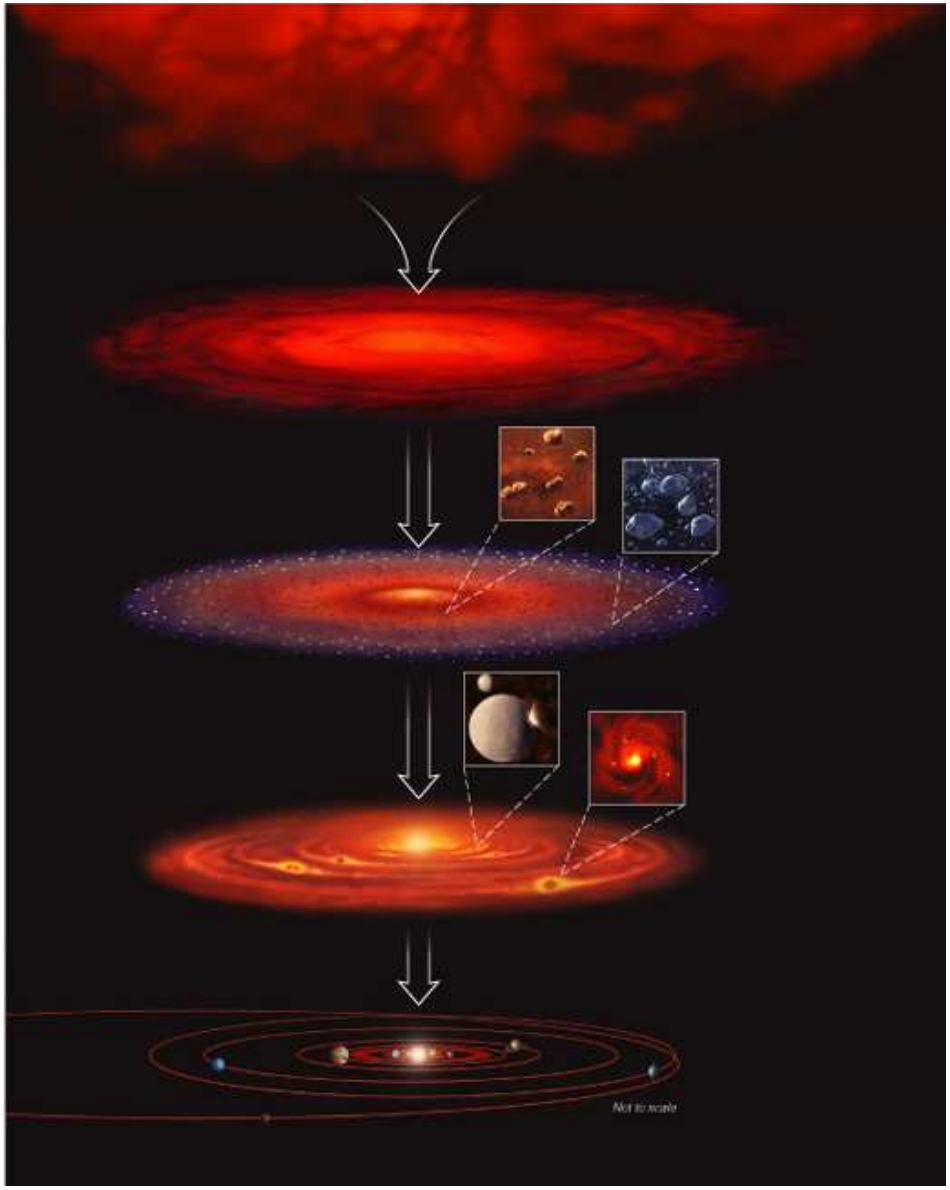


“The Sun, with all the planets revolving around it, and depending on it, can still ripen a bunch of grapes as though it had nothing else in the Universe to do.” Galileo Galilei

What We Will Learn Today

- Where did asteroids and comets come from?
- What was the early Solar System like?
- How did our Moon form?
- How do we know the age of our solar system?

Patterns Explained So Far…

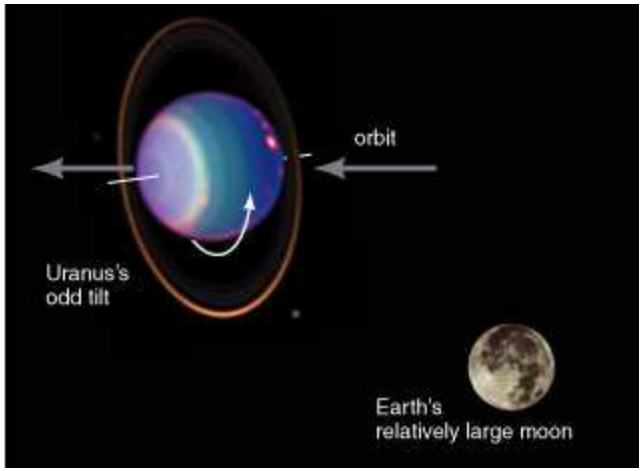
The nebular model seems to work

- ✓ Sun dominates the Solar System
  - 99.9% of mass, ~ 100% of light
- ✓ *All* planets roughly confined to a disk
- ✓ *All* planets' orbits are prograde
- ✓ The orbits have low eccentricity
- ✓ Most planets rotate prograde
- ✓ Most moons orbit & rotate prograde
- ✓ Two types of planets exist
  - Terrestrial close to Sun and Jovian farther out

Unexplained Patterns

- The many asteroids and comets in our solar system
  - Why do they live in specific zones?
  - Why did they not condense into planets?

- The exceptions observed
  - Retrograde orbits of Venus and Uranus
  - Retrograde orbits of several moons, including one large moon
  - Earth's relatively large moon



The Asteroid Belt

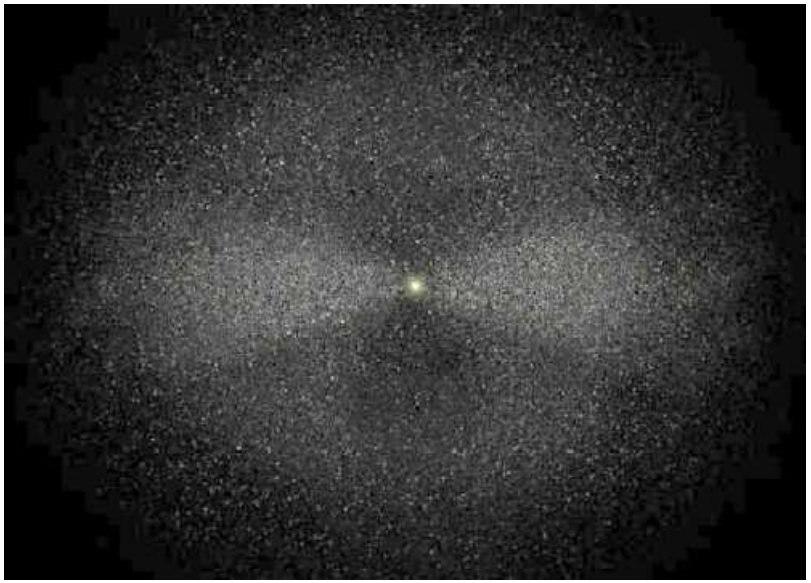
- Occupies the region between Mars and Jupiter
- The terrestrial planets cleared their orbits either by assimilation or ejection
- Asteroids are planetesimals that never became a planet
  - Jupiter's gravity prevented condensation
  - Found a home in this large vacant space
- The asteroids collectively are only a small fraction of the mass of a terrestrial planet
  - Probably were of planet mass early on
  - Most assimilated into planets or ejected out

The Kuiper Belt

- Comets initially inhabited the entire solar system
  - Ice-rich planetesimals
  - Out to beyond Neptune's orbit
- Beyond Neptune's orbit, they remained in stable orbits around the Sun
- Short-period comets come from the Kuiper belt
  - Including Halley's comet (P = 76 years)

The Oort Cloud

- Comets that started among Jovian planets or wandered too close were swallowed or ejected
  - Scattering is a lot more probable than collisions
  - Close encounters banished them to the outer reaches of the solar system
- No preferential direction of scattering
  - Not confined to the disk, Oort cloud is spherical
- Contains many billions of comets
  - 50,000 AU away
  - Have not been observed, except when they come close to the Sun



The Early Solar System Fireworks

- Heavy Bombardment
  - First few hundred million years
  - Left marks we clearly see on many planets and moons today
  - Enriched terrestrial planets with water and hydrogen compounds

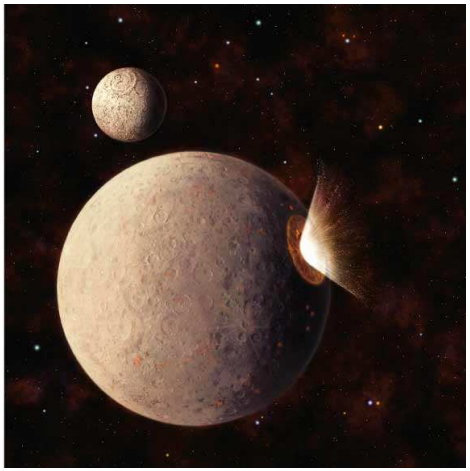
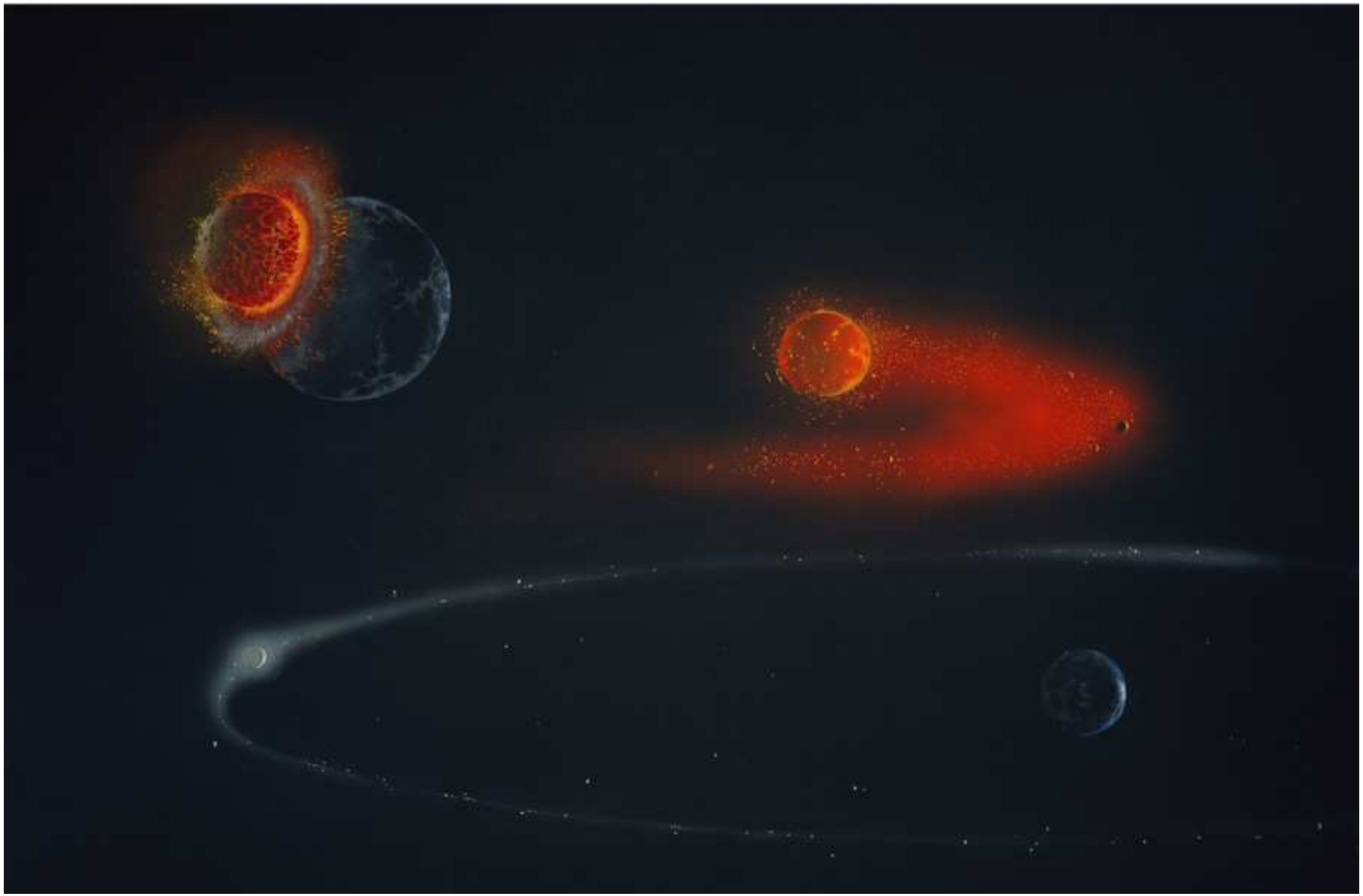


Fig 8.10

Captured Moons

- While capture does not explain the solar system formation, it is responsible for the orbits of several moons
- Captures are low probability
  - Extended atmosphere slowed object down
  - Multi-object interaction allowed capture
  - Only works for small objects
    - Consistent with observations
  - Captured moons can have high inclinations and retrograde orbits

Formation of Our Moon



Video from Kokubo et al (2000)

Fig 8.12

Support for Collision Theory

- Our moon is too large to have been captured
- Composition of Earth and Moon different
  - Can't have condensed from the same matter
  - Moon's overall composition is similar to Earth's crust
- Explains high density of the Earth
- Explains a large moon
- Supported by computer simulations
- Collision also thought to explain
  - Venus, Uranus retrograde orbits
  - Pluto's large moon and retrograde orbit

Review of Solar System Formation

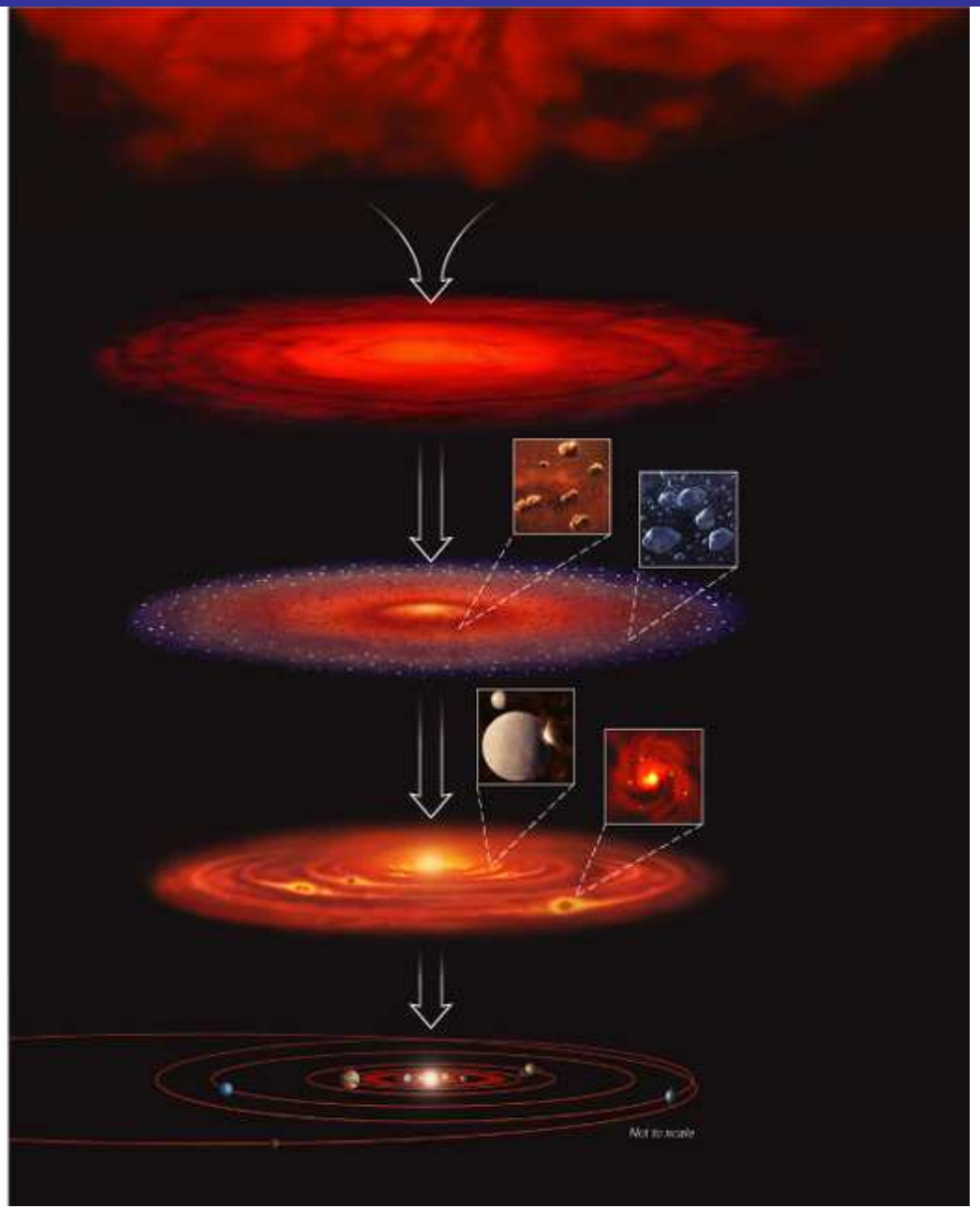


Fig 8.13

When Did the Solar System Form?

- Radioactive dating of the oldest rocks
  - Spontaneous radioactive decay
  - Converts a proton into a neutron, releasing an electron
  - Creates an isotope of a lower atomic number element
  - Random process, but overall rate very predictable for an element
  - **Half-life**: Time after which half of the original atoms have decayed

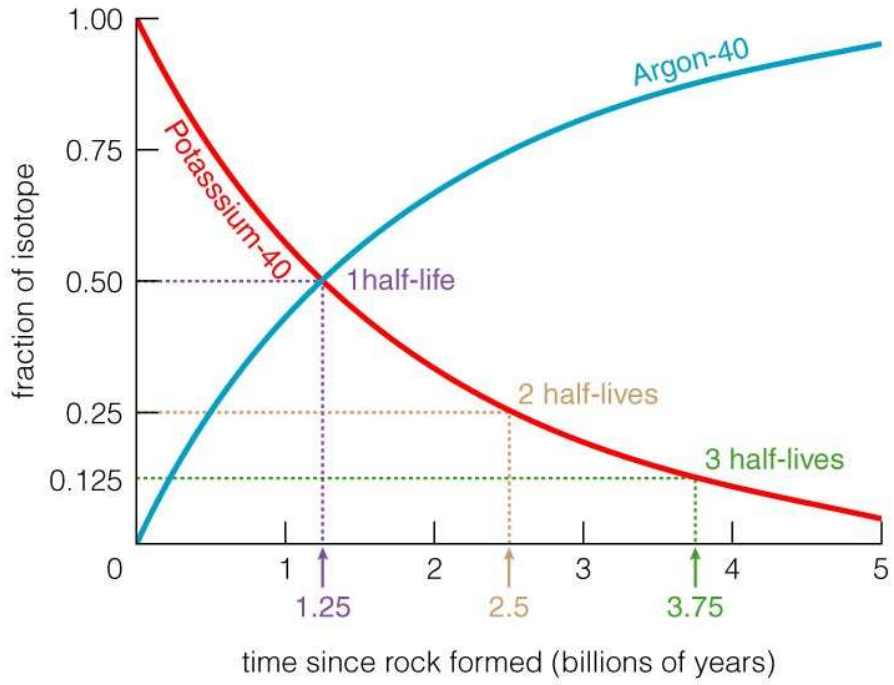


Fig 8.14

Radioactive Dating

- Rocks from Moon have roughly equal ^{238}U and ^{206}Pb
- Half-life of this decay is 4.5 billion years
- So, these rocks are about 4.5 billion years old
- Check multiple isotope aging to ensure consistency
- Oldest rocks on Earth are about 4 billion years old
- Most pristine rocks of the solar system are asteroids
- The oldest ones of these have an age of about 4.55 billion years
  - Beginning of accretion in the solar nebula
- The planets formed within 10s of million years
  - They are about 4.5 billion years old
- Solar model shows that the Sun is 4 – 5 billion years old
  - Consistent with radioactive dating