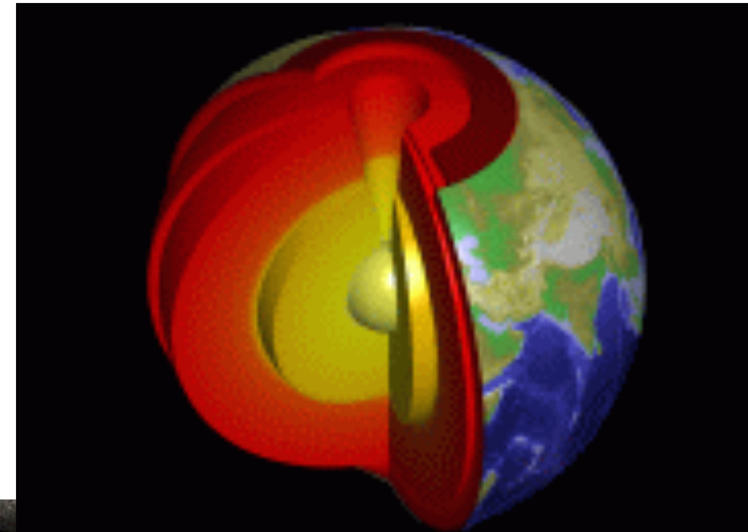
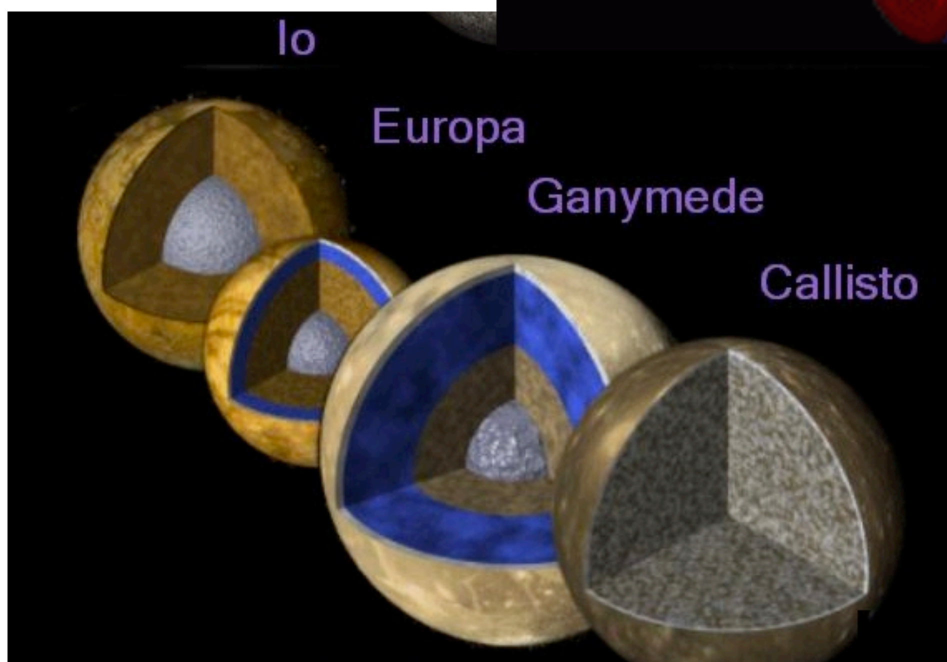
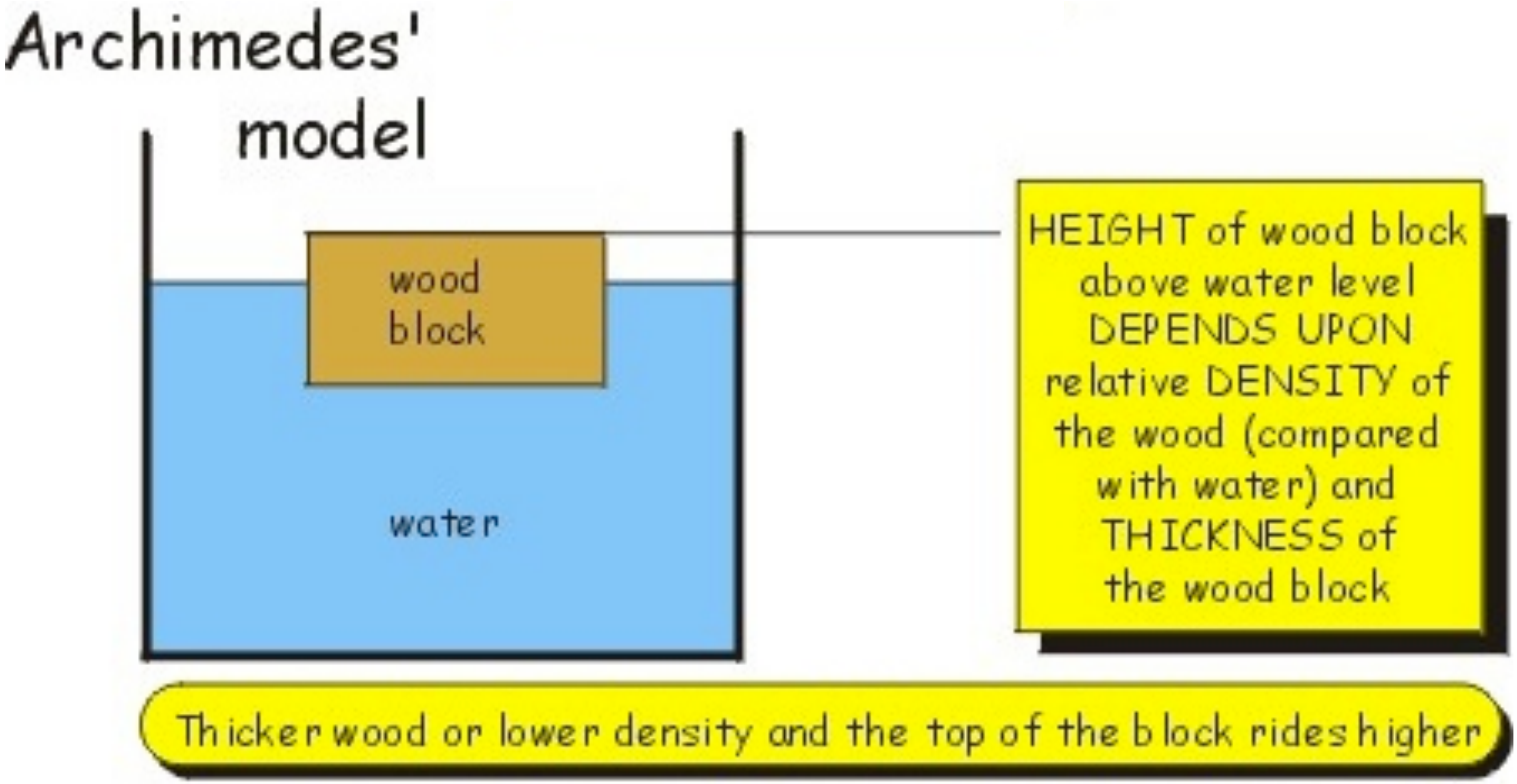
Planetary Interiors

Earth's Interior Structure
Hydrostatic Equilibrium
Heating
Constituent Relations
Gravitational Fields
Isostasy
Magnetism





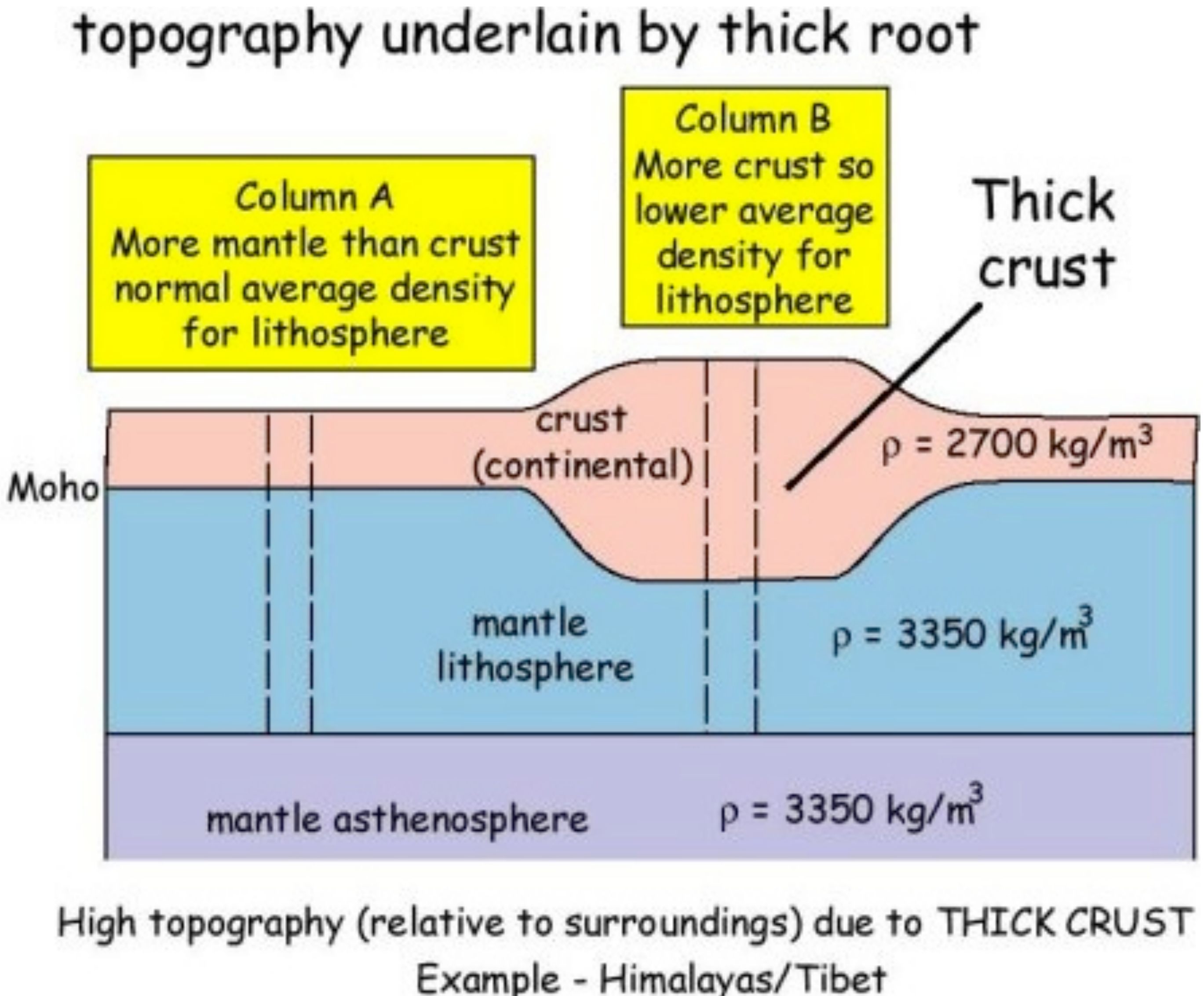
Isostasy



Courtesy of U of Leeds

Now apply this idea to topography and the crust…

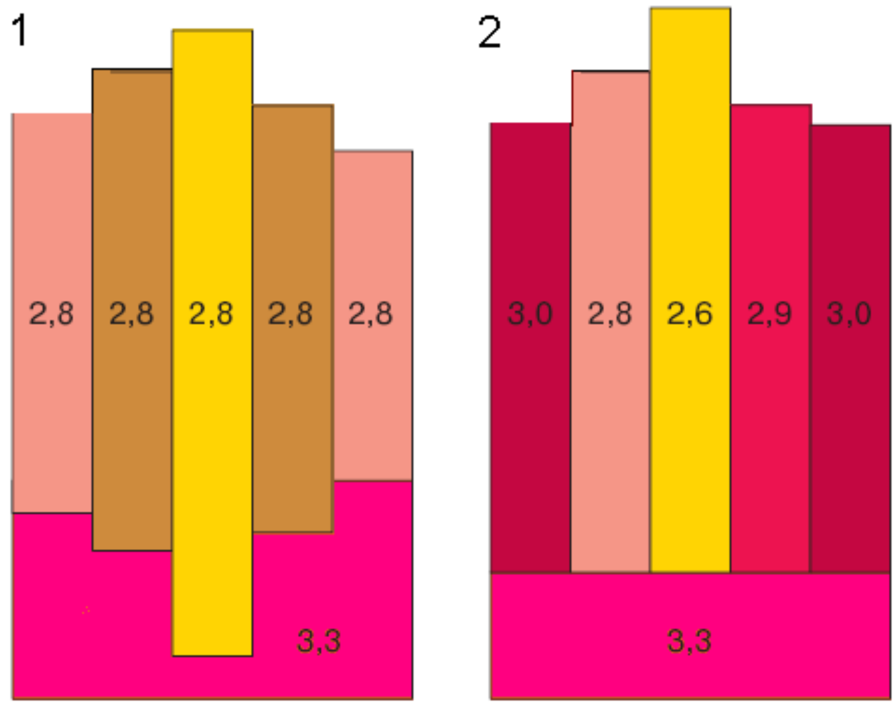
Airy Model



Courtesy of U of Leeds

The Earth's Crust

Credit: Wikipedia



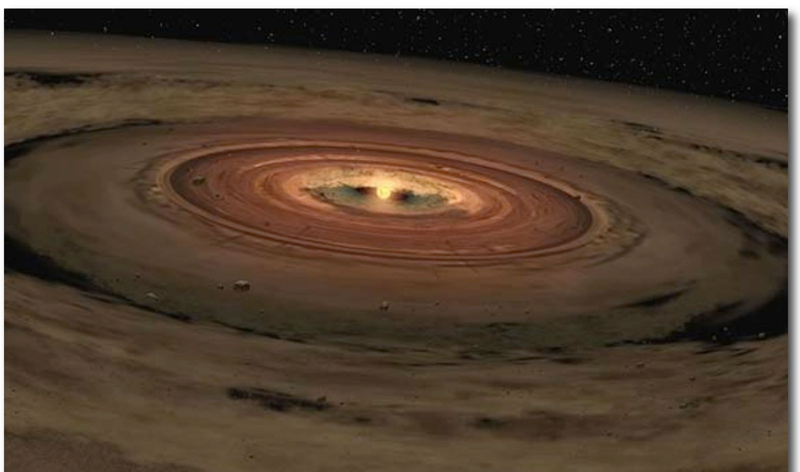
1. **Airy Scheme:** Accommodate topography with crustal 'root' (assumes same ρ for all of the crust)
2. **Pratt Scheme:** Lateral density variation causes topography

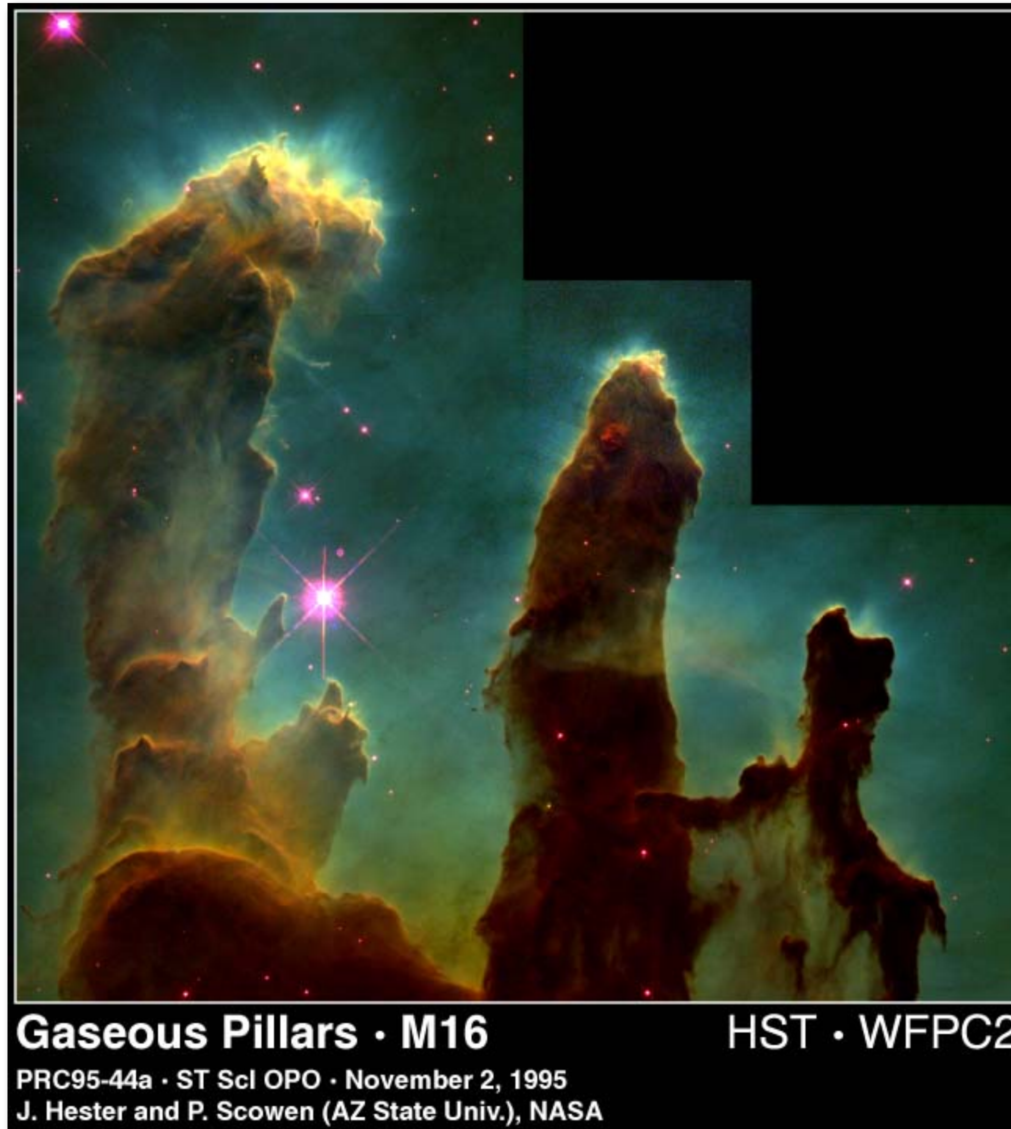
The Earth's granitic (lower density) continental crust varies from < 20 km under active margins to ~80 km thick under the Himalayas.

The basaltic (higher density) oceanic crust has an average thickness of 6 km with less near the spreading ridges.

Solar System/Planet Formation

For more details, read chapter 13…





Solar System Formation: Constraints

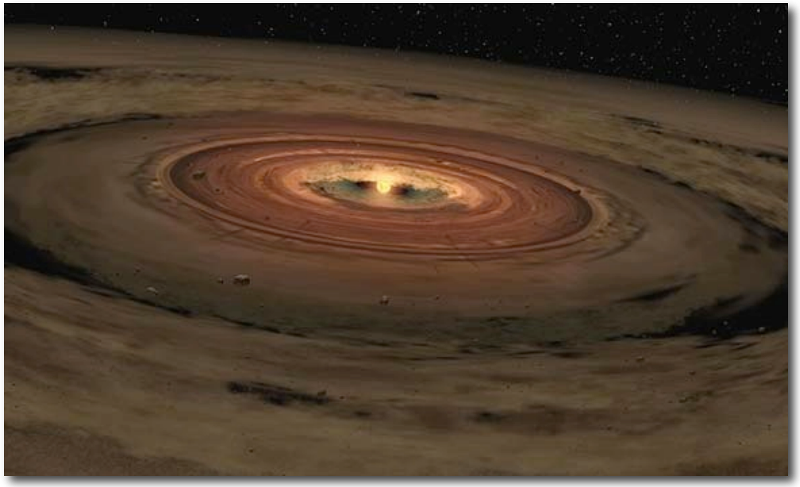
- Sun has 99.8% of mass, <2% of angular momentum
- Low inclination & eccentricity of planet orbits
- Most planets have low obliquity
- Large outer planets have ~solar composition
- Small inner planets enriched in heavy elements
- Impact craters on virtually every planetary body
- "Debris" in asteroid belt, Kuiper belt
- Meteorites have common age: ~4.6 Ga
- Oldest Moon rocks ~4.36 – 4.5 Ga

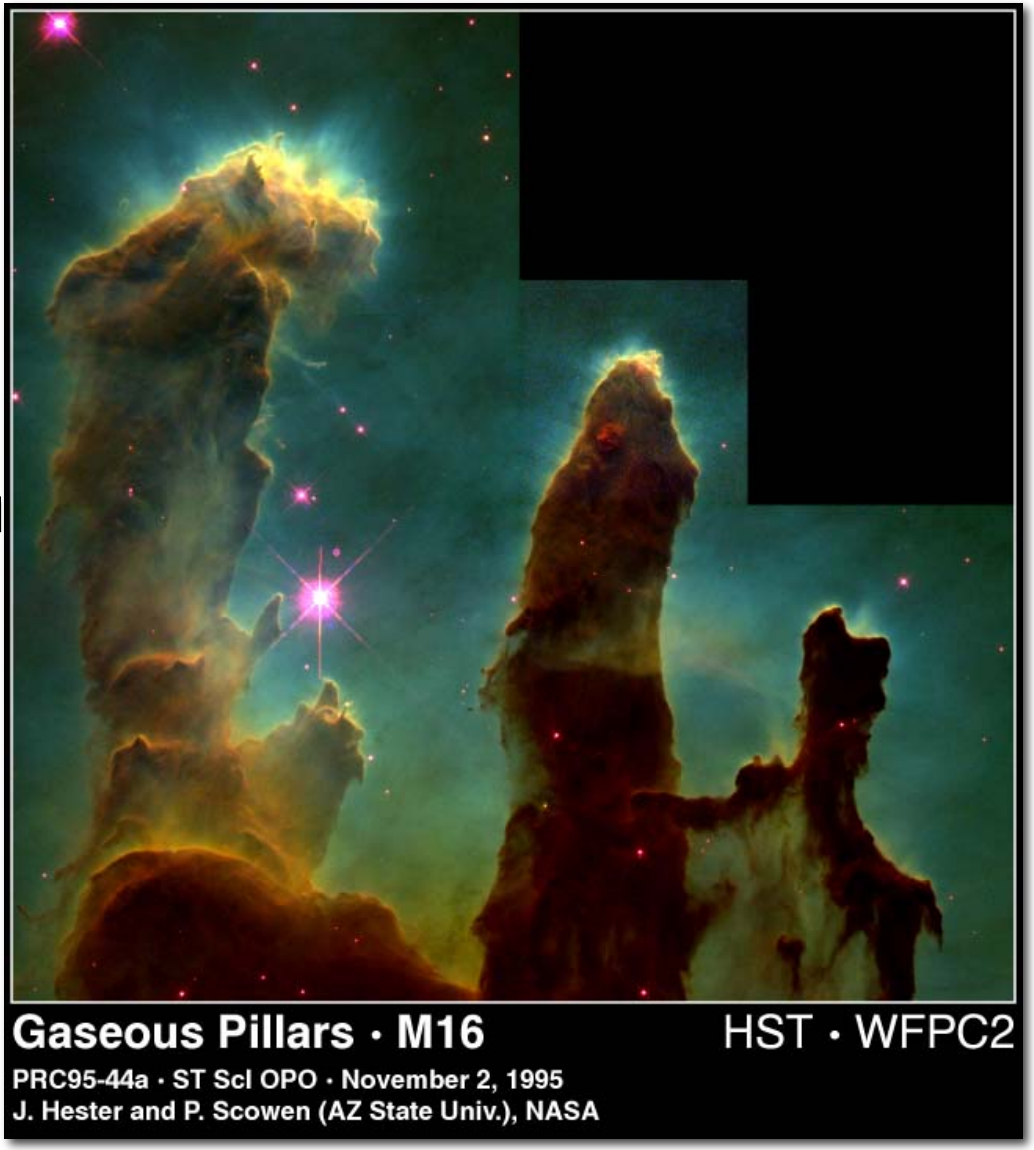
Solar System/Planet Formation

Gas Clouds to Stars/Planets

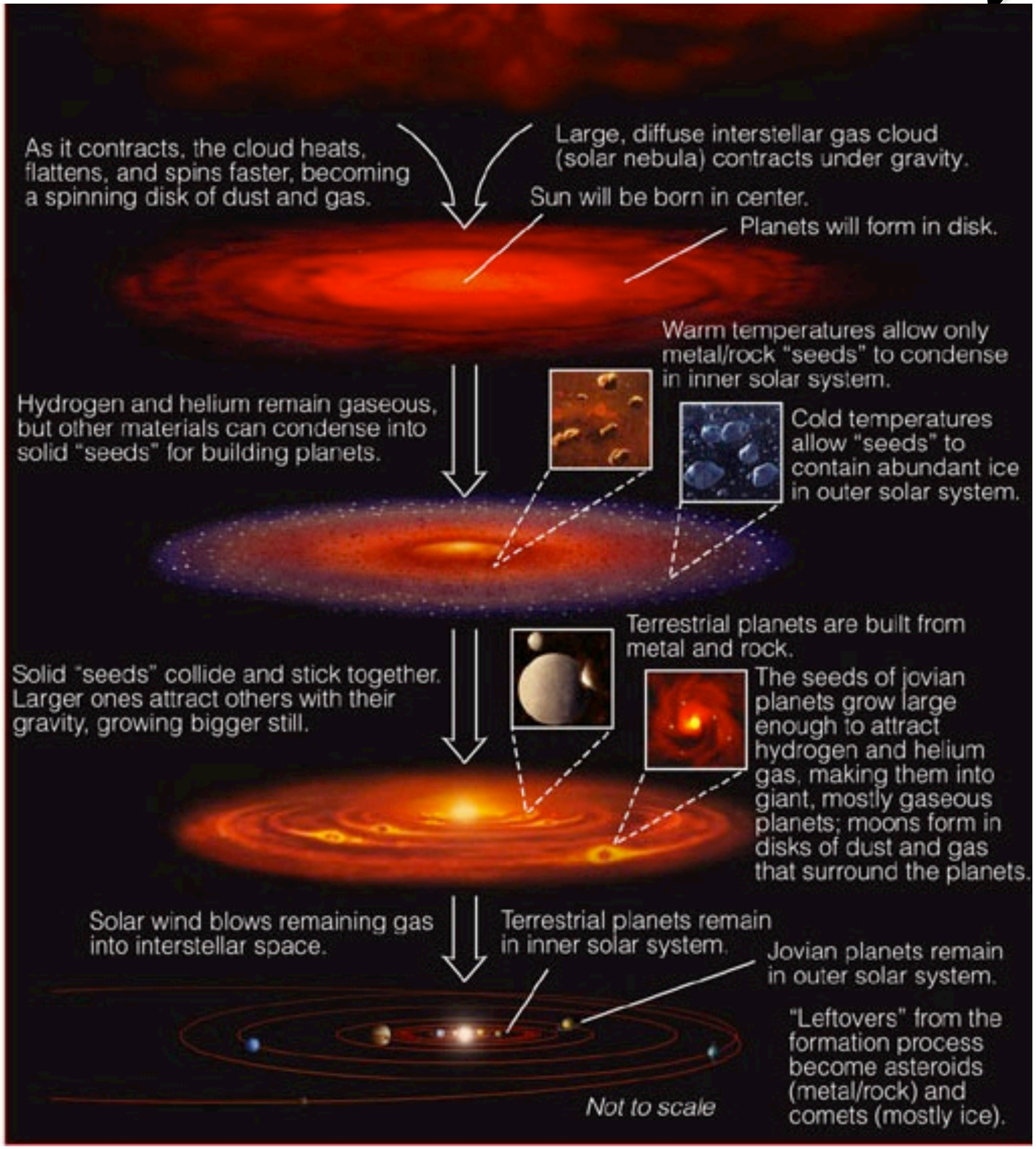
Planet Migration

Satellite Formation

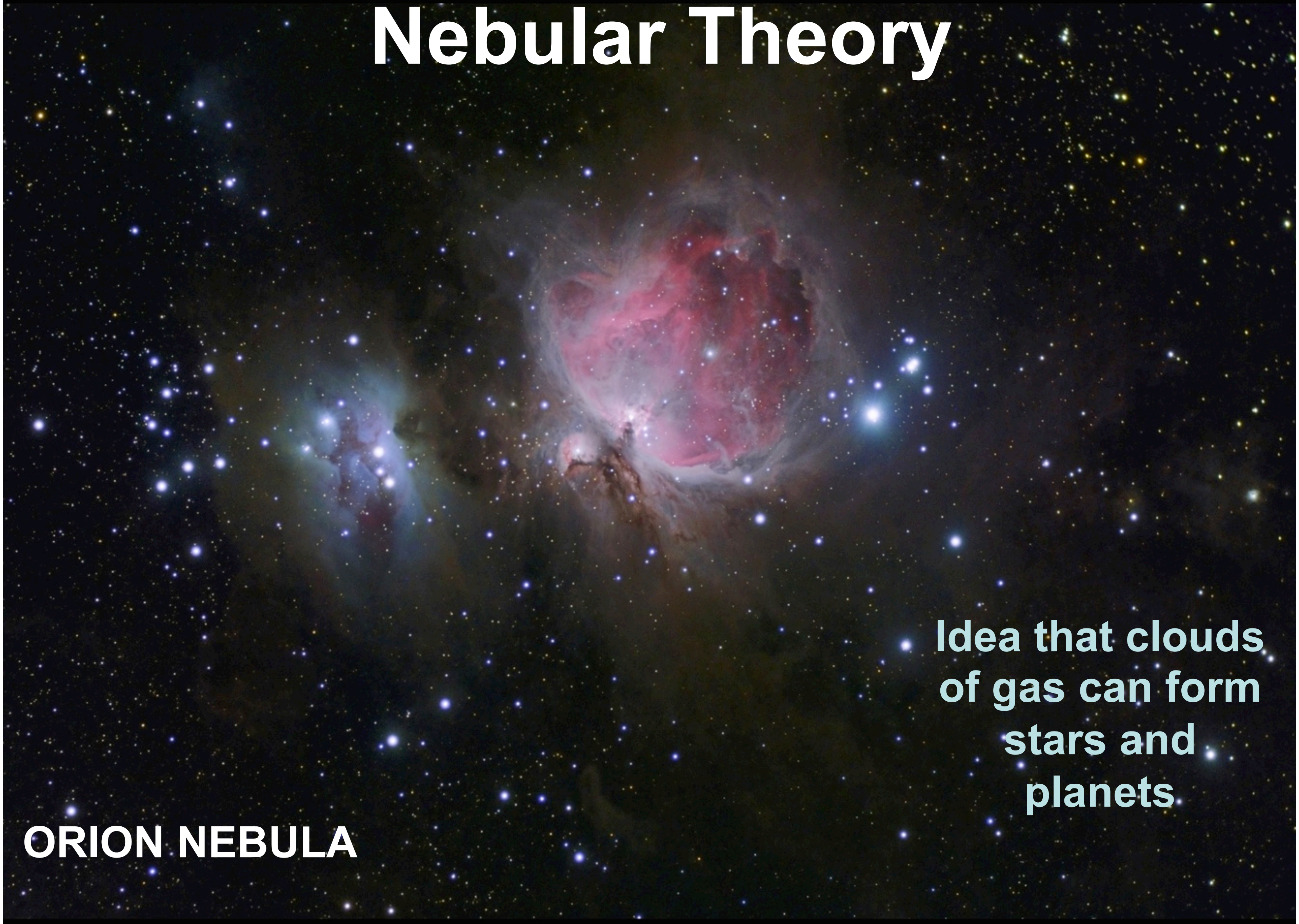




The Formation of the Solar System



Nebular Theory



Starting Conditions

<u>Giant Molecular Clouds</u>:

- COLD (10-30 K)
- LARGE (10^2s of light-years across, 10^6 M_{Sun})
- CHEMISTRY:

  98% H and He

  1.4% “ices”

  0.4% “rock”

  0.2% metal

*Cloud probably needs to be “nudged” to start forming stars

ORION NEBULA

Formation of the Solar System

STEPS: / **EVIDENCE:**

CLOUD COLLAPSE
- young stars seen in collapsing gas clouds

↓

ROTATING DISK
- planets orbit in same direction and same plane
- Sun and planets rotate in same direction
- disks seen around other stars

↓

CONDENSATION
- terrestrial planets and asteroids found near Sun
- jovian planets, icy moons, comets found farther away

↓

ACCRETION
- many meteorites are made of smaller bits
- heavy cratering on oldest planet surfaces
- asteroids, comets are "leftovers"

↓

GAS CAPTURE?
- Jupiter, Saturn are mostly hydrogen and helium

Formation of the Solar System

STEPS:

CLOUD COLLAPSE

↓

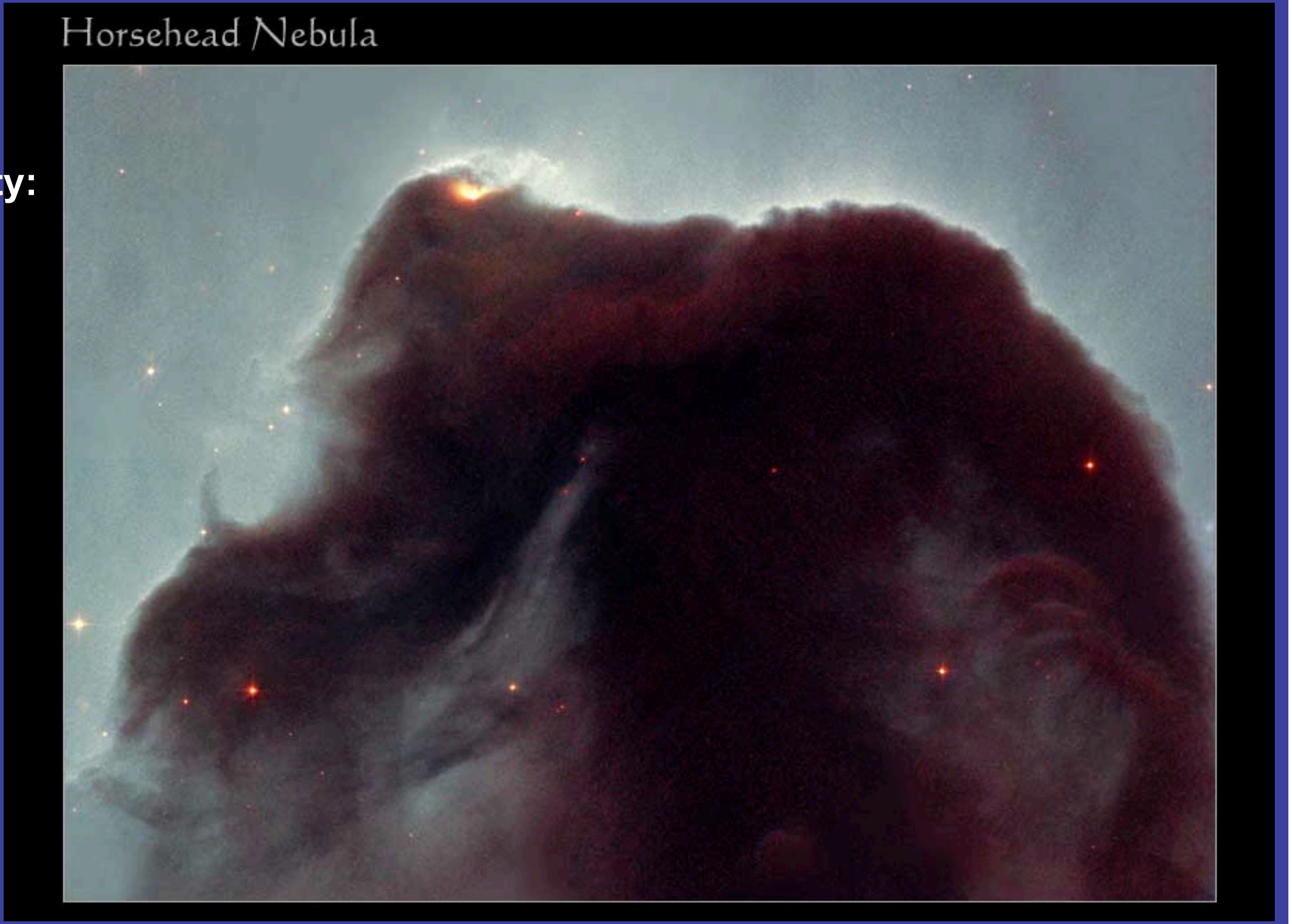
Considering only gravity:

$$t_{ff}^{1} = \sqrt{\frac{3\pi}{32 G \rho_{cl}}}$$

~10^5 years

EVIDENCE:

•young stars seen in collapsing gas clouds



Formation of the Solar System

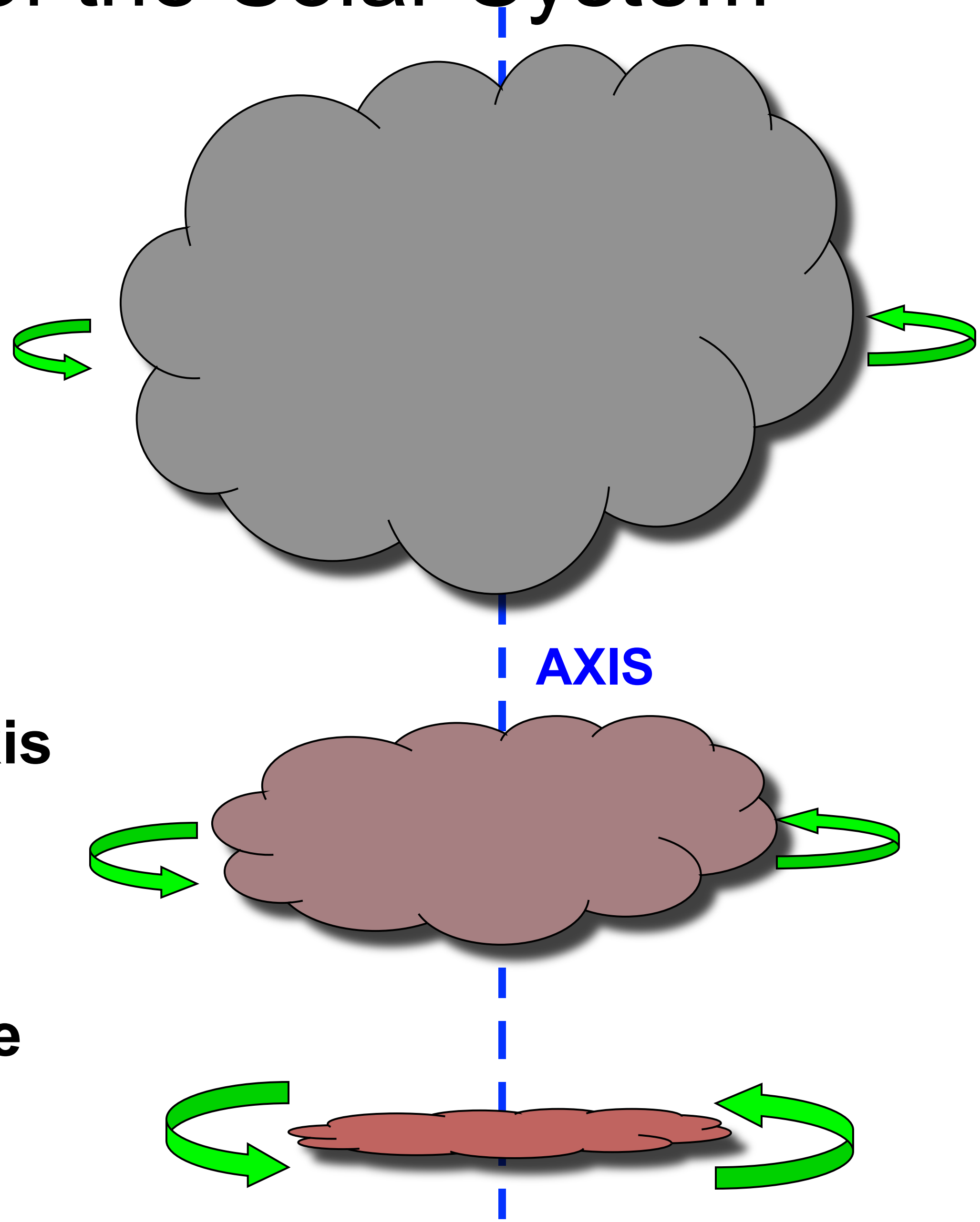
Cloud starts out with a tiny rotation…

<u>CONSERVATION OF ANGULAR MOMENTUM:</u>

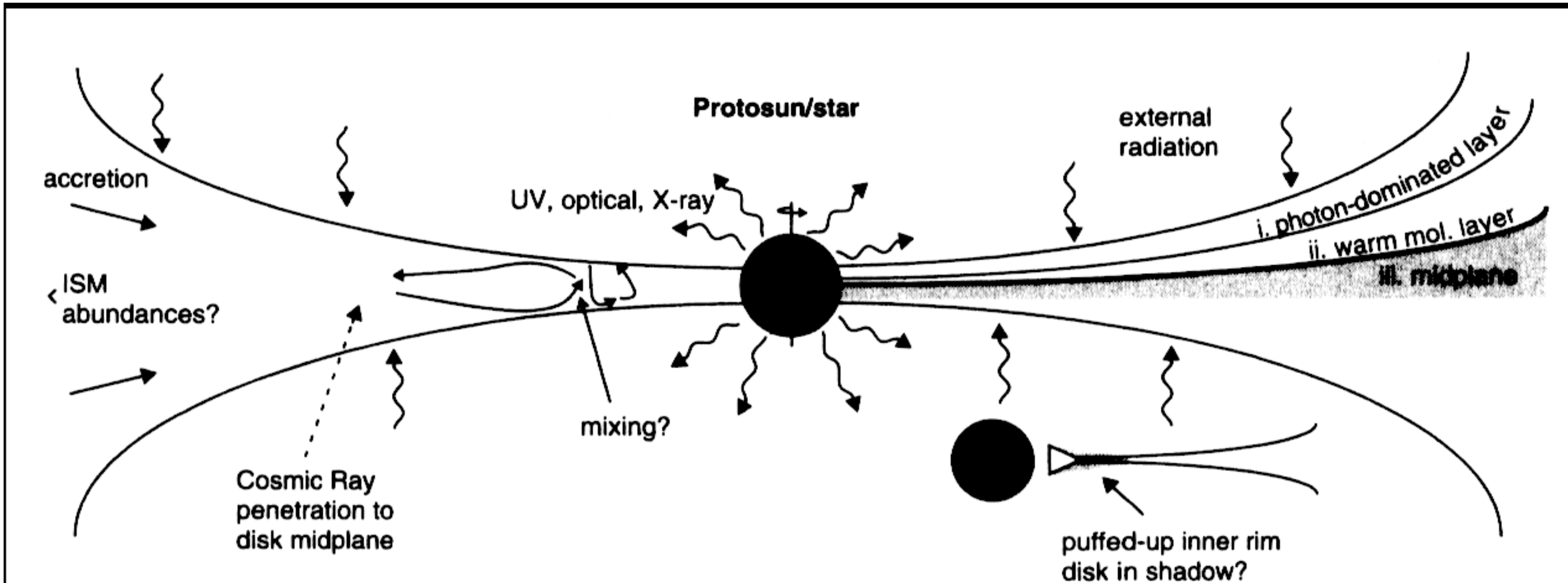
Gas falling <u>toward</u> axis starts rotating faster

Gas falling <u>parallel</u> to axis doesn't rotate faster

Fast rotation helps some gas orbit around center



Formation of the Solar System: Flared Disk



de Pater & Lissauer (2010)

$$\rho_{g_z} = \rho_{g_{z_0}} e^{-z^2/H_z^2}, \quad (13.10a)$$

$$P_z = P_{z_0} e^{-z^2/H_z^2}, \quad (13.10b)$$

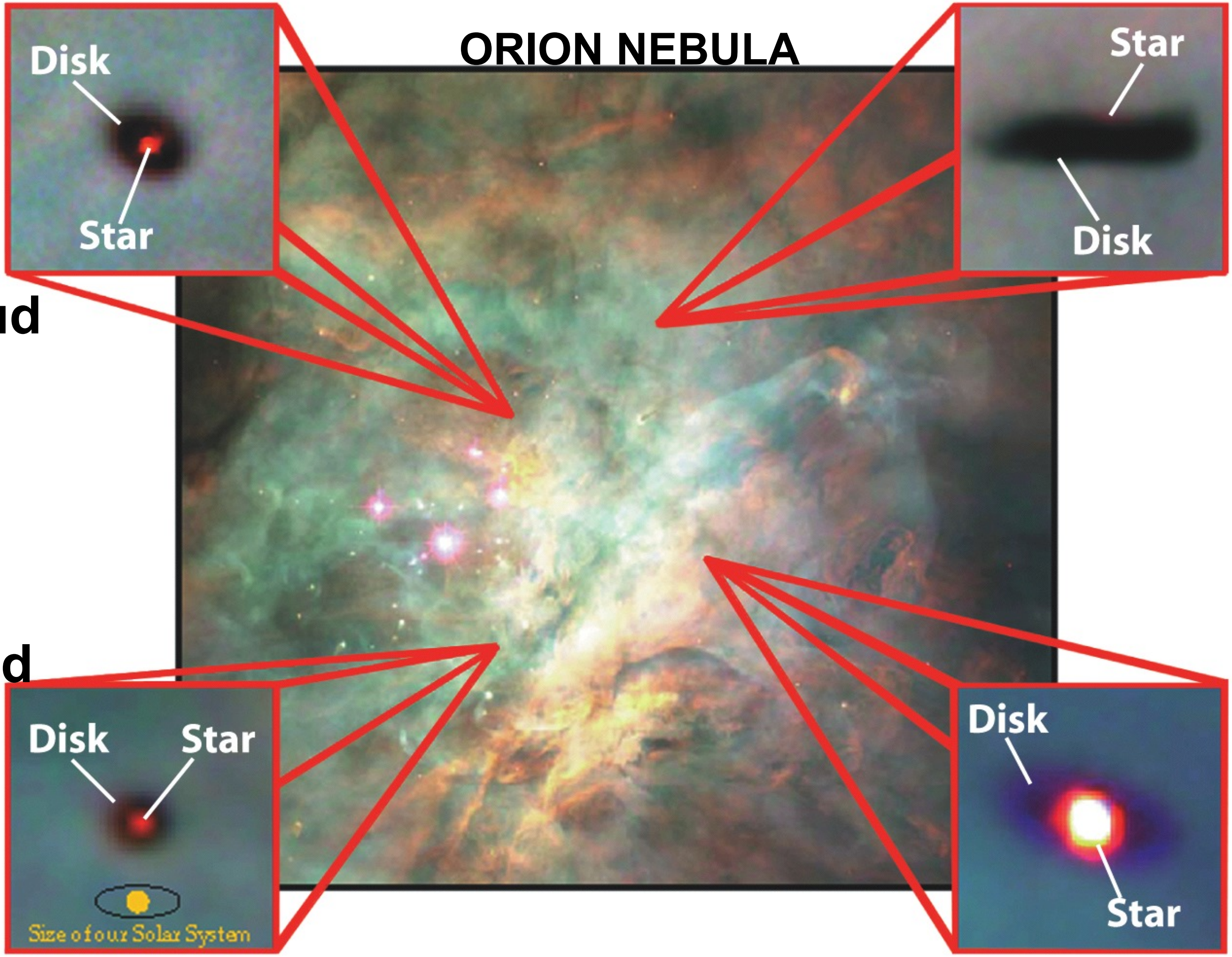
where the Gaussian scale height, H_z, is given by:

$$H_z = \sqrt{\frac{2kTr_\odot^3}{\mu_a m_{amu} G M_\odot}}. \quad (13.11)$$

The Rotating Disk

Part of cloud becomes flattened disk

Examples seen around other stars



Bipolar Outflows: An HST Film

Formation of the Solar System

STEPS:

CLOUD COLLAPSE

↓

ROTATING DISK

EVIDENCE:

- **young stars seen in collapsing gas clouds**
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- **Sun and planets rotate in same direction**
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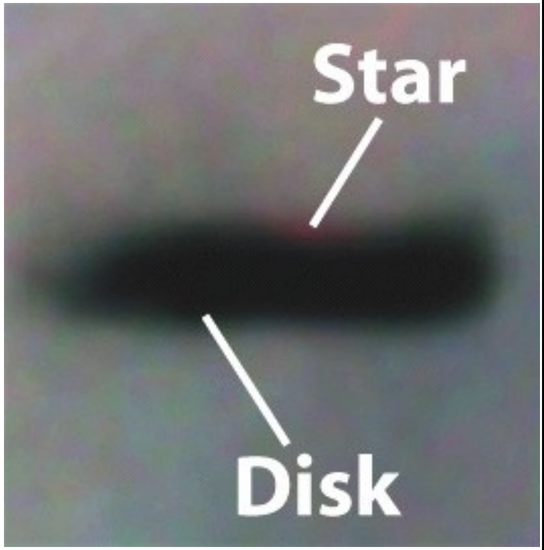
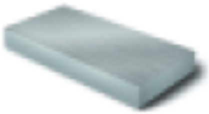
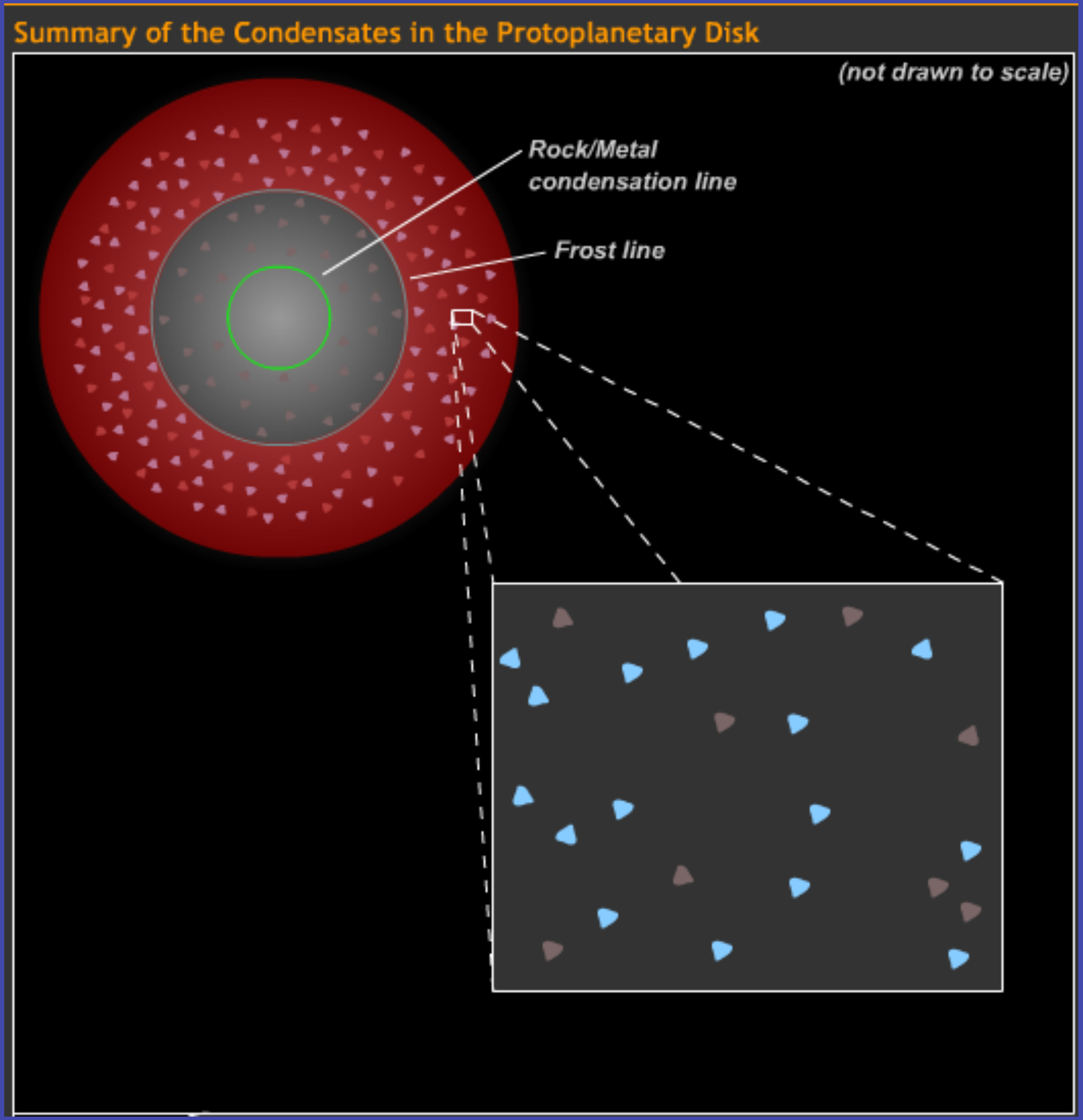


Raw Materials for Planets

The most abundant raw materials:

1. **H, He gases**
2. **“ices” (hydrogen compounds)**
3. **rock and metal**

	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	500–1,300 K	0.4%
Metals 	iron, nickel, aluminum	1,000–1,600 K	0.2%



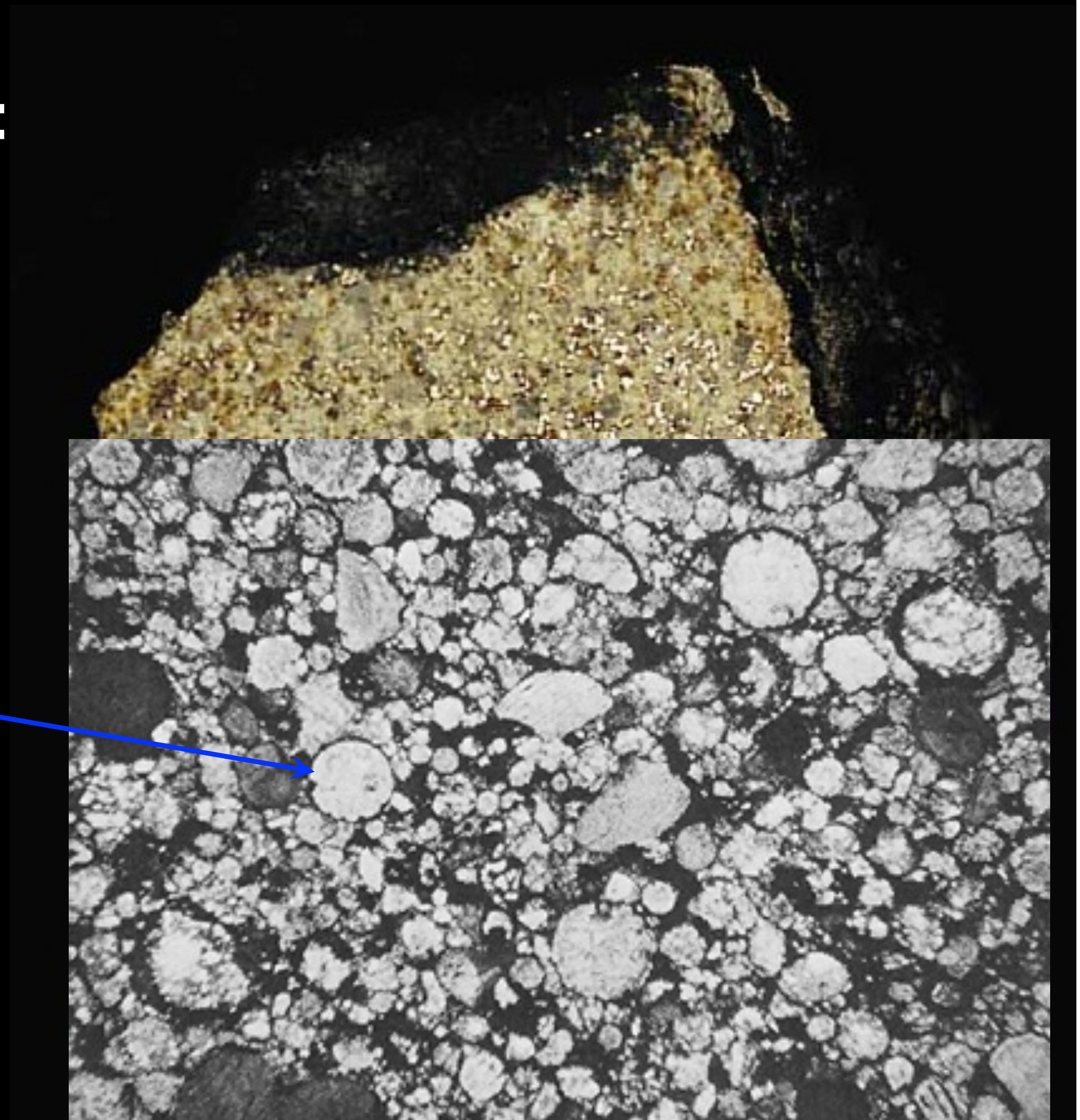
- Tiny ‘dirt’ particles formed from condensed rock/metal

- Tiny <u>ice crystals</u> condensed from hydrogen compounds like water… but ONLY far from Sun due to thermal gradient

Examples of Condensation

<u>Inner solar system</u>:

↔ rocky, metallic dust condensed together into small objects



meteorite cut-away:

Formation of the Solar System

STEPS:

CLOUD COLLAPSE

ROTATING DISK

CONDENSATION

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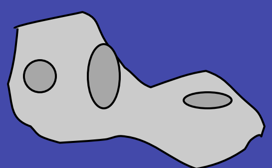
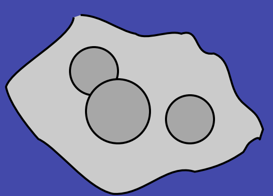
Accretion

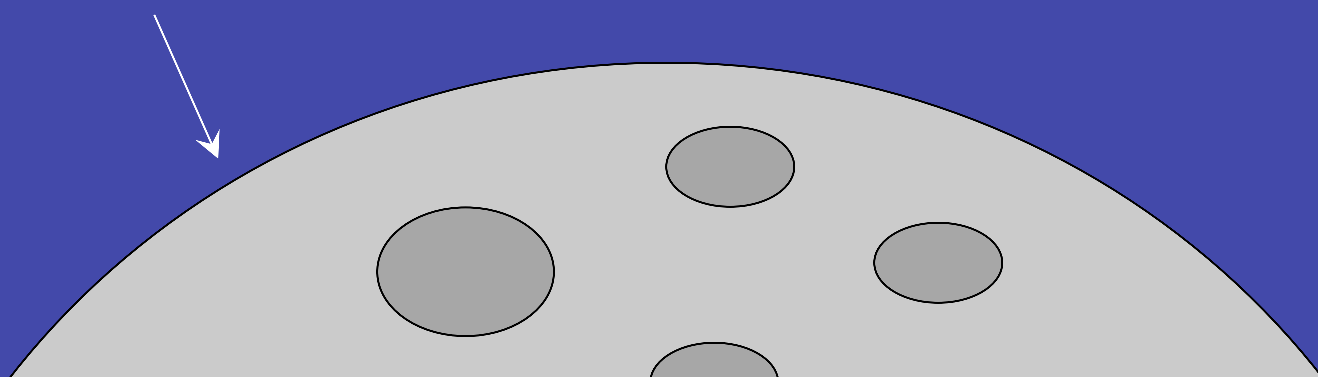
"Sticky" collisions of dust and snowflakes make bigger particles:

<u>Planetesimals</u> (like asteroids and comets: several km across) slowly form, until gravity is strong enough to help pull them together:

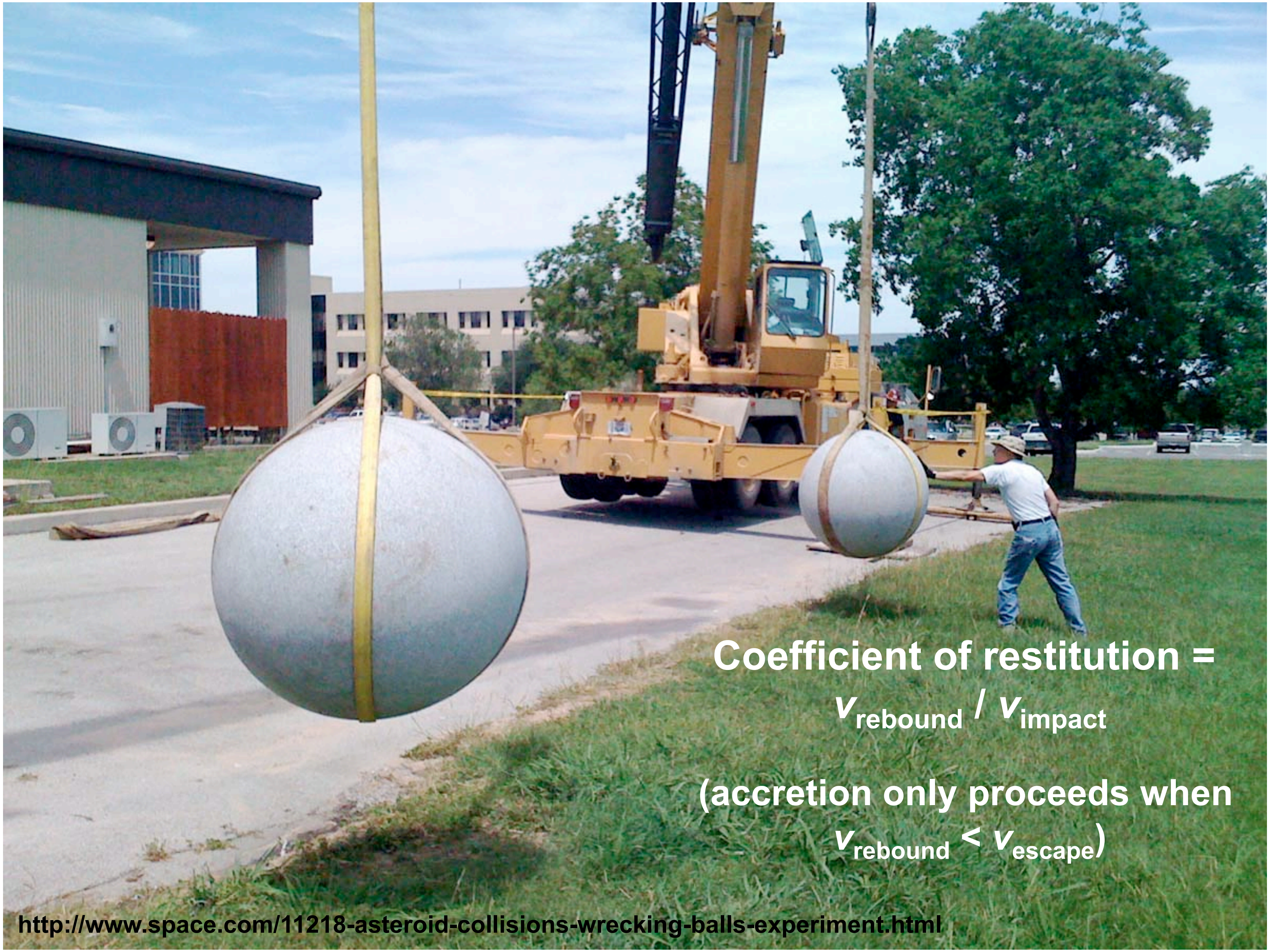




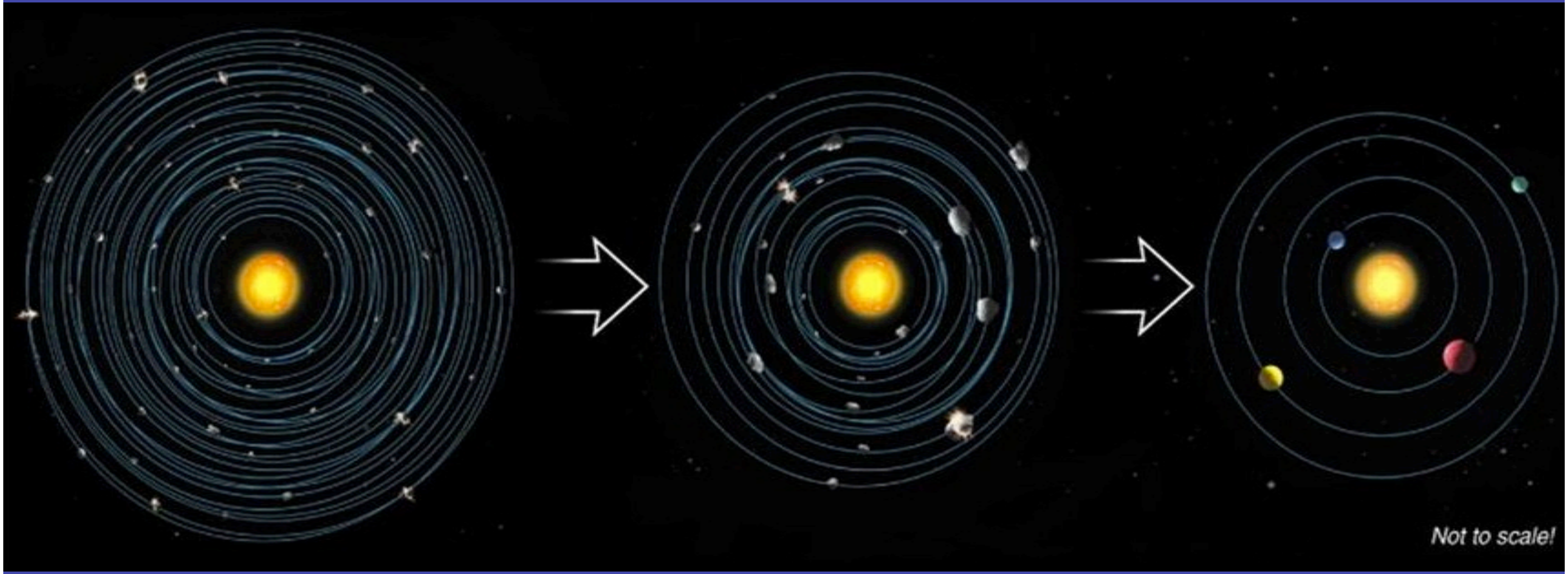
Larger <u>protoplanets</u> slowly form from these collisions:



Elastic or inelastic collisions?



Accretion



- many small objects collected into just a few large ones
- collisions become less frequent as more material becomes ‘stuck’ together

Formation of the Solar System

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