DOES THIS "NEBULAR THEORY" EXPLAIN THINGS?

- Things to explain:
  - Motions of large bodies: All in same direction and plane
  - Two major planet types: Terrestrial and Jovian
  - Swarms of small bodies: Asteroids and comets
- Notable exceptions: Rotation of Uranus, Earth's large moon

ANGULAR MOMENTUM

- Back to the ice skater
  - The rotation speed of the cloud from which our solar system formed increased as the cloud contracted.

PLAY

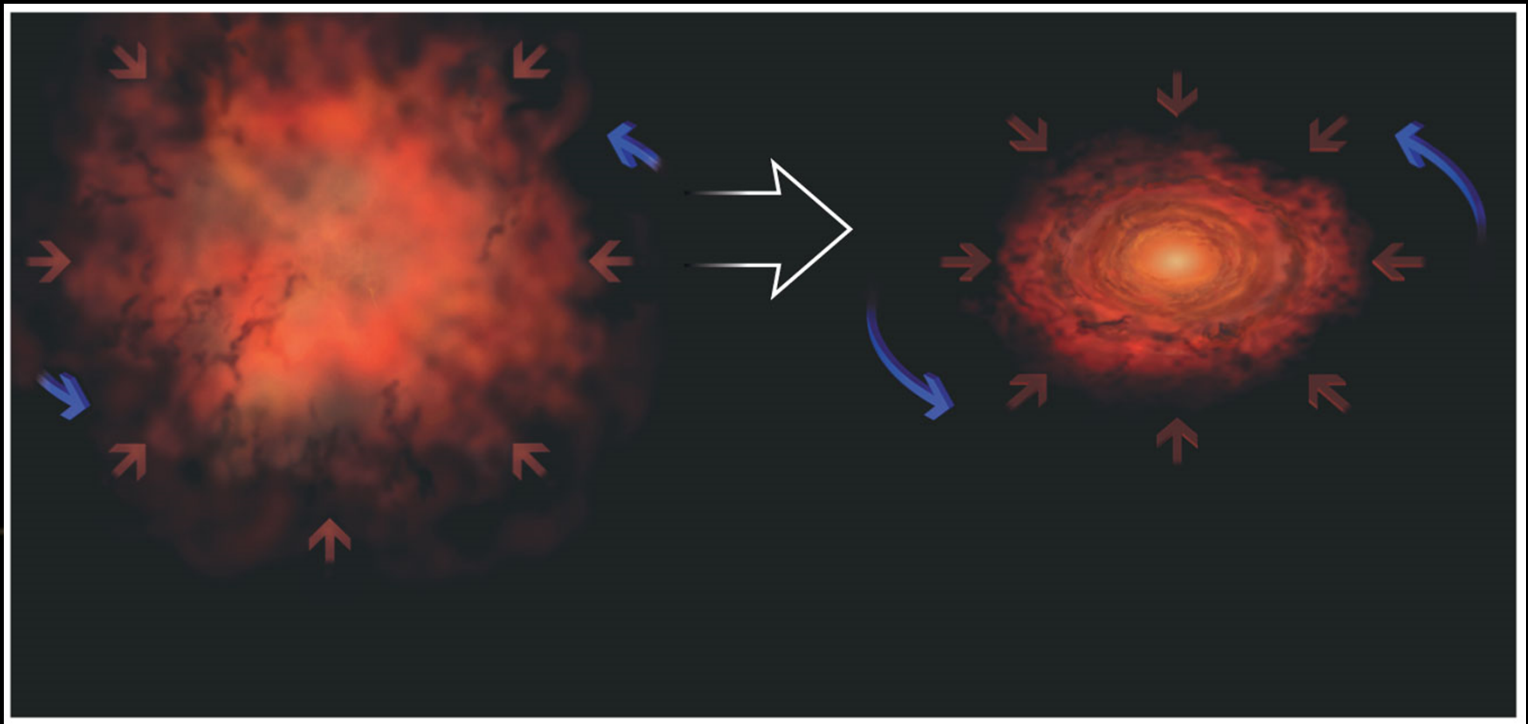


Fig.6.16

COLLISIONS

- As the cloud shrinks, collisions between gas particles become more common
- This does two things:
  - Makes motions more average and thus more cicular
  - Reduce the up-and-down motions, making a disk

PLAY PLAY

HOW BOUT TWO SORTS OF PLANETS?

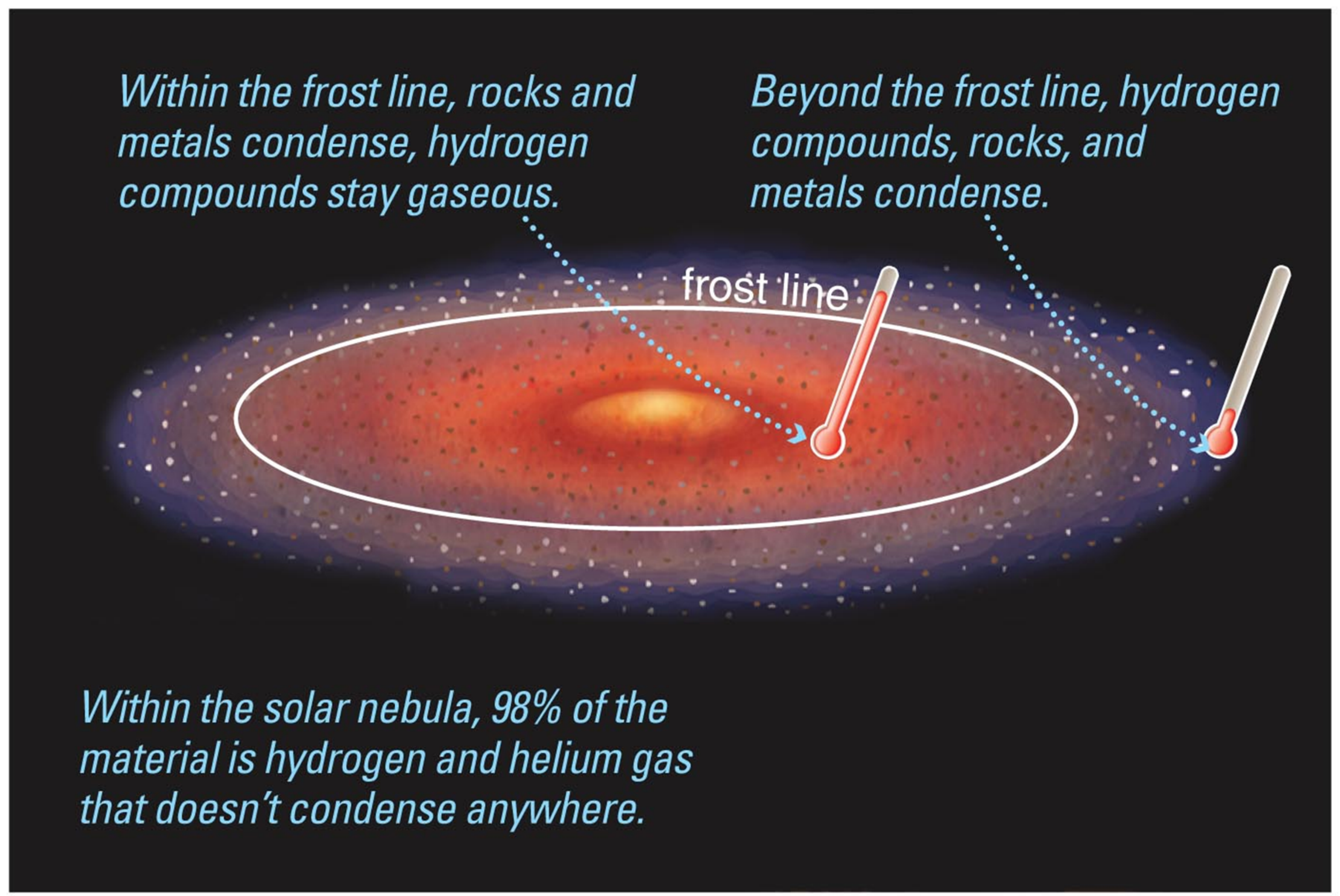
- Let's look at the stuff in the nebula available to build planets
  - We know this by examining not only other young solar systems but also comets, which are leftover crumbs from our solar system's formation

TABLE 6.3 Materials in the Solar Nebula

A summary of the four types of materials present in the solar nebula. The squares represent the relative proportions of each type (by mass).

	Examples	Typical condensation temperature	Relative abundance (by mass)
Hydrogen and Helium Gas 	hydrogen, helium	do not condense in nebula	98%
Hydrogen Compounds 	water (H_2O), methane (CH_4), ammonia (NH_3)	$<$150 K	1.4%
Rock 	various minerals	500–1300 K	0.4%
Metals 	iron, nickel, aluminum	1000–1600 K	0.2%

FROST LINE



PLAY

Fig.6.18

PLANETARY SEEDS

- Once you get bits of stuff condensing out to solid or liquid
  - It's denser
  - Gravity works better the more stuff is closer
  - So things "snowball" and denser things get more dense, "accreting" more stuff into "planetesimals"
  - Smashing things together heats things up

$$F = G\frac{m_1 m_2}{d^2}$$

PLAY

THINGS KEEP STICKING

- Many smaller planetesimals glom together to make fewer, bigger things

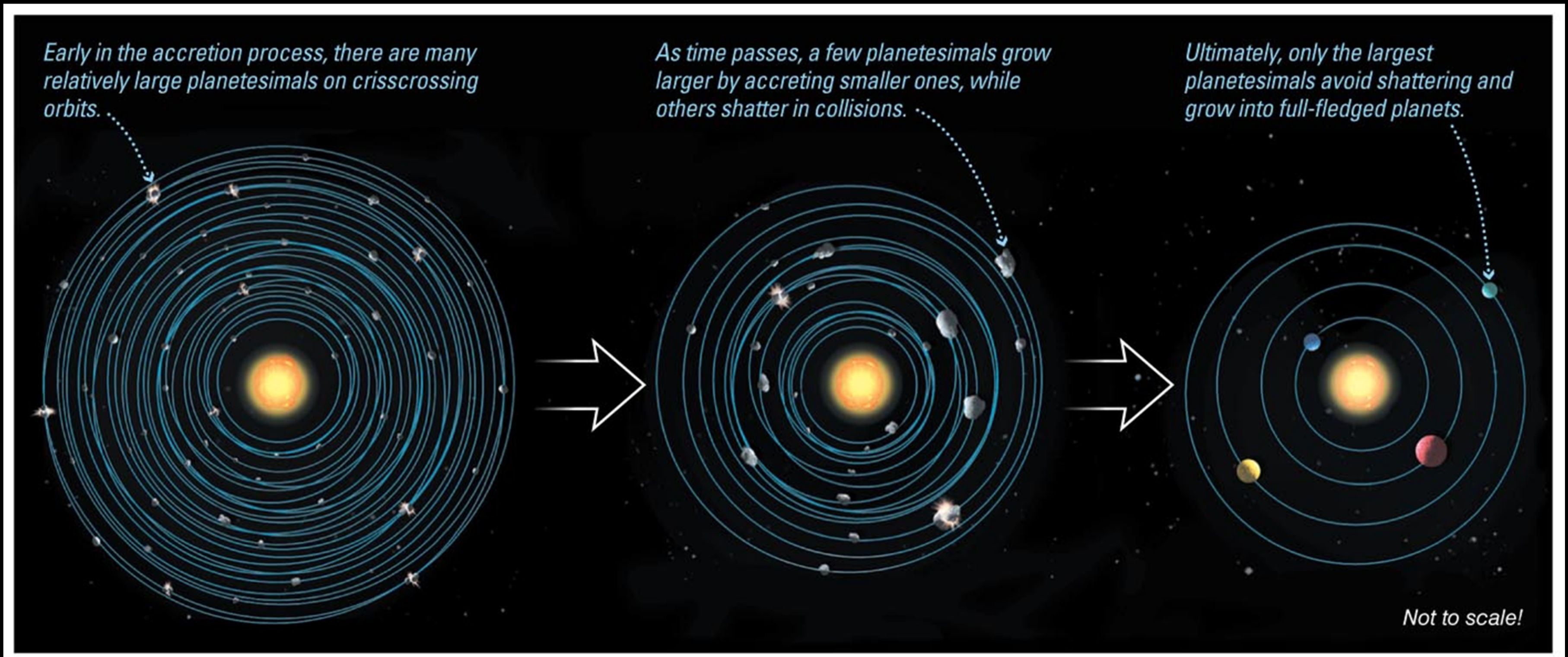


Fig.6.19

OK, BUT…

- So that's how you get rocky planets, fine
- But how about the huge gassy planets?
- Past the frost line, cool enough for hydrogen compounds to also condense out
  - So much more sticky stuff is available
  - … so you get bigger things
  - … that also have a lot more hydrogen in them

PLAY

BIGGER THINGS, MORE GRAVITY

- Gas gets captured too
- And moons form via their own "co-accretion"

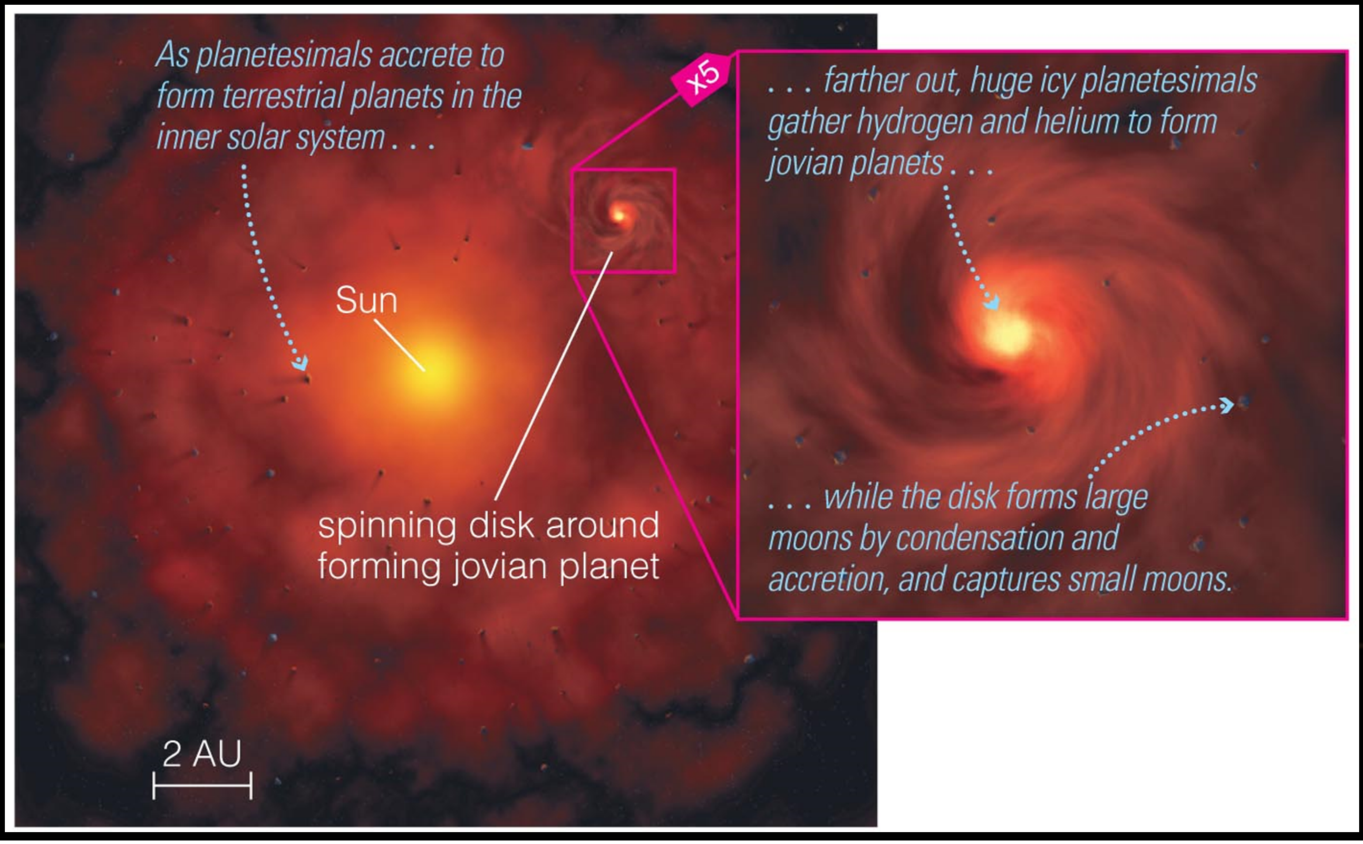


Fig.6.21

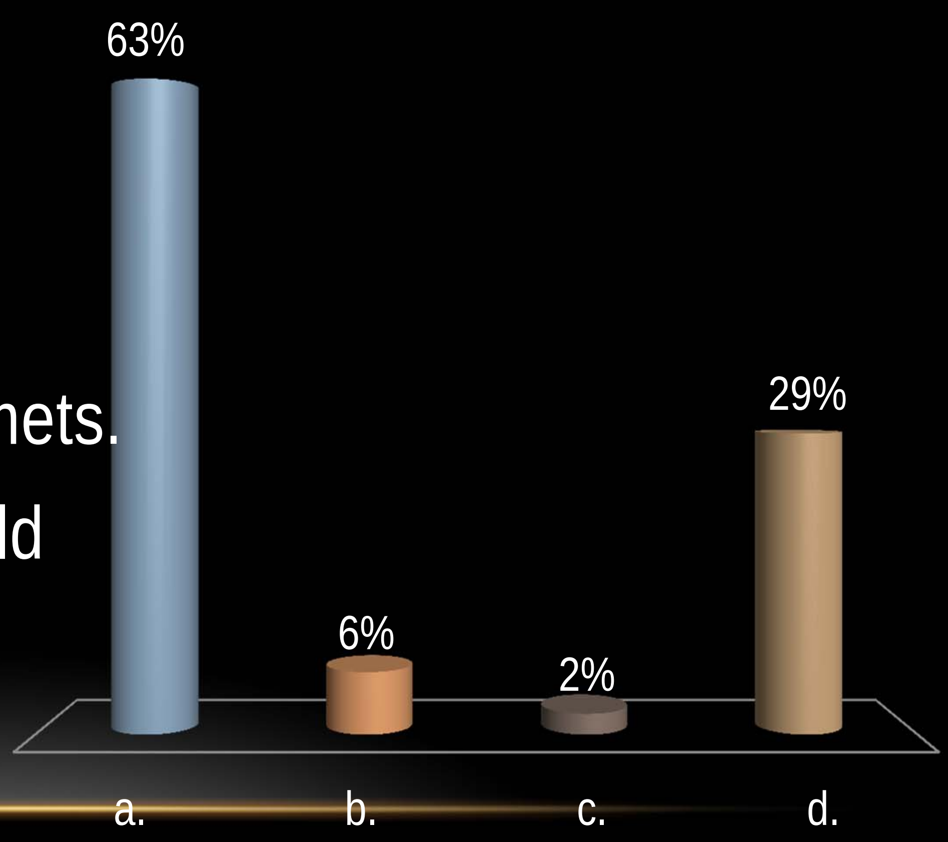
HOW WOULD THE SOLAR SYSTEM BE DIFFERENT IF THE SOLAR NEBULA HAD COOLED WITH A TEMPERATURE HALF ITS CURRENT VALUE?

✓ a. Jovian planets would have formed closer to the Sun.

b. There would be no asteroids.

c. There would be no comets.

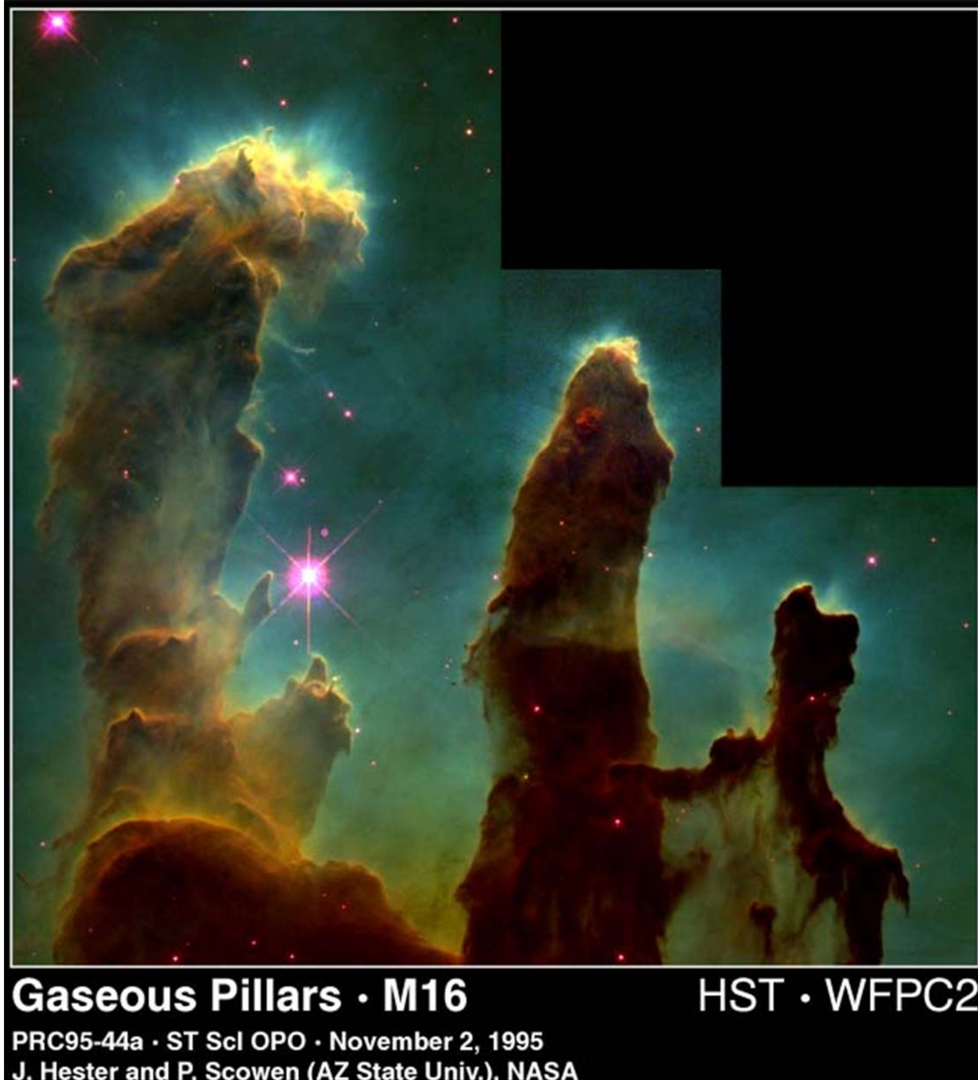
d. Terrestrial planets would be larger.



COMETS, ASTEROIDS?

- Close encounters with bigger planets slingshot planetesimals far out
  - Oort cloud
- Ones past Neptune don’t get knocked around
  - Kuiper Belt
- In between Jupiter and Mars, nothing to kick them out, but Jupiter’s gravity keeps them from glomming together
  - Asteroid belt: inside frost line, rocky
  - Comets are outside frost line, icy

SOLAR WIND



- As the Sun really cranks up, the solar wind blows away the remaining dust
- As time goes on, bigger chunks whack into things, make craters – but all get used up

PLAY

HST image of dust being blown away in the Eagle Nebula by Intense interstellar winds

IMPACTS

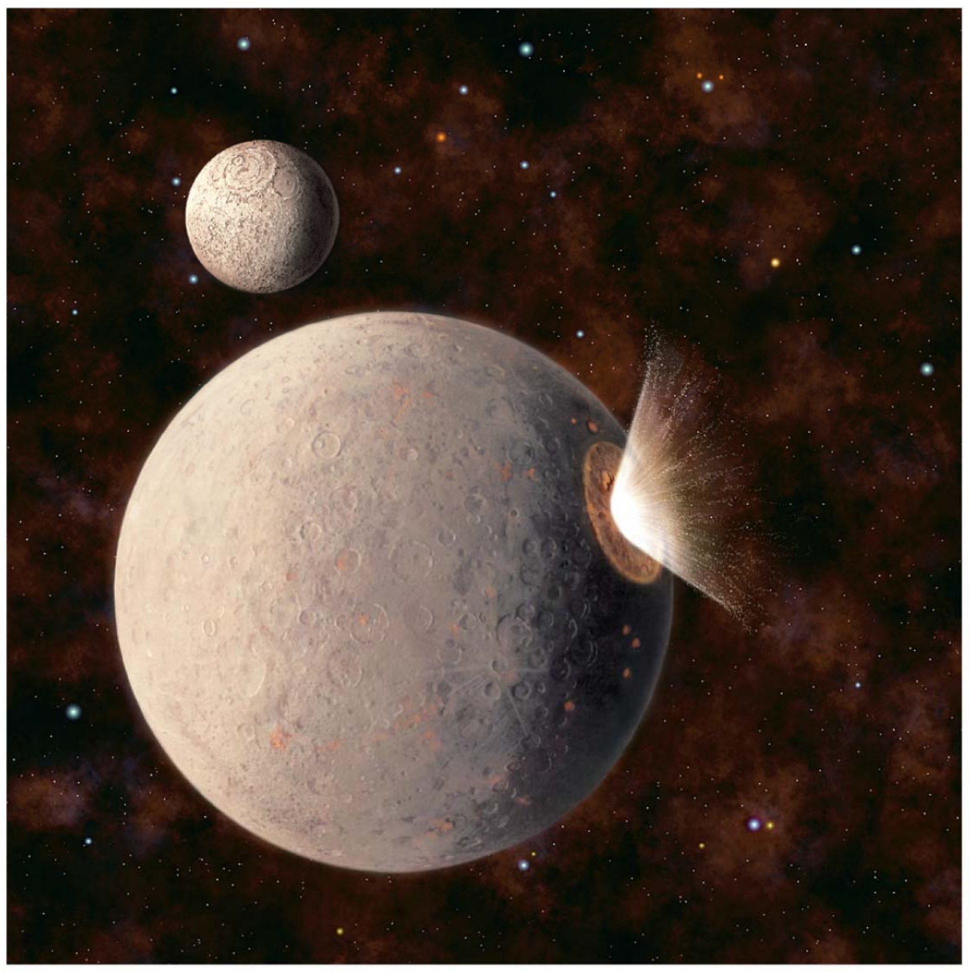


Fig.6.22

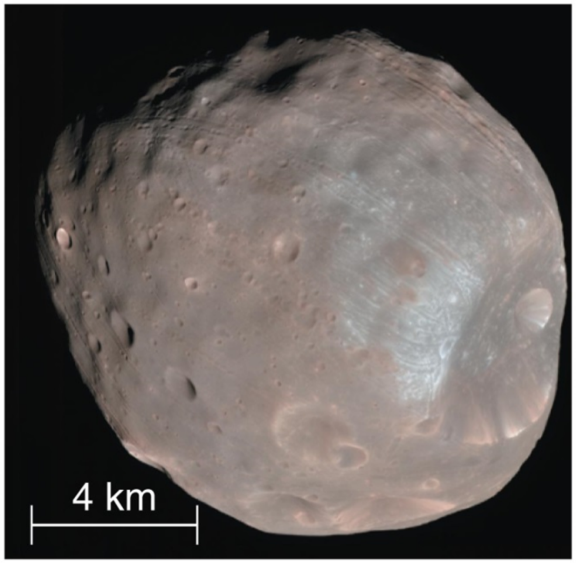
- About 4 billion years ago (0.5 billion after the initial formation)
- Leftover planetesimals "accrete" in a noticeable way
- We see the impact craters resulting from this heavy bombardment on old surfaces like the moon

WHAT ABOUT THE EXCEPTIONS?

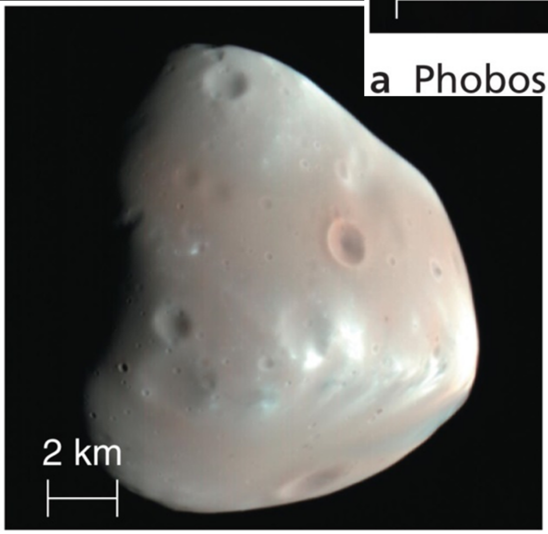
- Some things rotate or orbit the “wrong way”
- Earth’s moon is unusually large compared to earth
- Some things are tilted funny

SOME PLANETESIMALS GET CAPTURED INSTEAD

Fig.6.23



a Phobos



b Deimos

- For example, Mars' moons Phobos and Deimos are probably captured asteroids
- Don't need to orbit in the same direction as everything else
  - *eg*, Neptune's moon Triton

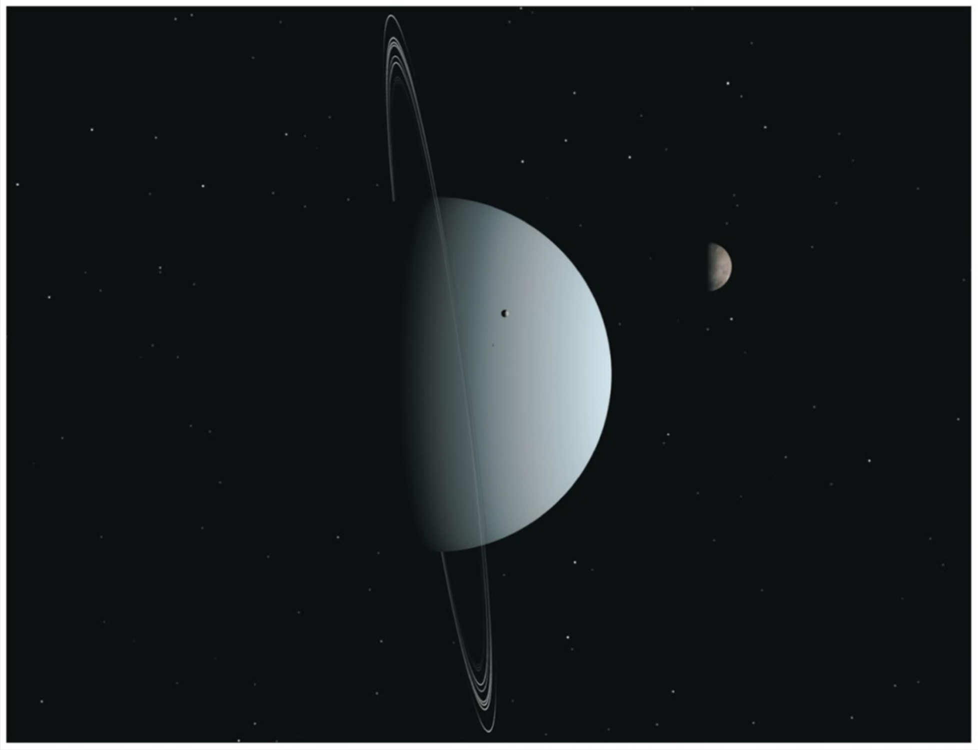
KER-POW

- Earth’s Moon is quite large compared to Earth
  - Can’t co-accrete or capture that
- However, a giant impact could make the moon

THE LARGE IMPACT THEORY

- The current best-fitting theory for where the moon came from
- A very young Earth is hit by a Mars-sized object (now called “Theia”)
  - Blasts loose a big chunk of crust, which coalesces into the Moon
- Things it explains:
  - Lighter density of moon explained, stuff blasted loose would be lighter
  - High temperature formation (from the composition)
  - Could also explain Earth’s 23.5^{o} tilt and fast rotation

TILTED?

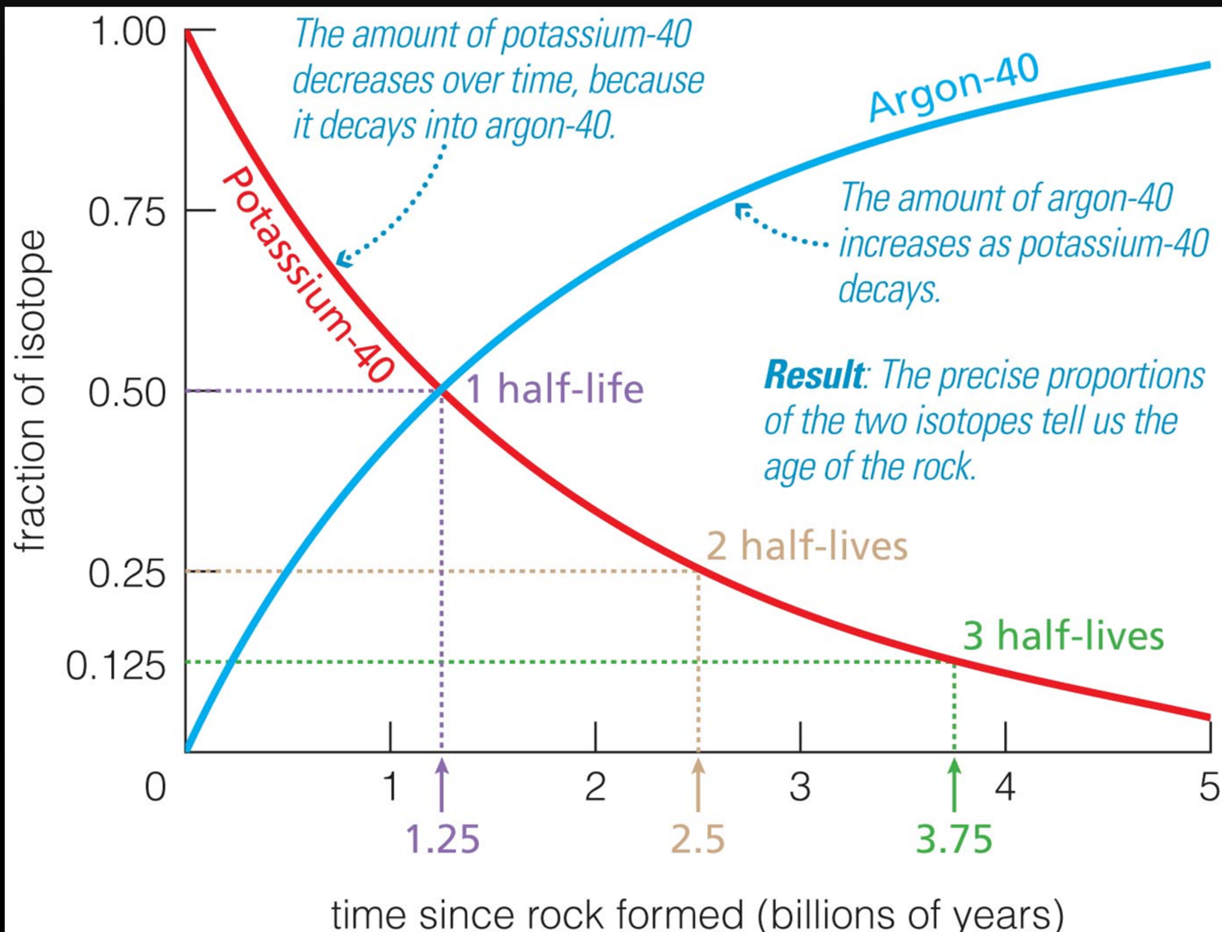


- Giant impacts could also explain Uranus' odd and much larger axial tilt

AGE OF SOLAR SYSTEM

- I keep saying “solar system is 4.5 billion years old”. How can we know that?
- While we can’t date a planet directly, we can date the rocks which make it up
  - And if the planet formed by an accretion melting-fest, that’s when the oldest rocks were formed: so not a bad way to measure it

RADIOACTIVE DECAY



- Some isotopes decay into other elements
- A "half-life" is the time it takes for ½ the original element to decay away
  - Measured in the lab for many isotopes

Fig.6.26