Today's Topics

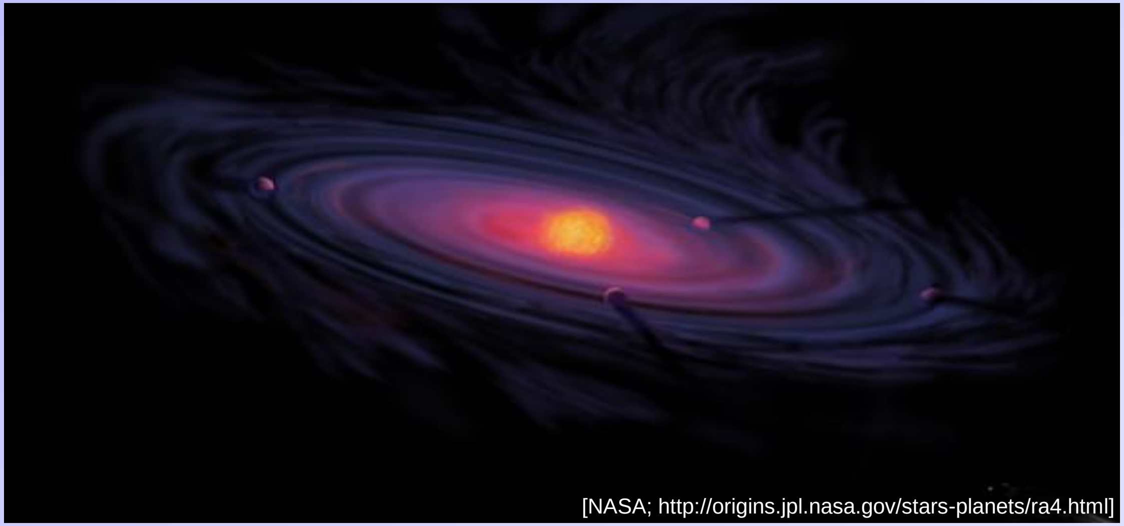
Friday, September 25, 2020 (Week 5, lecture 16) – Chapters 7.

1. Formation of the Solar System
2. Age of the Solar System
3. Radioactive dating

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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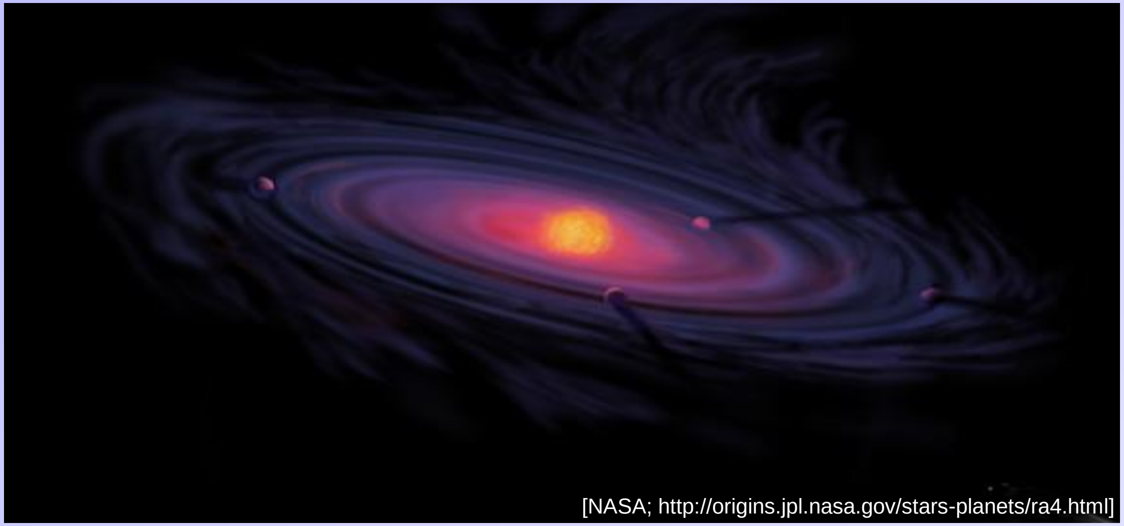

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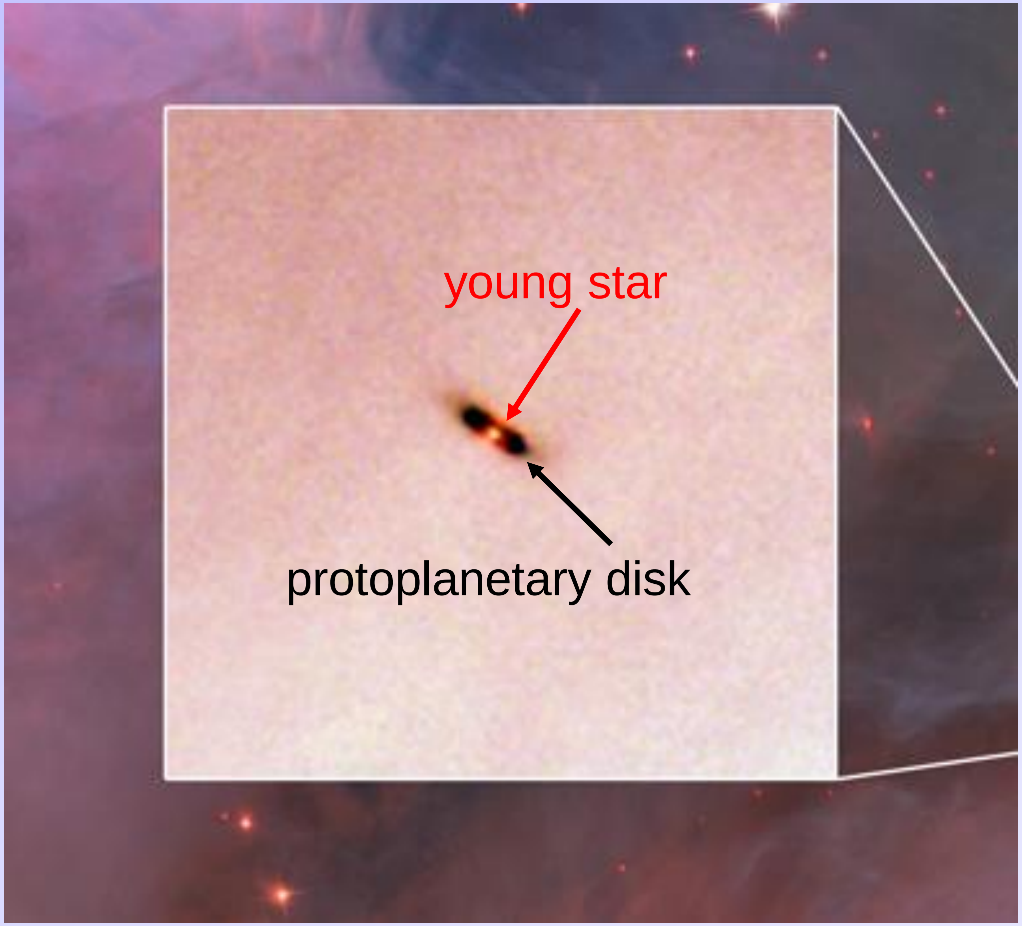
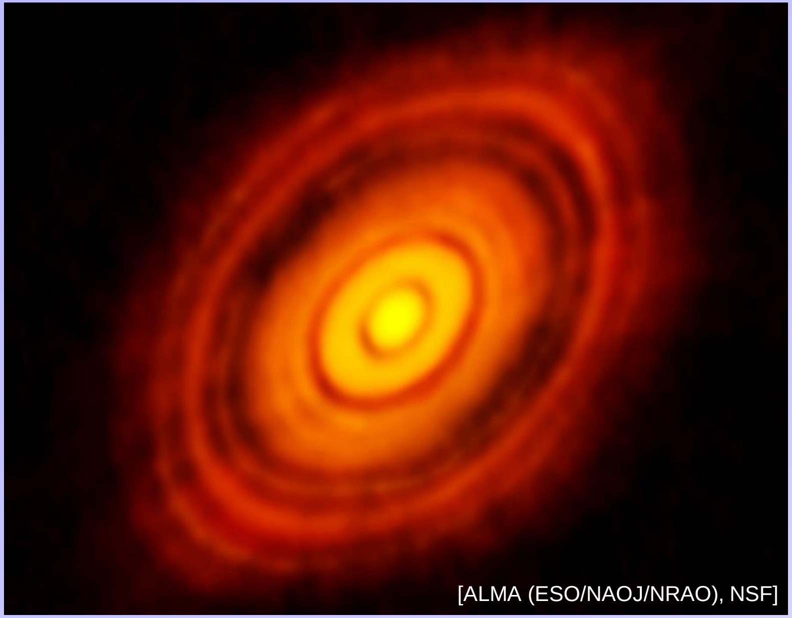
- **Solar nebula:** A large mass of space gas and dust contracts under gravity.
- **Contraction & condensation:** The solar nebula contracts, rotates faster, and flattens out: the center gets hot, while the out part heat up and then cool, leading to condensation of gas around the dust particles and the 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



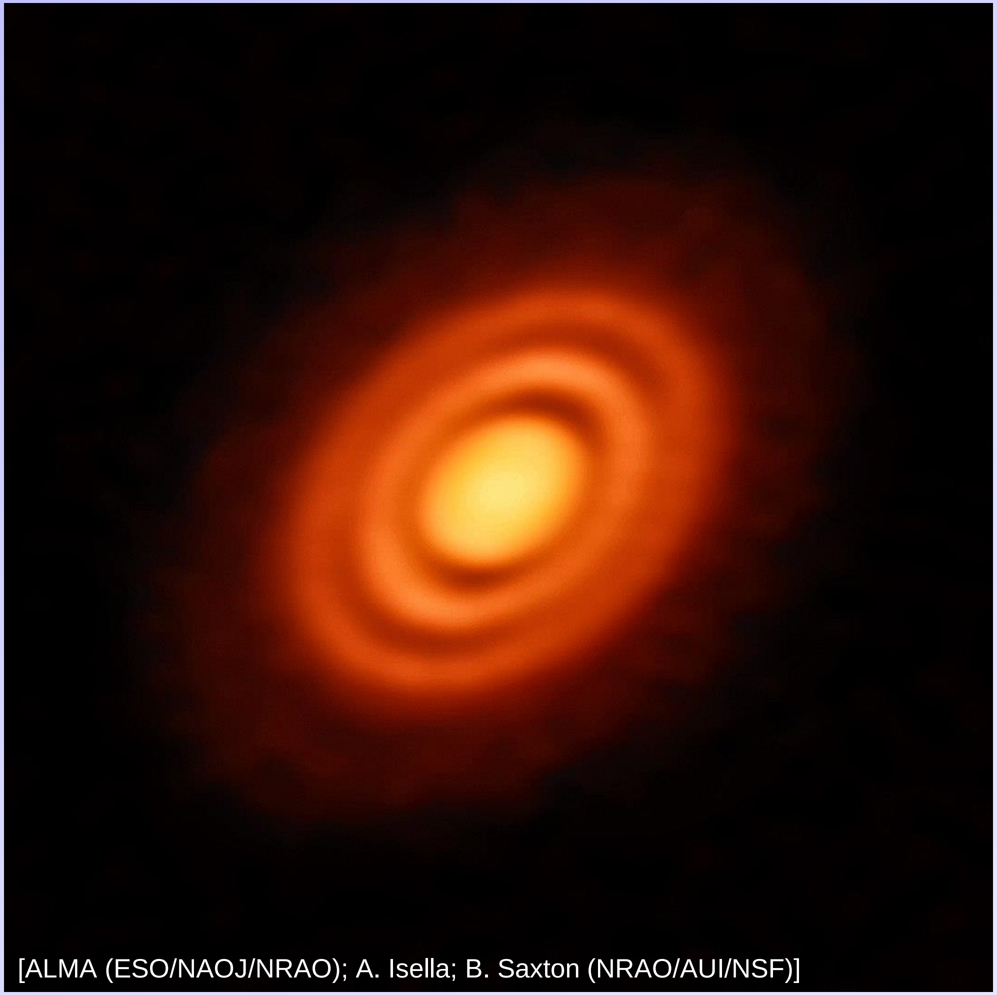
Evidence: Protoplanetary Disks – mm wave



[ALMA (ESO/NAOJ/NRAO), NSF]

The Protoplanetary Disk of the young star HL Tauri

(in Milky Way galaxy, Taurus constellation)



[ALMA (ESO/NAOJ/NRAO); A. Isella; B. Saxton (NRAO/AUI/NSF)]

Cloud of gas and dust surrounding the young star HD 163296.

(in Milky Way galaxy, Sagittarius 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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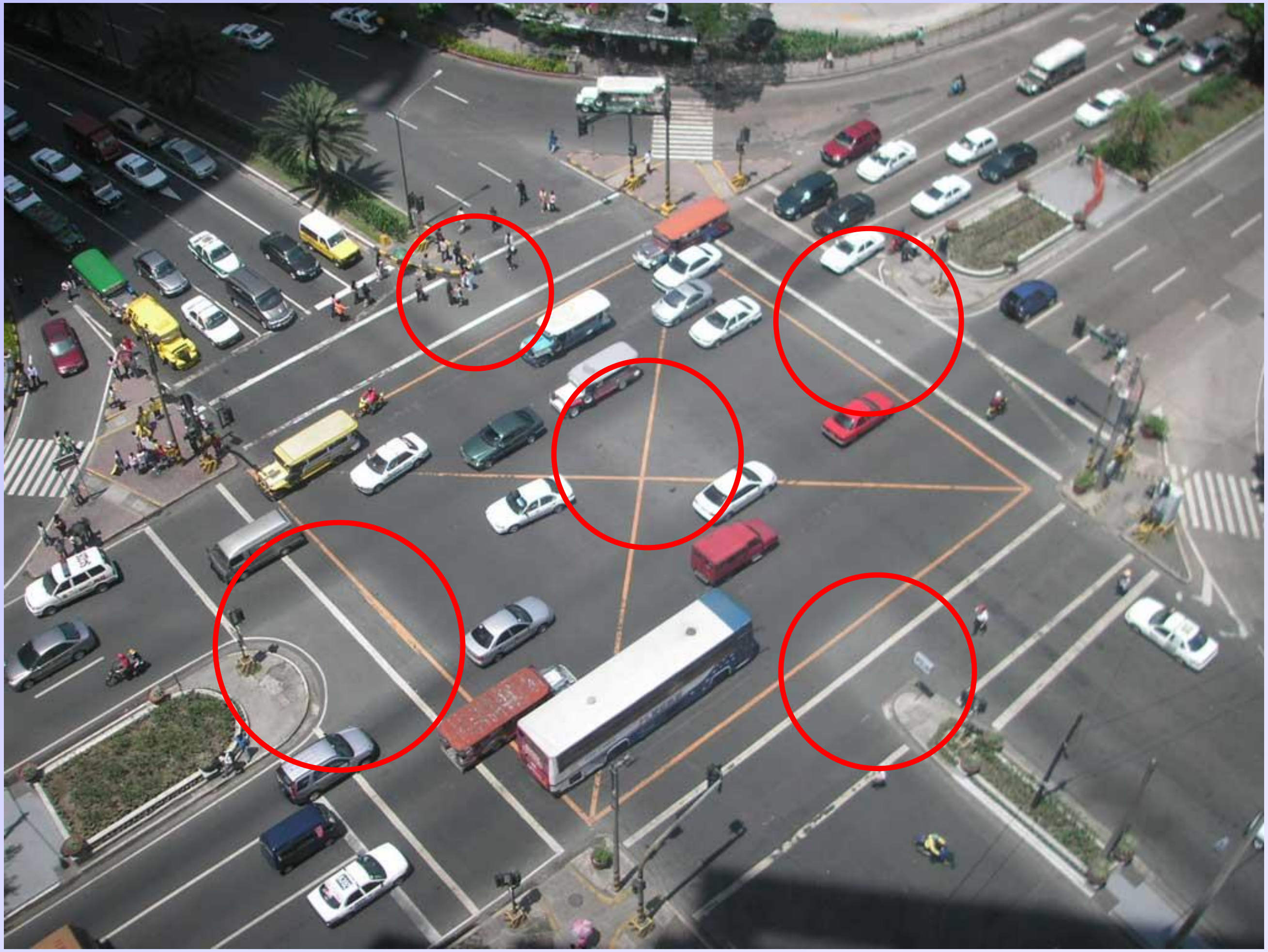
Physics is similar to the reason that there are "pebble patches" at an intersection:

- 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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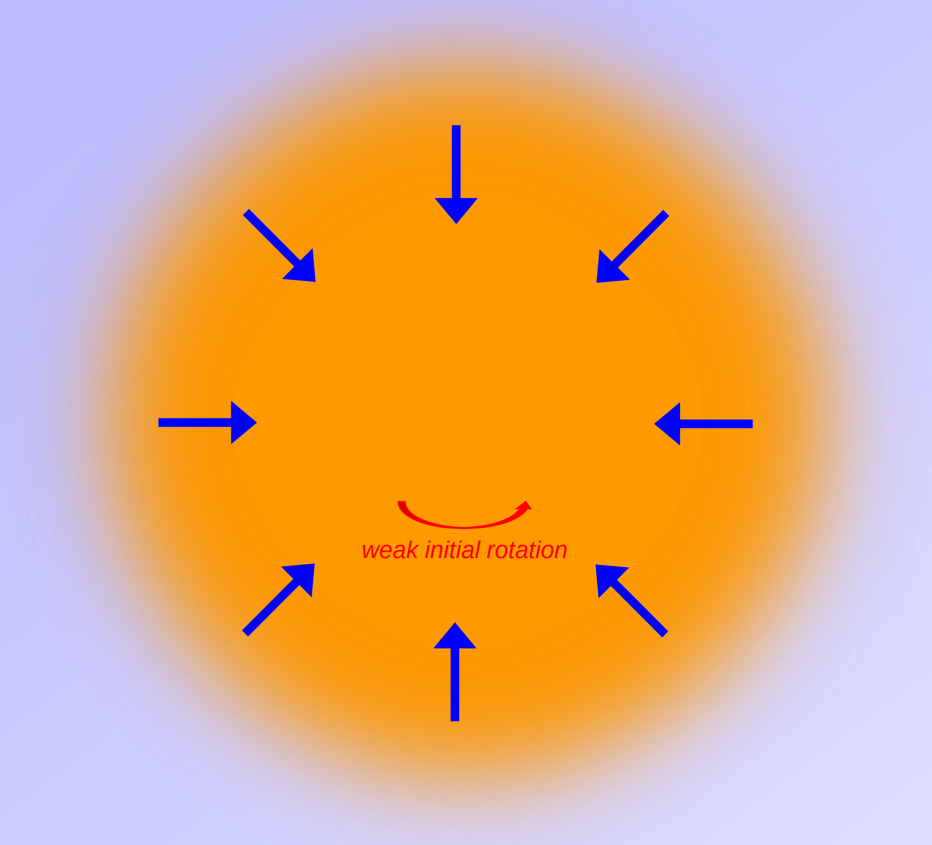

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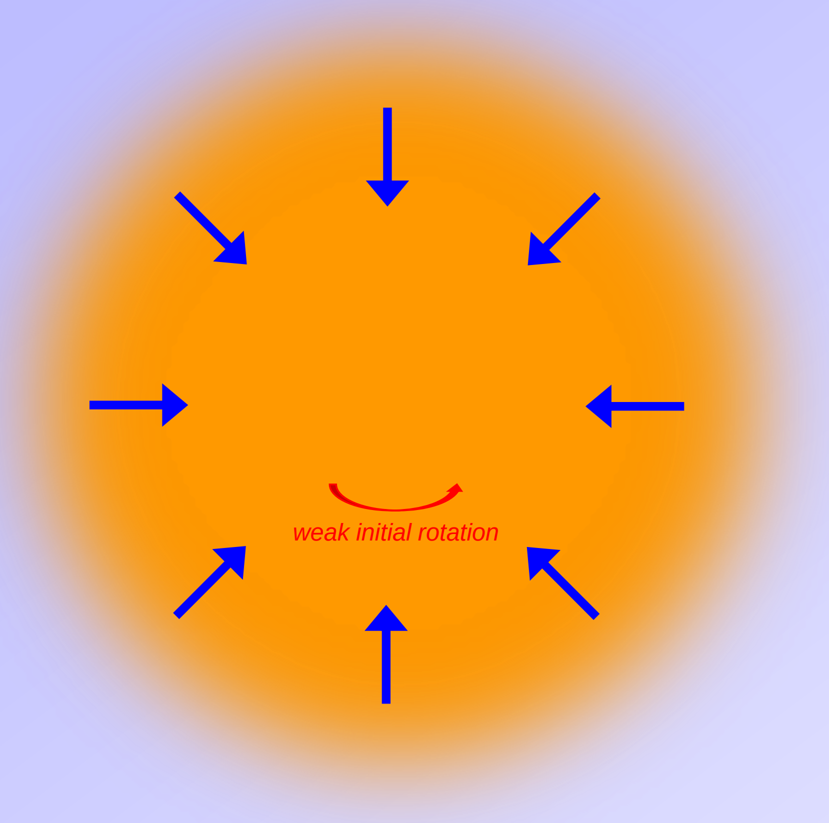

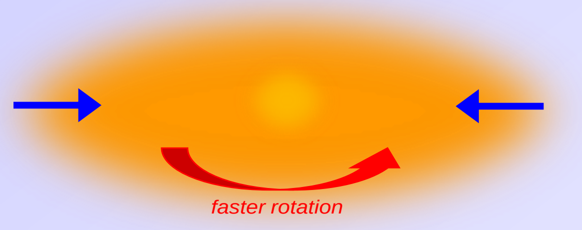

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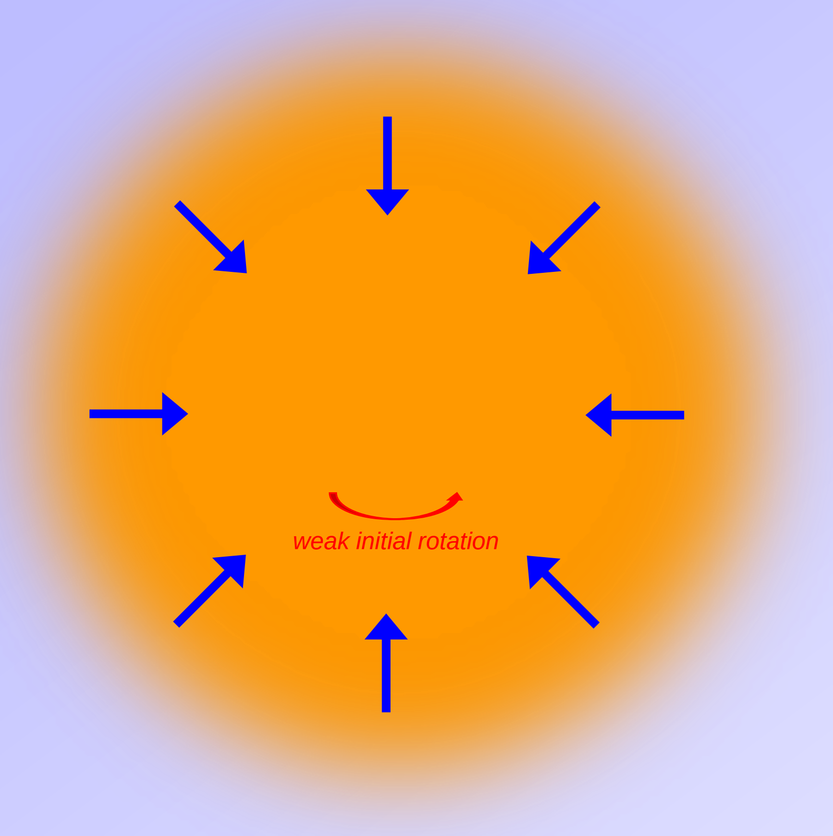

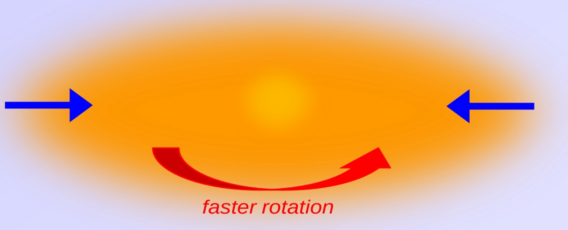

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Gas and dust that end up travelling with the rotation (and in-plane) will tend to collide less with each other (they are travelling in parallel & in sync), so this configuration is more stable.

How Old is the Solar System ?

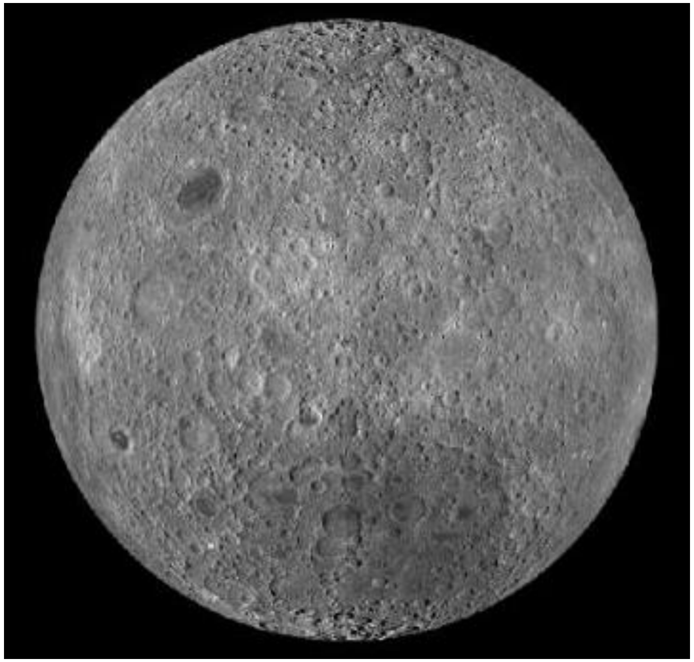
- Dating the entire Solar System is hard, but dating individual planets is easier.

- 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

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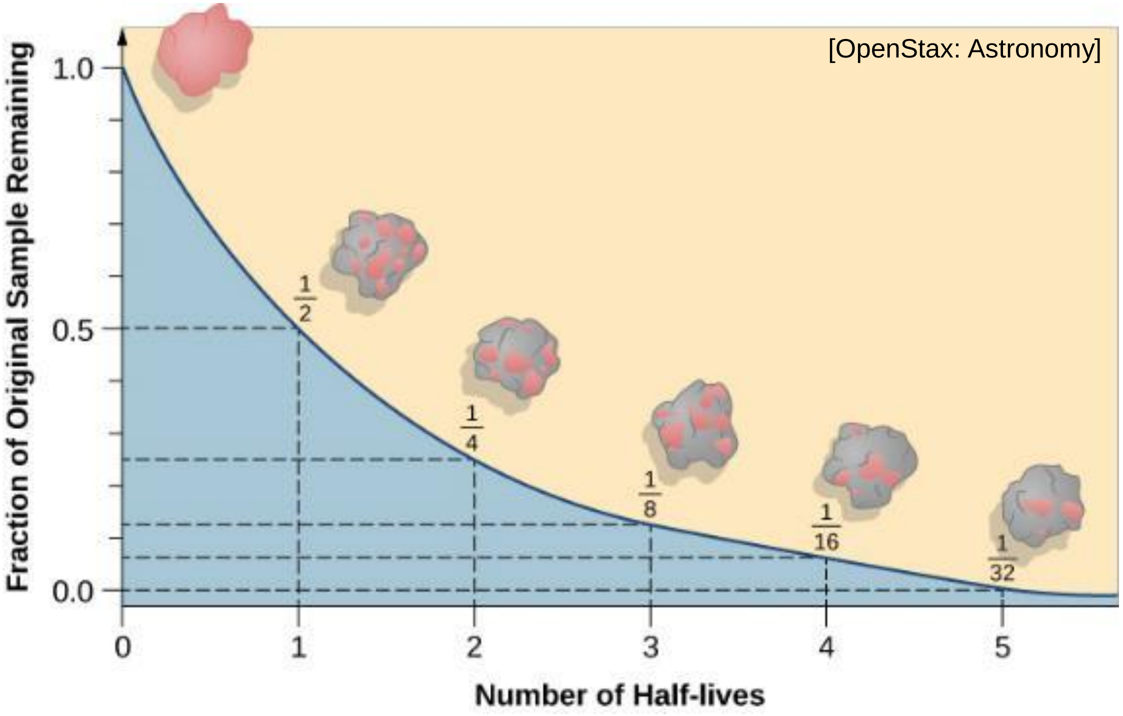

[OpenStax: Astronomy]

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

$$\left.\begin{aligned} {}^{40}_{19}\mathrm{K} + e^{-} &\rightarrow {}^{40}_{18}\mathrm{Ar} + \nu_{\mathrm{e}} \\ {}^{40}_{19}\mathrm{K} &\rightarrow {}^{40}_{18}\mathrm{Ar} + e^{+} + \nu_{\mathrm{e}} \end{aligned}\right\} 10.72\%$$

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$${}^{40}_{19}\mathrm{K} \rightarrow {}^{40}_{20}\mathrm{Ca} + e^- + \bar{\nu}_\mathrm{e} \qquad 89.28\%$$

anti-neutrino

Radioactive Decay Formula

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

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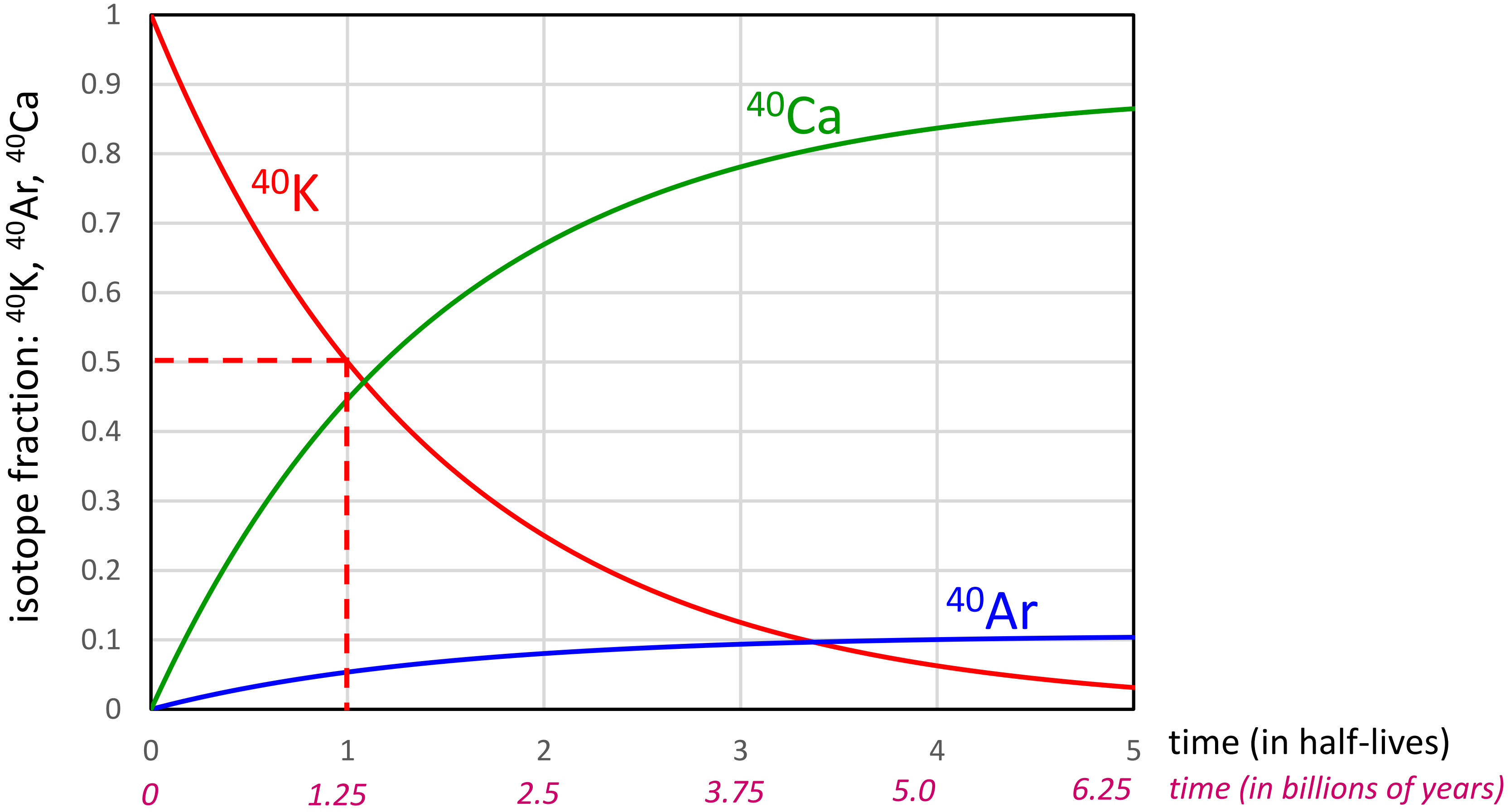

Potassium-40: Radiometric Dating

Key Facts

- Argon-40 is a noble **gas** and does <u>not react</u>.
- **In a liquid** (molten metal, lava, etc), argon-40 will escape, e.g. bubble out.
- **In a solid** (rock, meteorite), argon-40 cannot leave.

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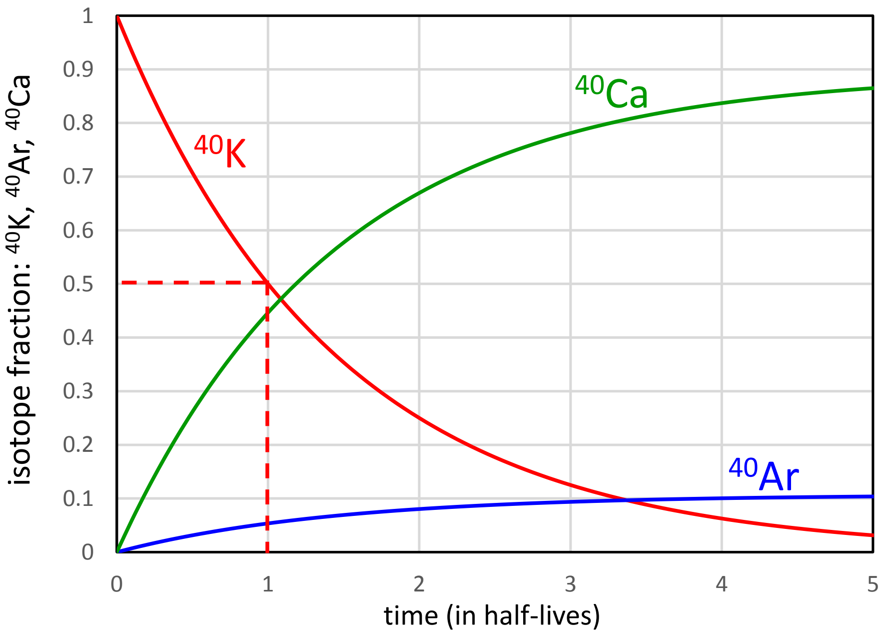
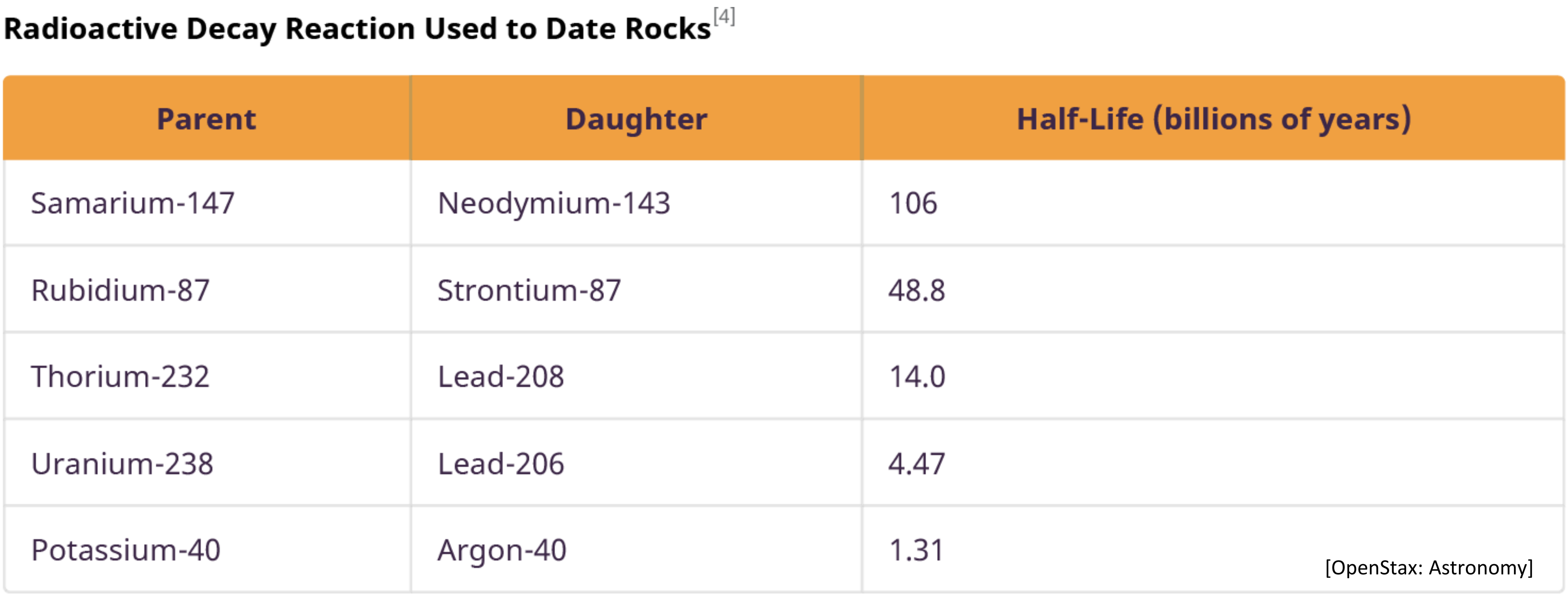
Radiometric Dating: Basic Idea

- 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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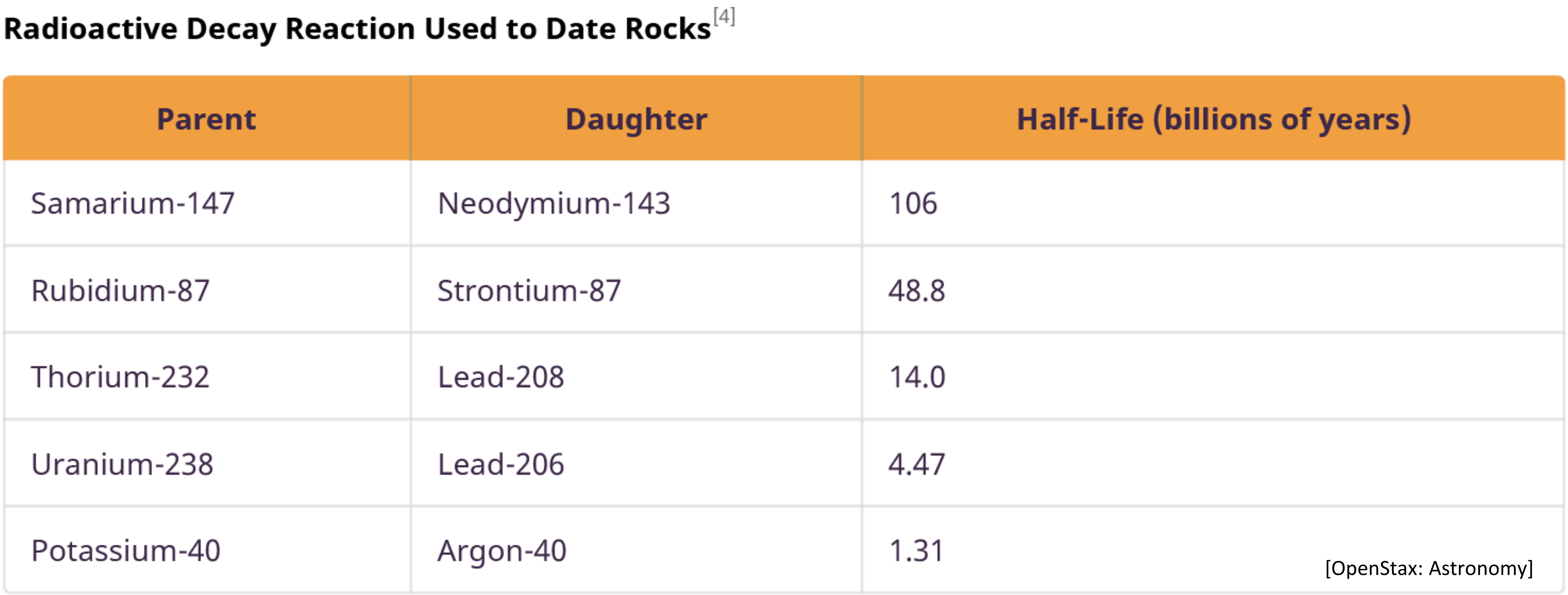

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[OpenStax: Astronomy]

Carbon-14 Nitrogen-14 5730 ± 40 years

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