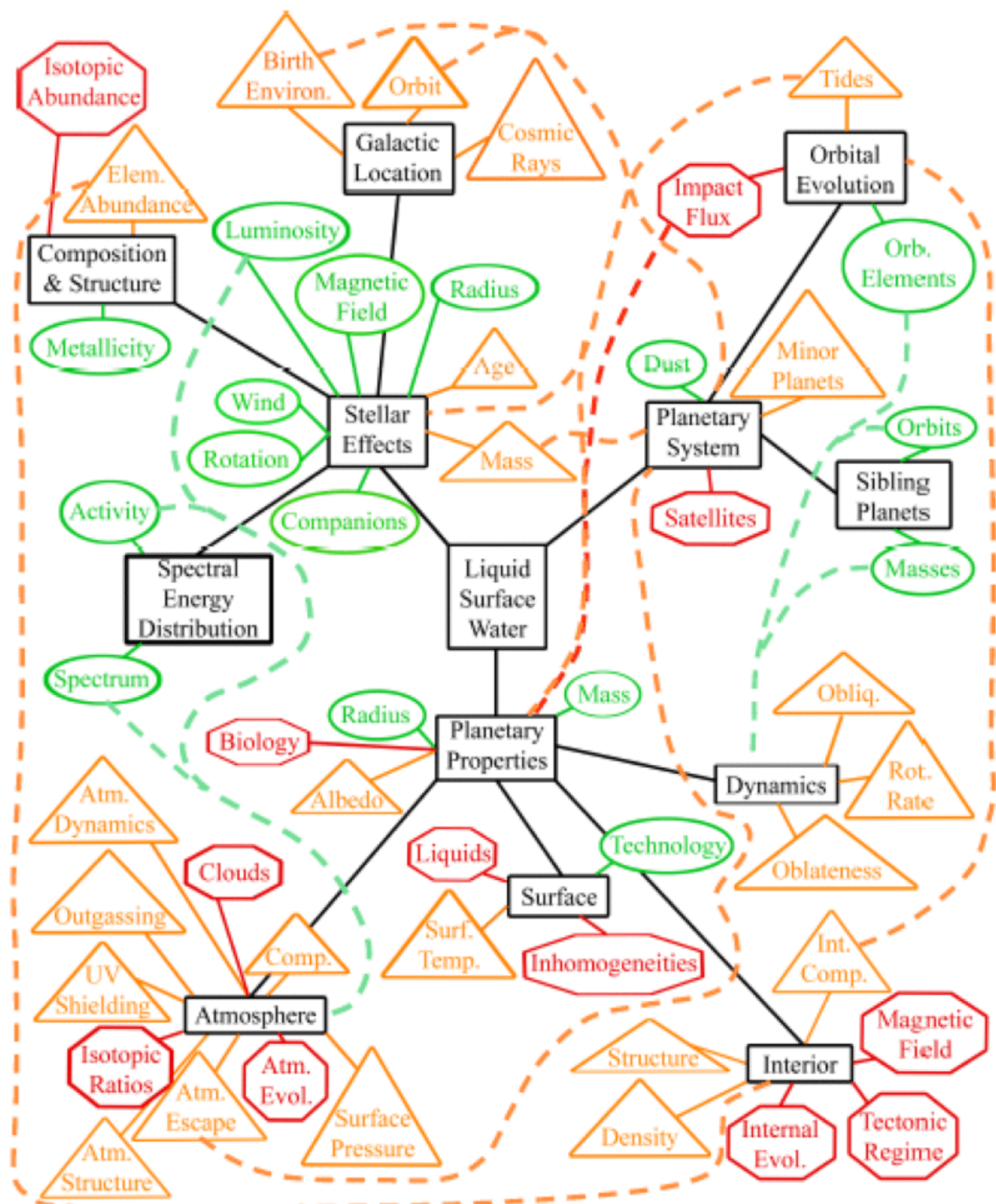
**3) Water can be in a liquid state at reasonably high temperatures, enabling faster reaction rates.**

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



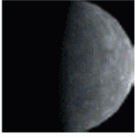
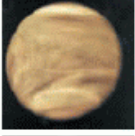

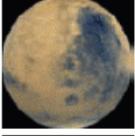
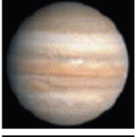

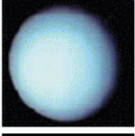
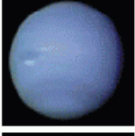
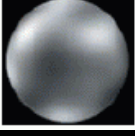
Liquid  
Surface  
Water



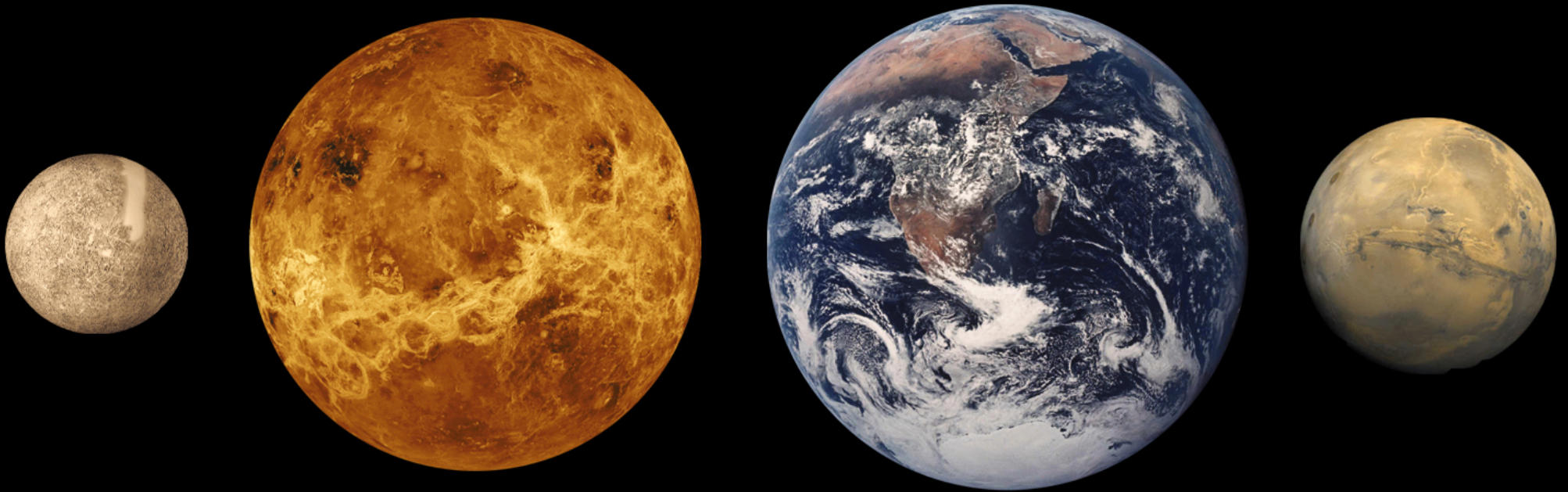


# **Planetary Habitability**

- **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?**

<i>Photo</i>	<i>Planet</i>	<i>Relative Size</i>	<i>Average Distance from Sun (AU)</i>	<i>Average Equatorial Radius (km)</i>	<i>Mass (Earth = 1)</i>	<i>Average Density (g/m<sup>3</sup>)</i>	<i>Orbital Period</i>	<i>Rotation Period</i>	<i>Axis Tilt</i>	<i>Average Surface (or Cloud-Top) Temperature†</i>	<i>Composition</i>	<i>Known Moons (2010)</i>	<i>Rings?</i>
	Mercury	·	0.387	2440	0.055	5.43	87.9 days	58.6 days	0.0°	700 K (day) 100 K (night)	Rocks, metals	0	No
	Venus	•	0.723	6051	0.82	5.24	225 days	243 days	177.3°	740 K	Rocks, metals	0	No
	Earth	•	1.00	6378	1.00	5.52	1.00 year	23.93 hours	23.5°	290 K	Rocks, metals	1	No
	Mars	·	1.52	3397	0.11	3.93	1.88 years	24.6 hours	25.2°	220 K	Rocks, metals	2	No
	Jupiter	●	5.20	71,492	318	1.33	11.9 years	9.93 hours	3.1°	125 K	H, He, hydrogen compounds <sup>§</sup>	63	Yes
	Saturn	●	9.54	60,268	95.2	0.70	29.4 years	10.6 hours	26.7°	95 K	H, He, hydrogen compounds <sup>§</sup>	60	Yes
	Uranus	●	19.2	25,559	14.5	1.32	83.8 years	17.2 hours	97.9°	60 K	H, He, hydrogen compounds <sup>§</sup>	27	Yes
	Neptune	●	30.1	24,764	17.1	1.64	165 years	16.1 hours	29.6°	60 K	H, He, hydrogen compounds <sup>§</sup>	13	Yes
	Pluto	·	39.5	1160	0.0022	2.0	248 years	6.39 days	112.5°	40 K	Ices, rock	3	No

# Our sample of terrestrial planets



# The Inner Solar System's Habitability Through Time

**Anthony D. Del Genio**

*NASA Goddard Institute for Space Studies*

**David Brain**

*University of Colorado*

**Lena Noack**

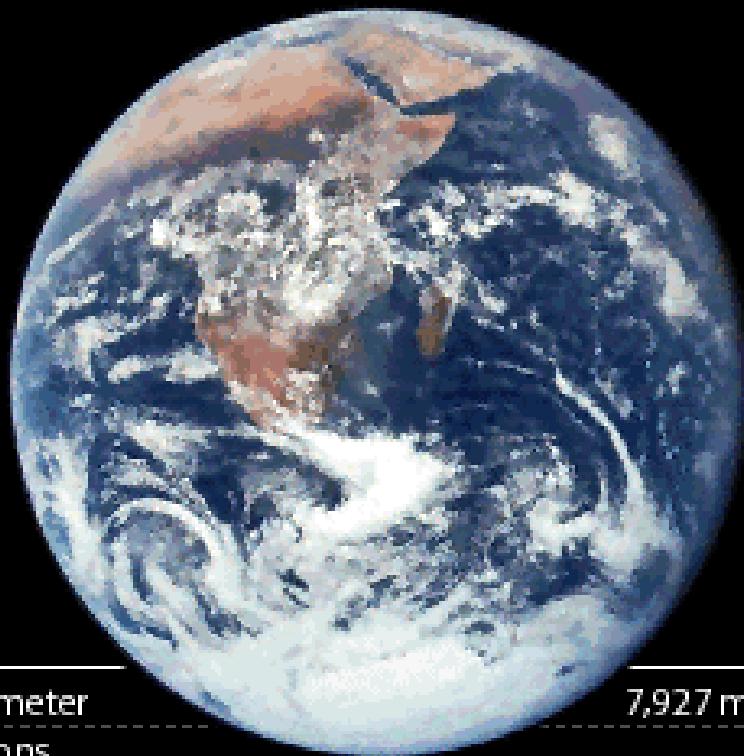
*Free University Berlin*

**Laura Schaefer**

*Arizona State University*

## ABSTRACT

Earth, Mars, and Venus, irradiated by an evolving Sun, have had fascinating but diverging histories of habitability. Although only Earth's surface is considered to be habitable today, all three planets might have simultaneously been habitable early in their histories. We consider how physical processes that have operated similarly or differently on these planets determined the creation and evolution of their atmospheres and surfaces over time. These include the geophysical and geochemical processes that determined the style of their interior dynamics and the presence or absence of a magnetic field; the surface-atmosphere exchange processes that acted as a source or sink for atmospheric mass and composition; the Sun-planet interactions that controlled escape of gases to space; and the atmospheric processes that interacted with these to determine climate and habitability. The divergent evolutions of the three planets provide an invaluable context for thinking about the search for life outside the Solar System.



## EARTH

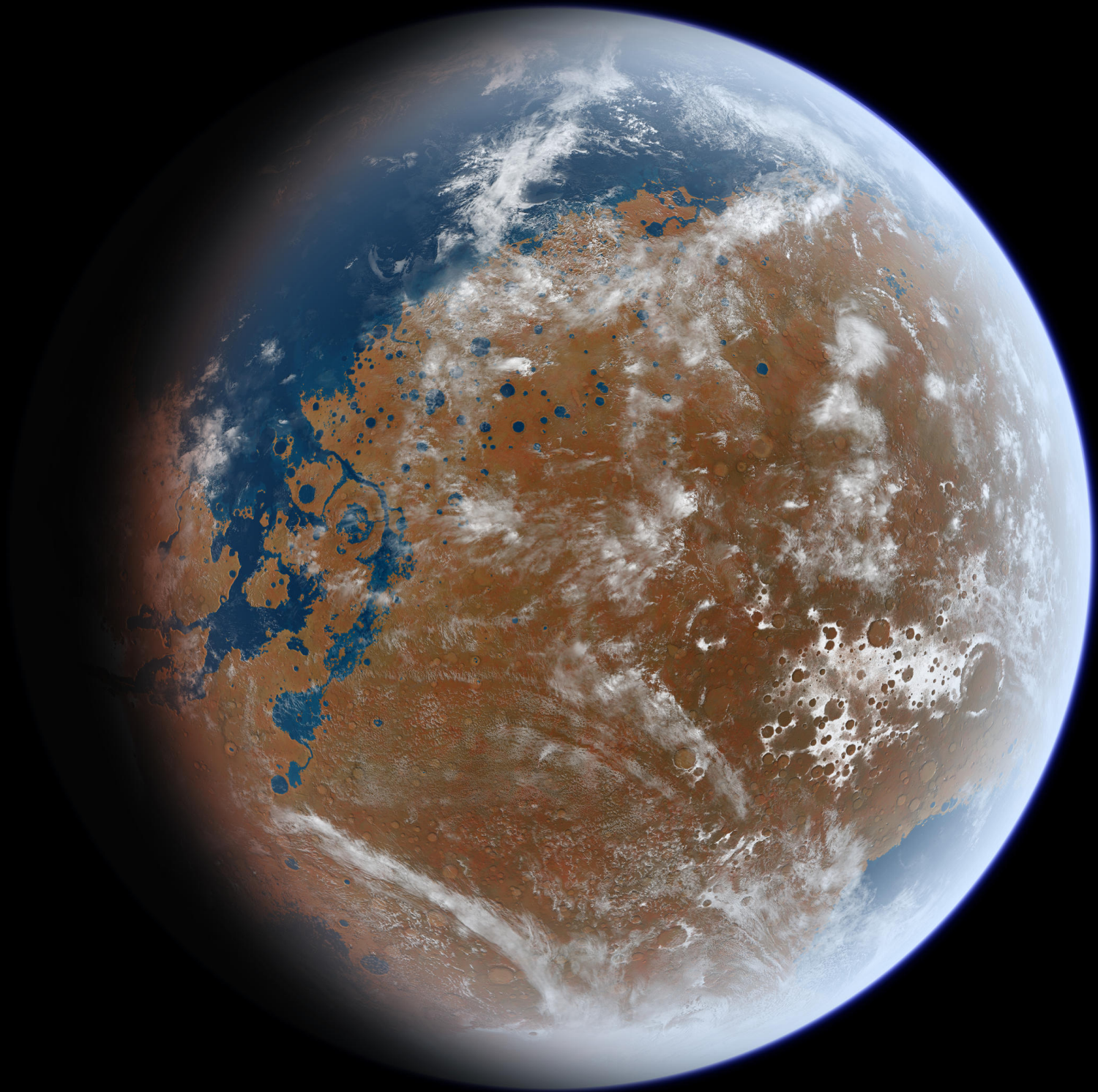
Diameter	7,927 miles (12,756 km)
Moons	One
Gravity	1.000
Average temperature	56.93° F (13.85° C)
Average distance from the sun	92.6 million miles (149.6 million km)

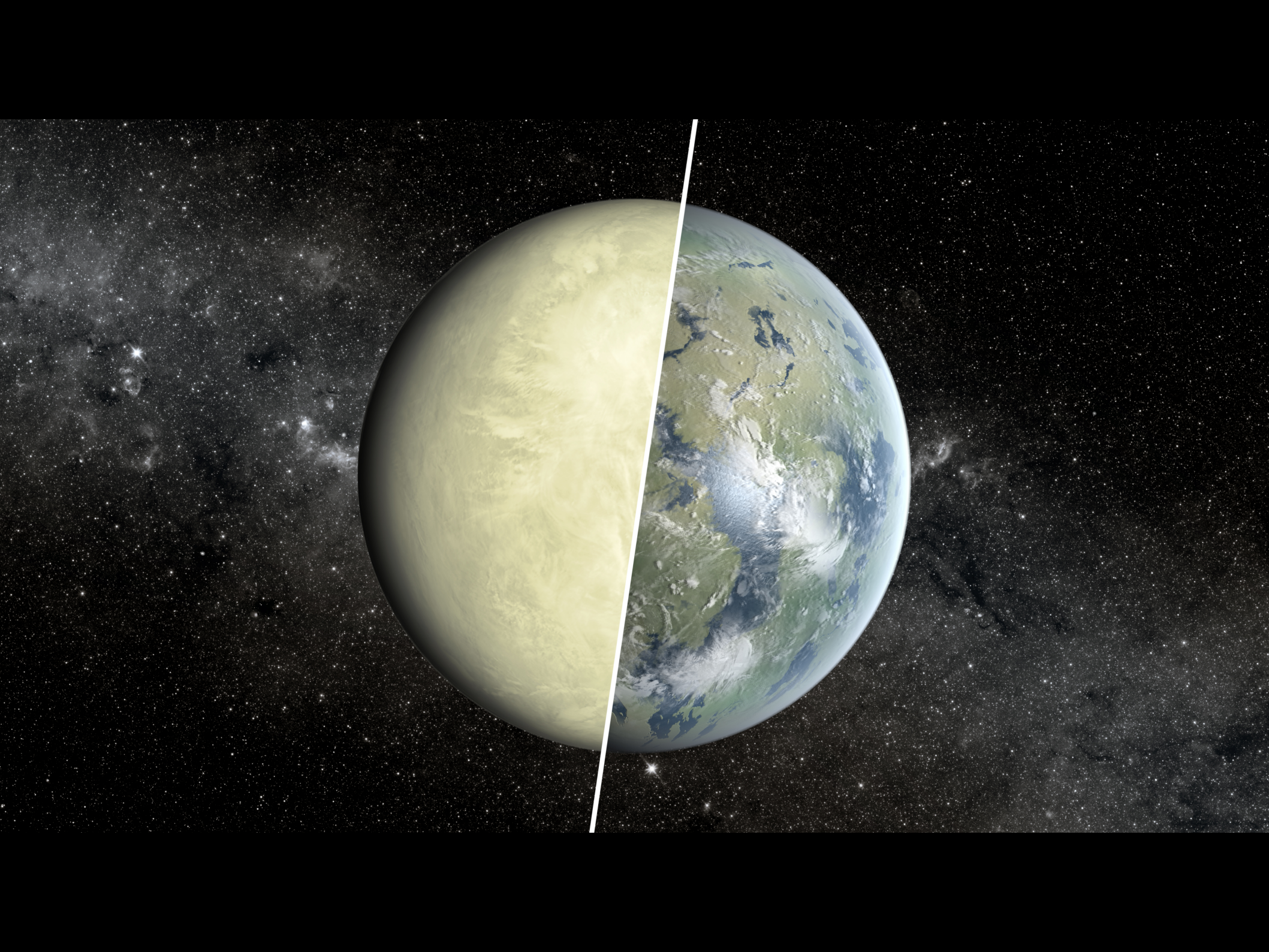


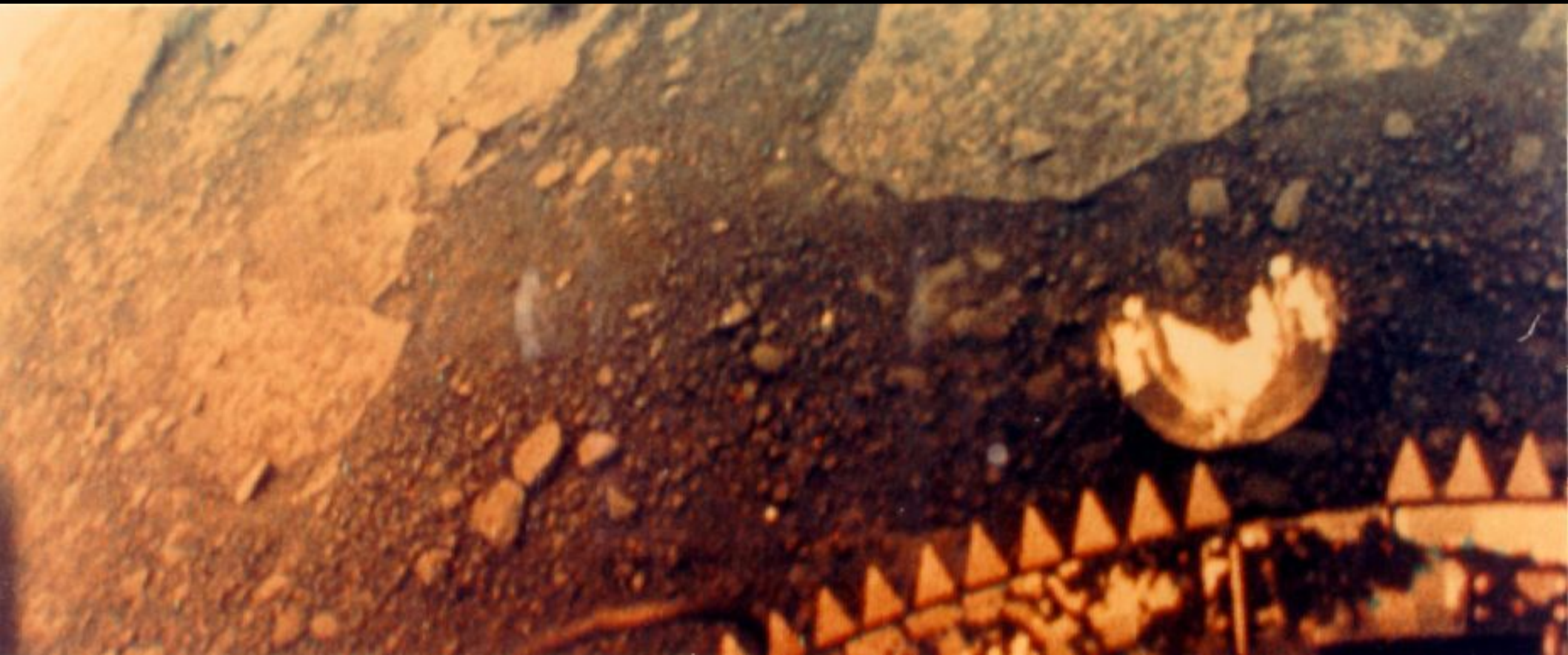
## MARS

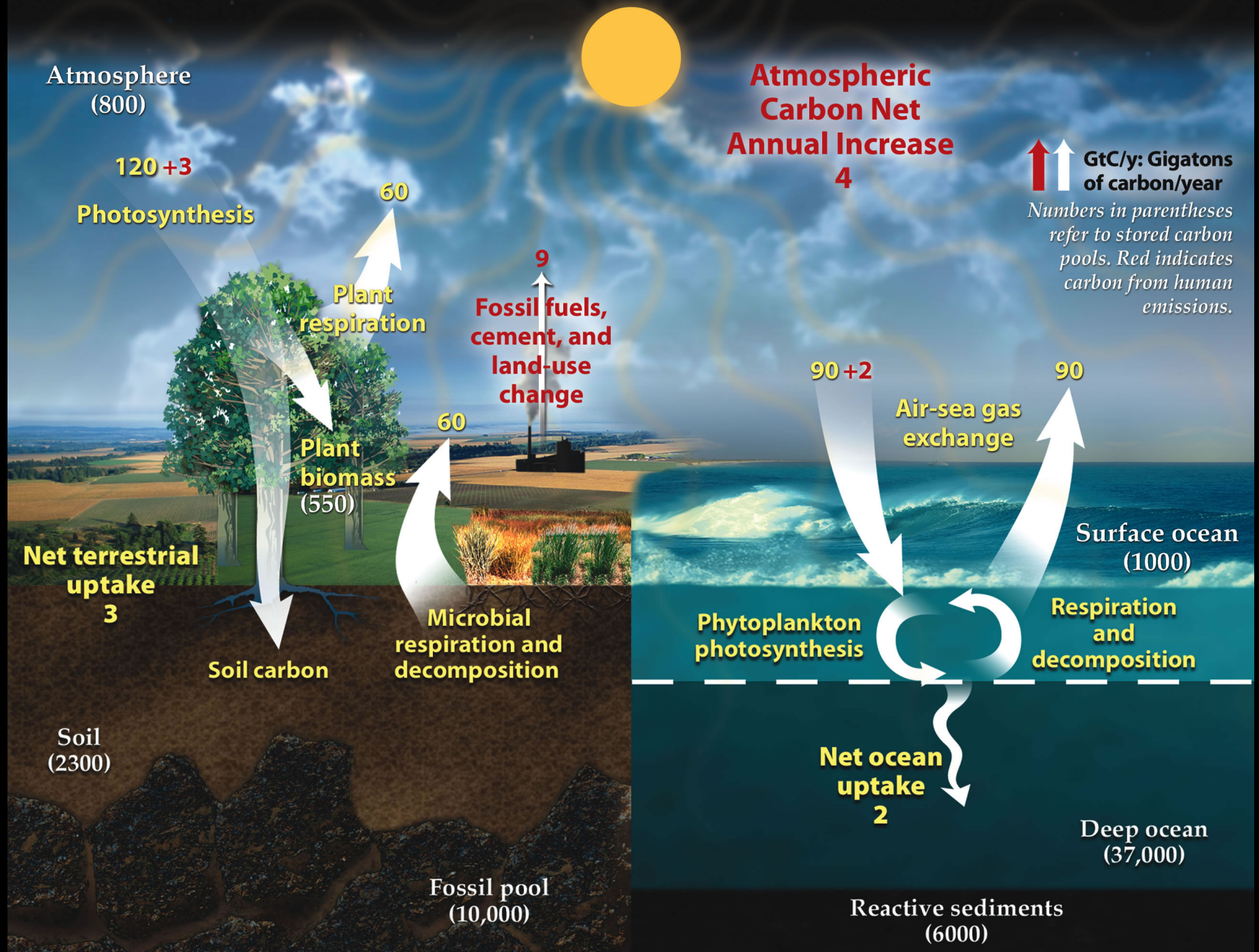
Diameter	4,222 miles (6,794 km)
Moons	Two (Phobos/Deimos)
Gravity	0.379
Average temperature	-67.27° F (-55.15° C) <sup>o</sup>
Average distance from the sun	141.6 million miles (227.9 million km)

SOURCE: NASA

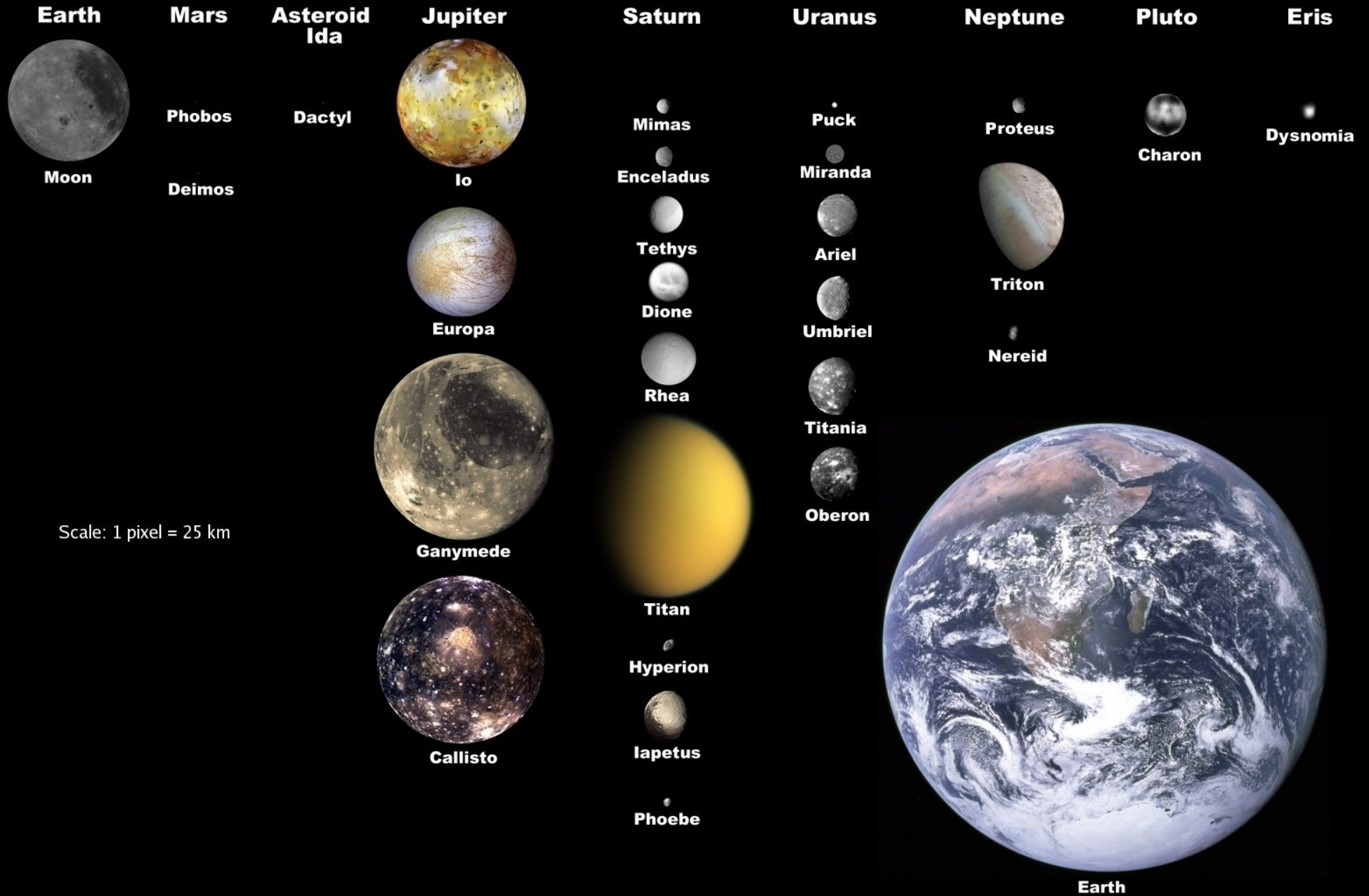


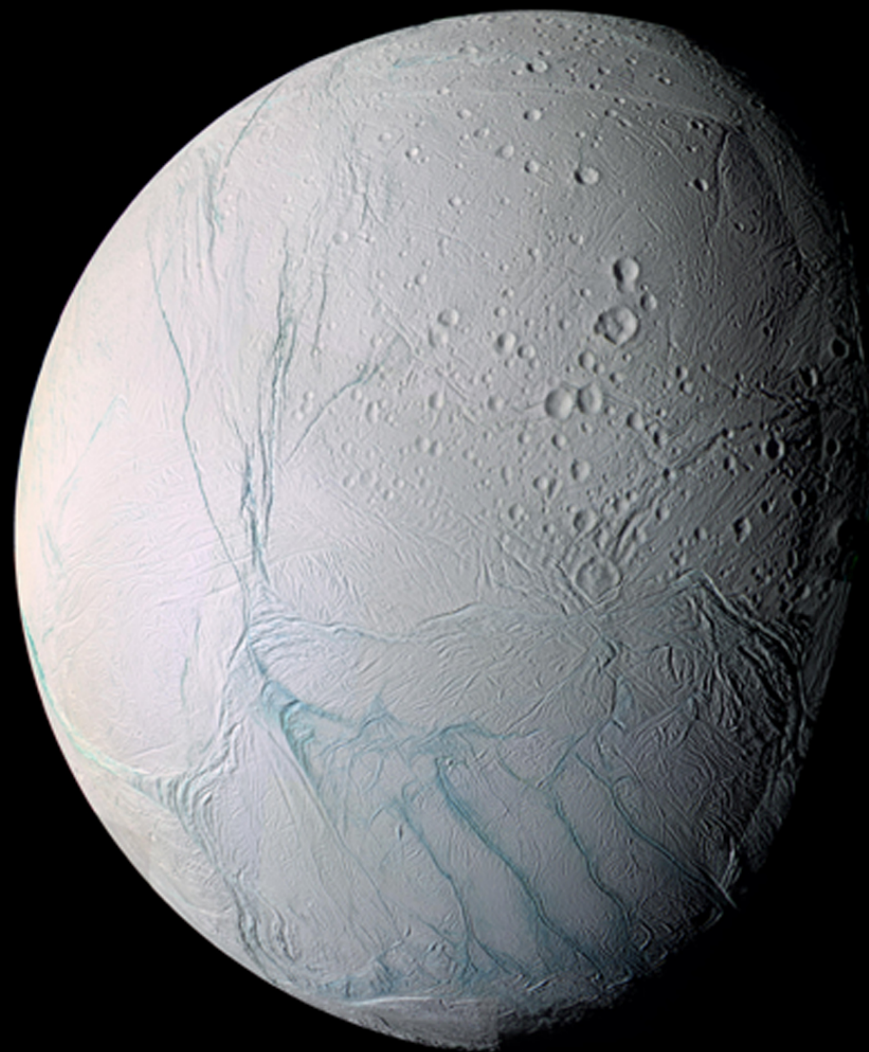
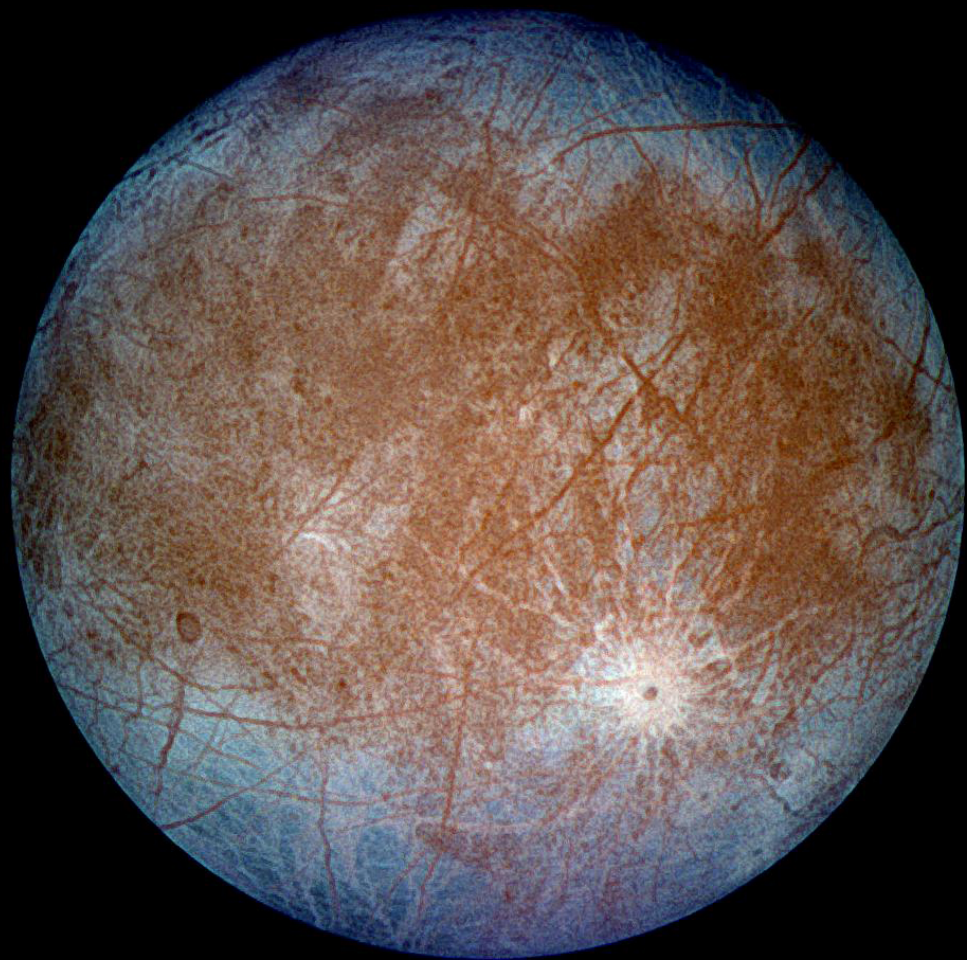




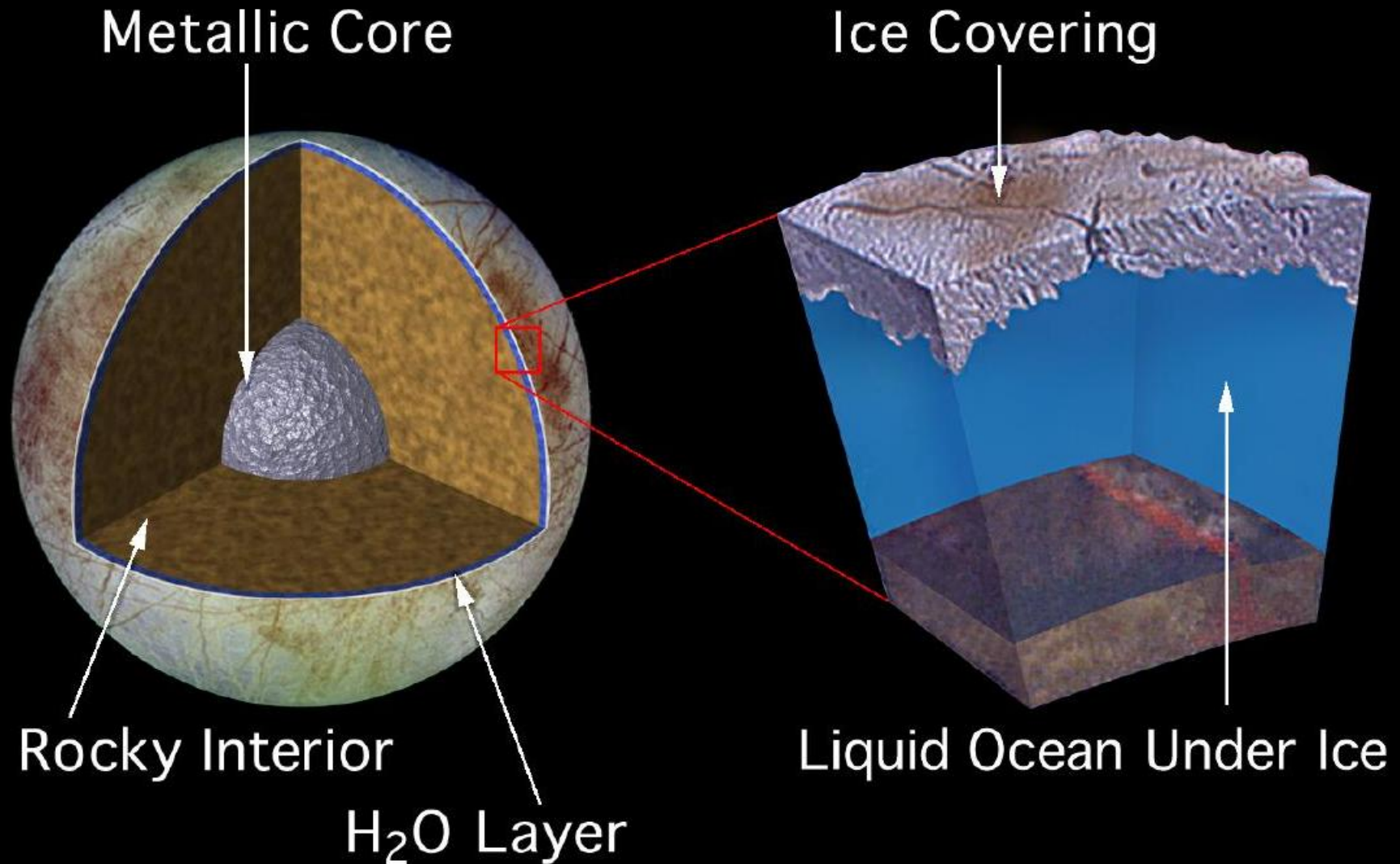


# Selected Moons of the Solar System, with Earth for Scale



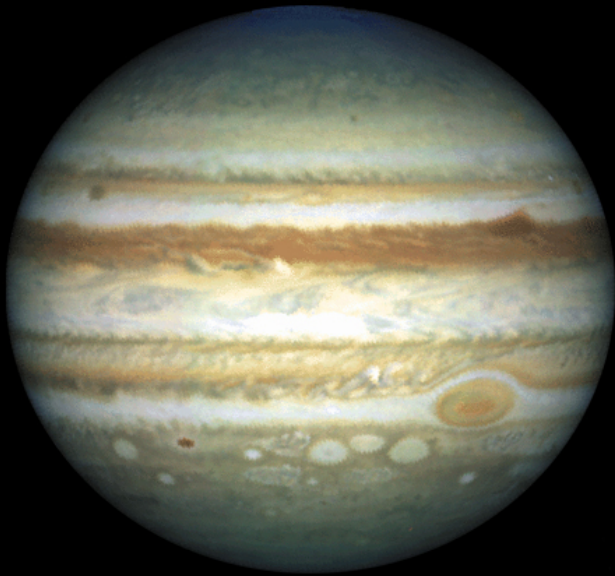


# Europa : The Water World?

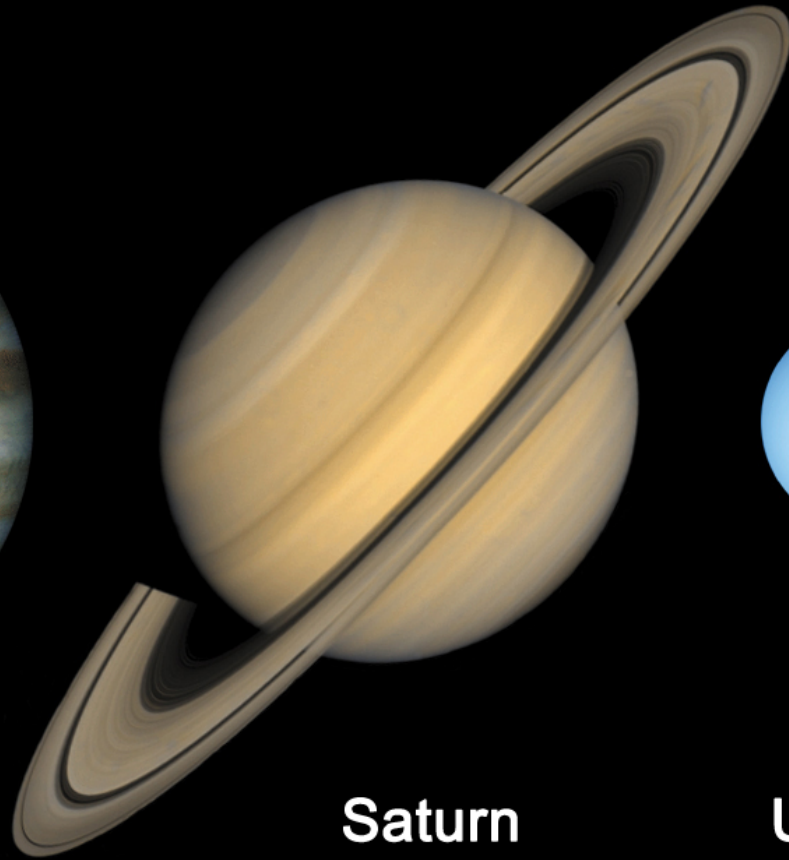


The center is the metallic core. The top shows the thin wafer like a layer of water ice and beneath that, up to a thickness of about 150 km, there could be liquid water. The radius of Europa is about 3000 km.

# The role of giant planets



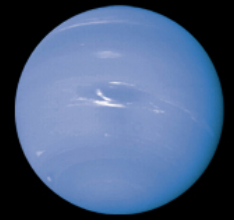
**Jupiter**



**Saturn**

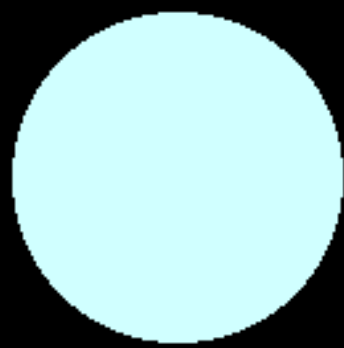


**Uranus**



**Neptune**

## Main Sequence Stars



	O	B	A	F	G	K	M
Spectral Type:	O	B	A	F	G	K	M
Temperature:	40 000K	20 000K	8500K	6500K	5700K	4500K	3200K
Radius (Sun=1):	10	5	1.7	1.3	1.0	0.8	0.3
Mass (Sun=1):	50	10	2.0	1.5	1.0	0.7	0.2
Luminosity (Sun=1):	100 000	1000	20	4	1.0	0.2	0.01
Lifetime (million yrs):	10	100	1000	3000	10 000	50 000	200 000
Abundance:	0.00001%	0.1%	0.7%	2%	3.5%	8%	80%

### Giant Stars

Low mass stars near the end of their lives.

Spectral Type:	Mainly G, K or M
Temperature:	3000 to 10 000K
Radius (Sun=1):	10 to 50
Mass (Sun=1):	1 to 5
Luminosity (Sun=1):	50 to 1000
Lifetime (million yrs):	1000
Abundance:	0.4%

### White Dwarfs

Dying remnant of an imploded star.

Spectral Type:	D
Temperature:	Under 80 000K
Radius (Sun=1):	Under 0.01
Mass (Sun=1):	Under 1.4
Luminosity (Sun=1):	Under 0.01
Lifetime (million yrs):	-
Abundance:	5%

### Supergiant Stars

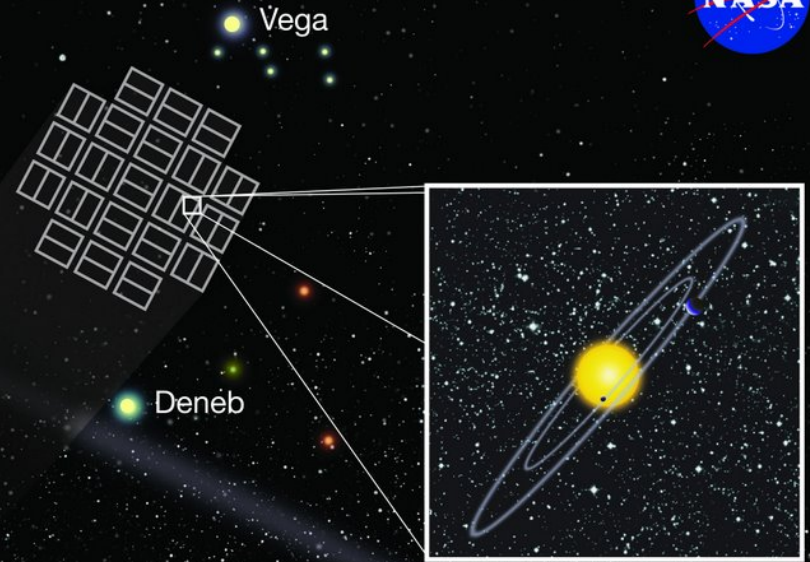
High mass stars near the end of their lives.

Spectral Type:	O, B, A, F, G, K or M
Temperature:	4000 to 40 000K
Radius (Sun=1):	30 to 500
Mass (Sun=1):	10 to 70
Luminosity (Sun=1):	30 000 to 1000 000
Lifetime (million yrs):	10
Abundance:	0.0001%



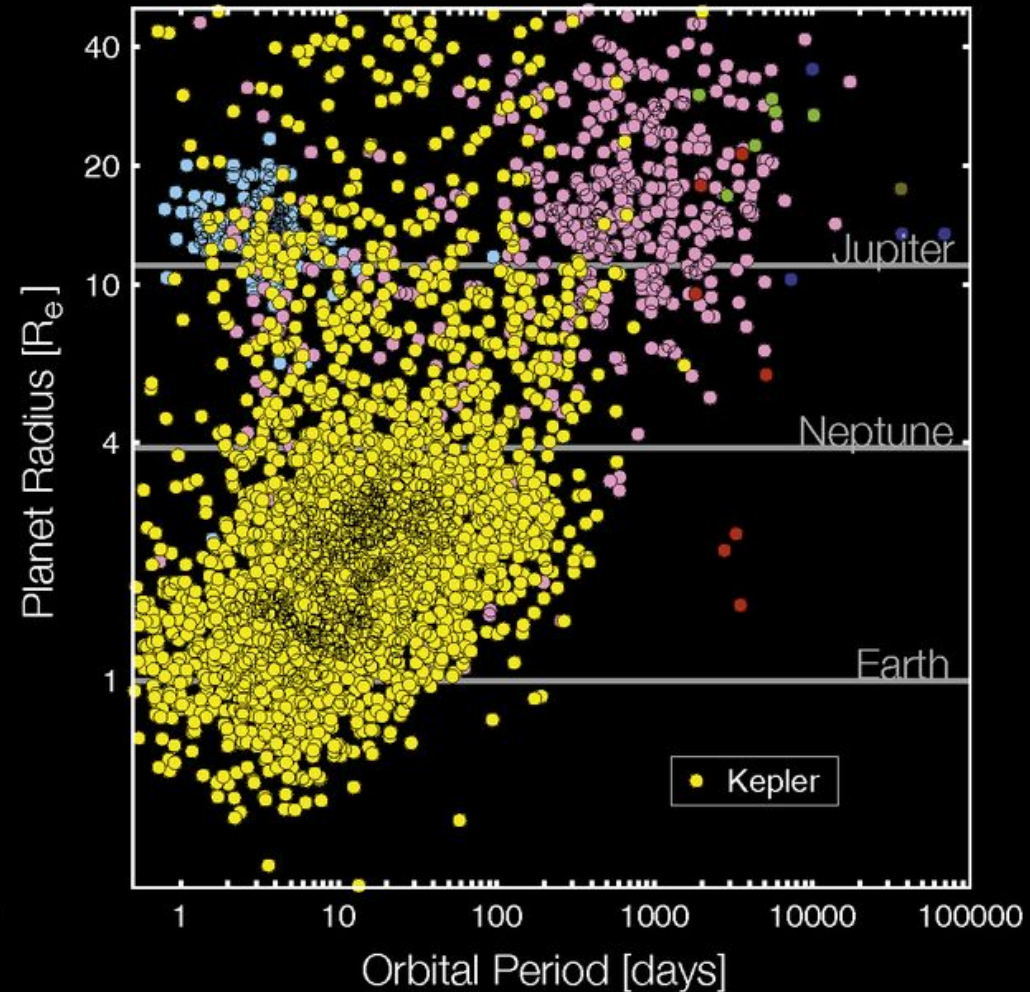
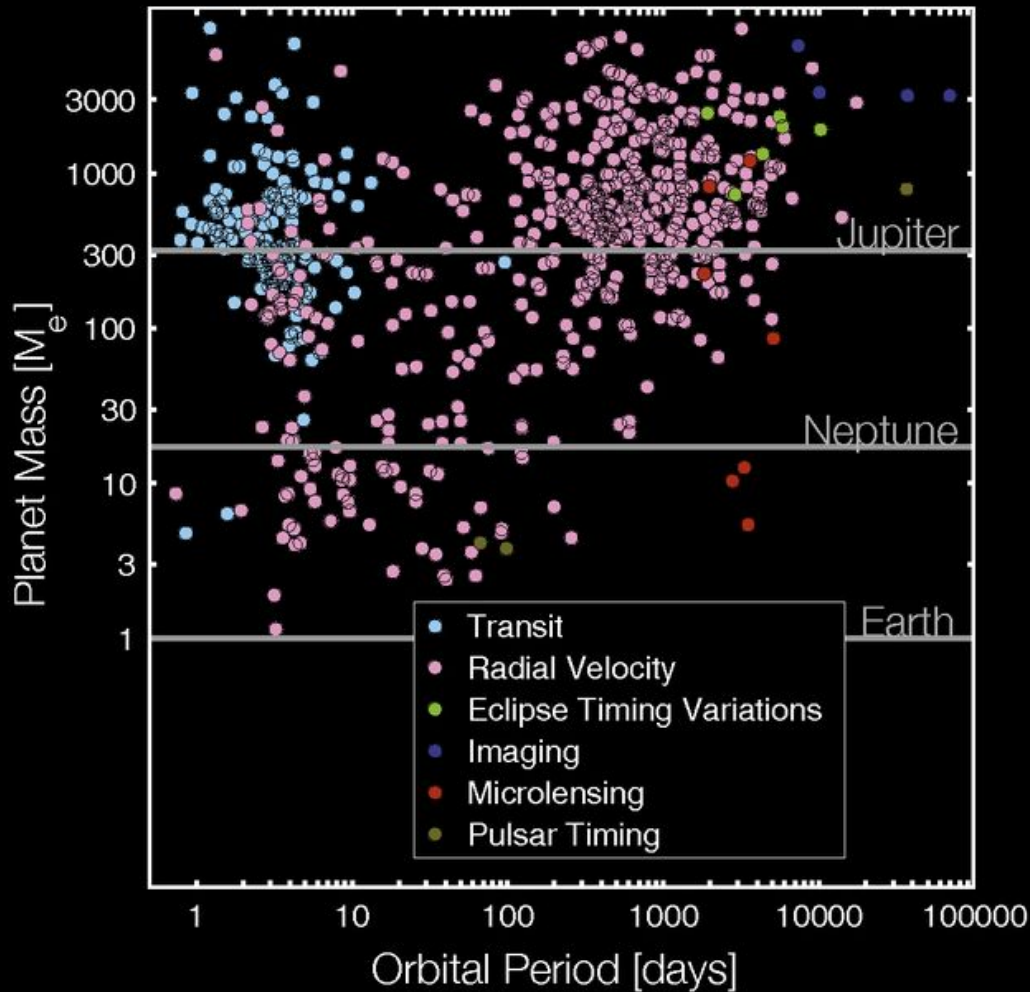
# Kepler

NASA's First Mission Capable of Finding Earth-size & Smaller Planets



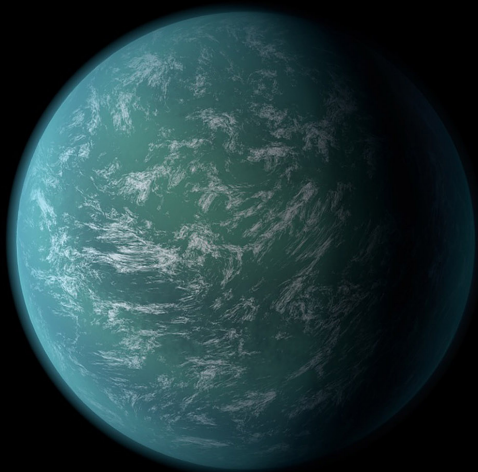
WARNING: OBJECTS IN THIS RENDITION APPEAR LARGER AND CLOSER TOGETHER THAN THEY ARE IN REALITY.

# The Exoplanet Inventory

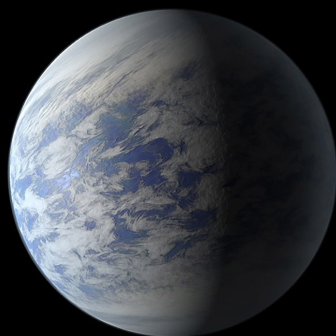


**The occurrence rate of planets increases to smaller sizes.**

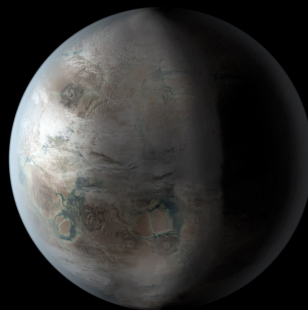
Kepler-22b



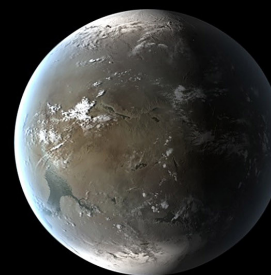
Kepler-69c



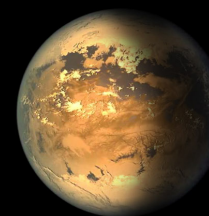
Kepler-452b



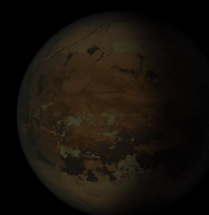
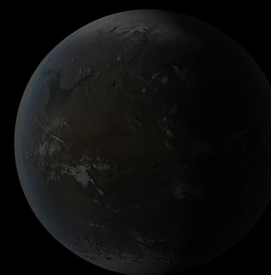
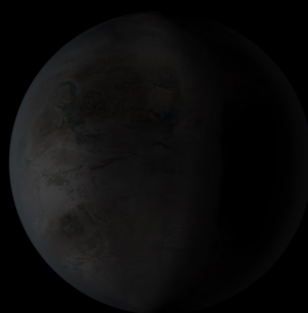
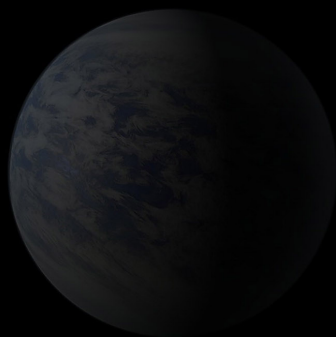
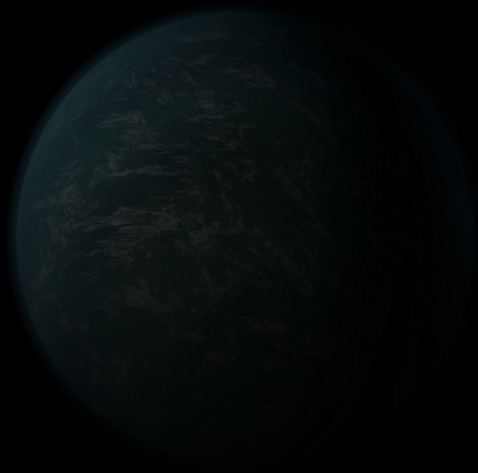
Kepler-62f



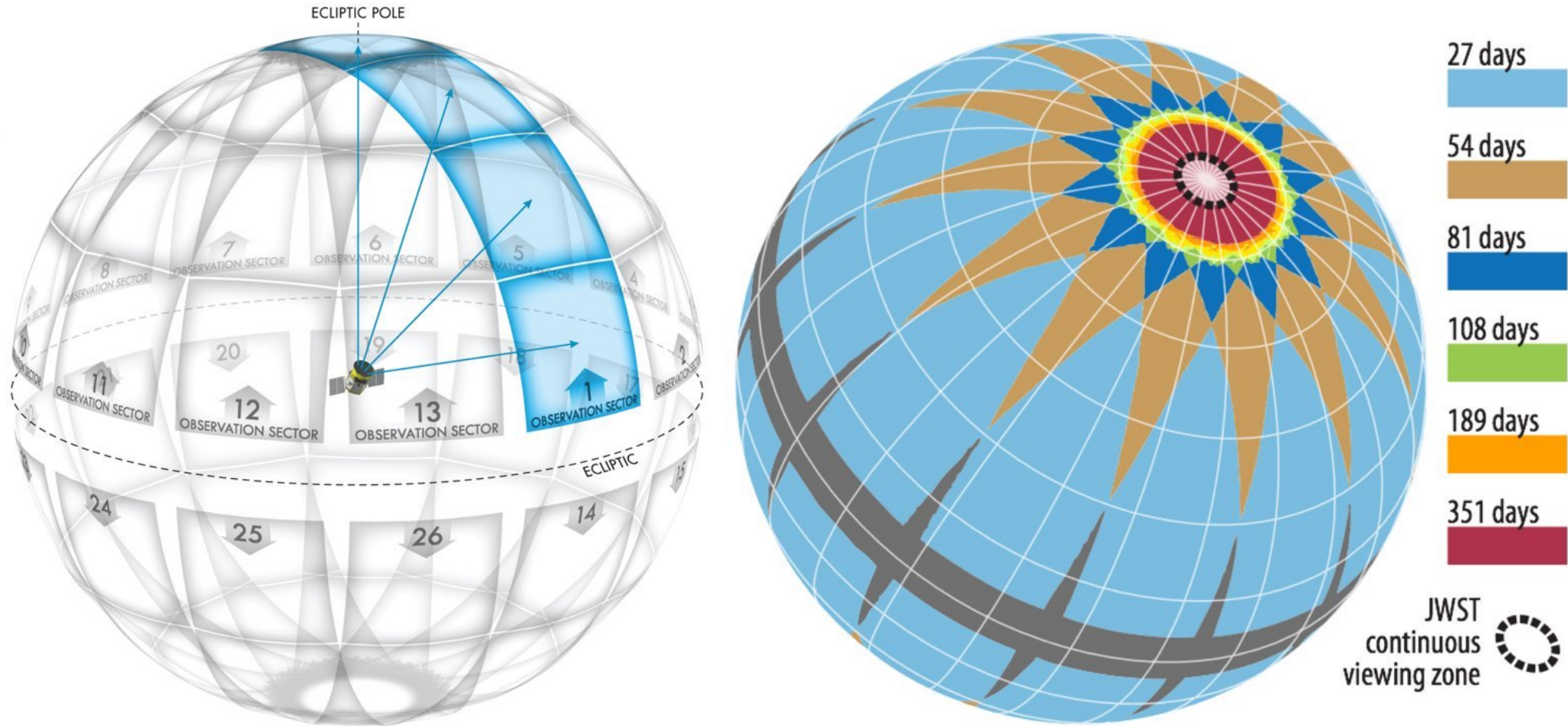
Kepler-186f



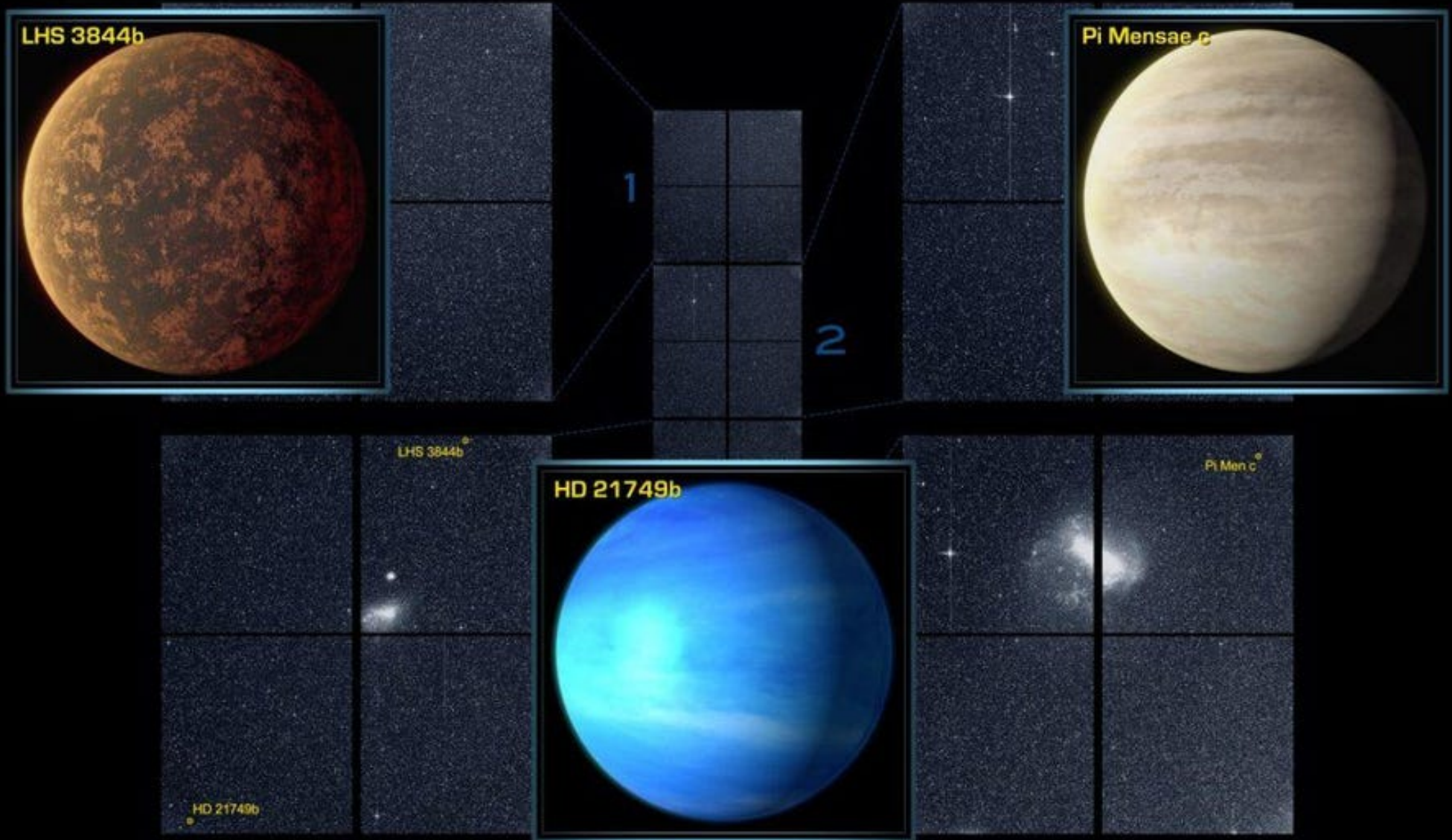
Earth



# Transiting Exoplanet Survey Satellite (TESS)



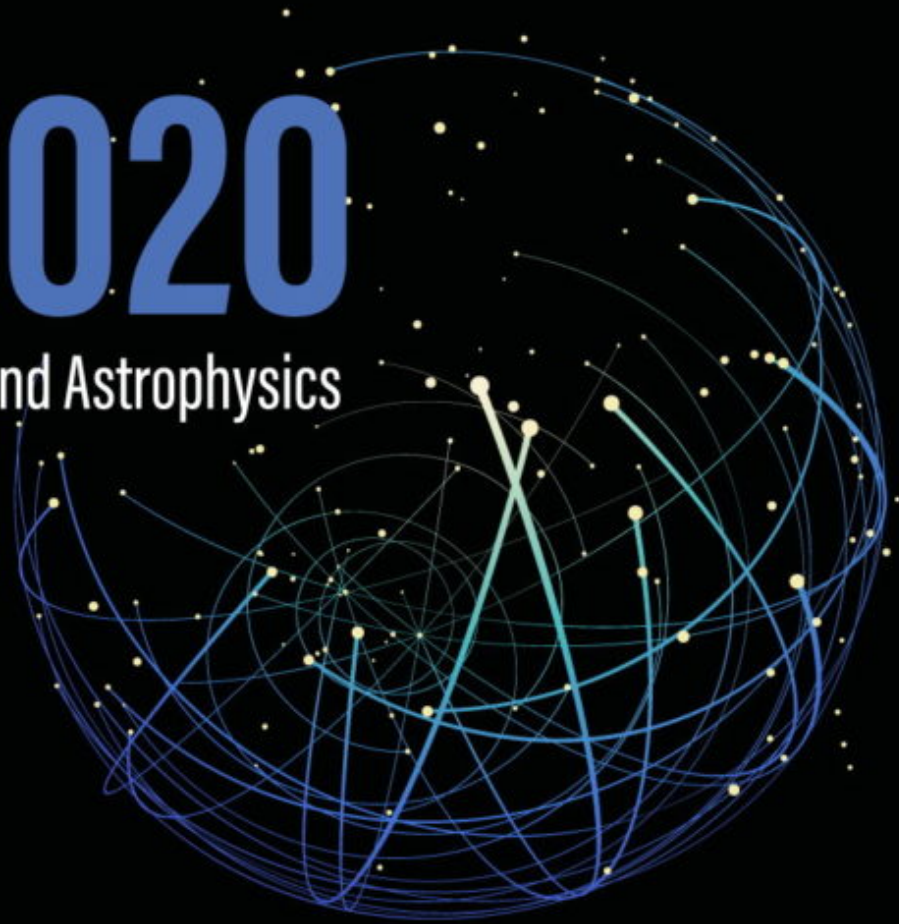
# Transiting Exoplanet Survey Satellite (TESS)



# Astro 2020

Decadal Survey on Astronomy and Astrophysics

*The National  
Academies of* | SCIENCES  
ENGINEERING  
MEDICINE



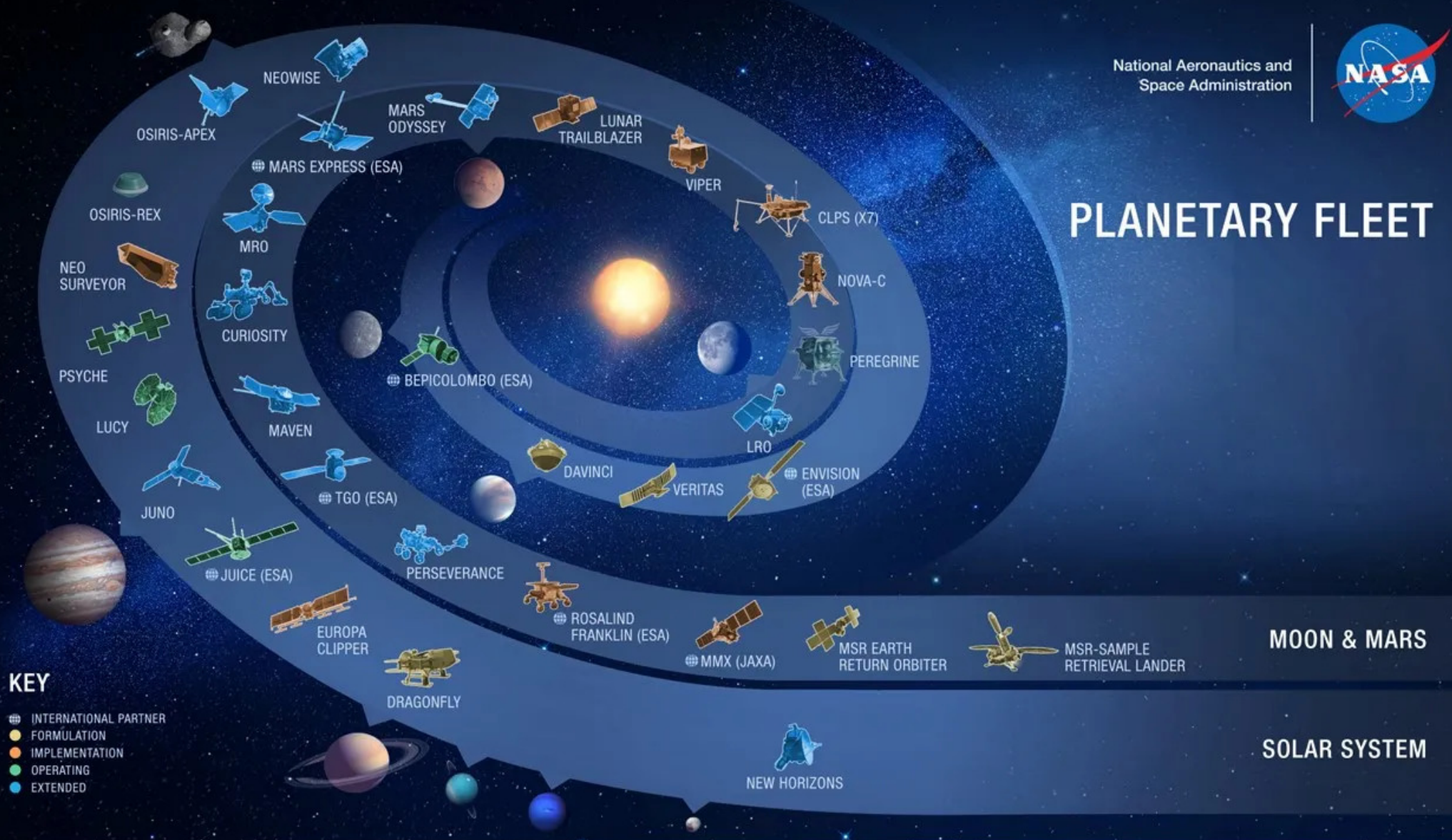
H A B I T A B L E

W  R L D S

O B S E R V A T O R Y



# PLANETARY FLEET



## KEY

- INTERNATIONAL PARTNER
- FORMULATION
- IMPLEMENTATION
- OPERATING
- EXTENDED

MOON & MARS

SOLAR SYSTEM

# An Incomplete List of Habitability Caveats

- 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?
- Why don't we have a super-Earth?
- What does the T-P profile of a super-Earth look like?
- Does a giant planet beyond the snow line matter?
- Can life survive extreme eccentric orbits?
- How do terrestrial atmospheres respond to flux variations?
- Are circumbinary planets habitable?
- How does atmospheric erosion depend on magnetic field?
- Does a substantial moon create a more habitable world?
- How well do we need to understand the star?
- ***What observations/measurements do we need to make to test the Habitable Zone hypothesis?***