Today's Topics

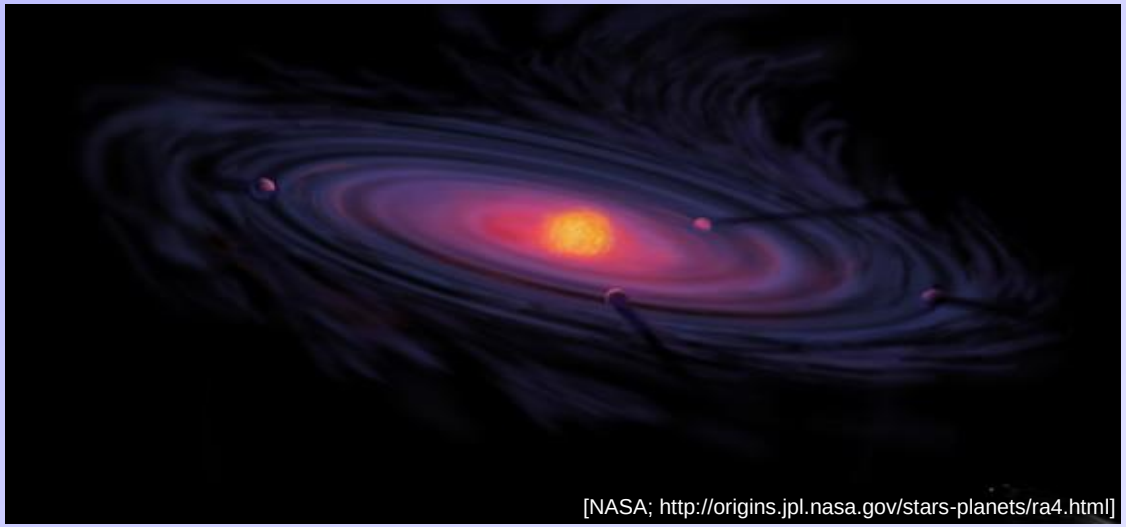
Monday, October 7, 2019 (Week 6, lecture 16) – Chapters 7 & 8.

1. Formation of the Solar System
2. Age of the Solar System
3. Earth as a Planet

Formation of the Solar System

Solar nebula hypothesis

- Proposed independently by **Pierre Simon Laplace** and **Immanuel Kant** (late 1700s).
- Many other hypotheses have been proposed.
- Nebula hypothesis has become widely accepted since 1970s-80s.
- Hypothesis still has some issues.



[NASA; http://origins.jpl.nasa.gov/stars-planets/ra4.html]

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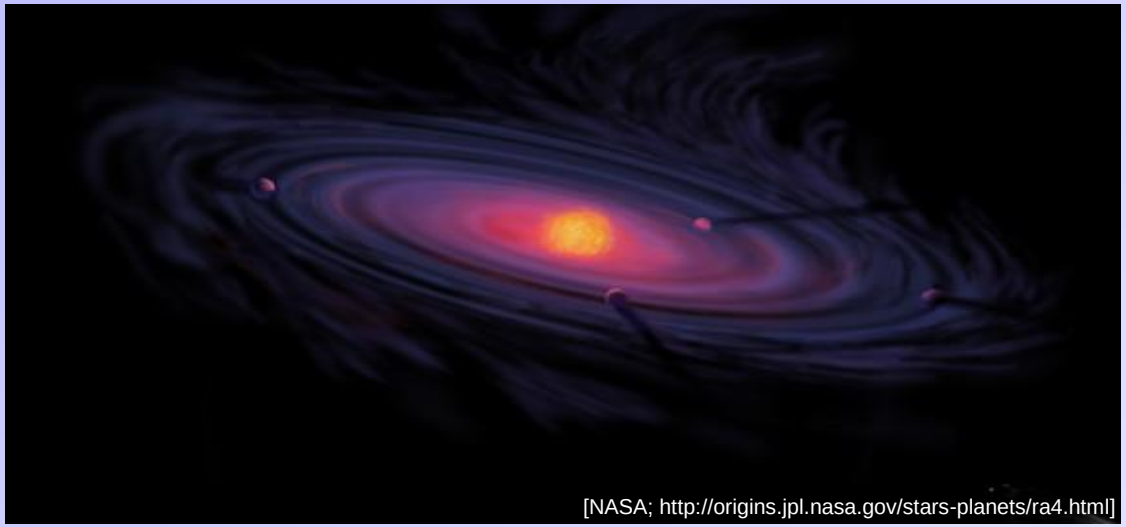
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- **Solar nebula:** A large mass of space gas and dust contracts under gravity.
- **Contraction & condensation:** The solar nebula contracts, rotates faster, and flattens out: the center gets hot, while the out part heat up and then cool, leading to condensation of gas around the dust particles and the creation of planetesimals.
- **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.*
  - → *Sun turns ON. Radiation pressure pushes remaining gas out of Solar System.*

Evidence: Nascent Protoplanetary Systems

Constellation: **Orion**

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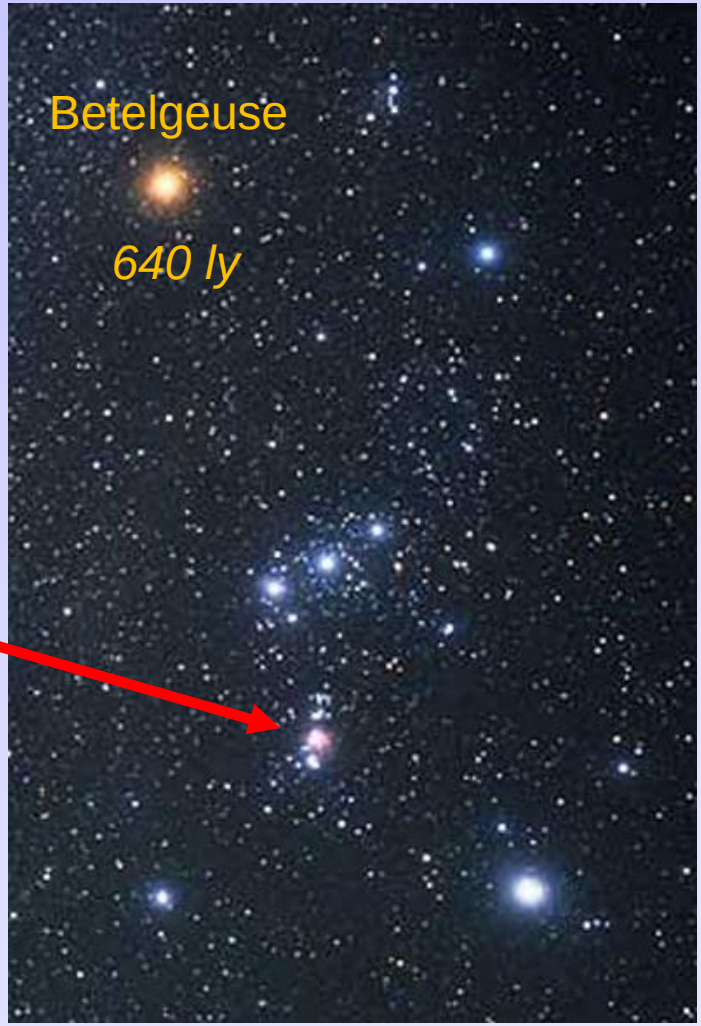
Orion Nebula



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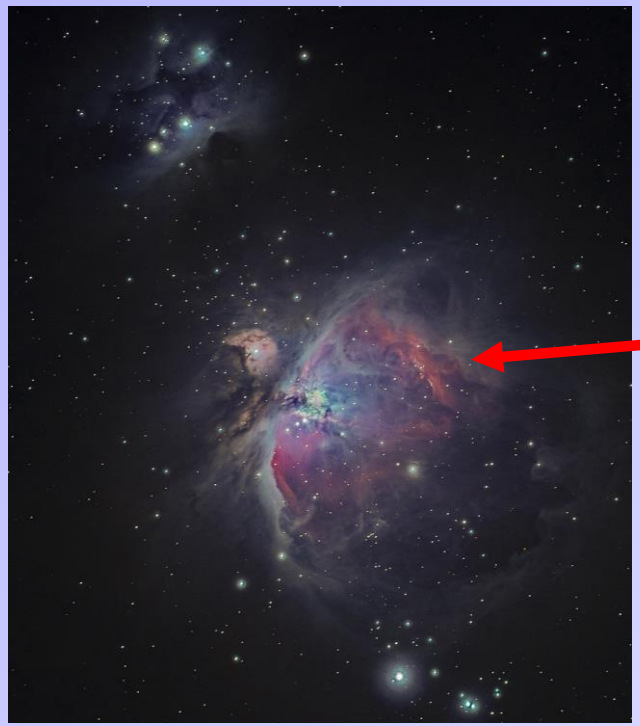
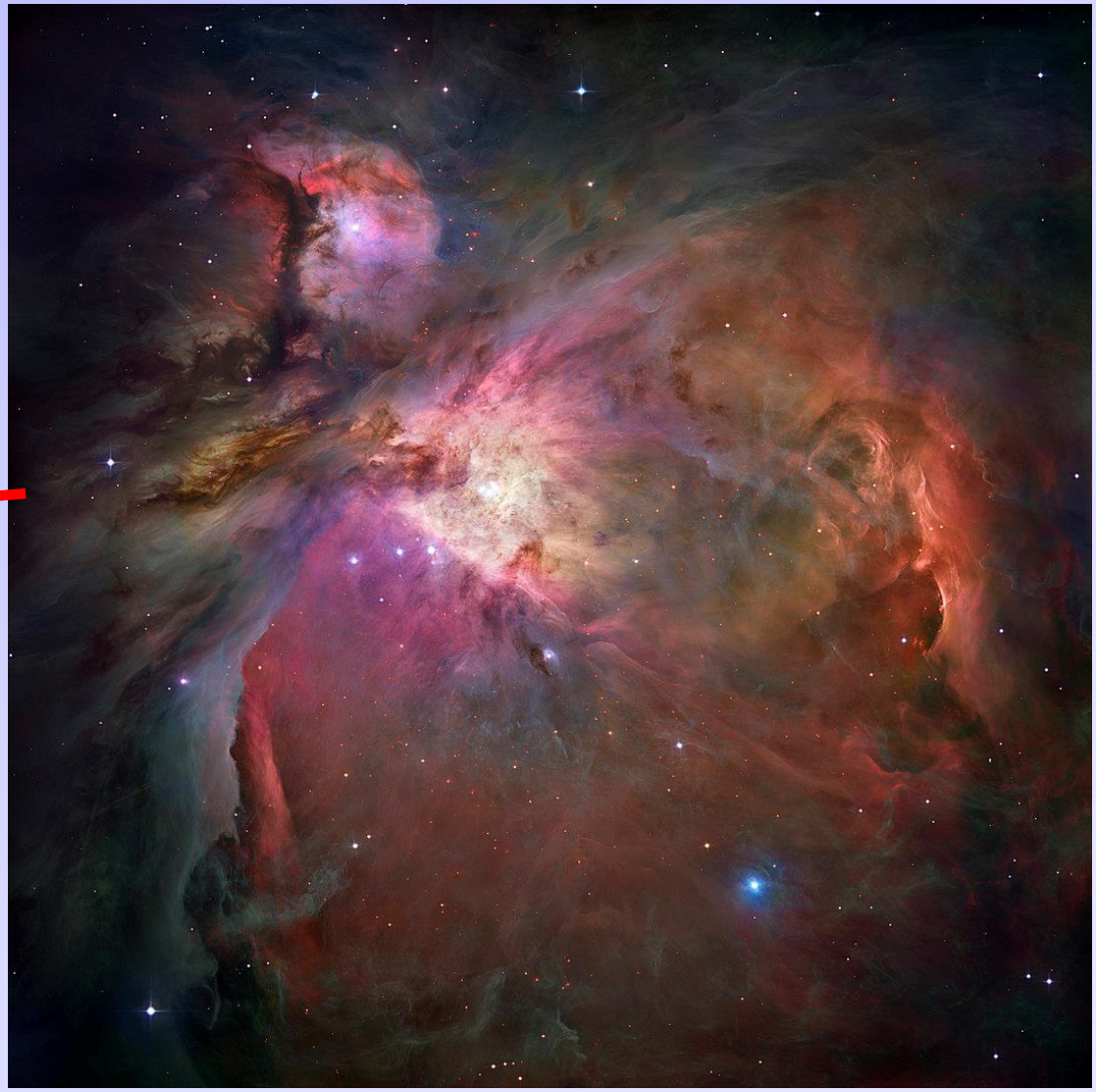


Orion Nebula



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

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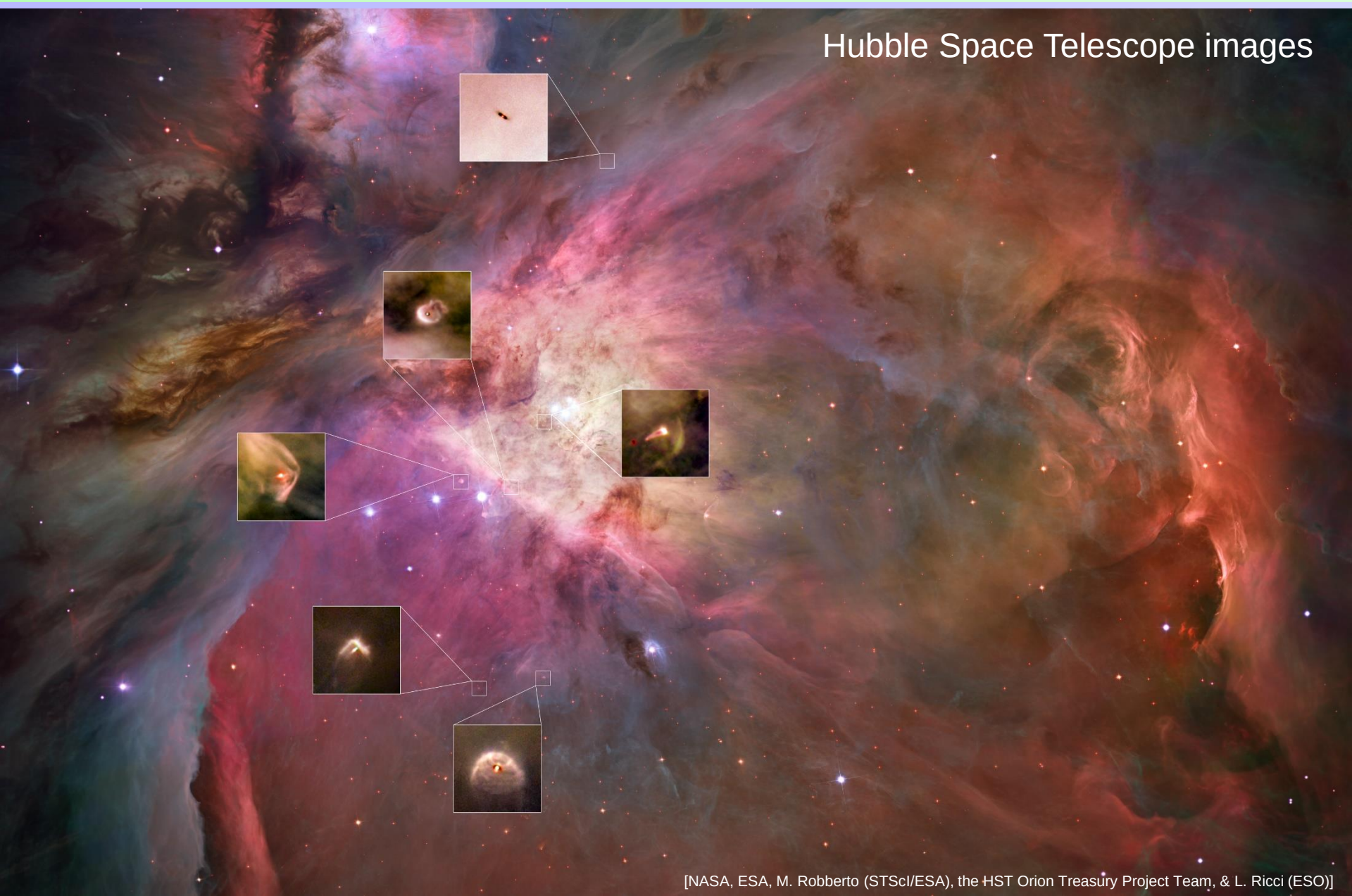

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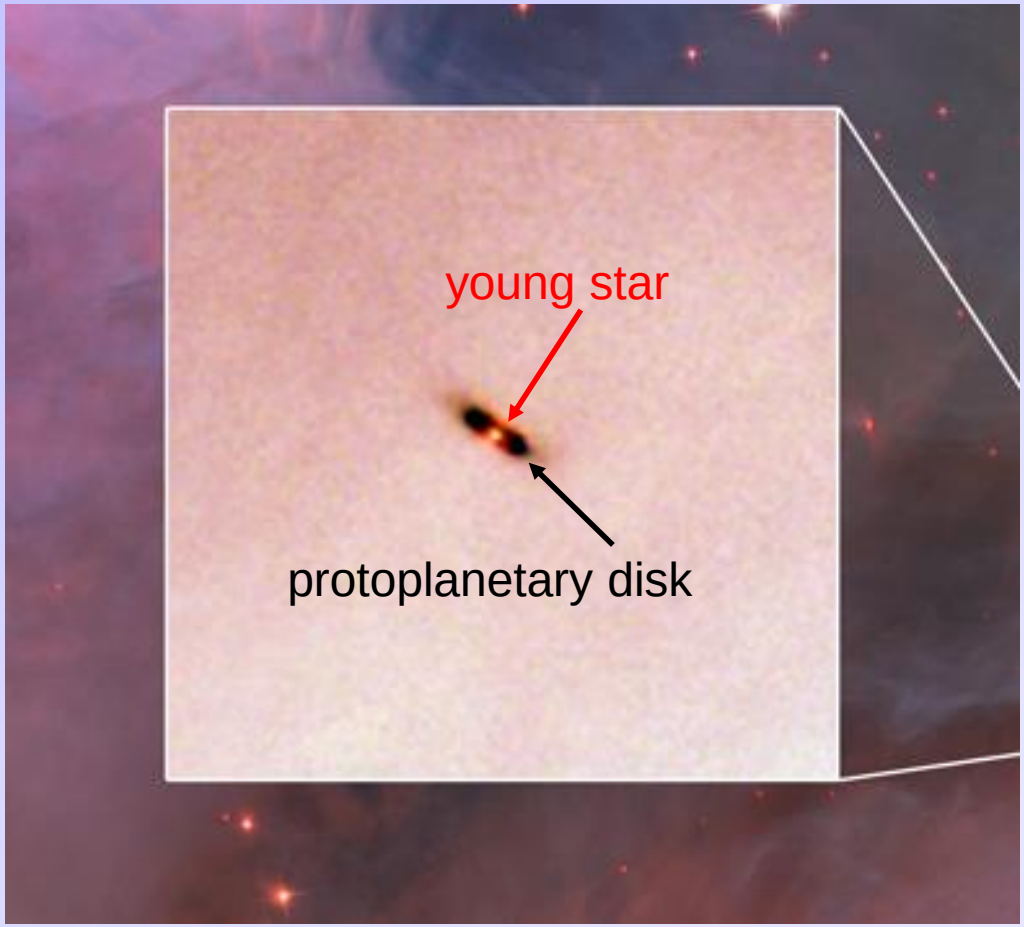
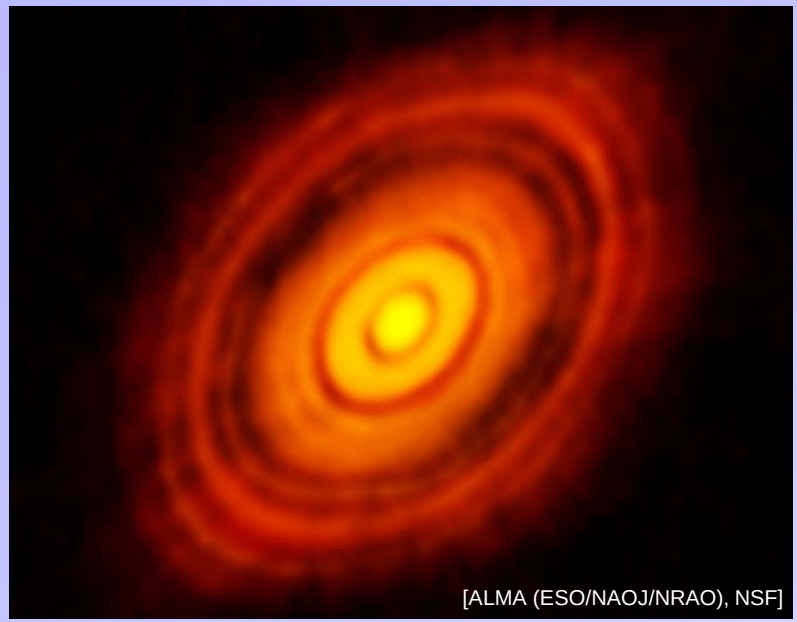
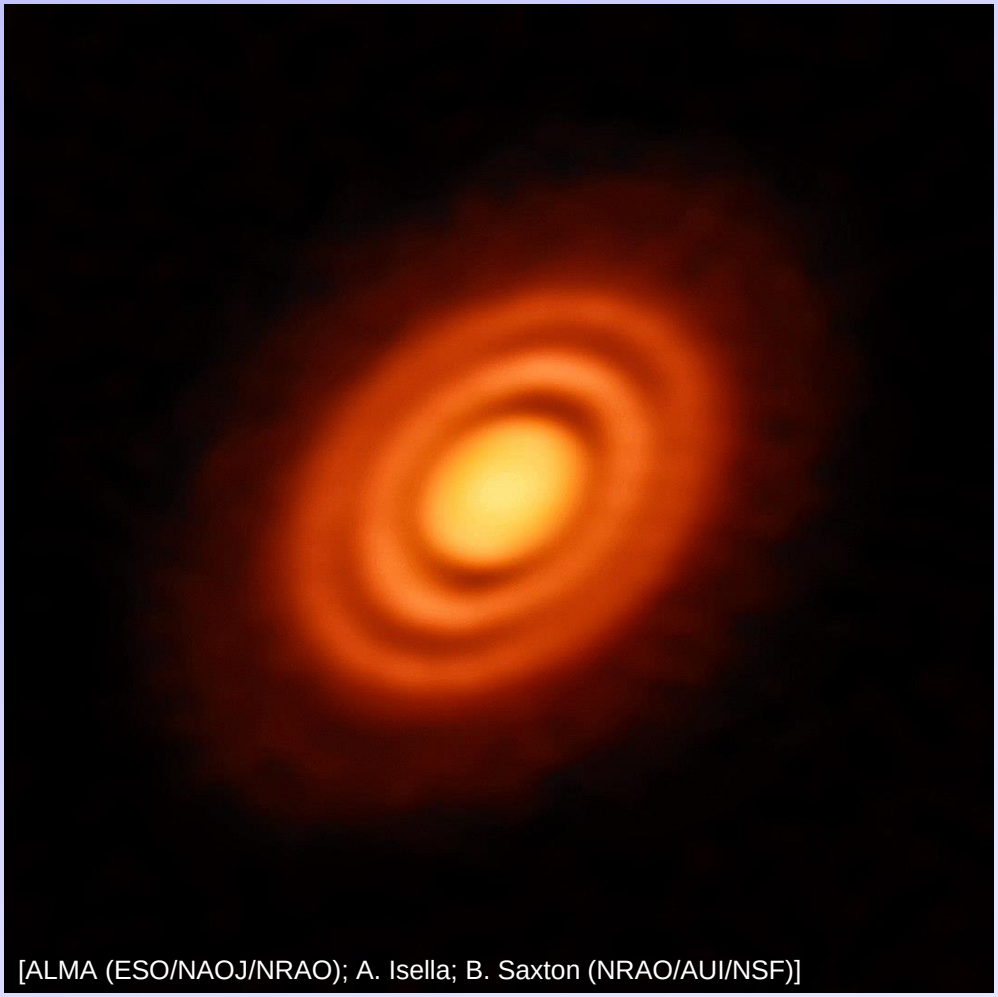


Protoplanetary Disks – mm wave



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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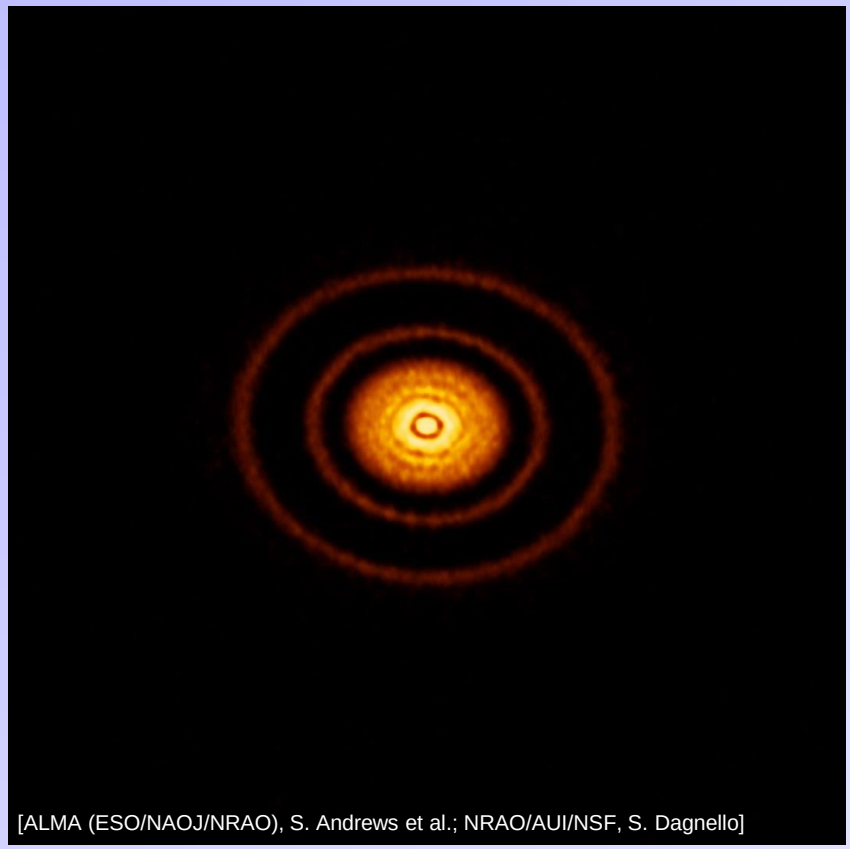

Protoplanetary disk around the young star AS 209.

(in Milky Way galaxy, Ophiuchus constellation)

Why a disk?

Short answer: Gas & dust particles in a rotating disk interact with each other the least (i.e. the collisions are minor & cannot eject), so **it is the most stable configuration.**

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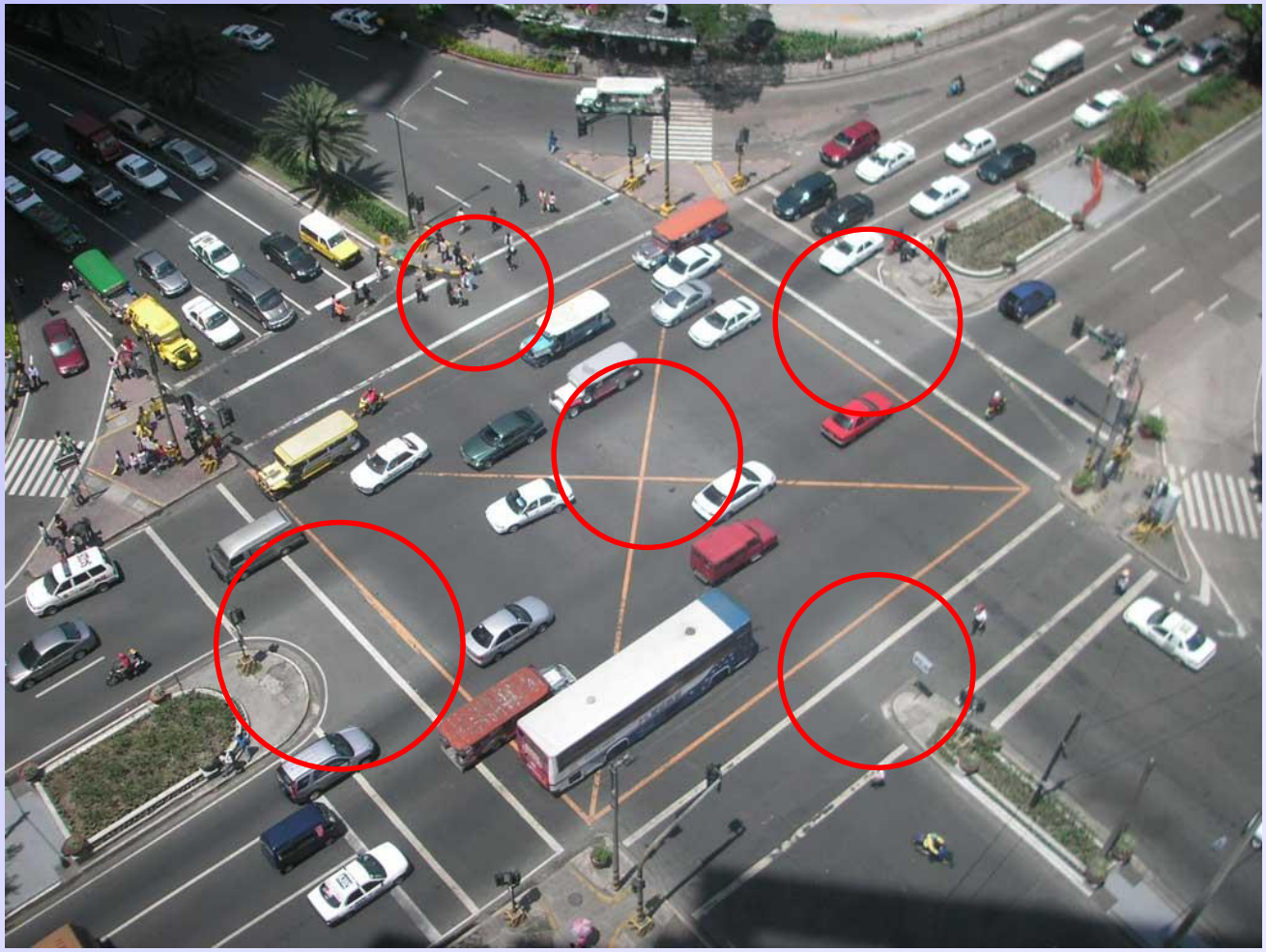
Physics is similar to the reason that there are "pebble patches" at an intersection:

- The pebbles/sand are not attracted to the patch.
- But, if a pebble lands in the patch, then there are few passing cars to kick it out.



[Source: Wikipedia By Mike Gonzalez CC-BY-SA 3.0 via Wikimedia Commons]

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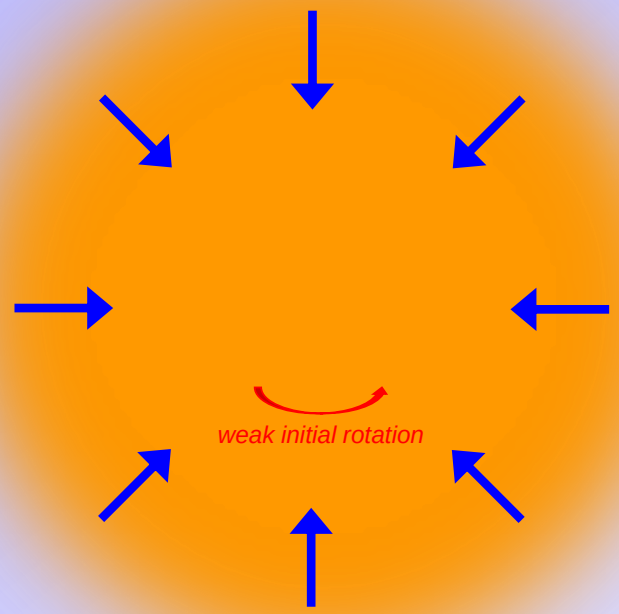

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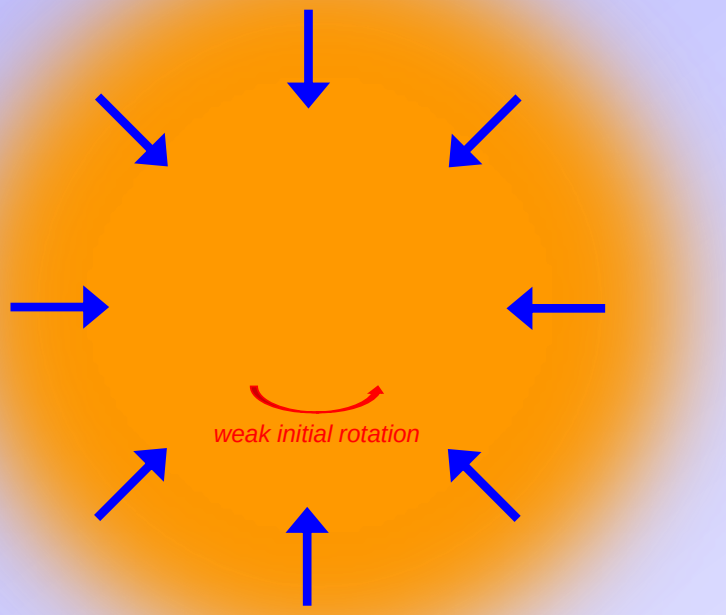

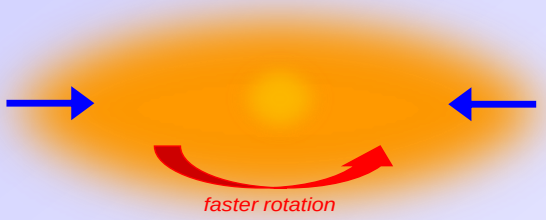

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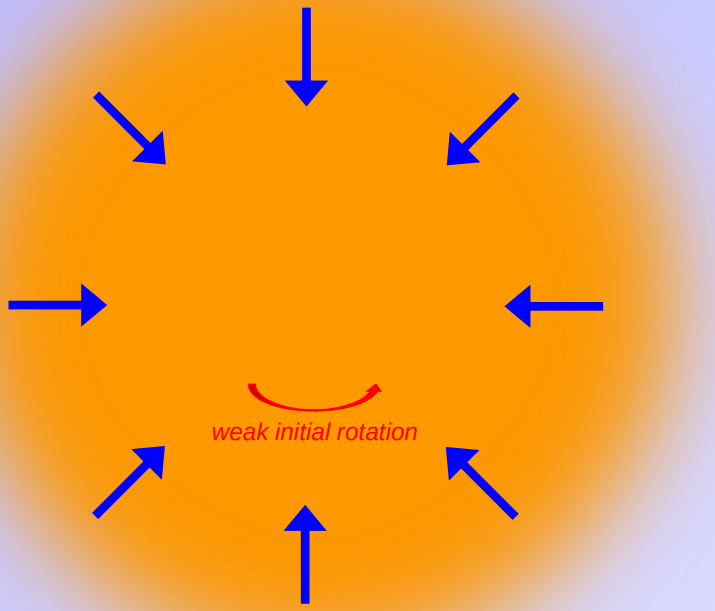

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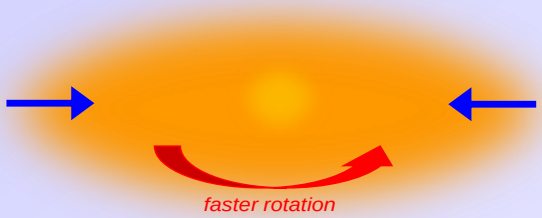

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Gas and dust that end up travelling with the rotation (and in-plane) will tend to collide less with each other (they are travelling in parallel & in sync), so this configuration is more stable.

How Old is the Solar System ?

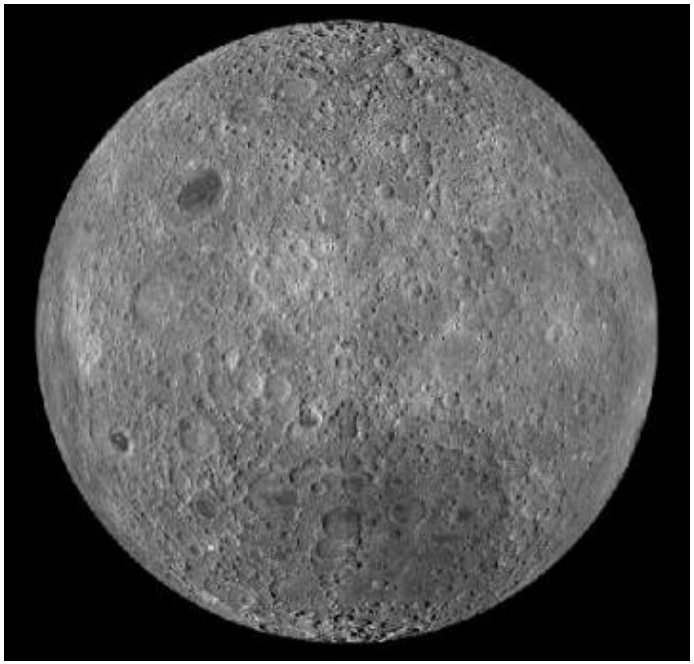
- Dating the entire Solar System is hard, but dating individual planets is easier.

- Earth and Moon are both ~ 4.5 billion years old (4.5×10^9 yrs).

  → Radioactive dating of Earth rocks, Moon rocks, meteorites.

  → Crater counting (Moon).

[Wikipedia: H. Raab, own work]



[OpenStax: Astronomy]

- Solar system age: ~4.5×10^9 yrs.

Radioactive Decay

- Radioactive decay is a random process. You cannot predict when an atom/nucleus will decay.
- If you average over many atoms, the decay process looks smooth.
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  - → After 1 half-life, half the sample is left.
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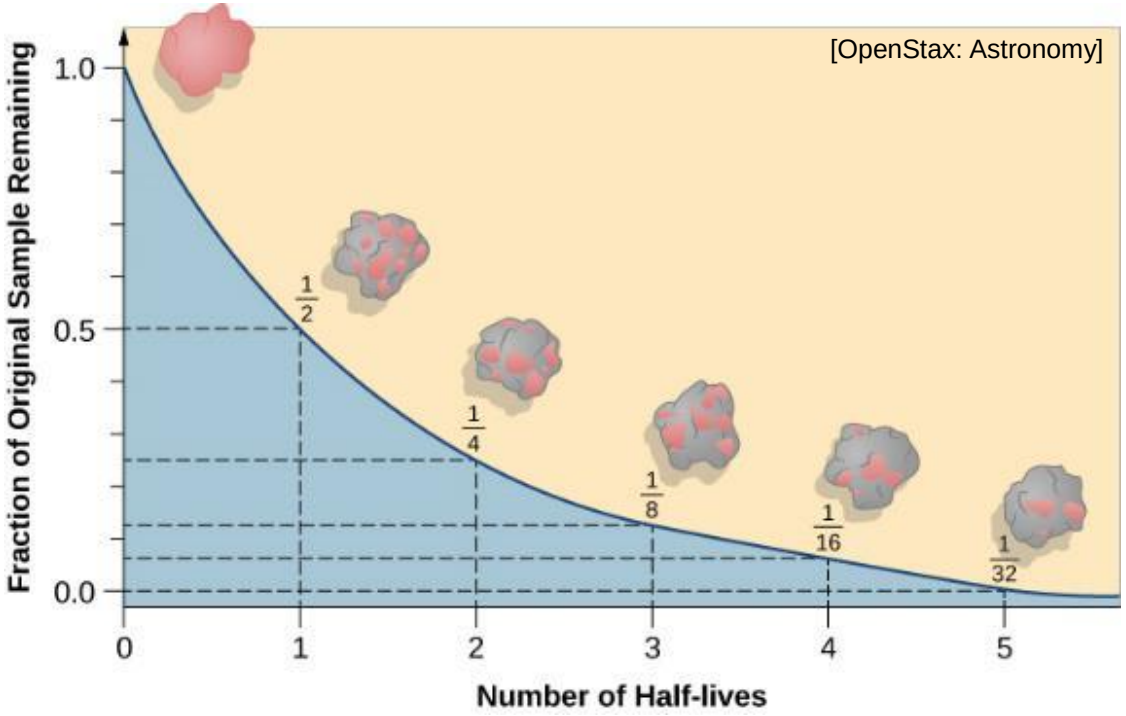

Note: *In reality, the decay of radioactive elements in a rock sample would not visibly change the appearance of the rock; the color change shown here is for illustration purposes only.*

Radioactive Potassium-40

- Potassium-40, i.e. ^{40}K, has a half-life of $t_{1/2} = 1.25 \times 10^9$ years.
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neutrons + protons

protons

neutrino

$$^{40}_{19}\mathrm{K} + e^- \rightarrow {}^{40}_{18}\mathrm{Ar} + \nu_e$$

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$$^{40}_{19}\mathrm{K} \rightarrow {}^{40}_{20}\mathrm{Ca} + e^- + \bar{\nu}_e$$

89.28%

anti-neutrino

Radioactive Decay Formula

Fraction of remaining $^{40}K = x_{K40} = \left(\frac{1}{2}\right)^{t/t_{1/2}}$

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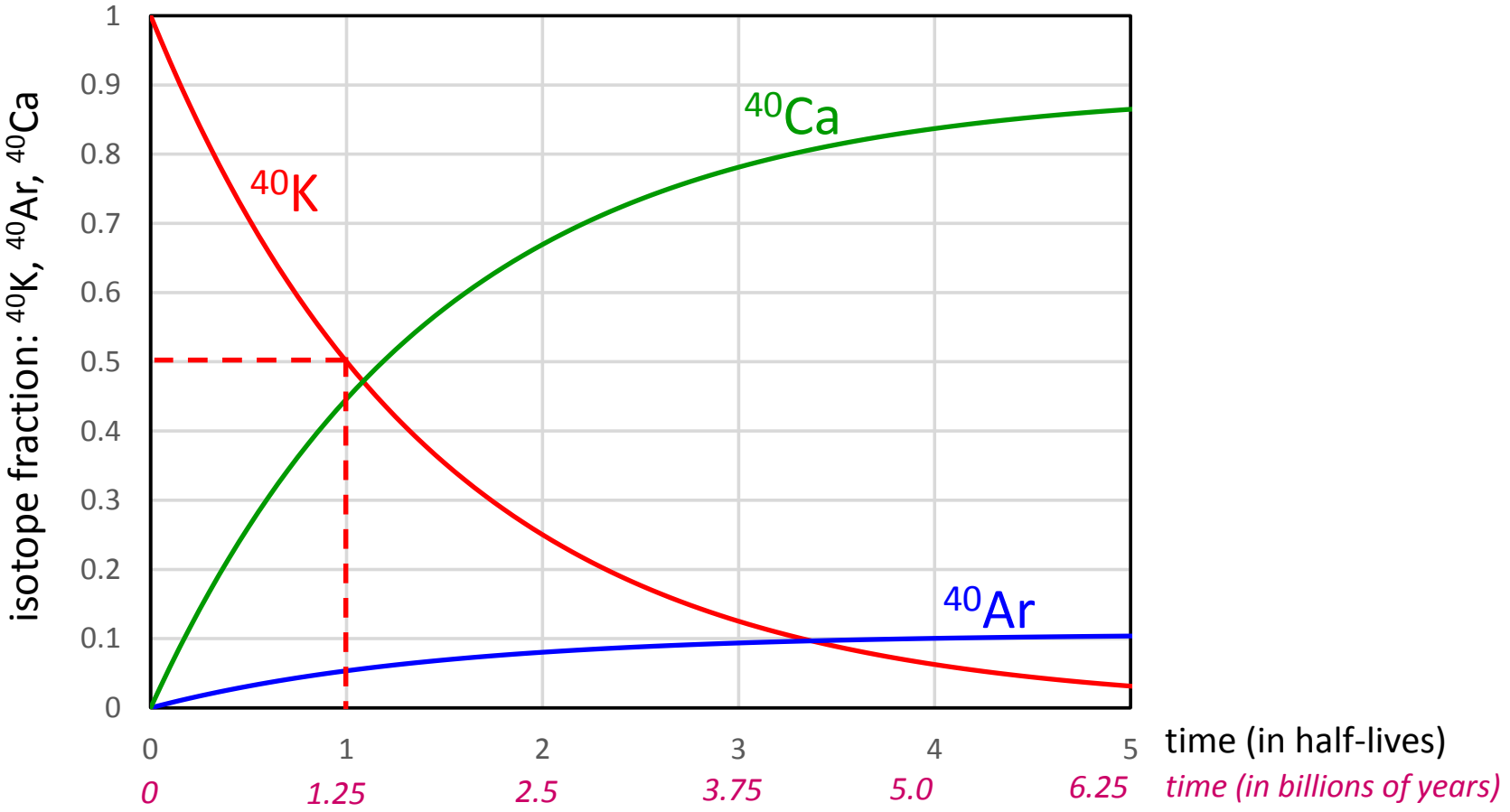

Potassium-40: Radiometric Dating

Key Facts

- Argon-40 is a noble **gas** and does not react.
- **In a liquid** (molten metal, lava, etc), argon-40 will escape, e.g. bubble out.
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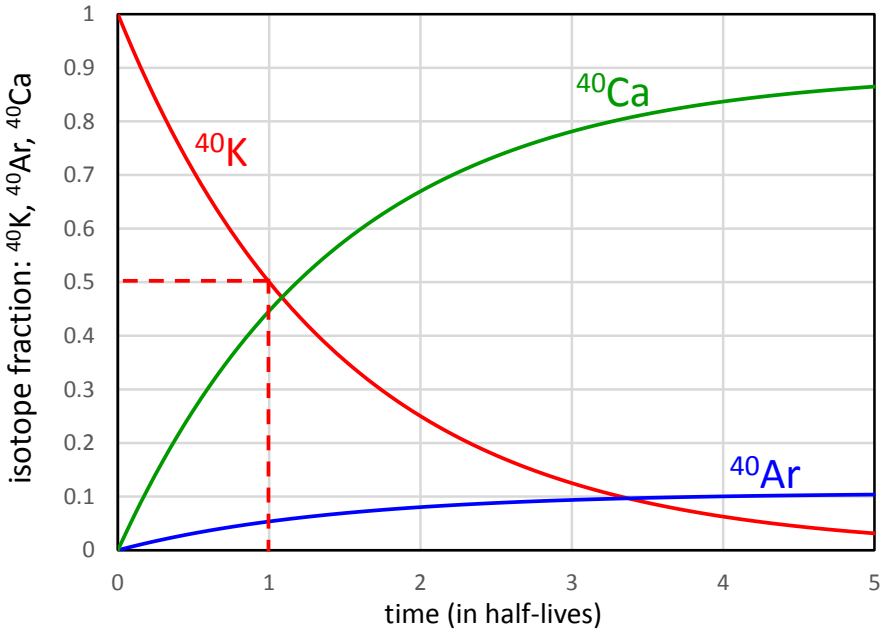
Radiometric Dating: Basic Idea

- Measure the ratio of potassium-40 to argon-40.
- This ratio gives the age at which the rock/meteorite became a solid.



Radiometry Decay Reactions

Radioactive Decay Reaction Used to Date Rocks[4]

Parent	Daughter	Half-Life (billions of years)
Samarium-147	Neodymium-143	106
Rubidium-87	Strontium-87	48.8
Thorium-232	Lead-208	14.0
Uranium-238	Lead-206	4.47
Potassium-40	Argon-40	1.31

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[OpenStax: Astronomy]

Carbon-14 Nitrogen-14 5730 ± 40 years

(not useful for astronomy dating, but very useful for archeological dating)

Earth as a Planet

- Interior of Earth
  - → Geology
- Magnetosphere
- Atmosphere
  - → Life's effect on Earth.
  - → Greenhouse effect.
- Asteroids impacts

Earth as seen from Apollo 17