Today's Topics

Monday, October 19, 2020 (Week 9, lecture 25) – Chapters 14.4, 30.1-3.

A. 2019 Nobel Prize in Physics

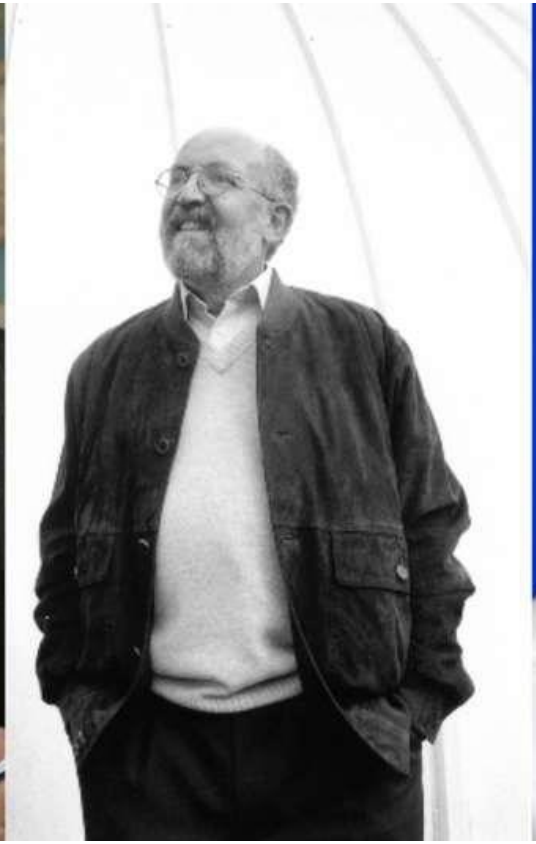
→ Discovery of Exoplanets

B. Exoplanets

C. Life in the Solar System?

2019 Nobel Prize in Physics … and Astronomy

James Peebles
(Princeton U.)



Michel Mayor
(U. of Geneva)

Didier Queloz
(U. of Geneva)

[Image credits: Royal Swedish Academy of Sciences; University of Geneva]

2019 Nobel Prize in Physics … and Astronomy

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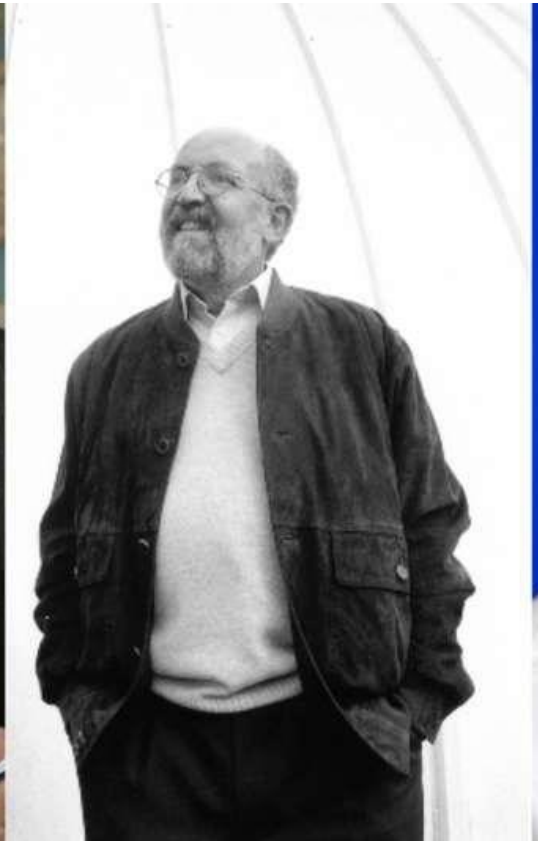
Big Bang theory,
dark matter & energy



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Discovery of first star-based **exo-planet** (in 1995)

[Image credits: Royal Swedish Academy of Sciences; University of Geneva]

2019 Nobel Prize in Physics … and Astronomy

- **Cosmic Microwave Background** (CMB) is the remnant blackbody radiation from the Big Bang.
- This radiation used to much more energetic, but it has been "Doppler-shifted" by the expansion of the universe. Apparent temperature is **T = 2.726 K** (peak at λ = 1 mm).

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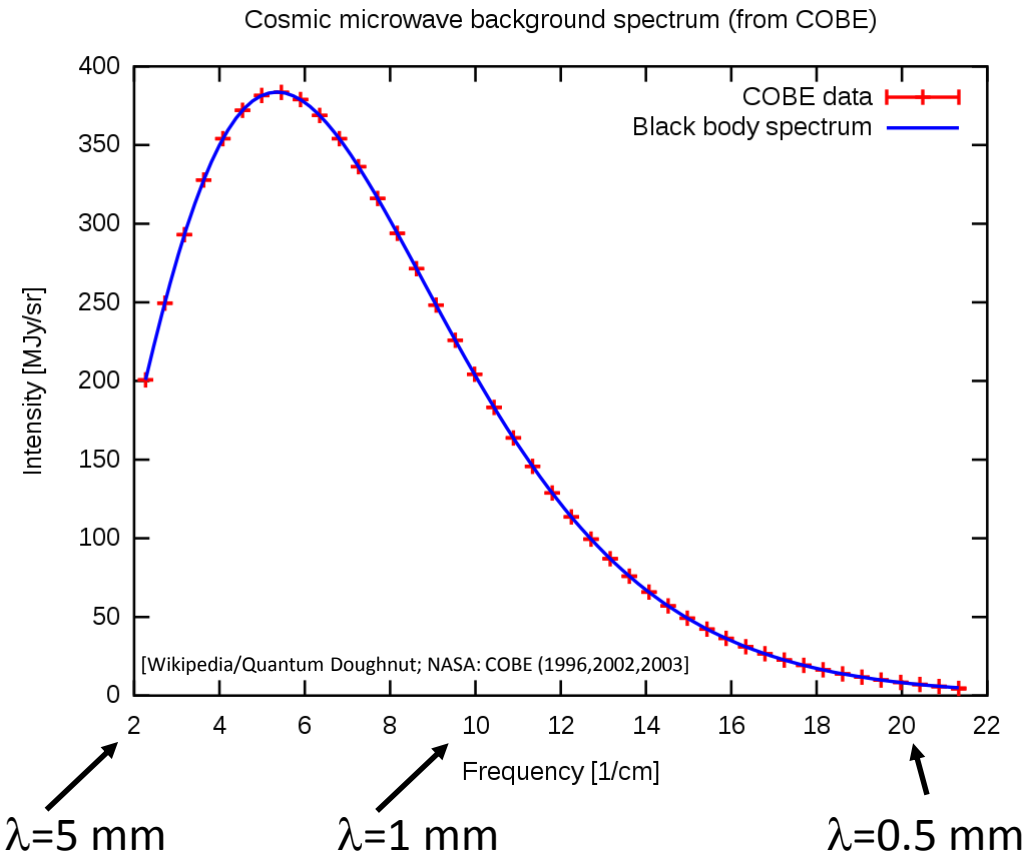

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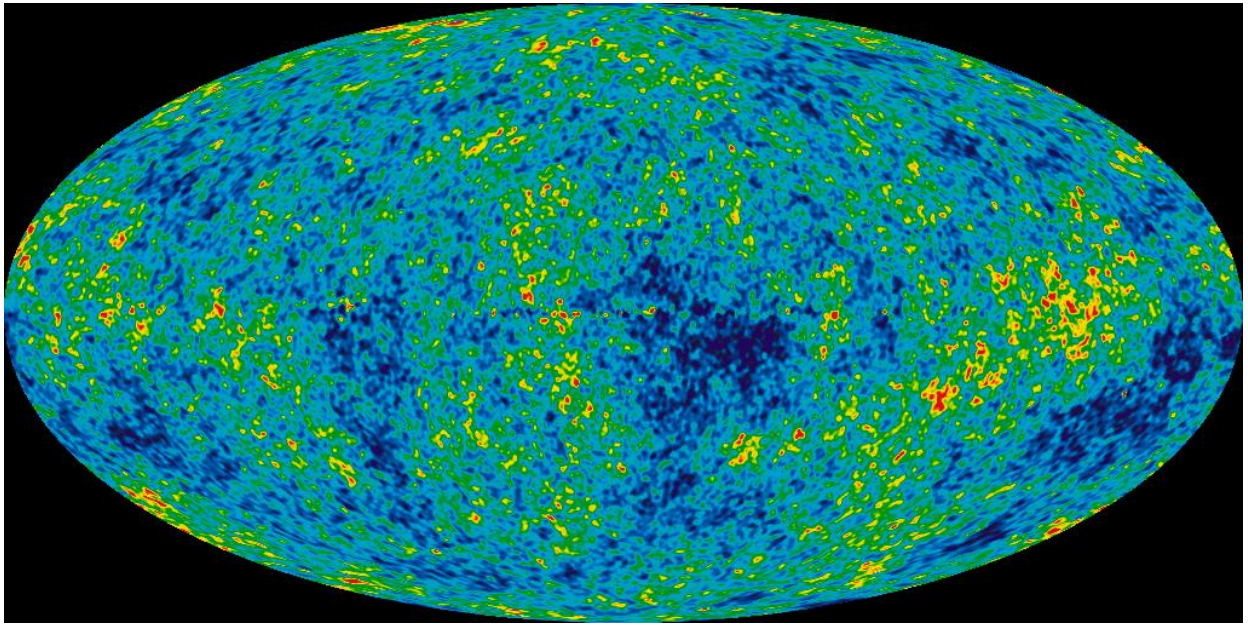
- **Spatial/angular variations of CMB** (~ 0.01% level) are thought to have given rise to galactic superclusters, galaxies, and stars.



[https://map.gsfc.nasa.gov/media/121238/index.html]

Spatial variations in the Cosmic Microwave Background (WMAP).

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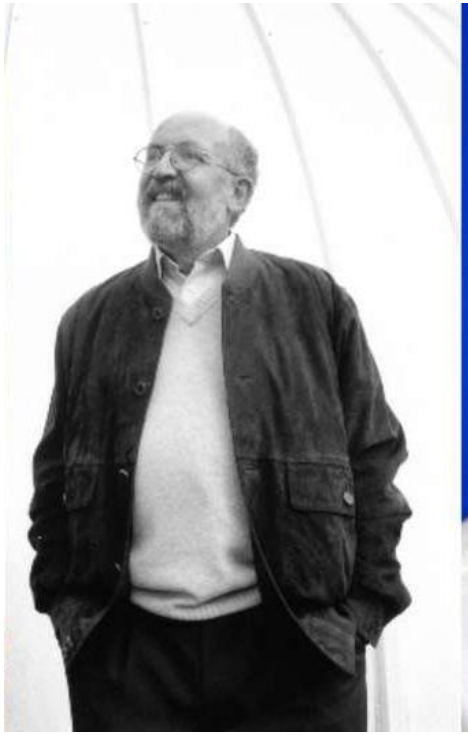
[Image credits: Royal Swedish Academy of Sciences; University of Geneva]

2019 Nobel Prize in Physics … and Astronomy

- **1995: First discovery of a planet orbiting another star** (51 Pegasi) at about 50 ly.
  → *Pegasus constellation.*
- Discovered by seeing the **Doppler shift** in the star's light caused by orbiting the center-of-mass of the star-planet system.
- Planet is 0.5 lighter than Jupiter, but with a 4 day orbit (i.e. closer than Mercury)



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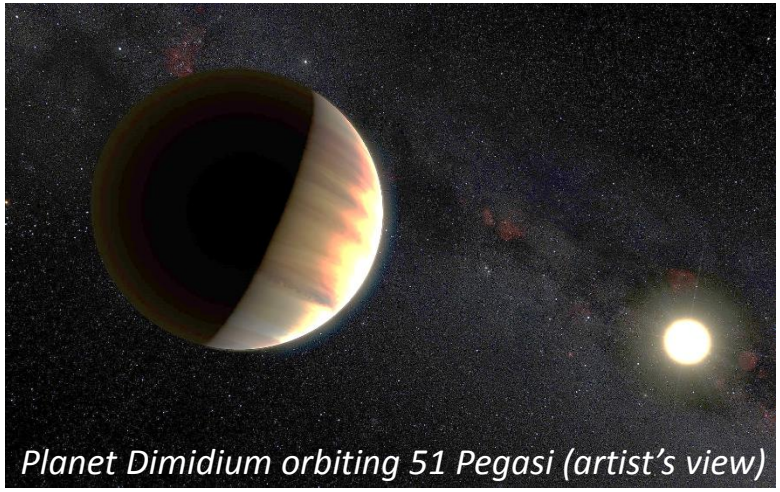
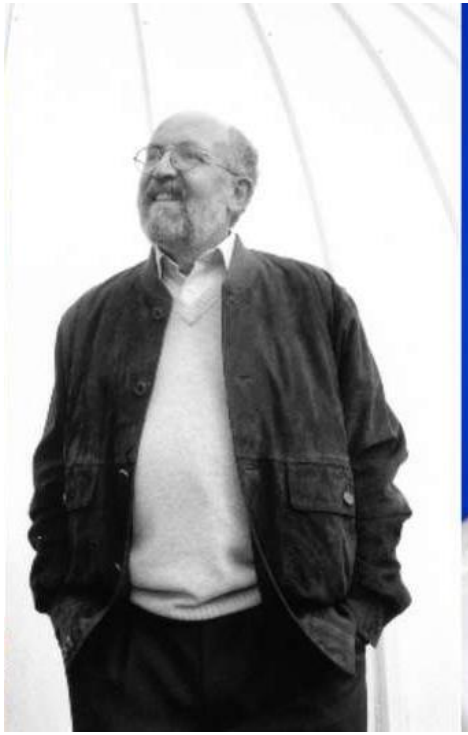


Planet Dimidium orbiting 51 Pegasi (artist's view)

[Wikipedia: ESO/M. Kornmesser/Nick Risinger (skysurvey.org) - ESO website]



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Discovery launched exo-planet astronomy.
→ ~ 4000 exo-planets discovered so far.

Exoplanets

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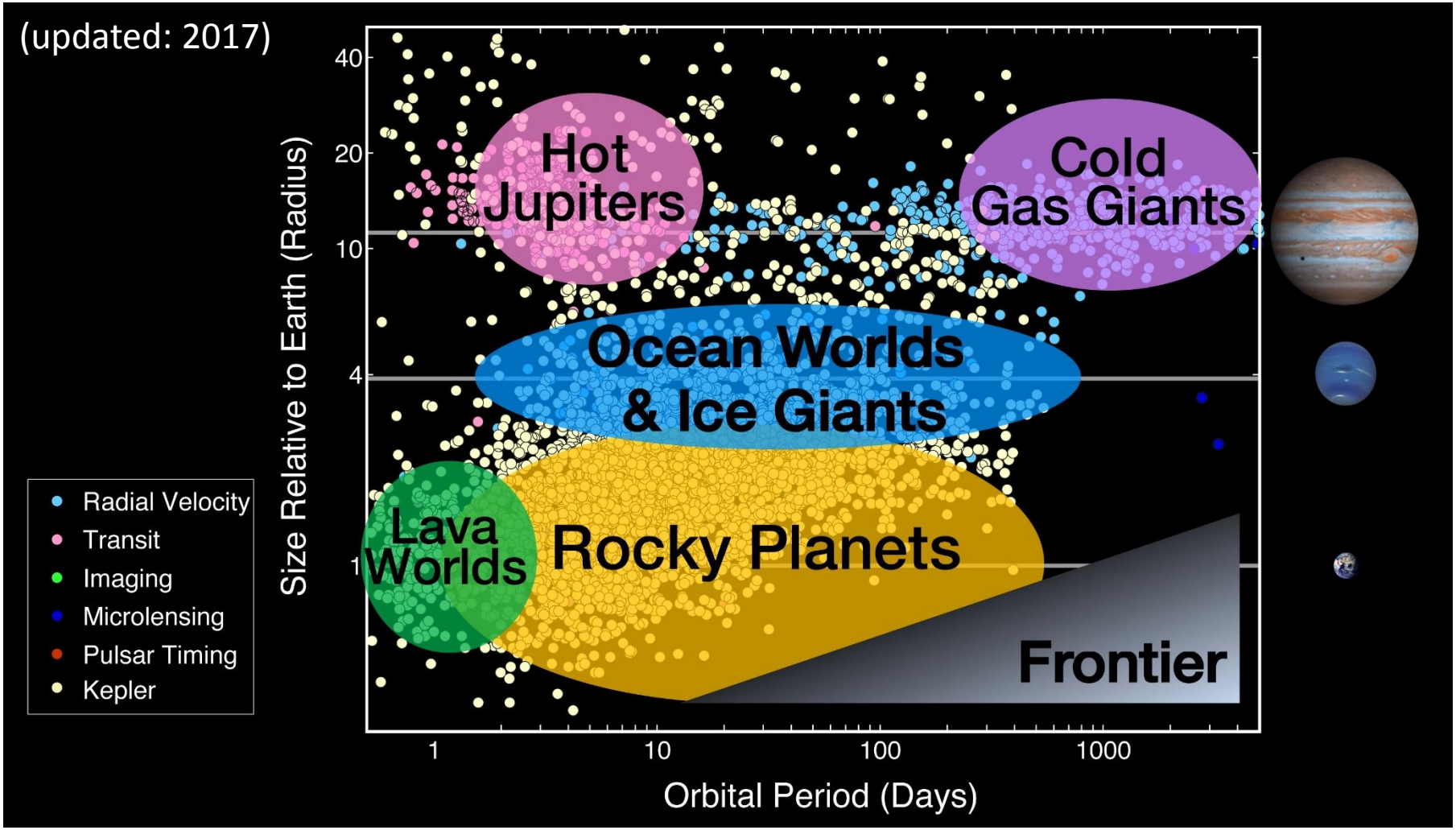
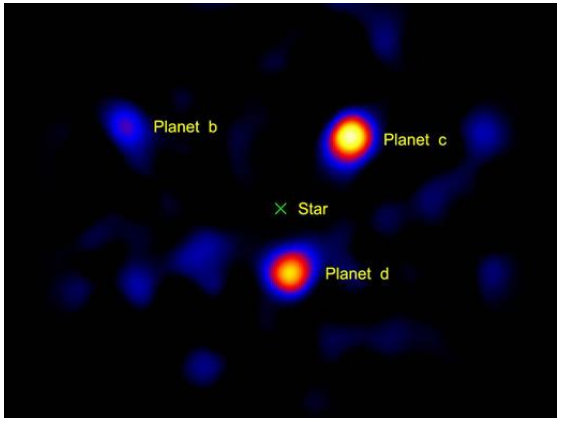


[https://www.nasa.gov/image-feature/ames/kepler/exoplanet-populations]

Exoplanets

What we know so far

- **Most stars (possibly all) have planets.**



3 planets around star HR8799 (120 ly)
Orbits: 24 AU, 38 AU, 68 AU.
[Hale telescope, 2010]

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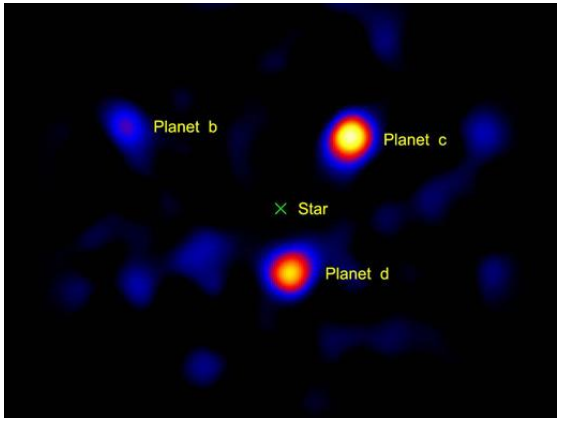
- We see many **gas giants** <u>inside the frost line</u>.

  Models of evolution for solar systems show that planets often perturb the orbits of other planets and **move them towards the star** (or shoot them out).



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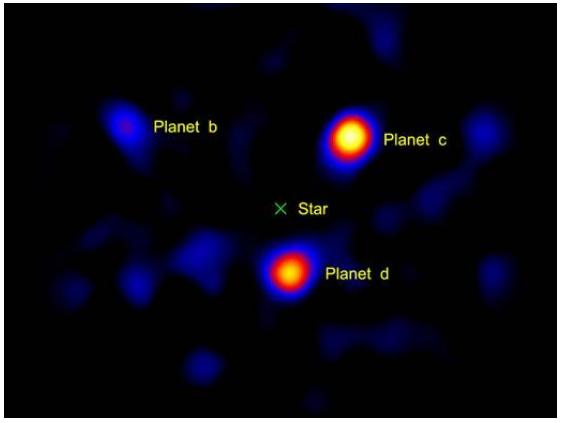
- Roughly 40% of Sun-like stars have terrestrial planets in the **"goldilocks"** region.

  → Above freezing and below boiling for water.
- **Earth-like** planets are very common

  They are harder to detect than larger ones, so we have not seen very many yet.



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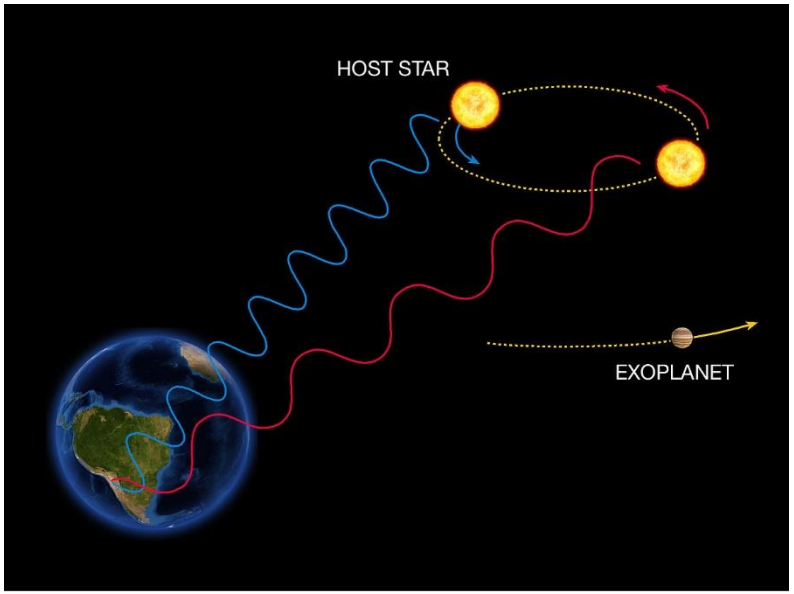
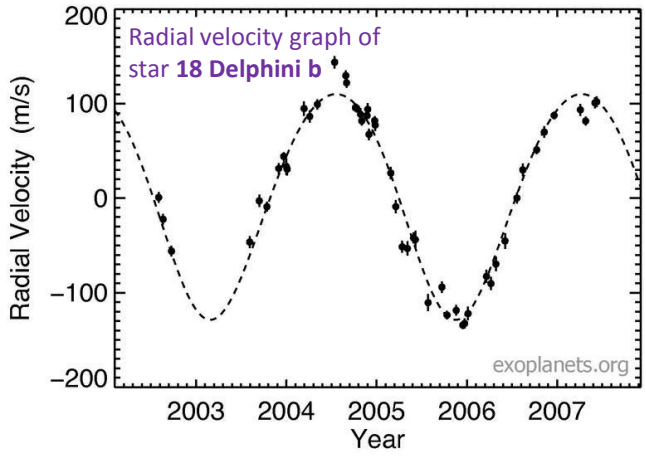
Main Detection Methods



The Radial Velocity Method

ESO Press Photo 22e/07 (25 April 2007)



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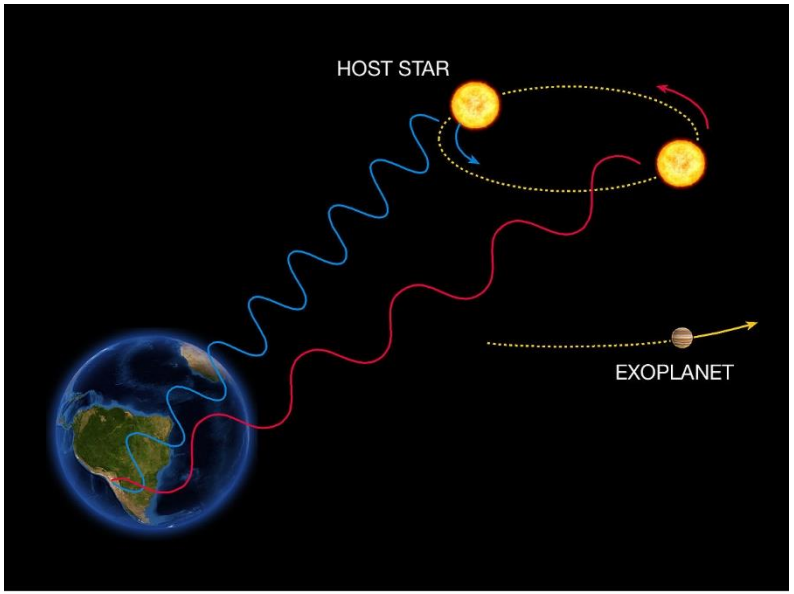

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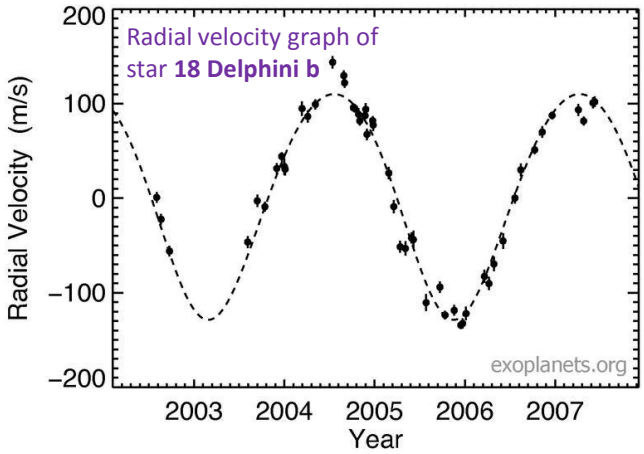
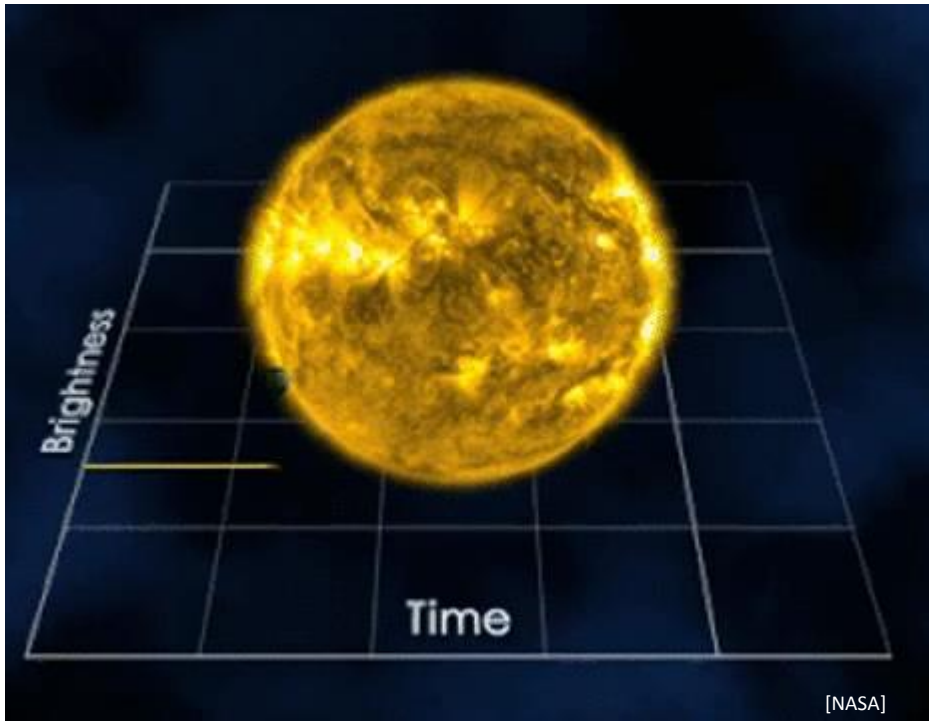


Transit Photometry



Signal is typically 1 part per 10,000 dimming.

What is Life ?

Definitions of Life (biology) – *there are many definitions (no consensus)*

Definition 1

Life is considered a characteristic of something that preserves, furthers or reinforces its existence in the given environment *[Wikipedia]*.

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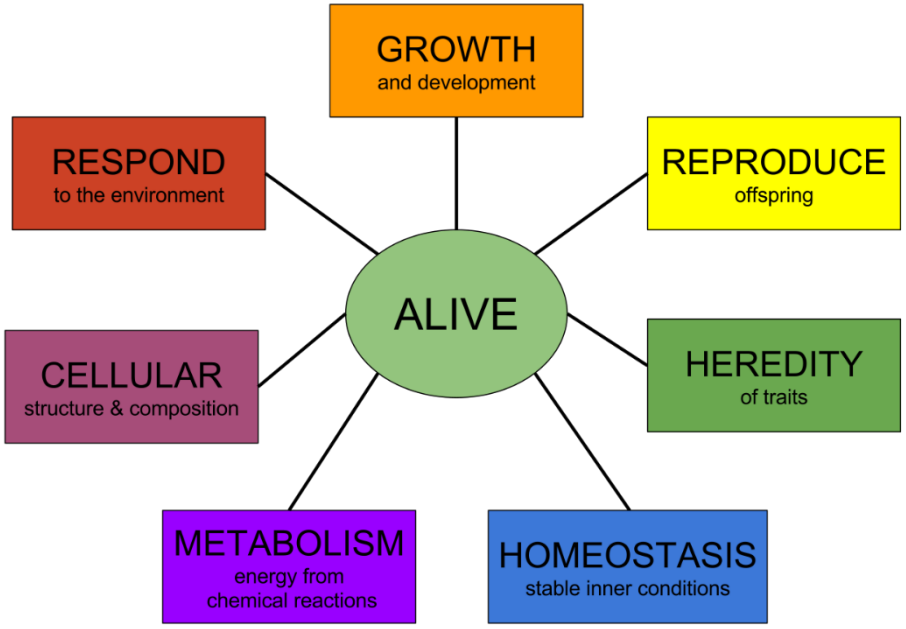

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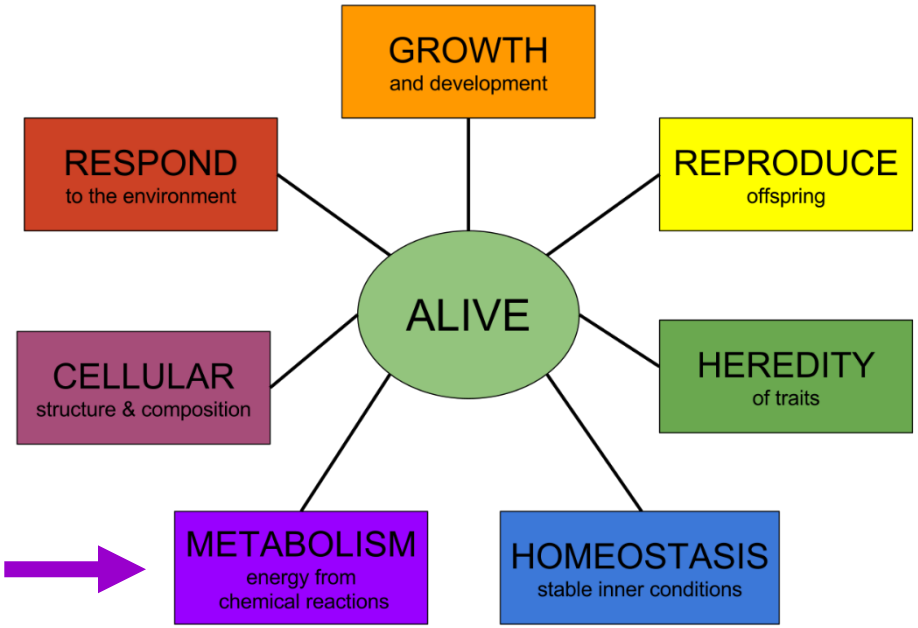
Life requires specific environmental conditions →

… Also, life can modify its environment.



Life requires an **energy source** →

[Wikipedia: Chris Packard - Own work, CC BY-SA 4.0]

What are the environmental requirements for Earth-style Life?

Ingredients for Earth-style life

- **Liquid water** (solvent).
- Carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur.
- **Temperature range: -25° C to 120° C.**
- Not too much ionizing radiation.
- **An energy source:** solar energy, chemical energy, heat.

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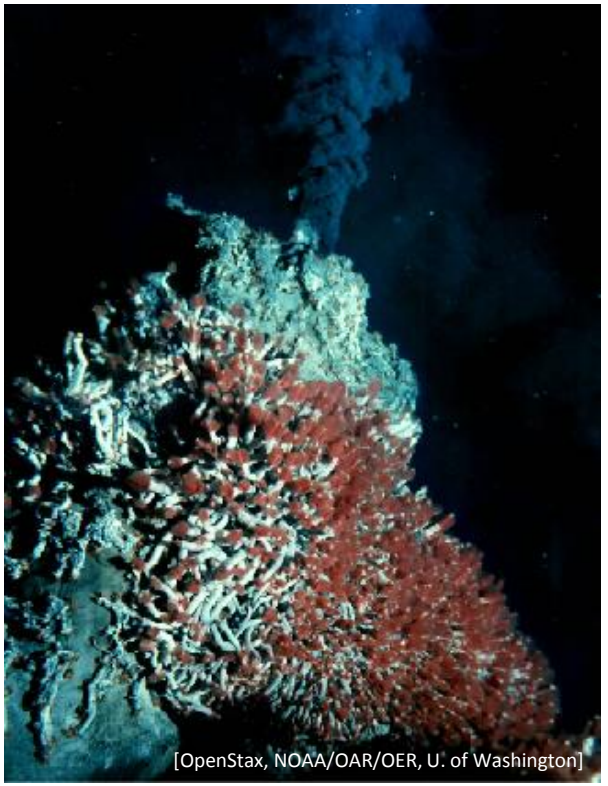
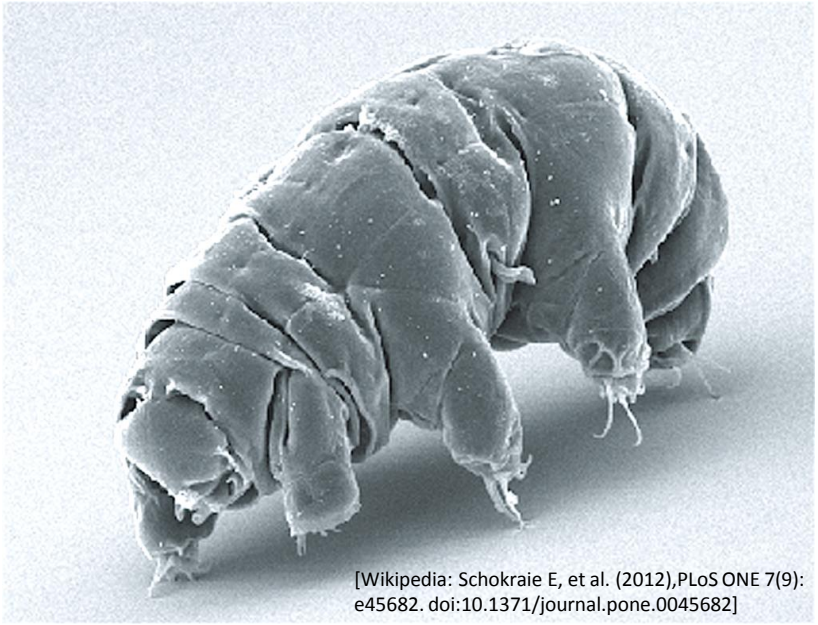
Hot spring (Yellowstone Nat. Park): multi-colored photosynthesizing bacteria (solar energy). Central pool (92 ° C) bacteria use chemical energy.



Hydrothermal vent: chemical energy (metal sulfides).

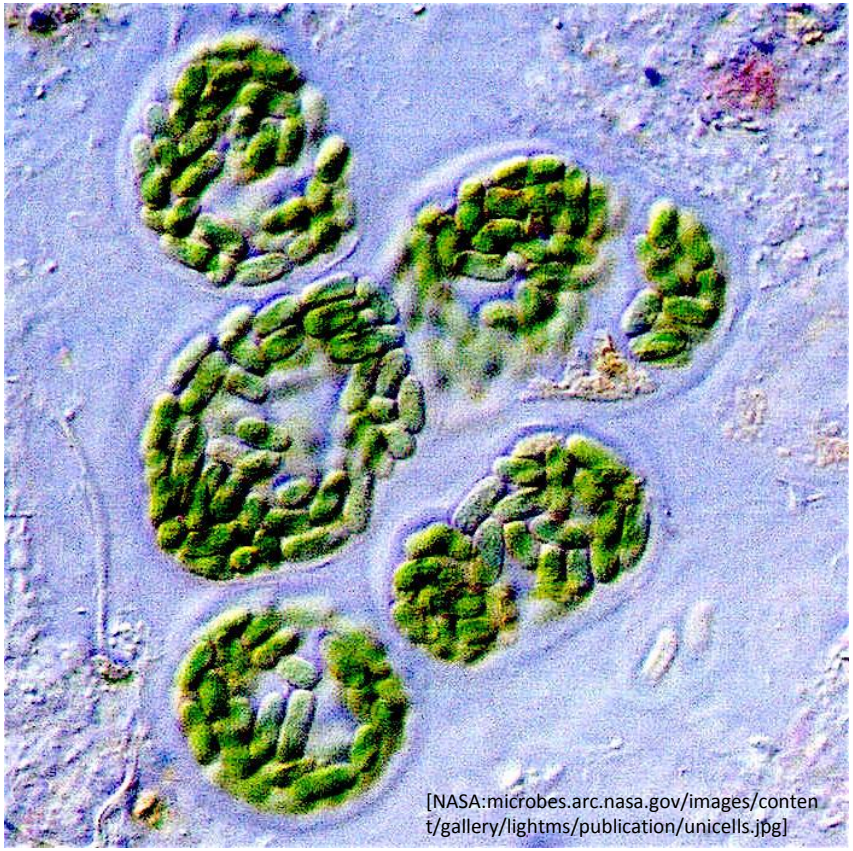
Examples of Hardy Life



[Wikipedia: Schokraie E, et al. (2012),PLoS ONE 7(9): e45682. doi:10.1371/journal.pone.0045682]

The Tardigrade (length: ~0.5 mm) can survive

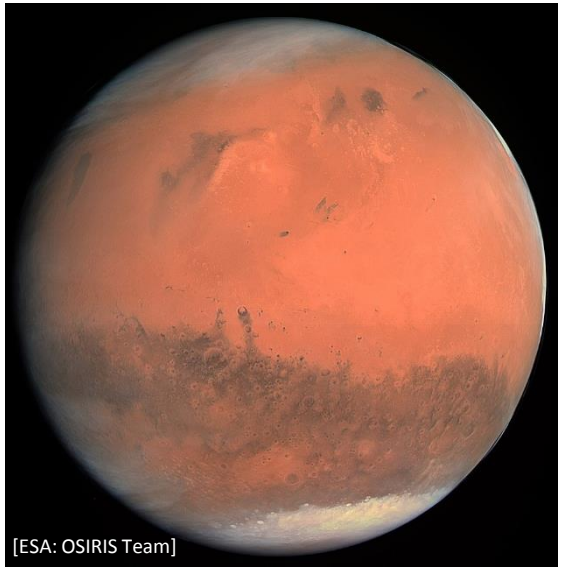
- -270° C to 150° C for a few minutes.
- Vacuum to 1000 bars.
- Years of dehydration.
- 1000x lethal radiation dose of animals.



[NASA:microbes.arc.nasa.gov/images/content/gallery/lightms/publication/unicells.jpg]

Cyanobacteria are photosynthesizing bacteria that have existed on Earth for 2.1 billion years ago (maybe longer)

Where to look for life In the Solar System ?


[ESA: OSIRIS Team]

Mars may have suitable conditions for life just below its surface:

- **Liquid water.**
- Reasonable temperature range.
- Limited ionizing radiation.

→ **Methane** detected in Mars' atmosphere (possible bio origin).

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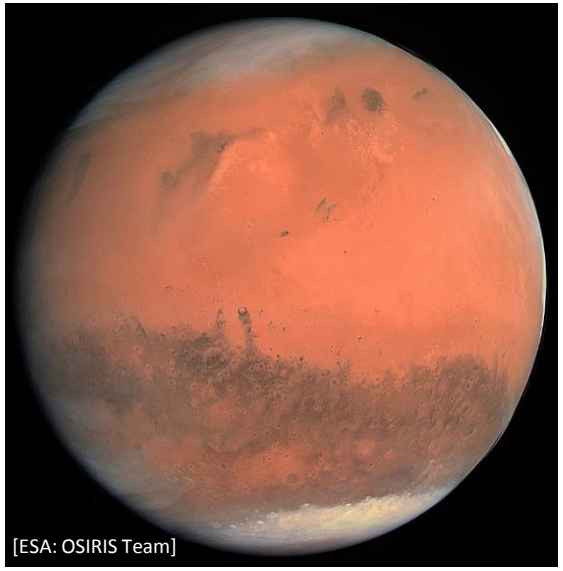

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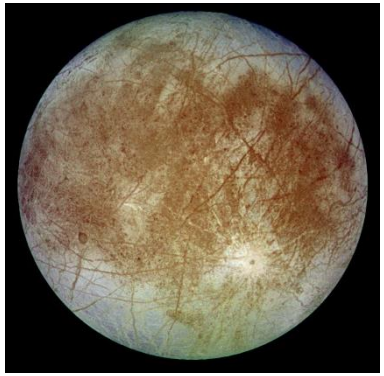

[NASA/JPL/DLR: Gallileo mission, 1996]

Europa (Jupiter moon)

- Possible **water ocean** (under ice crust).
- **Tidal heating.**
- Limited ionizing radiation below surface.

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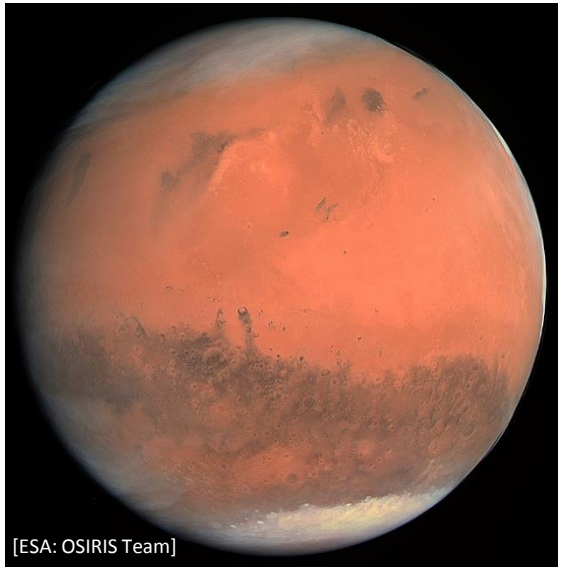
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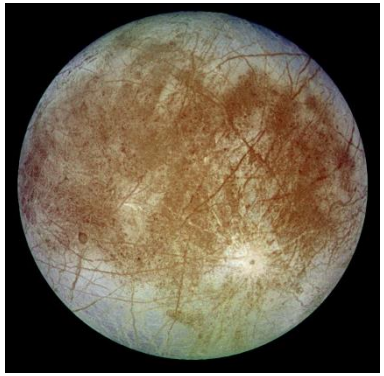
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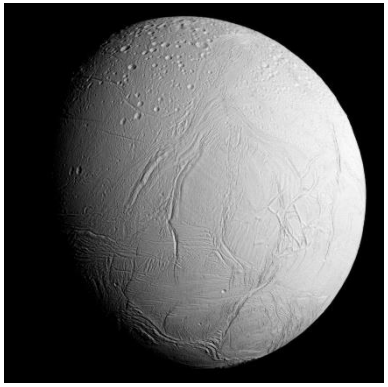
[NASA: Cassini mission, 2015]

Enceladus (Saturn moon)

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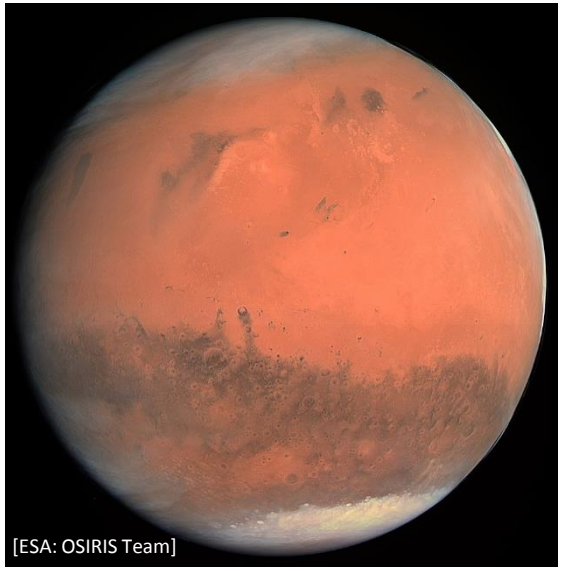
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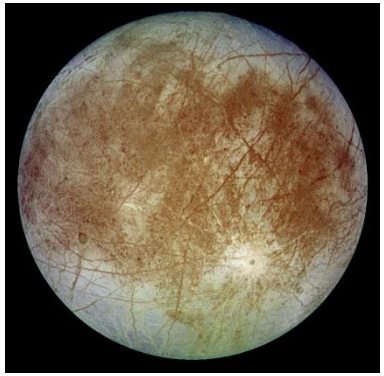
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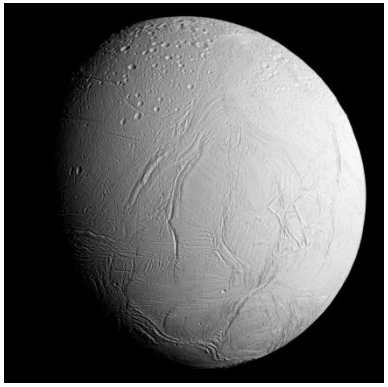
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More speculative: Ganymede sub-surface water, upper atmosphere of Venus.