Today's Topics

Friday, April 9, 2025 (Week 10, Lecture 26) – Chapter 7, 14.3-4, 30.1-3.

A. Review: Solar system formation

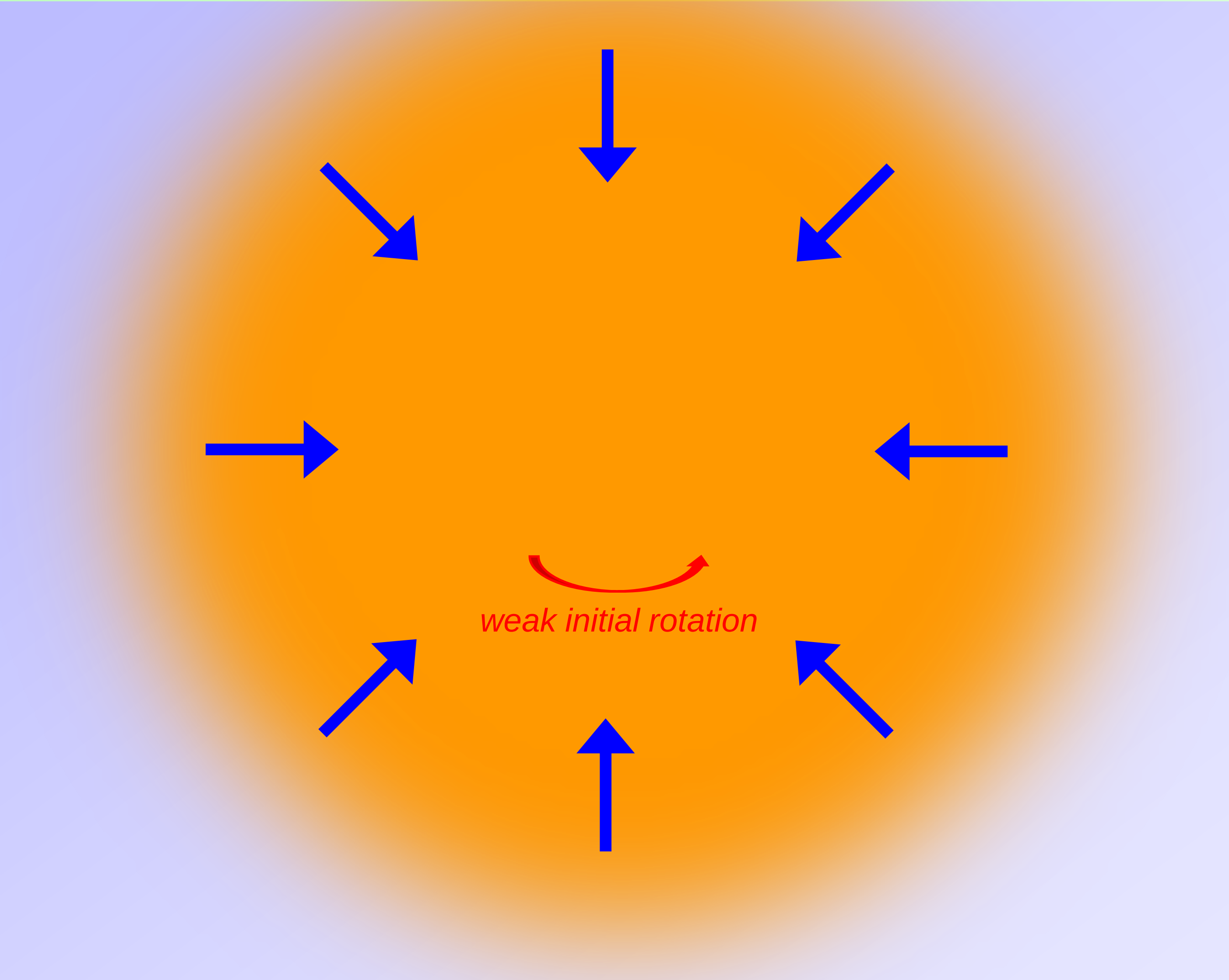
B. Examples of Protoplanetary systems

C. Exoplanets

D. Exolife?

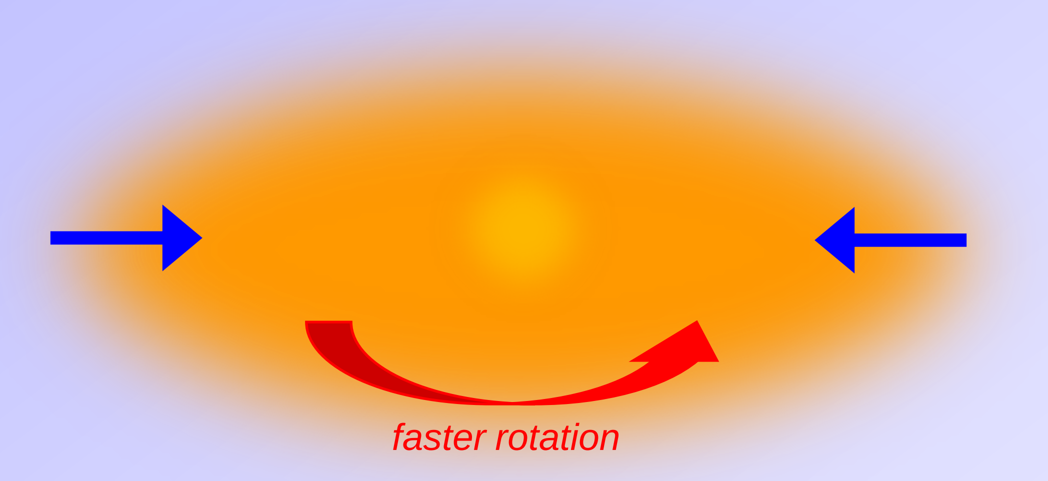
Problem Set #8 is due on ExpertTA on Friday, April 11, 2025, by 9:00 AM

Step 0: large cloud of gas & dust



Mutual gravity pulls gas, dust, particles, and material inwards.

Step 1: Contraction



As the solar nebula contracts it **heats up** (energy conservation), spins faster (angular momentum conservation), and flattens out.

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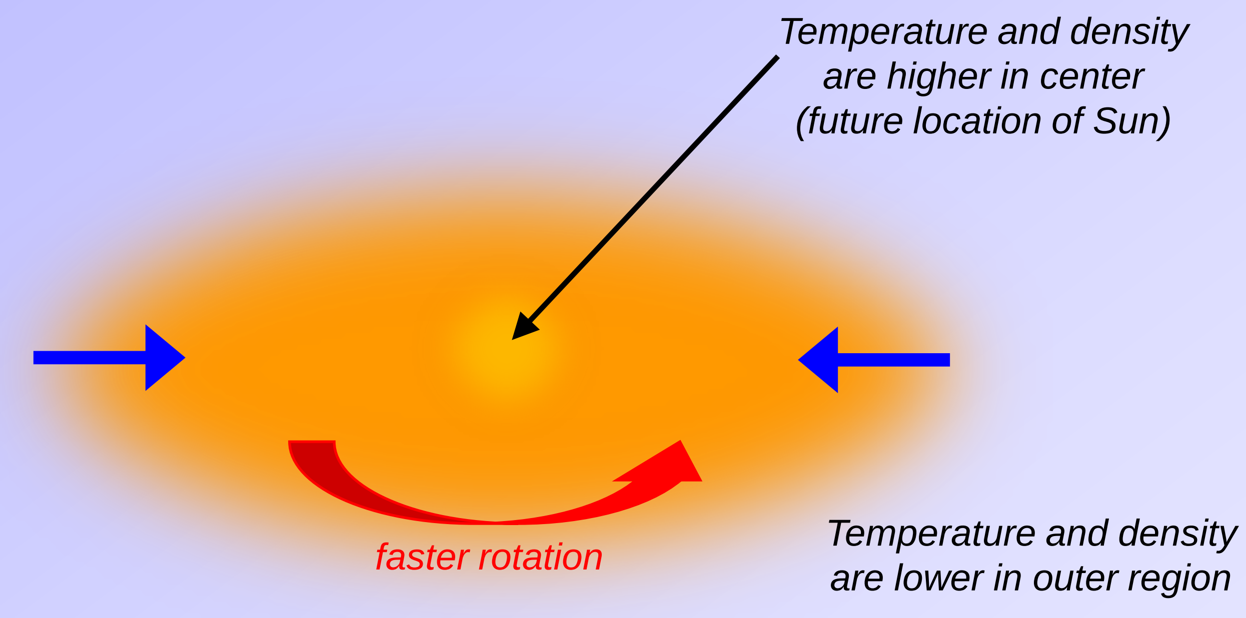

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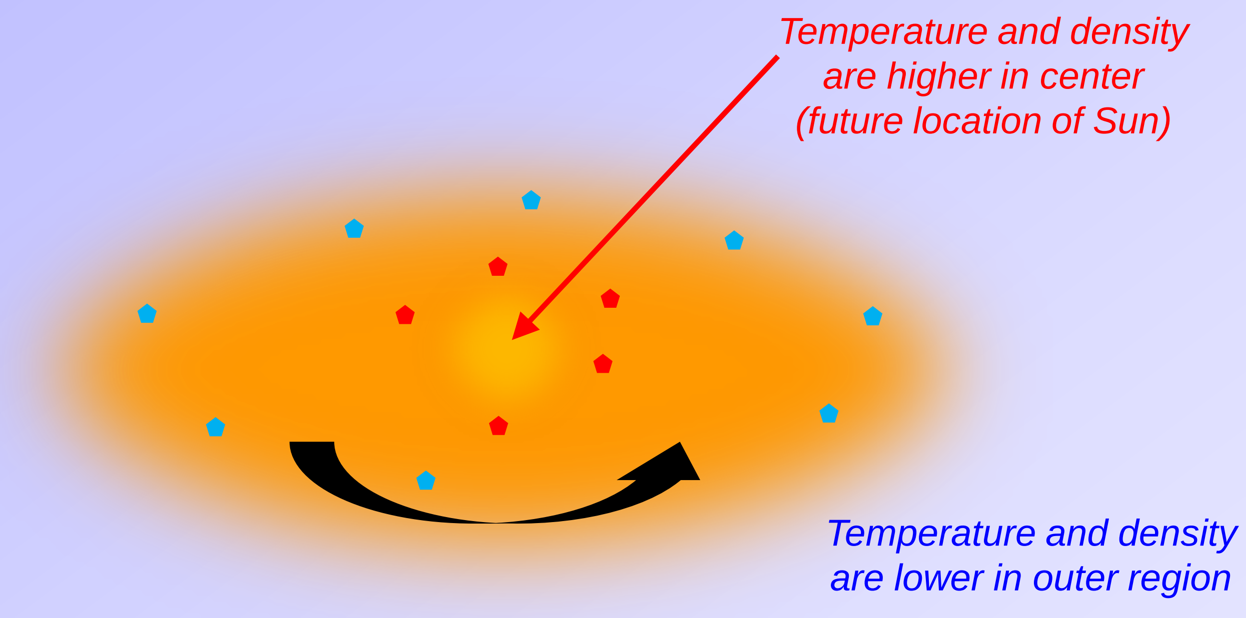
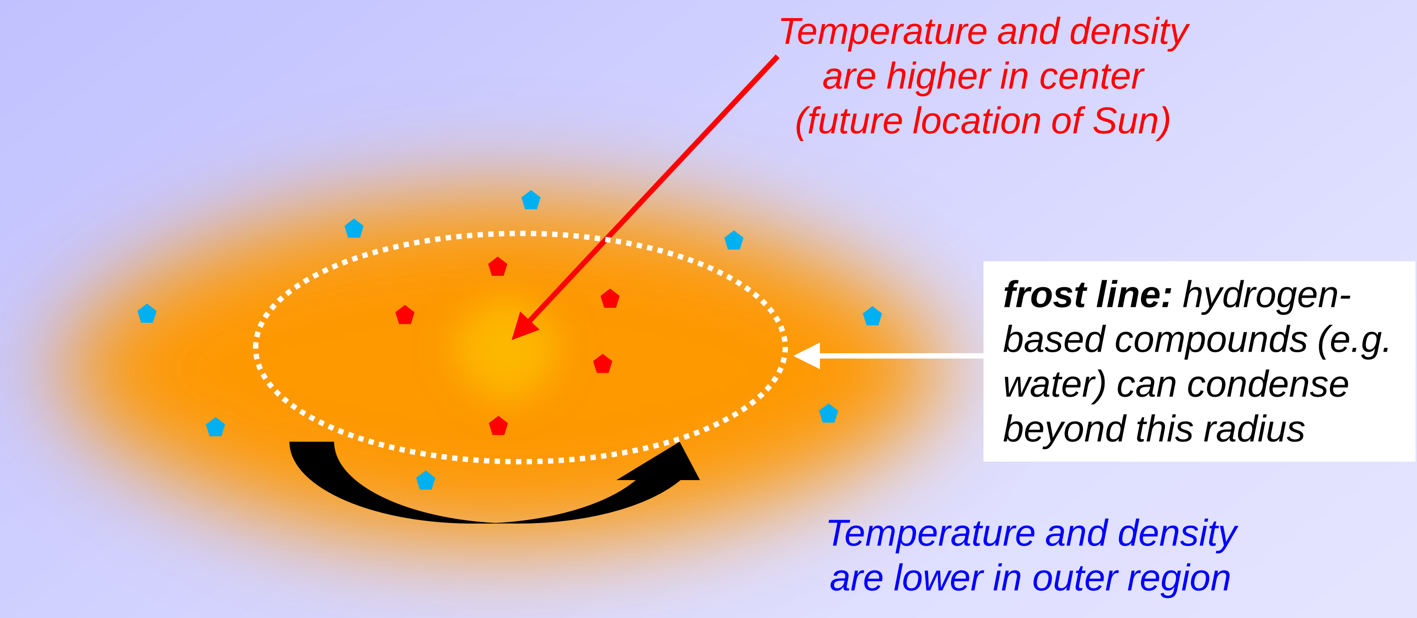
Step 2: Condensation



As the nebula cools (blackbody radiation) <u>heavy element gases</u> condense around dust particles. Hydrogen and helium do not condense, but hydrogen-based molecules can in the cooler outer parts.

Step 2: Condensation – “frost line”



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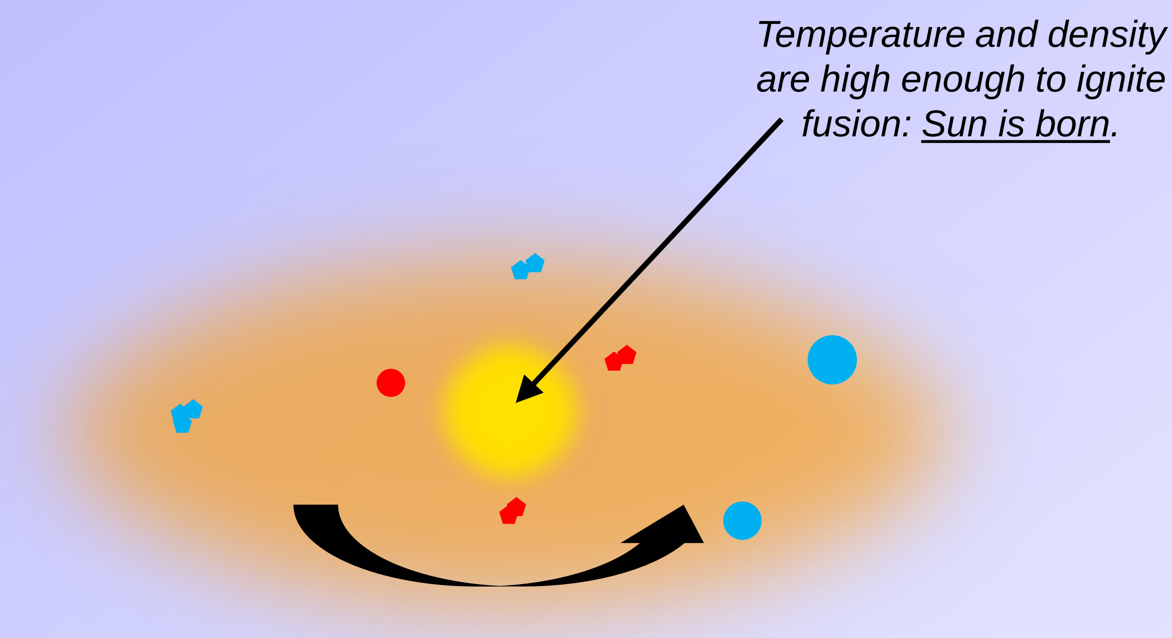
Step 3: Accretion of Planetesimals

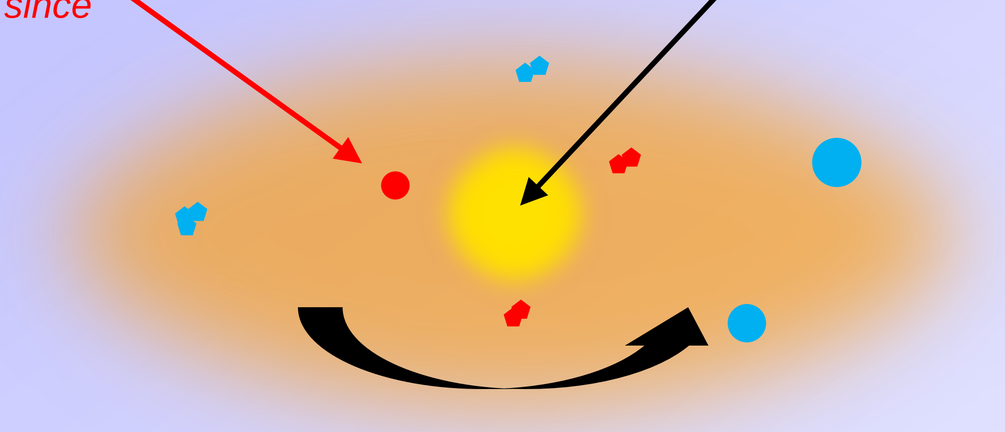


- **Accretion of planetesimals:** Solid particles collide and stick together to progressively start planets. Their gravity becomes strong enough to collect gases.
- **Star ignition:** The central region gets dense enough to **ignite fusion**.

Step 3: Accretion of Planetesimals

Inner planetesimal tend to be richer in heavy elements, which condense at higher temperature. They tend to be smaller, since they sweep a smaller area (gathering less material).

Temperature and density are high enough to ignite fusion: Sun is born.



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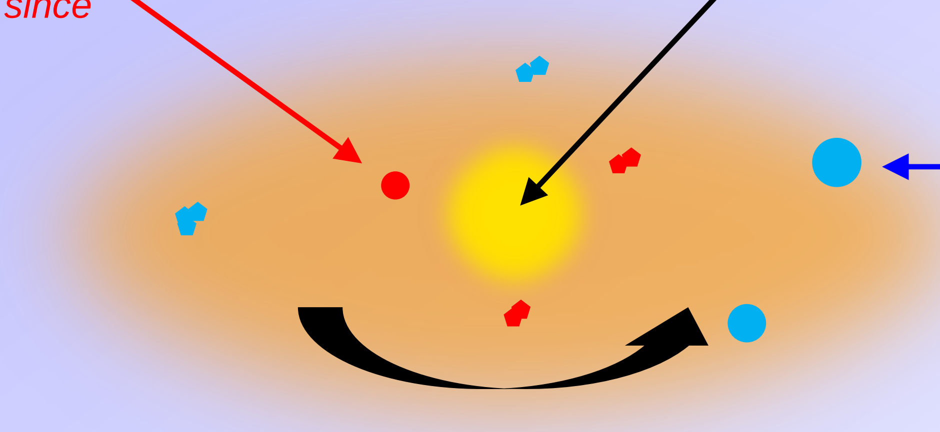

Outer planetesimals tend to be more icy and hydrogen rich.
They tend to be bigger because they sweep out a larger region, so they can gather more material.

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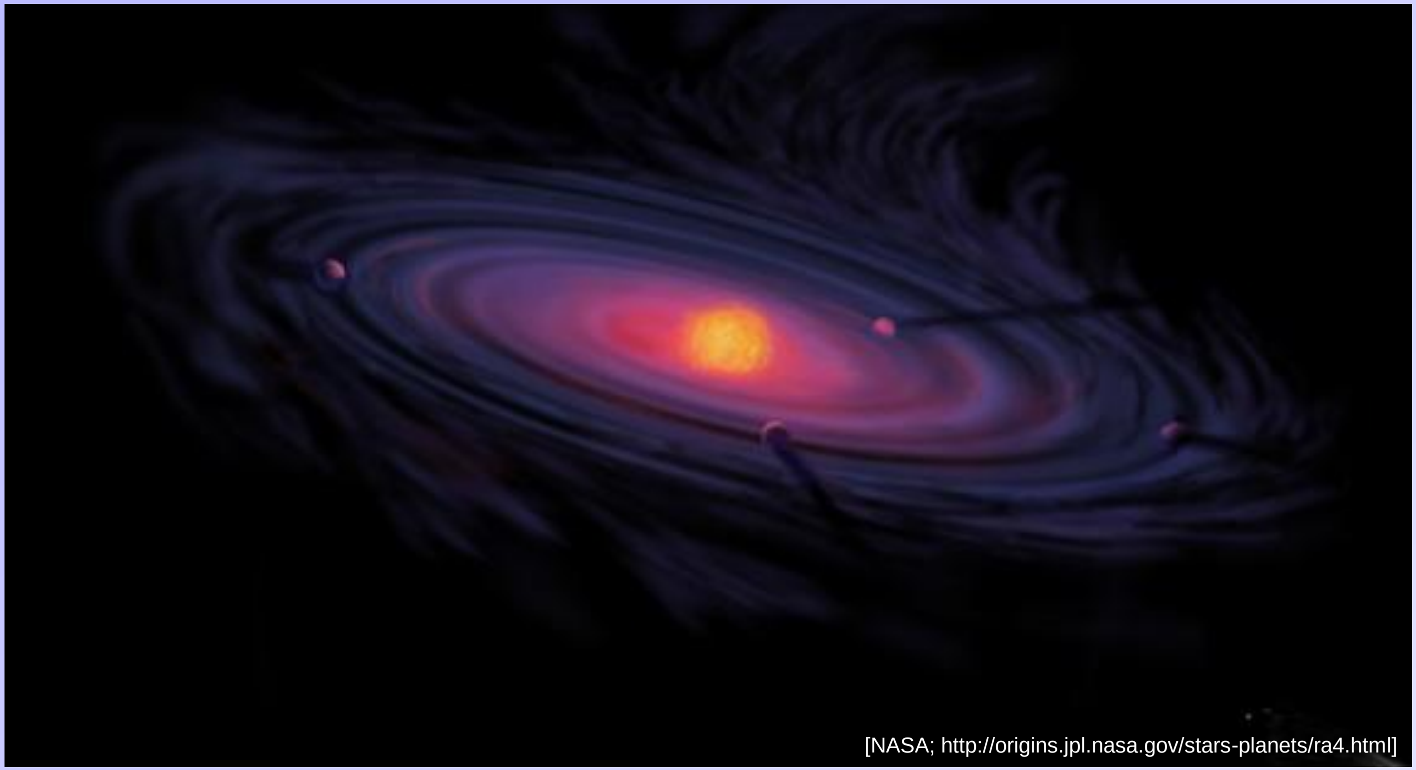
Step 3: Planetesimals to Planets

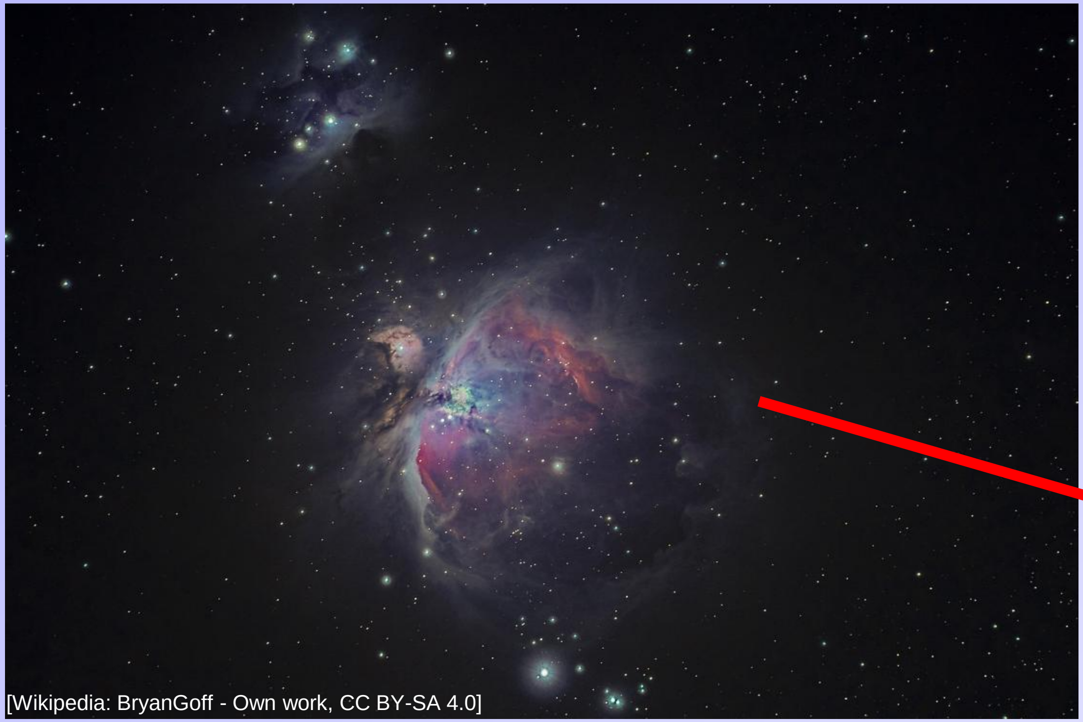


- As the planetesimal collide and stick together, they become bigger and evolve into planets. In doing so, they clear out their orbits.
- Near circular orbits are more stable, since more eccentric elliptical ones can lead to collisions between planetesimals/planets.

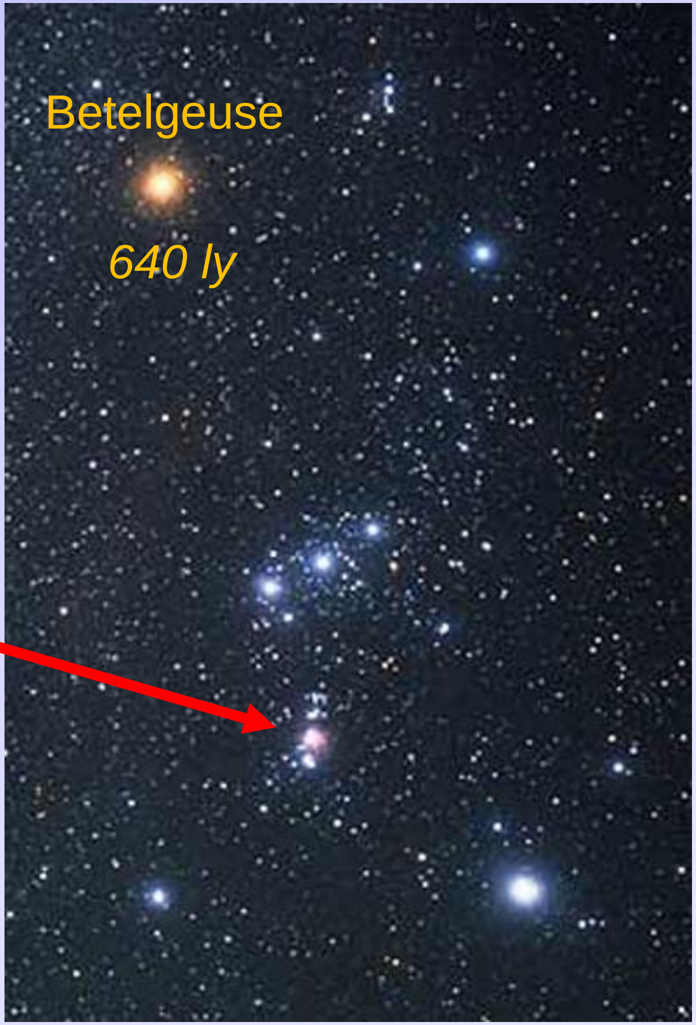
Nascent Protoplanetary Systems

Constellation: **Orion**

Nascent Protoplanetary Systems



Orion Nebula



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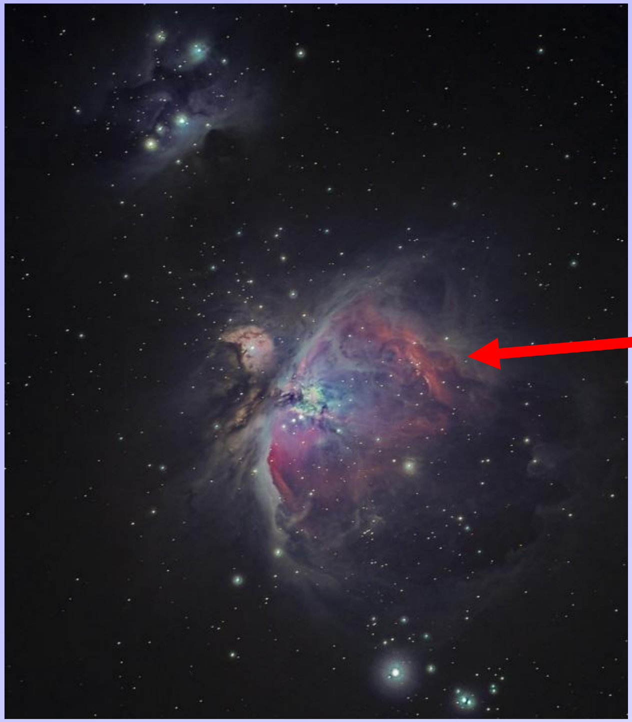
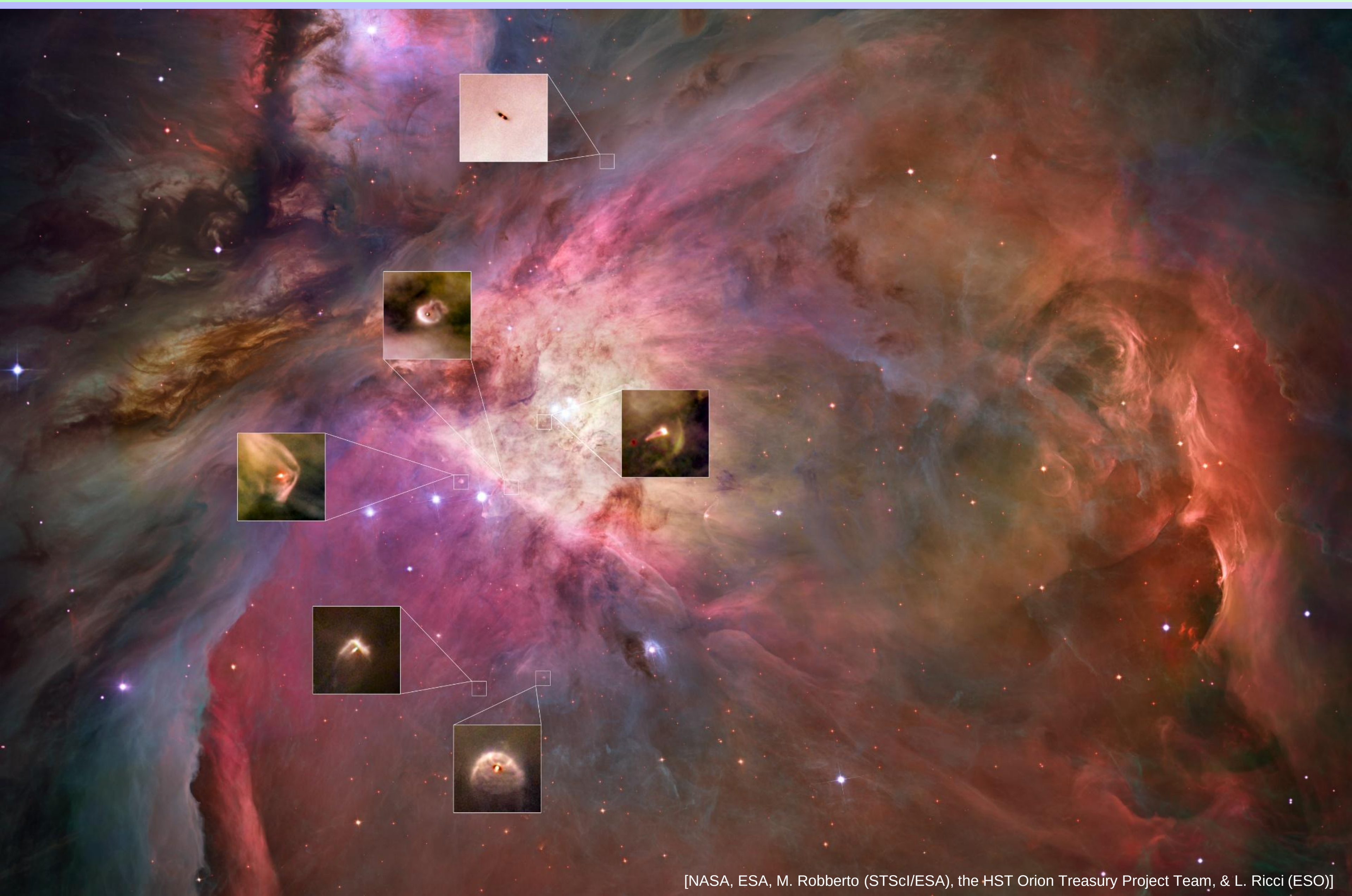


Orion Nebula

[NASA, ESA, M. Robberto (Space Telescope Science Institute/ESA) and the Hubble Space Telescope Orion Treasury Project Team]

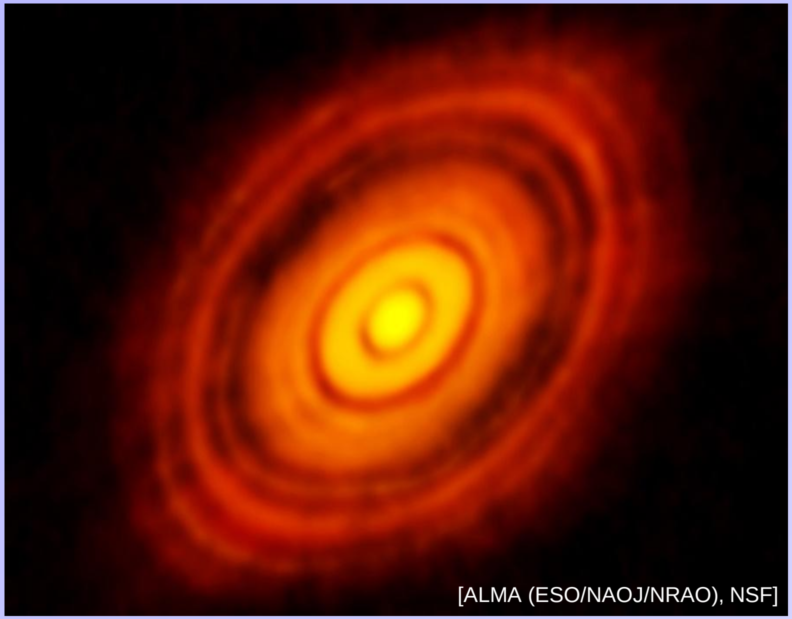
Nascent Protoplanetary Systems



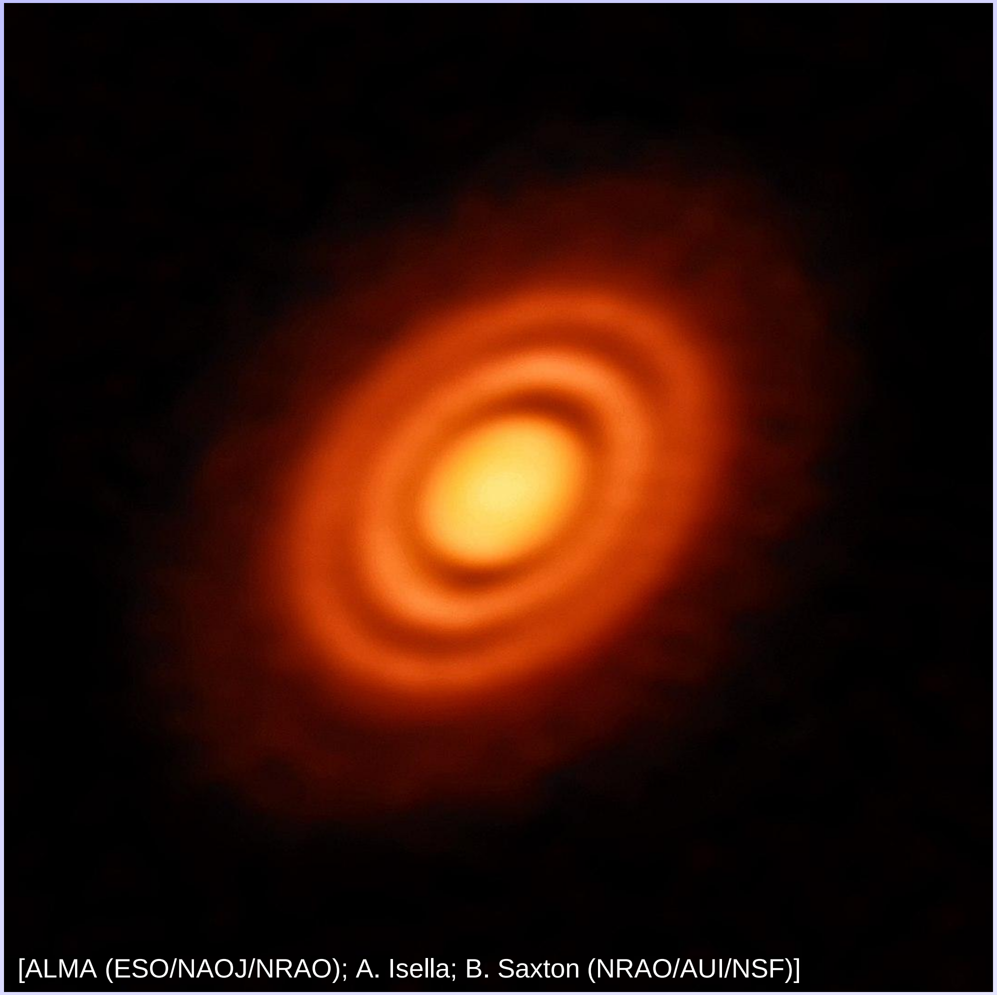
[NASA, ESA, M. Robberto (STScI/ESA), the HST Orion Treasury Project Team, & L. Ricci (ESO)]

Nascent Protoplanetary Systems

Protoplanetary Disks – mm wave



The Protoplanetary Disk of the young star HL Tauri
(in Milky Way galaxy, Taurus constellation)



Cloud of gas and dust surrounding the young star HD 163296.
(in Milky Way galaxy, Sagittarius constellation)

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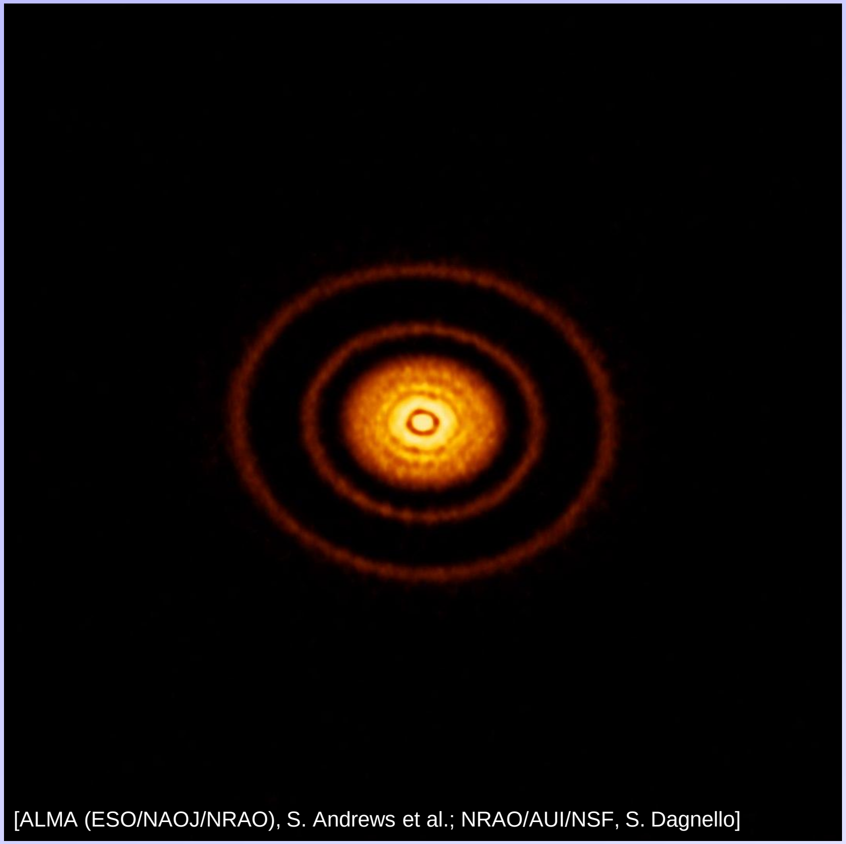

Protoplanetary disk around the young star AS 209.

(in Milky Way galaxy, Ophiuchus constellation)

Exoplanets

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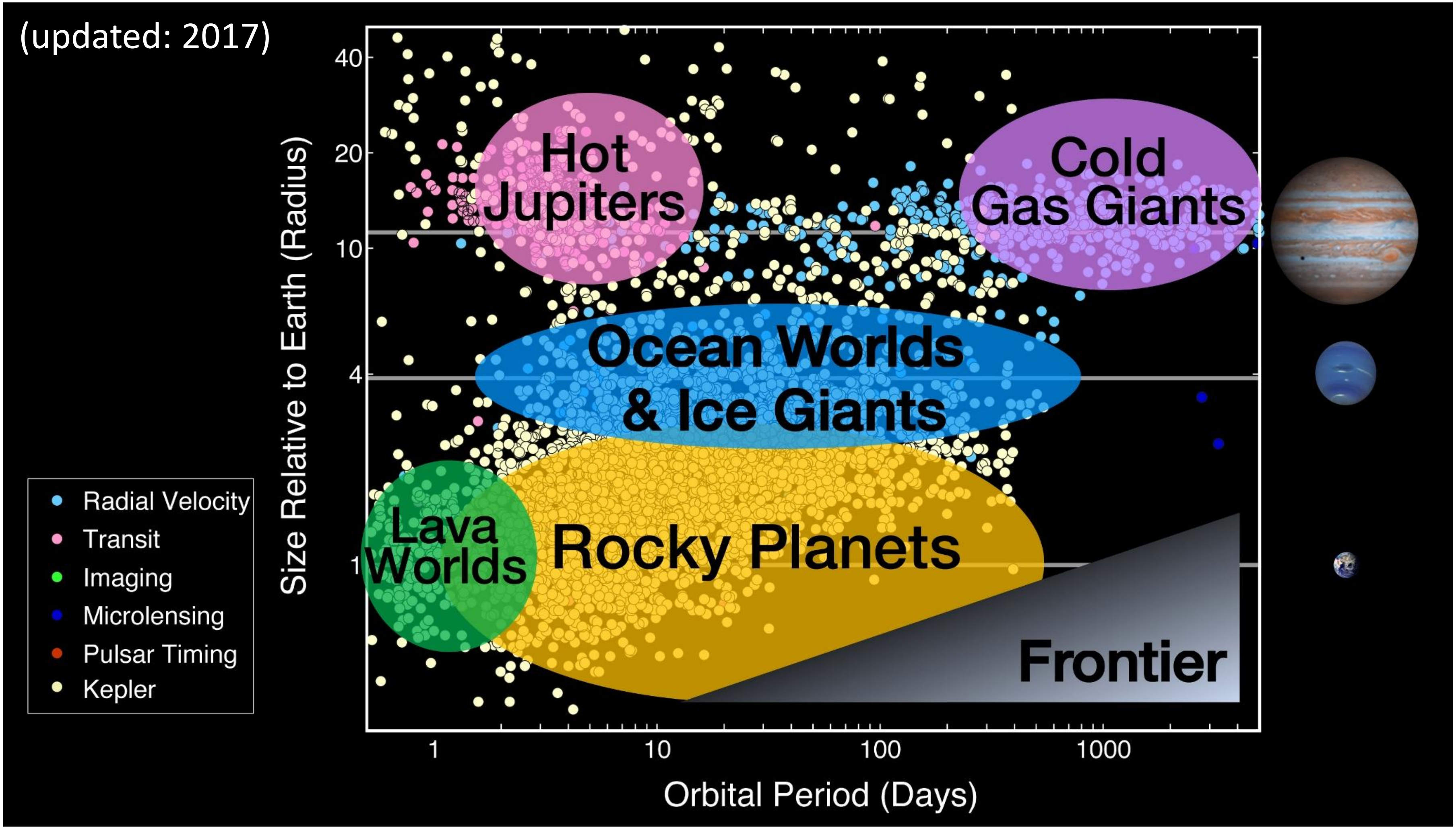
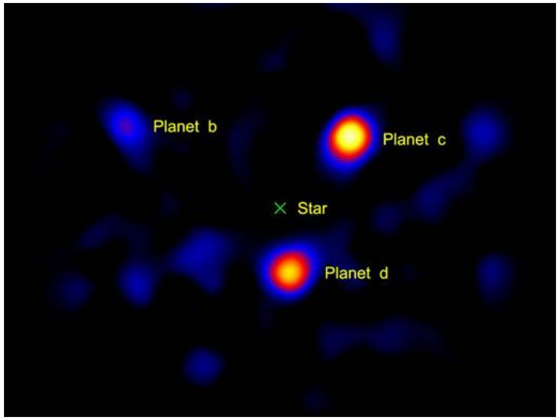


[https://www.nasa.gov/image-feature/ames/kepler/exoplanet-populations]

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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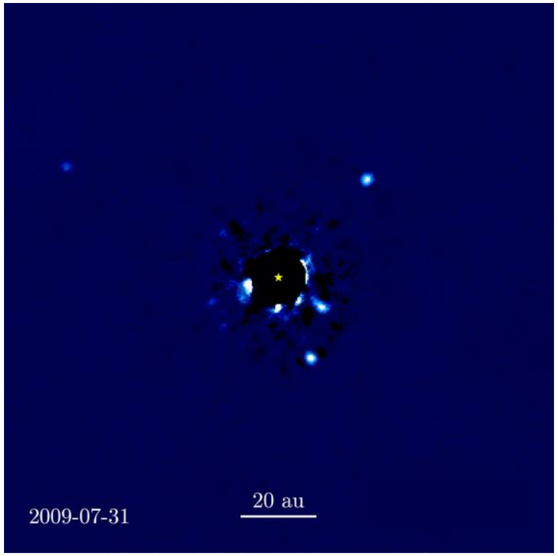

4 planets around star HR8799 (120 ly) [Keck telescope, 2009-2016, J. Wang, C. Marois]

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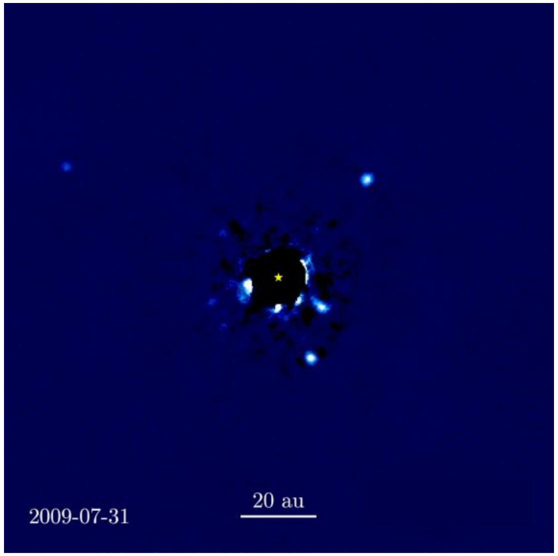
  Models of evolution for solar systems show that planets often perturb the orbits of other planets and **move them towards the star** (or shoot them out).



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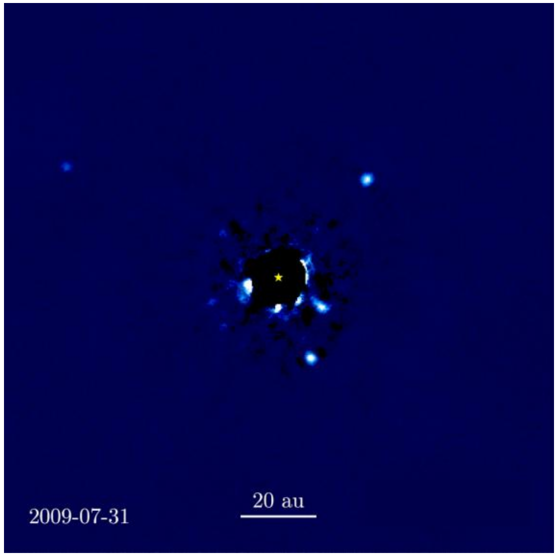
- Roughly 40% of Sun-like stars have terrestrial planets in the **"goldilocks"** region.

  → 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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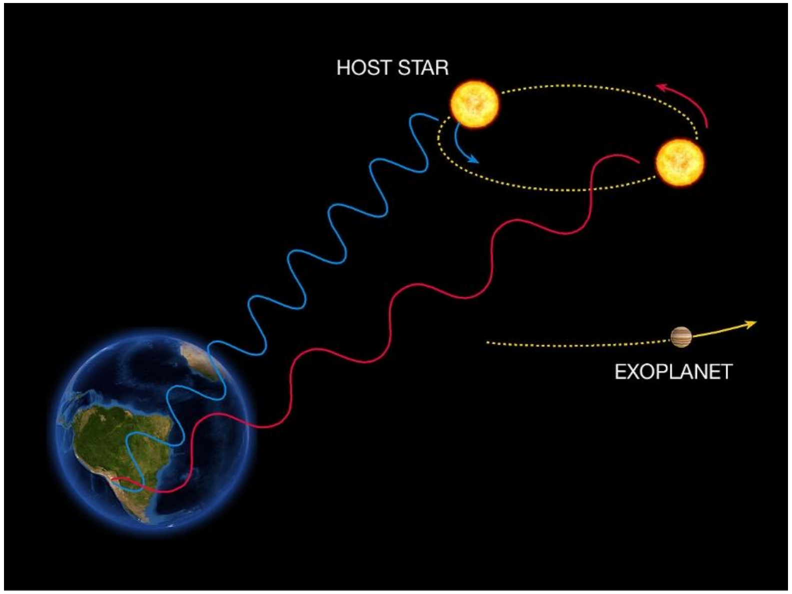
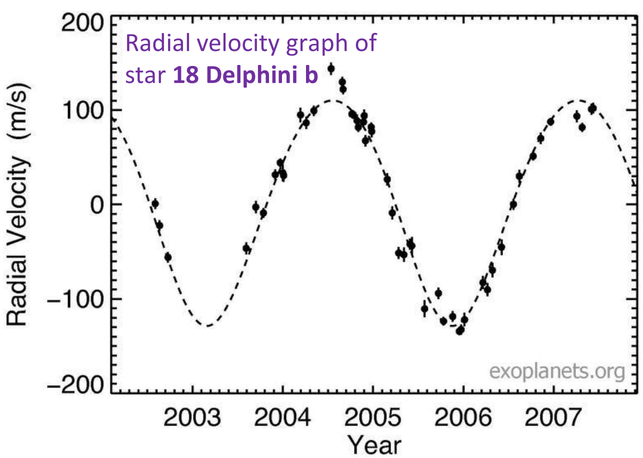
Main Detection Methods



The Radial Velocity Method

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



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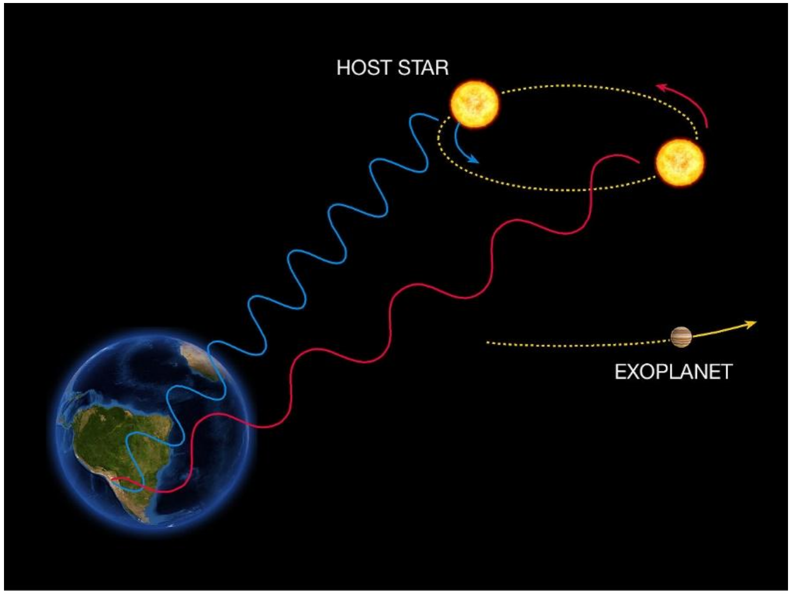

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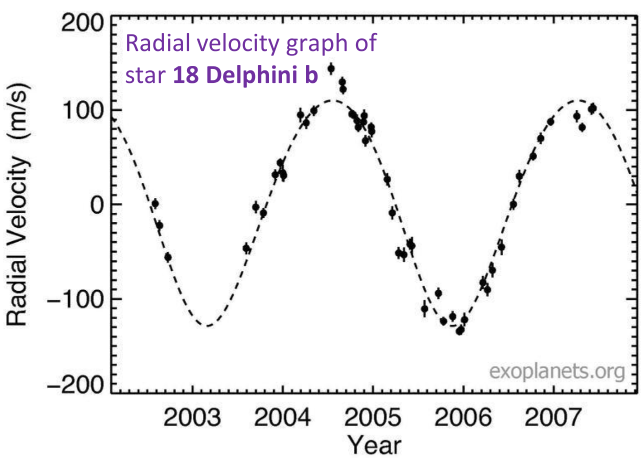
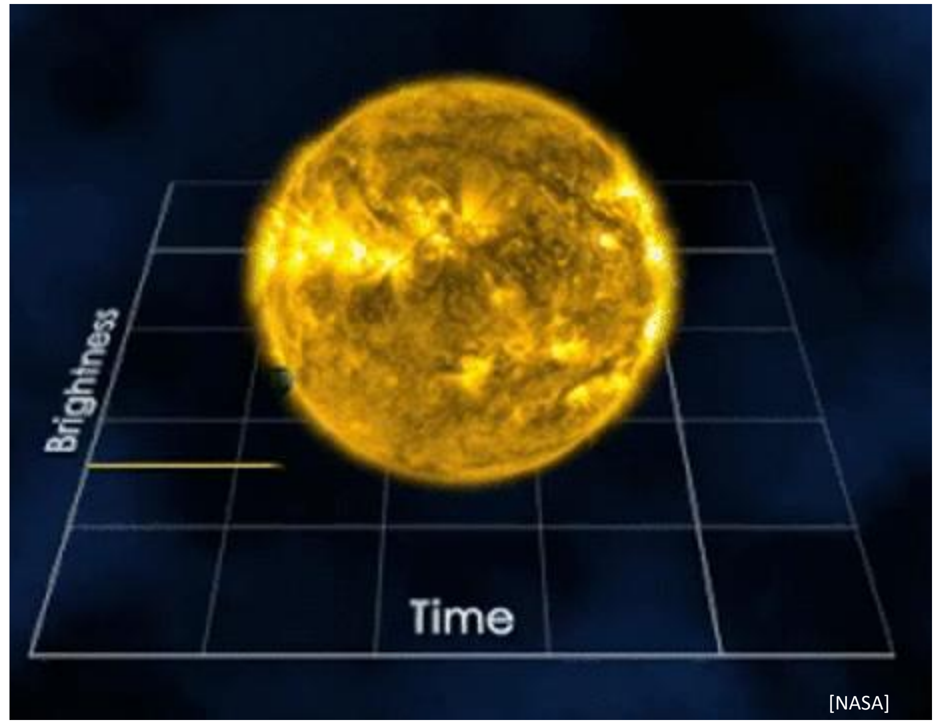


Transit Photometry



Signal is typically 1 part per 10,000 dimming.

PollEv Quiz: PollEv.com/sethaubin

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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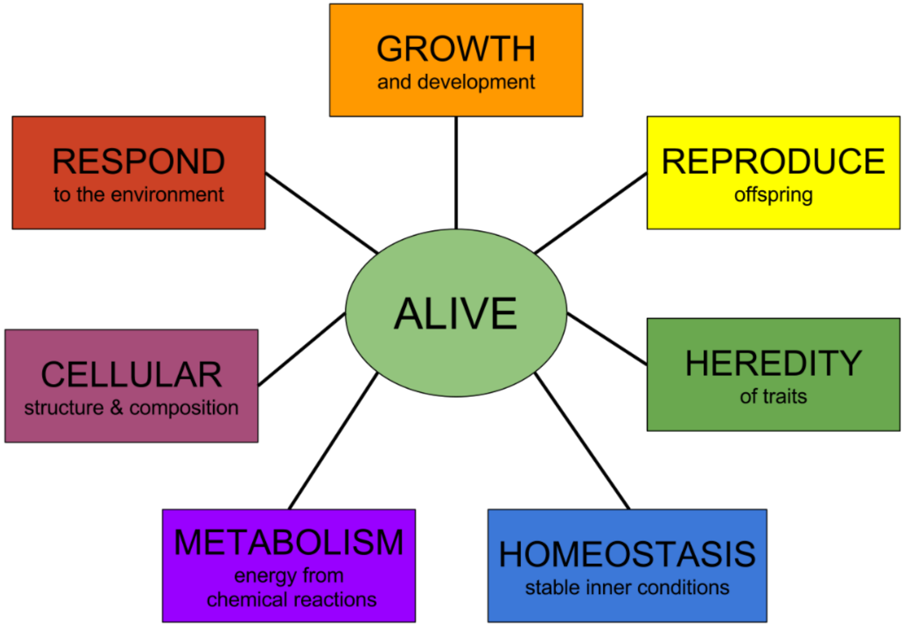

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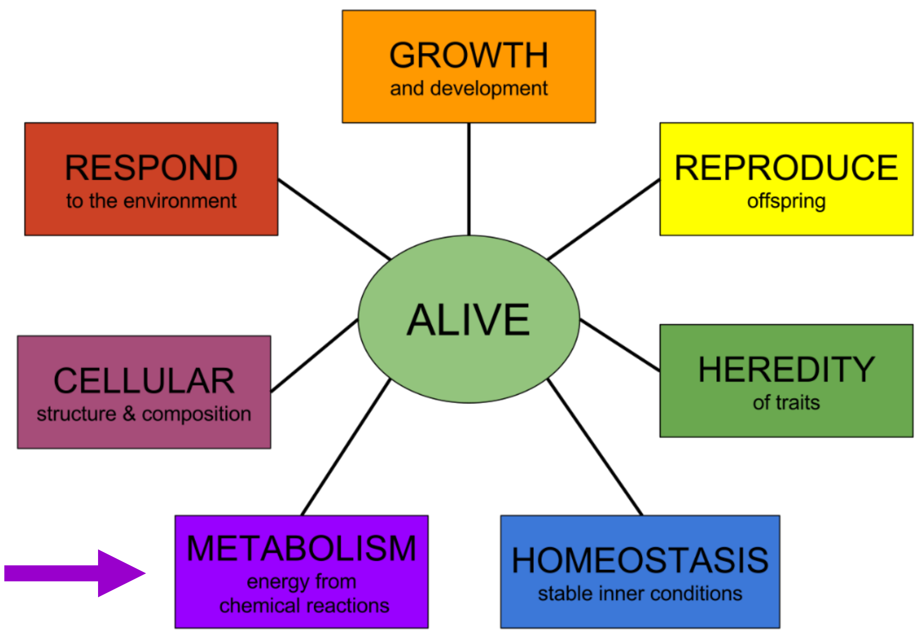
Life requires specific environmental conditions
… Also, life can modify its environment.

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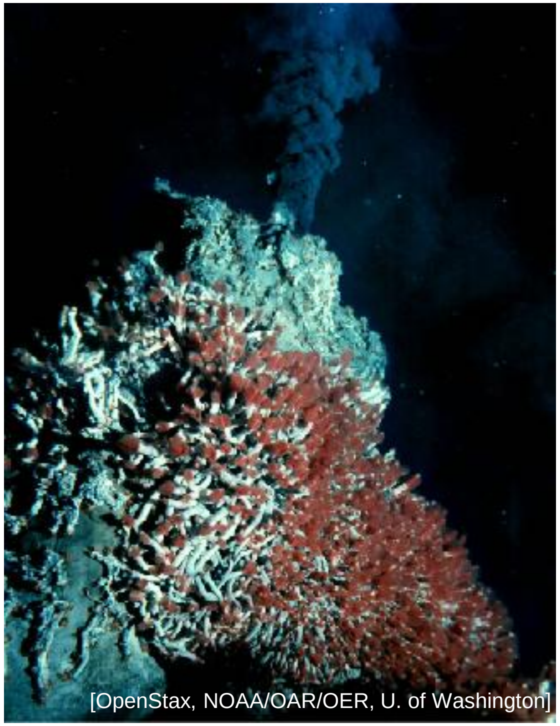
Hot spring (Yellowstone Nat. Park): multi-colored photosynthesizing bacteria (solar energy). Central pool (92° C) bacteria use chemical energy.



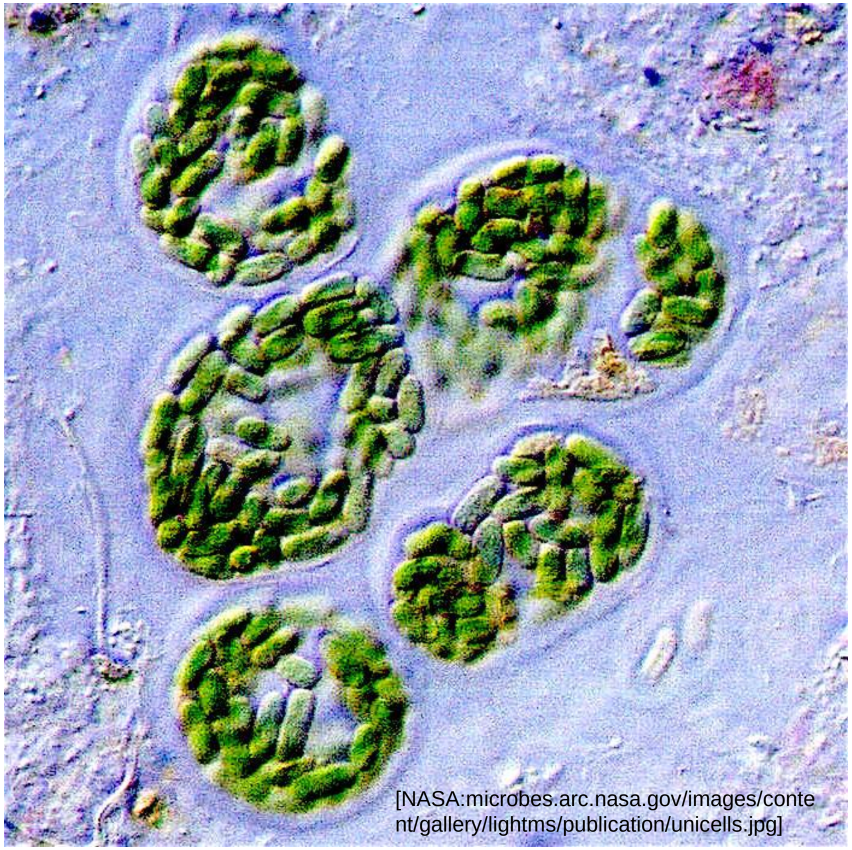
Hydrothermal vent: chemical energy (metal sulfides).

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

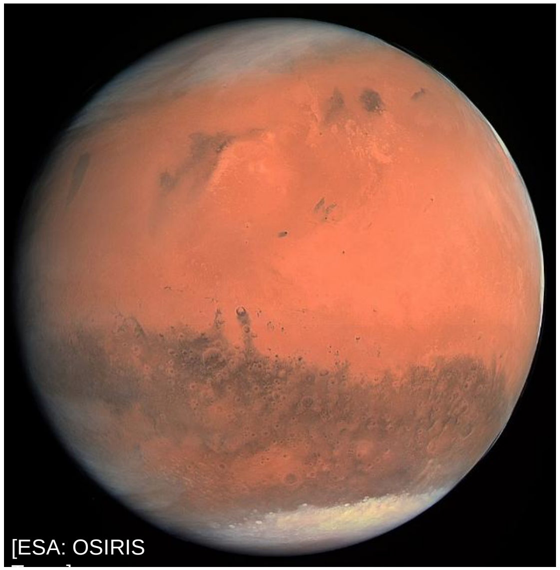
- -270° C to 150° C for a few minutes.
- Vacuum to 1000 bars.
- Years of dehydration.
- 1000x lethal radiation dose of animals.



[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

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

- **Liquid water.**
- Reasonable temperature range.
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→ **Methane** detected in Mars' atmosphere (possible bio origin).

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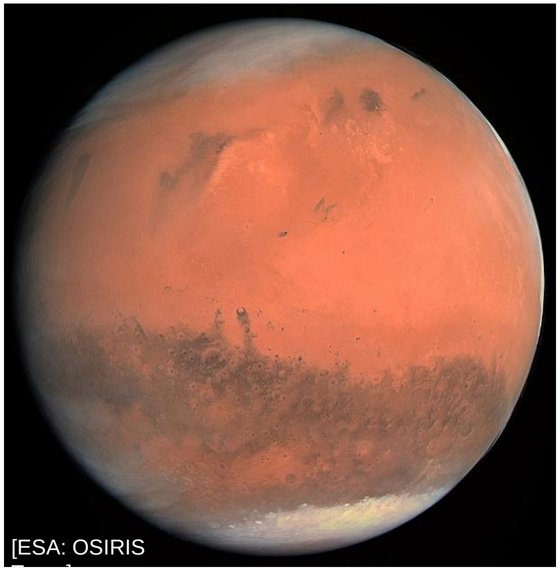

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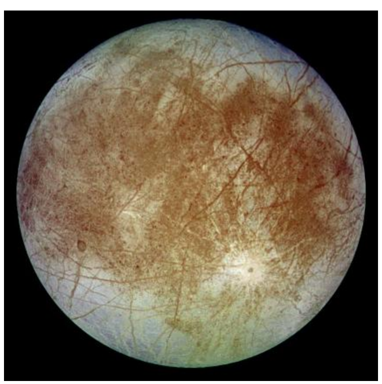

[NASA/JPL/DLR: Gallileo mission, 1996]

Europa (Jupiter moon)

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

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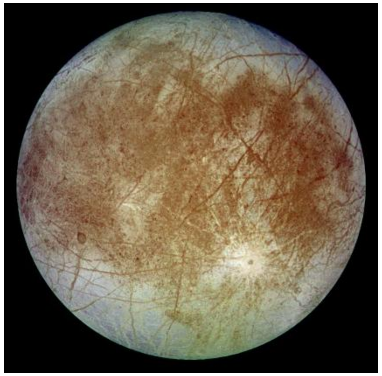

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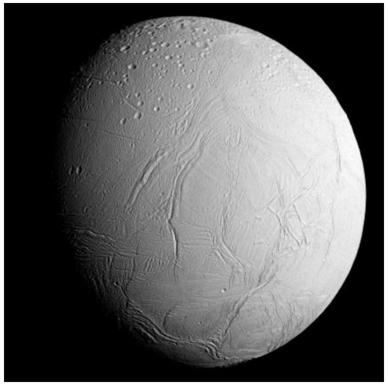

[NASA: Cassini mission, 2015]

Enceladus (Saturn moon)

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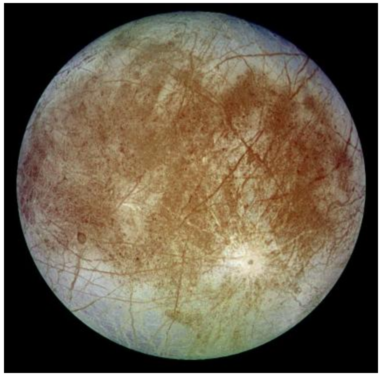
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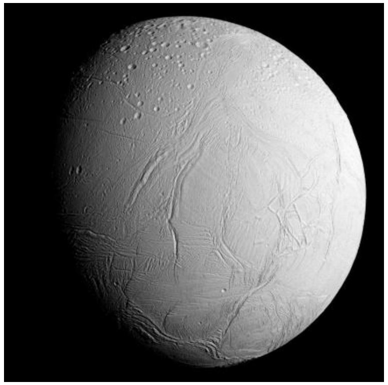
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More speculative: <u>Ganymede</u> sub-surface water, upper atmosphere of <u>Venus</u>.