

Planetary Interiors

Earth's Interior Structure

Hydrostatic Equilibrium

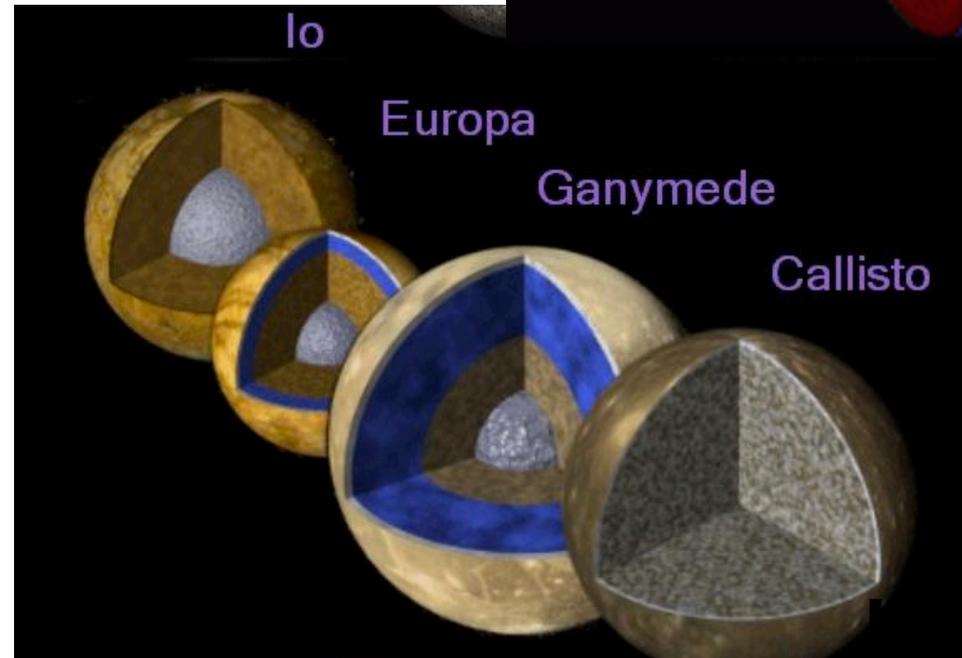
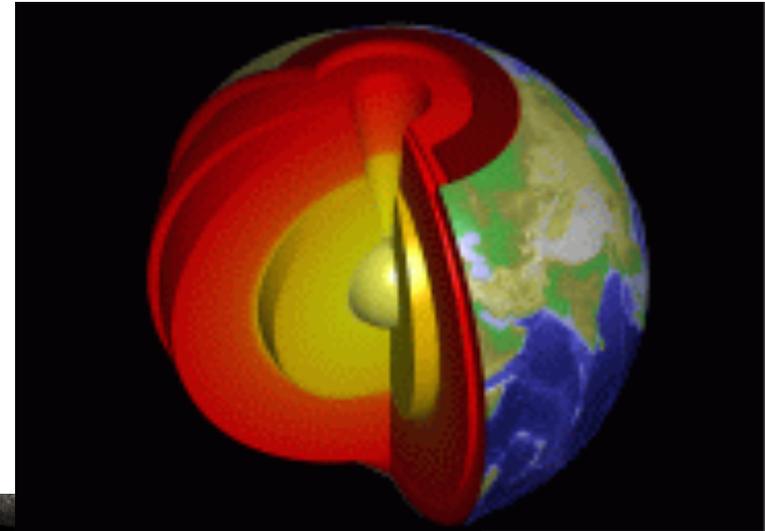
Heating

Constituent Relations

Gravitational Fields

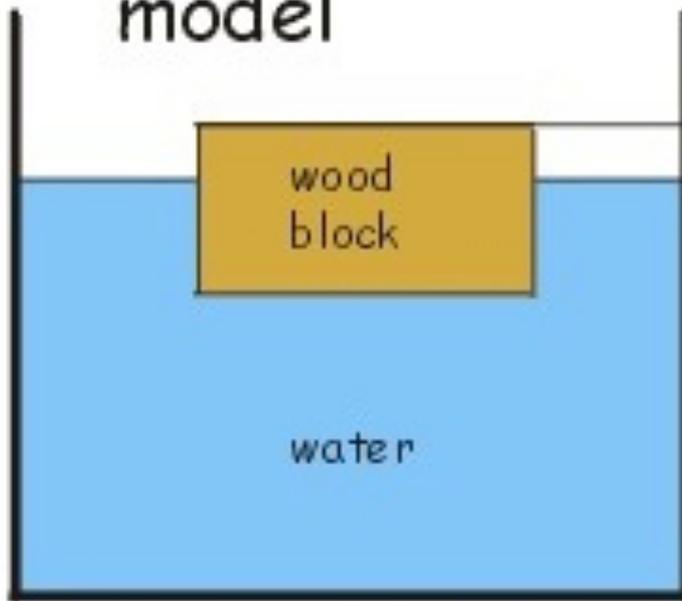
Isostasy

Magnetism



Isostasy

Archimedes'
model



HEIGHT of wood block
above water level
DEPENDS UPON
relative DENSITY of
the wood (compared
with water) and
THICKNESS of
the wood block

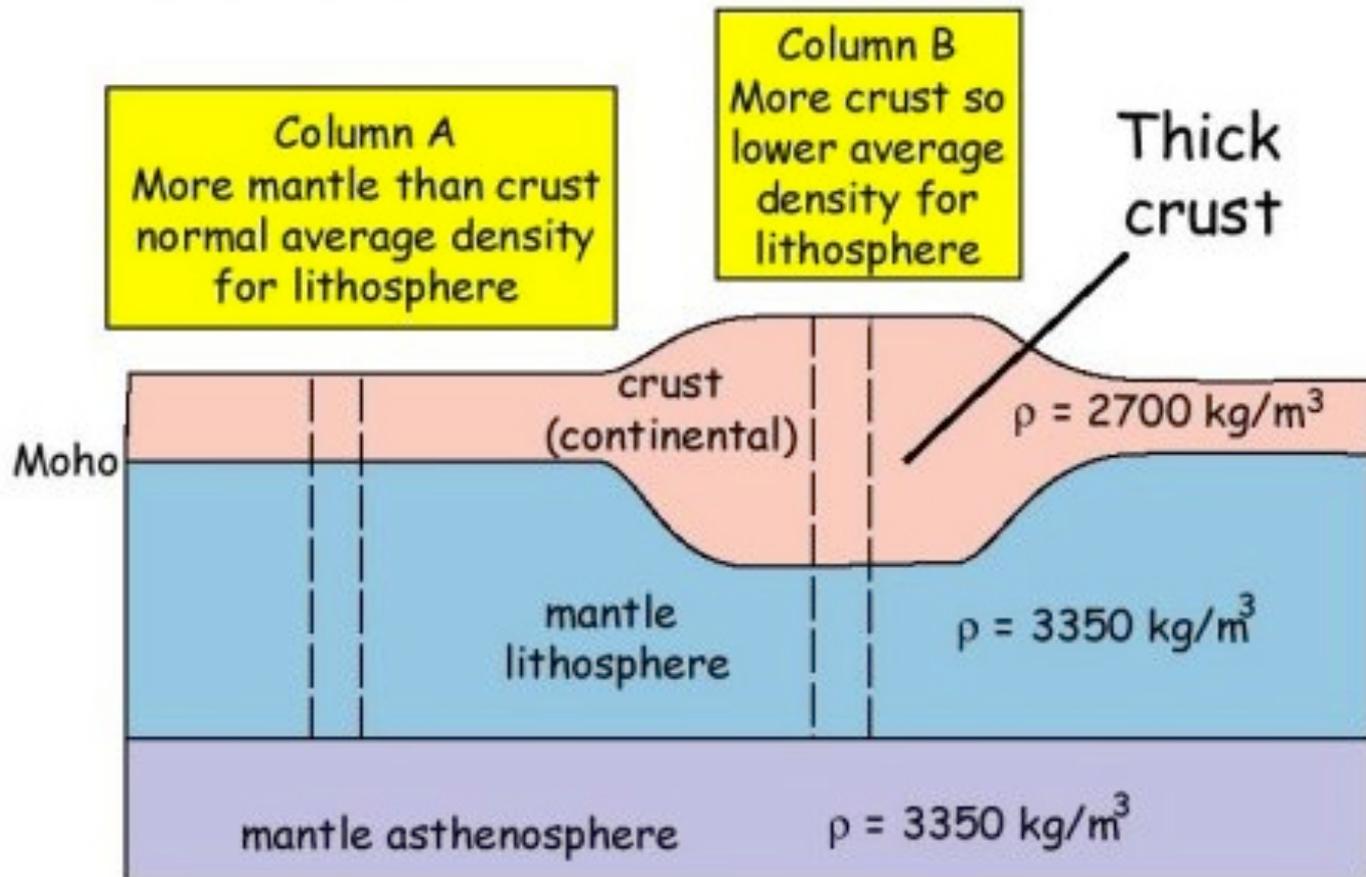
Thicker wood or lower density and the top of the block rides higher

Courtesy of U of Leeds

Now apply this idea to topography and the crust...

Airy Model

topography underlain by thick root

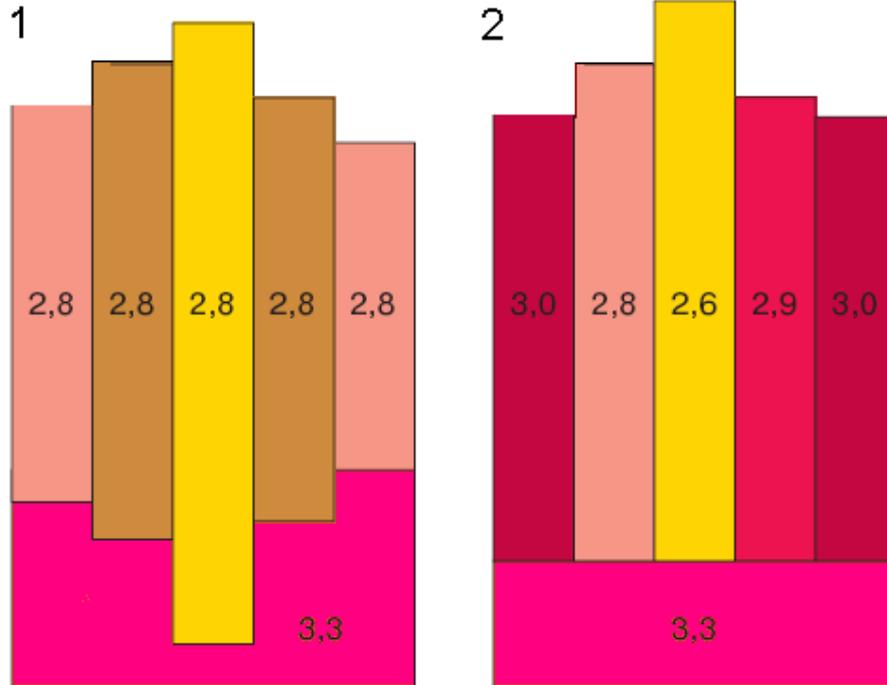


High topography (relative to surroundings) due to THICK CRUST
Example - Himalayas/Tibet

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)

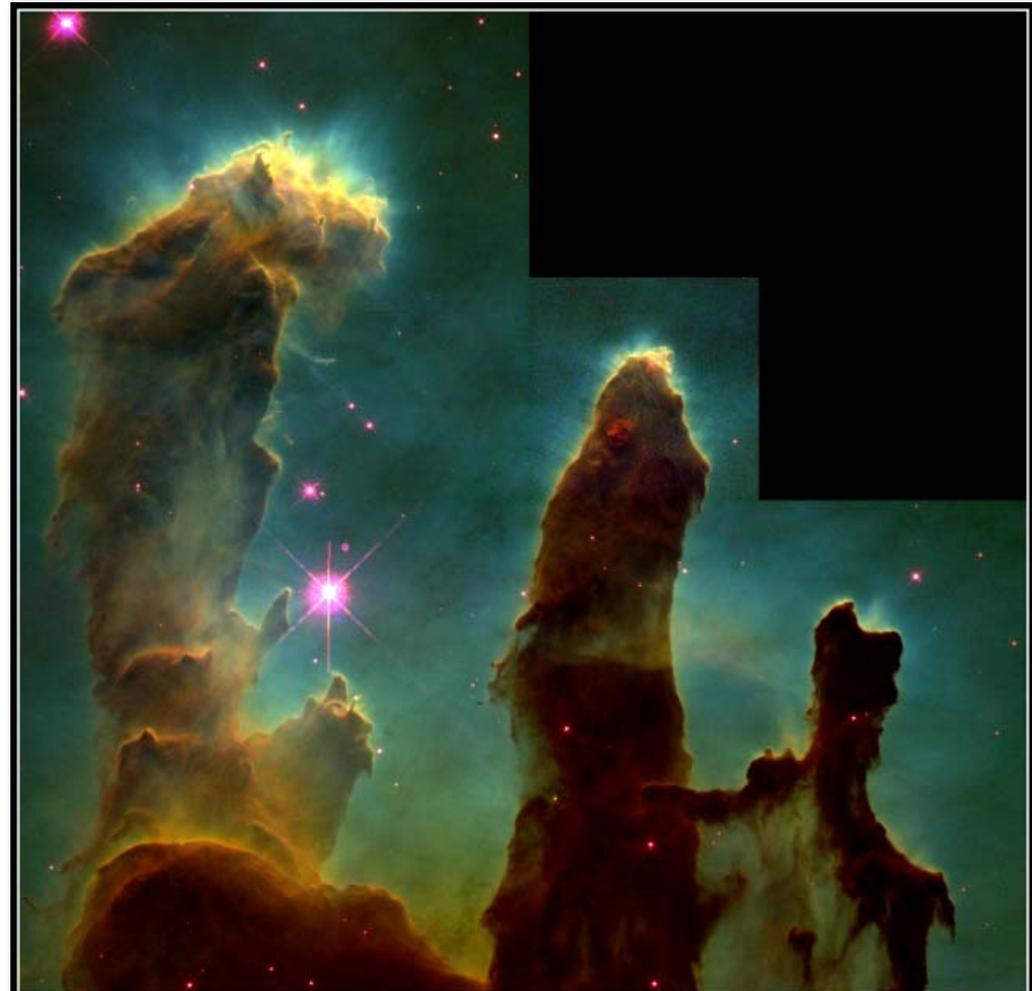
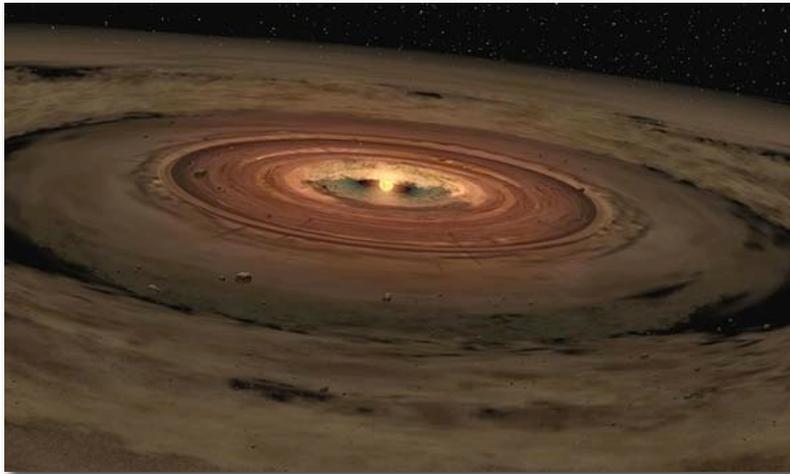
2. Pratt Scheme:
Lateral density variation
causes topography

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...*



Gaseous Pillars · M16

HST · WFPC2

PRC95-44a · ST Sci OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

Solar System Formation: Constraints

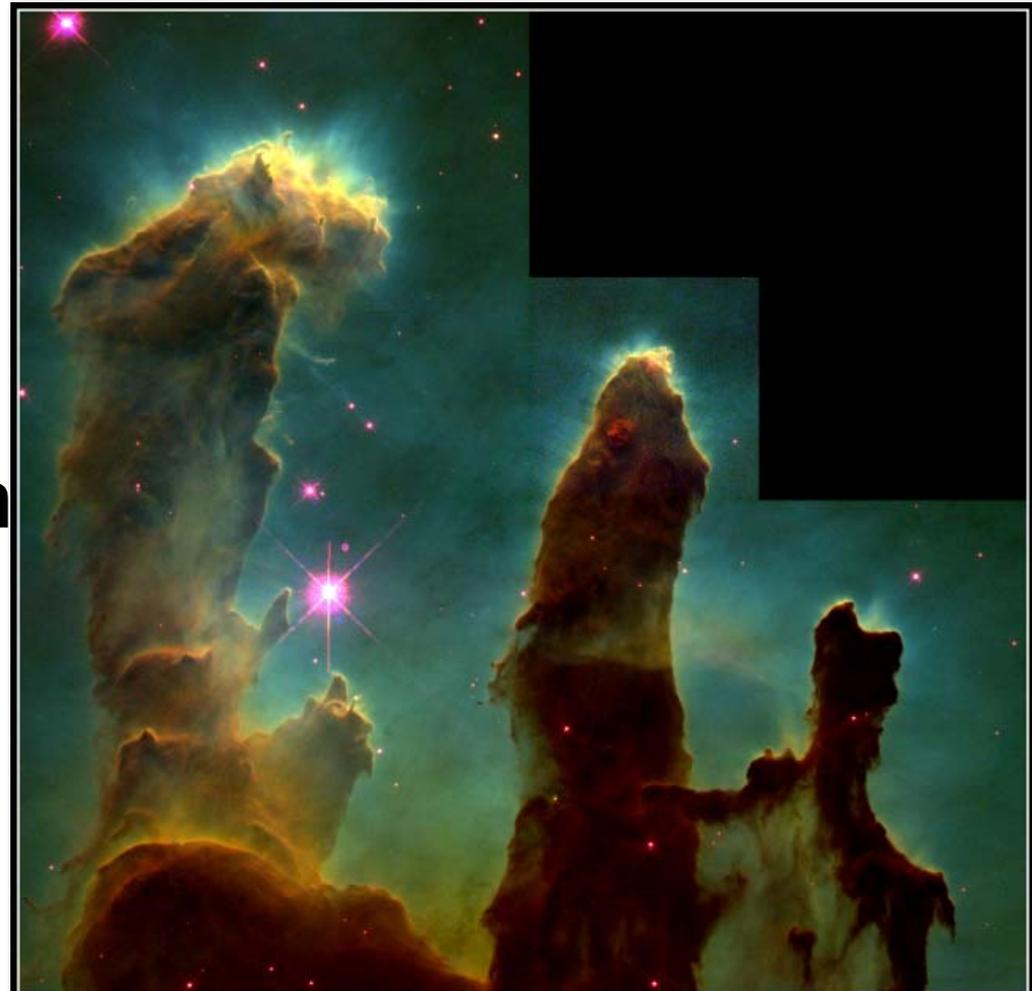
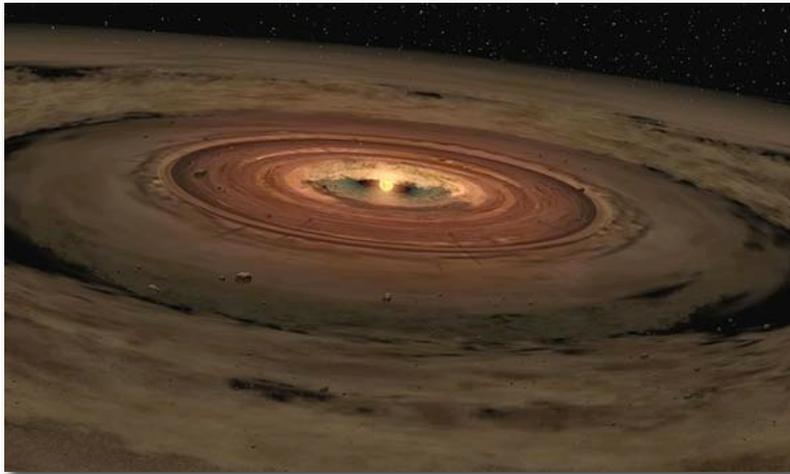
- Sun has 99.8% of mass, <2% of angular momentum
- Low inclination & eccentricity of planet orbits
- Most planets have low obliquity
- Large outer planets have ~solar composition
- Small inner planets enriched in heavy elements
- Impact craters on virtually every planetary body
- “Debris” in asteroid 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

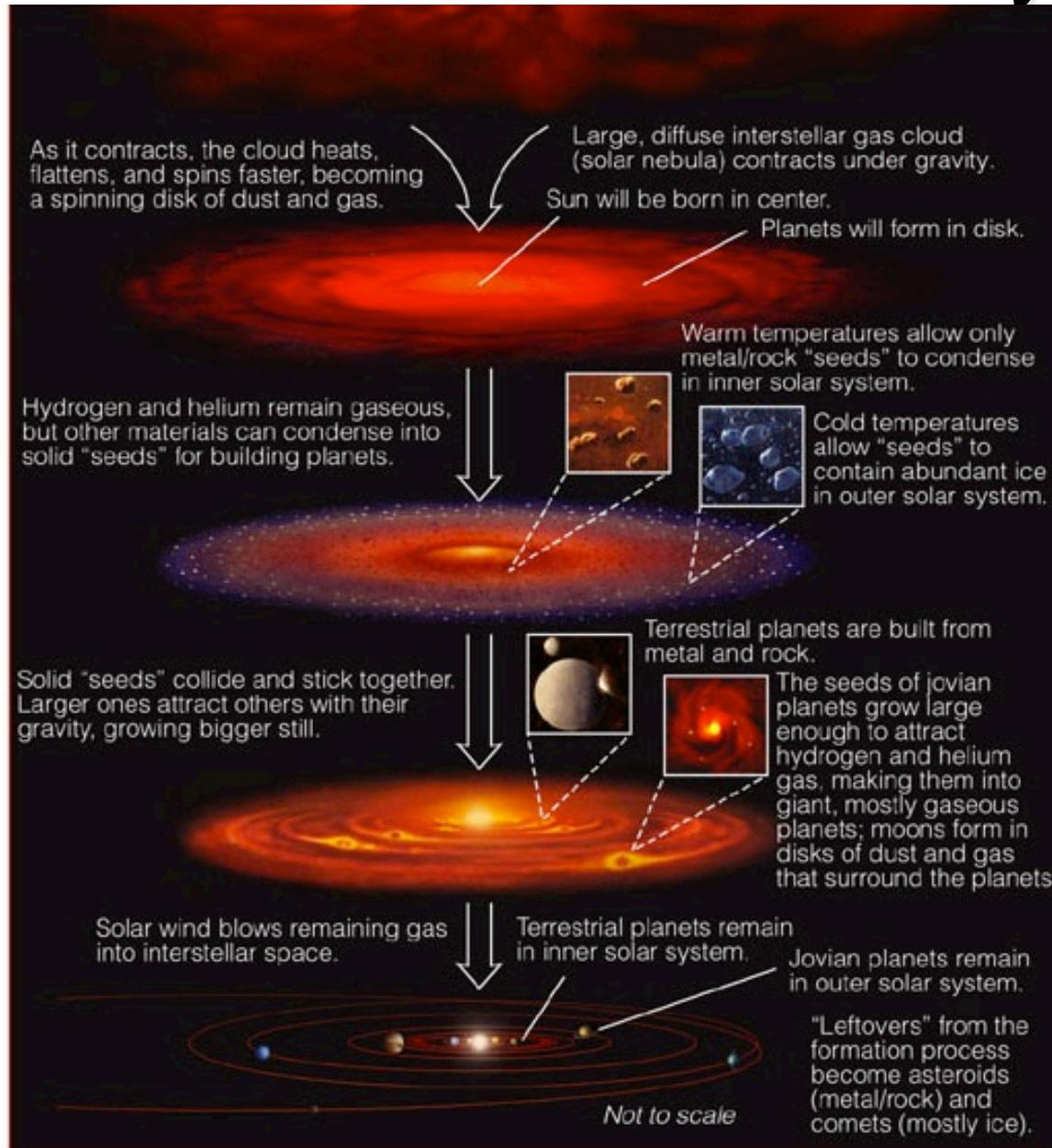


Gaseous Pillars · M16

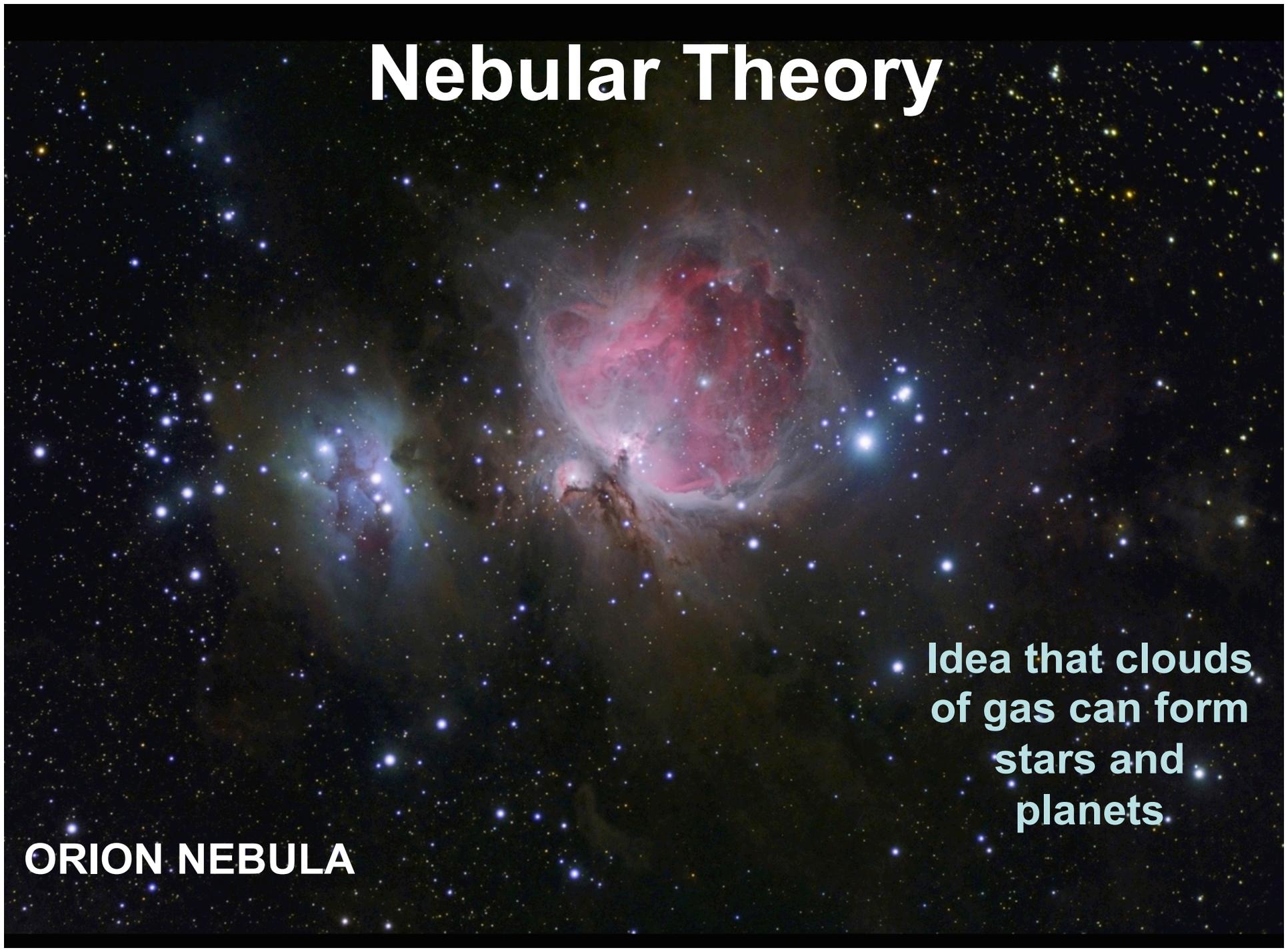
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The Formation of the Solar System



Nebular Theory

A photograph of the Orion Nebula, a large, colorful nebula in the constellation Orion. The nebula is composed of glowing clouds of gas and dust, with a prominent red and pink central region. The background is filled with numerous stars of various colors, including blue, white, and yellow.

Idea that clouds
of gas can form
stars and
planets

ORION NEBULA

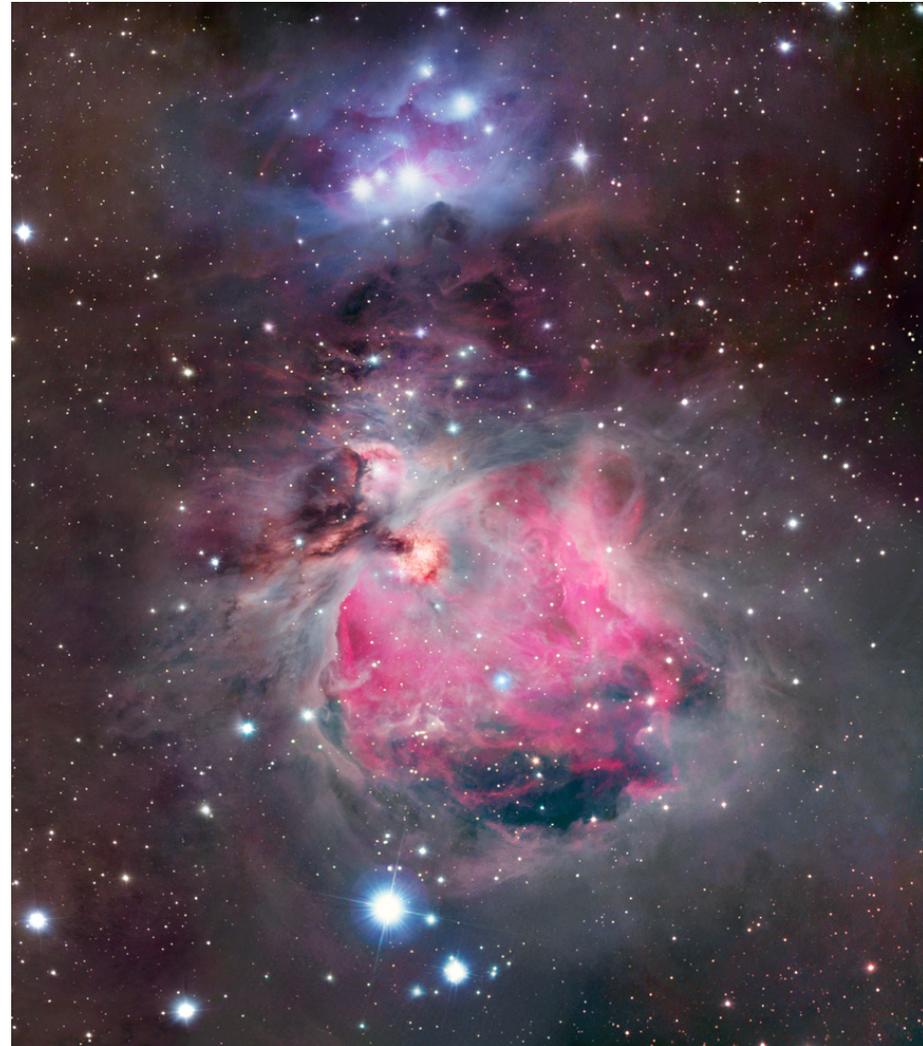
Starting Conditions

Giant Molecular Clouds:

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

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

$\sim 10^5$ years

EVIDENCE:

- young stars seen in collapsing gas clouds

Horsehead Nebula



Formation of the Solar System

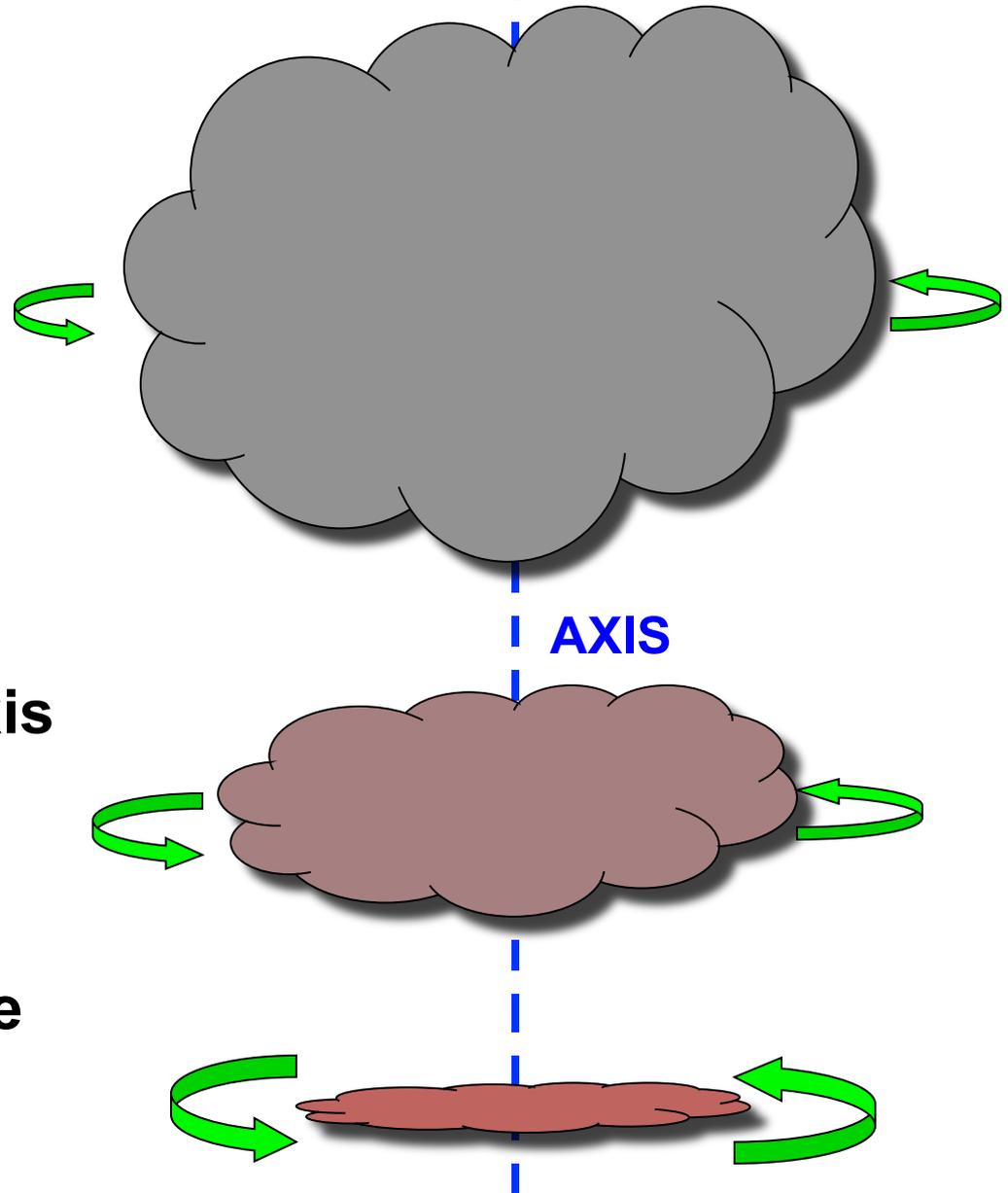
Cloud starts out with a tiny rotation...

CONSERVATION OF ANGULAR MOMENTUM:

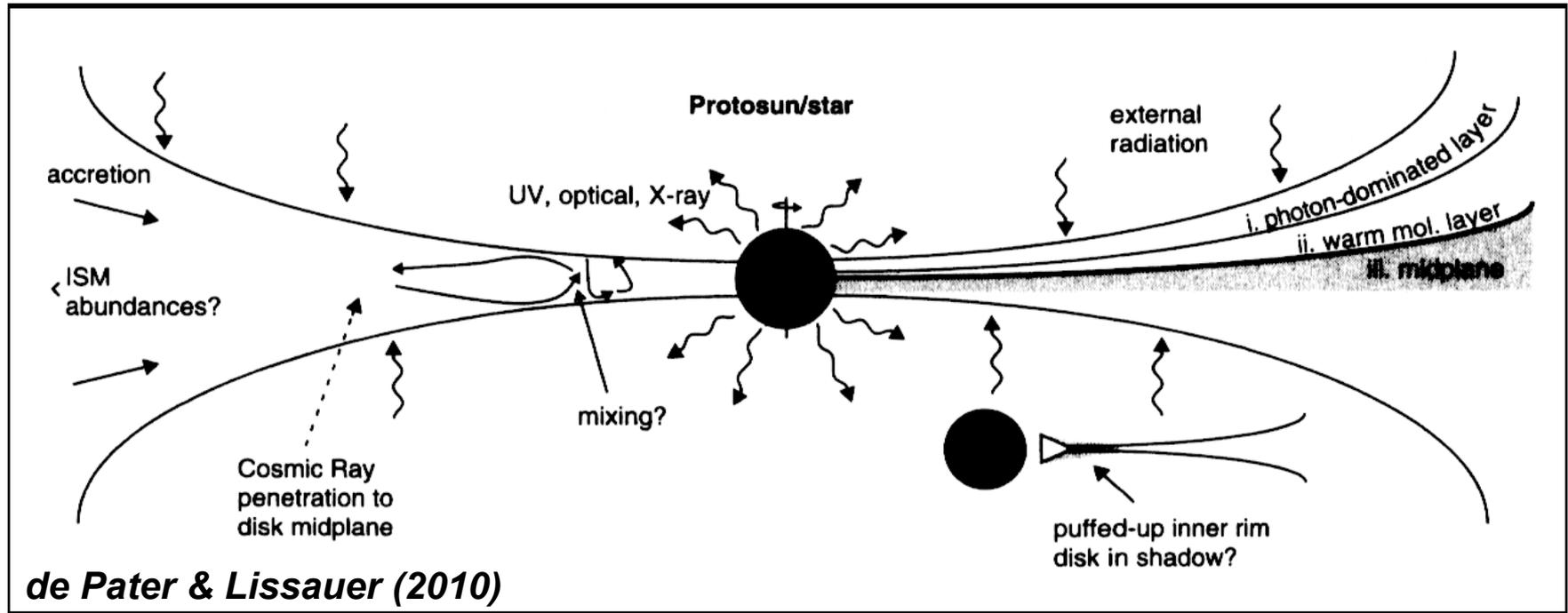
Gas falling toward axis starts rotating faster

Gas falling parallel to axis doesn't rotate faster

Fast rotation helps some gas orbit around center



Formation of the Solar System: Flared Disk



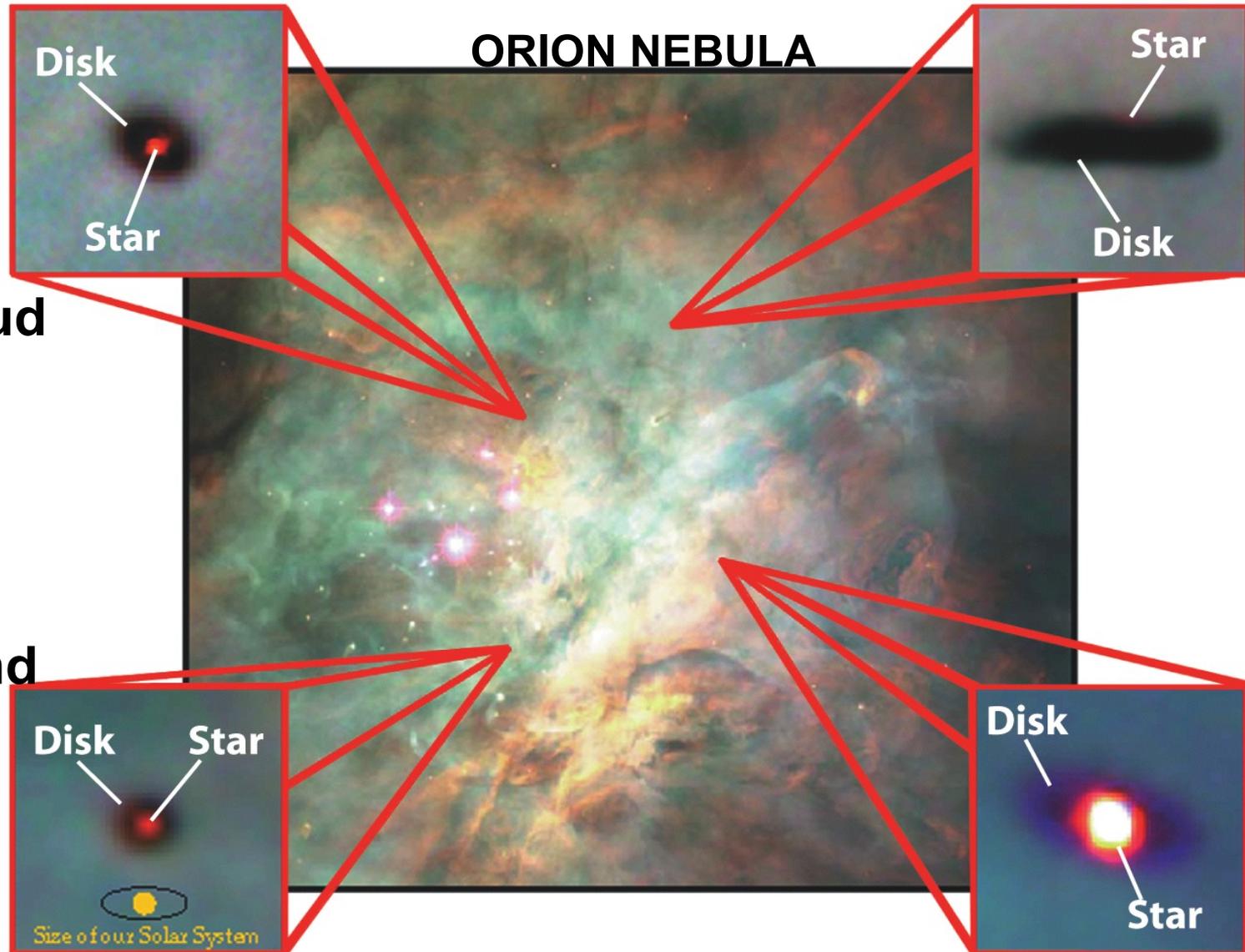
$$\rho_{gz} = \rho_{gz_0} e^{-z^2/H_z^2}, \quad (13.10a)$$

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

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

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

The Rotating Disk



Part of cloud
becomes
flattened
disk

Examples
seen around
other stars

Bipolar Outflows: An HST Film



HH47

1994

Formation of the Solar System

STEPS:

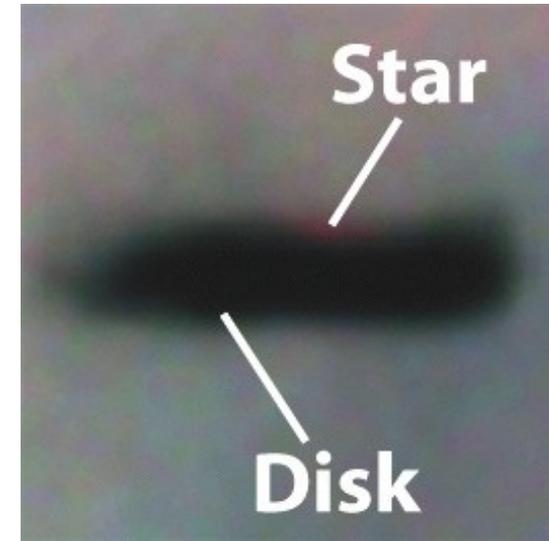
CLOUD
COLLAPSE



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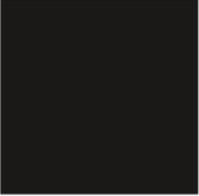


Raw Materials for Planets



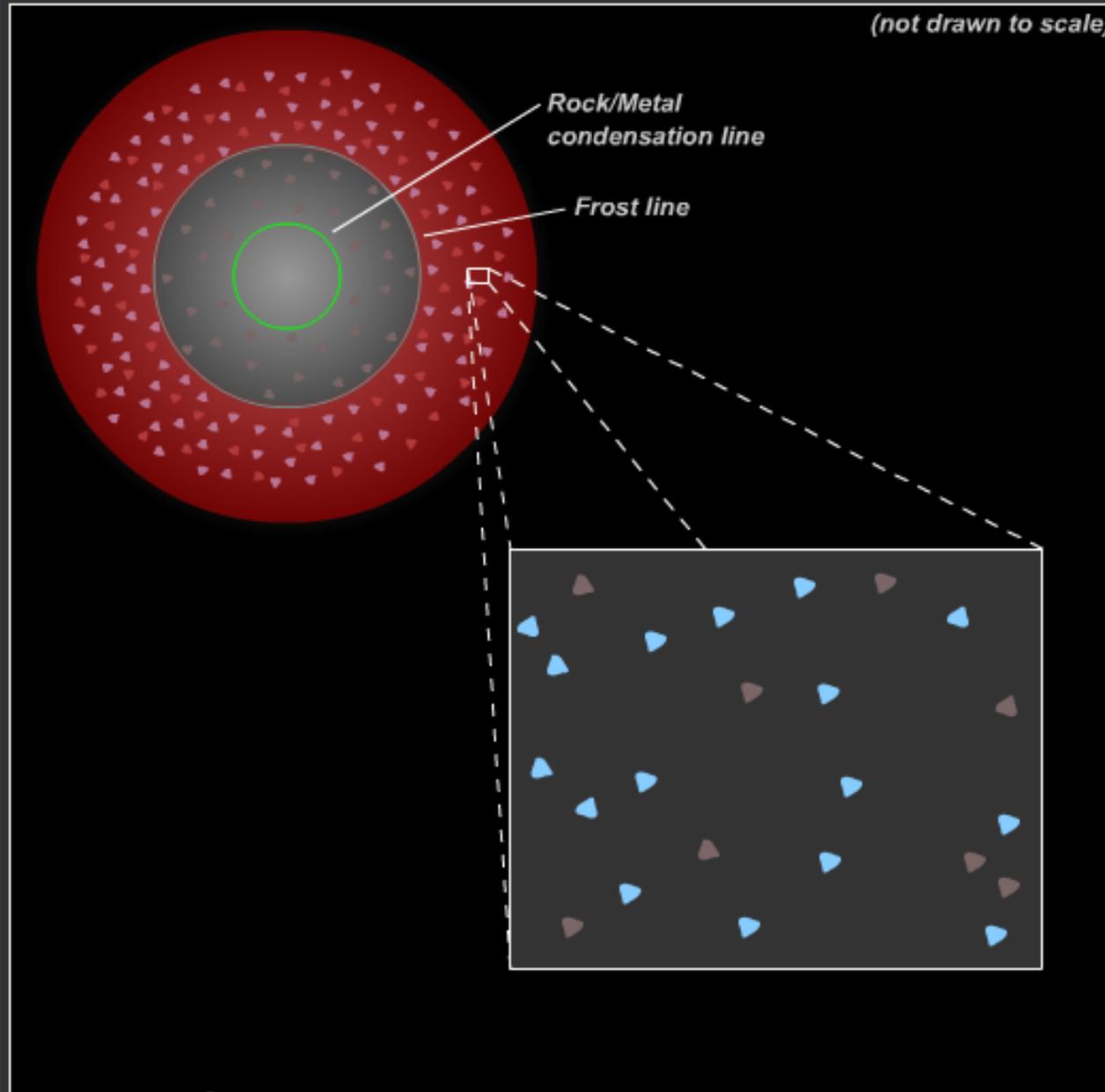
The most abundant raw materials:

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

| | <i>Examples</i> | <i>Typical Condensation Temperature</i> | <i>Relative Abundance (by mass)</i> |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Hydrogen and Helium Gas | hydrogen, helium  | do not condense in nebula |  98% |
| Hydrogen Compounds | water (H ₂ O) 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% |

Summary of the Condensates in the Protoplanetary Disk

(not drawn to scale)

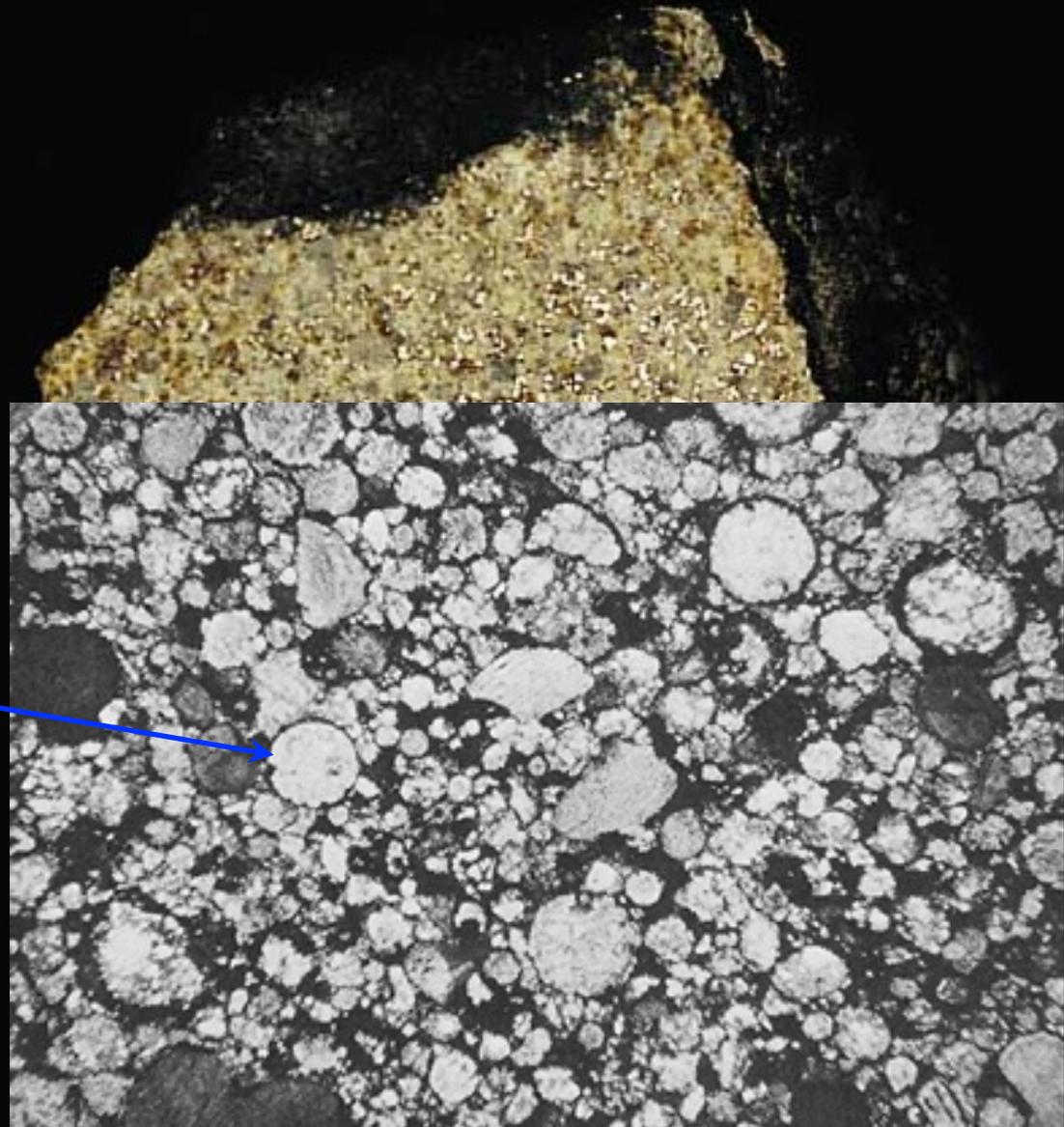


- Tiny 'dirt' particles formed from condensed rock/metal
- Tiny ice crystals condensed from hydrogen compounds like water... but **ONLY** far from Sun due to thermal gradient

Examples of Condensation

Inner solar system:

↔ 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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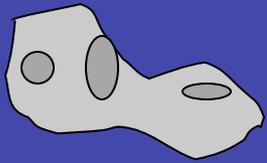
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Accretion

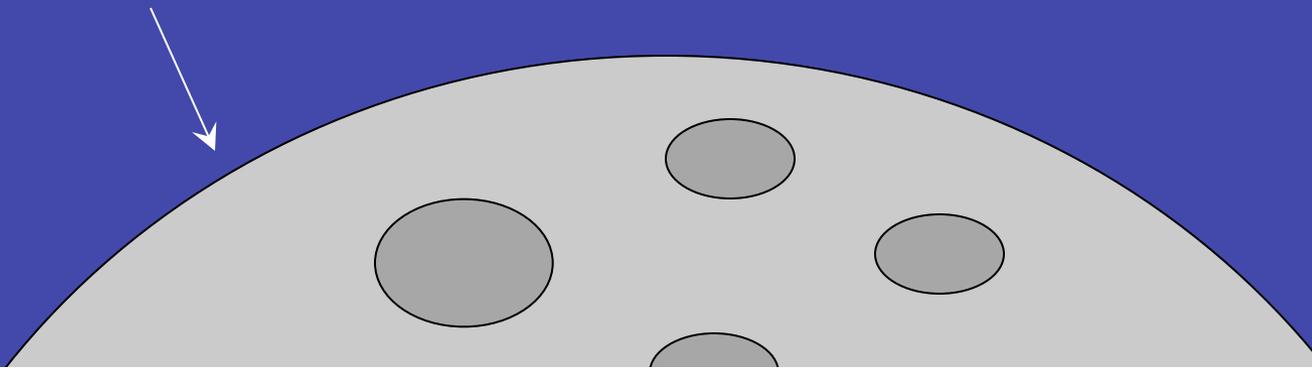
“Sticky” collisions of dust and snowflakes make bigger particles:



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



Larger protoplanets slowly form from these collisions:



Elastic or inelastic collisions?



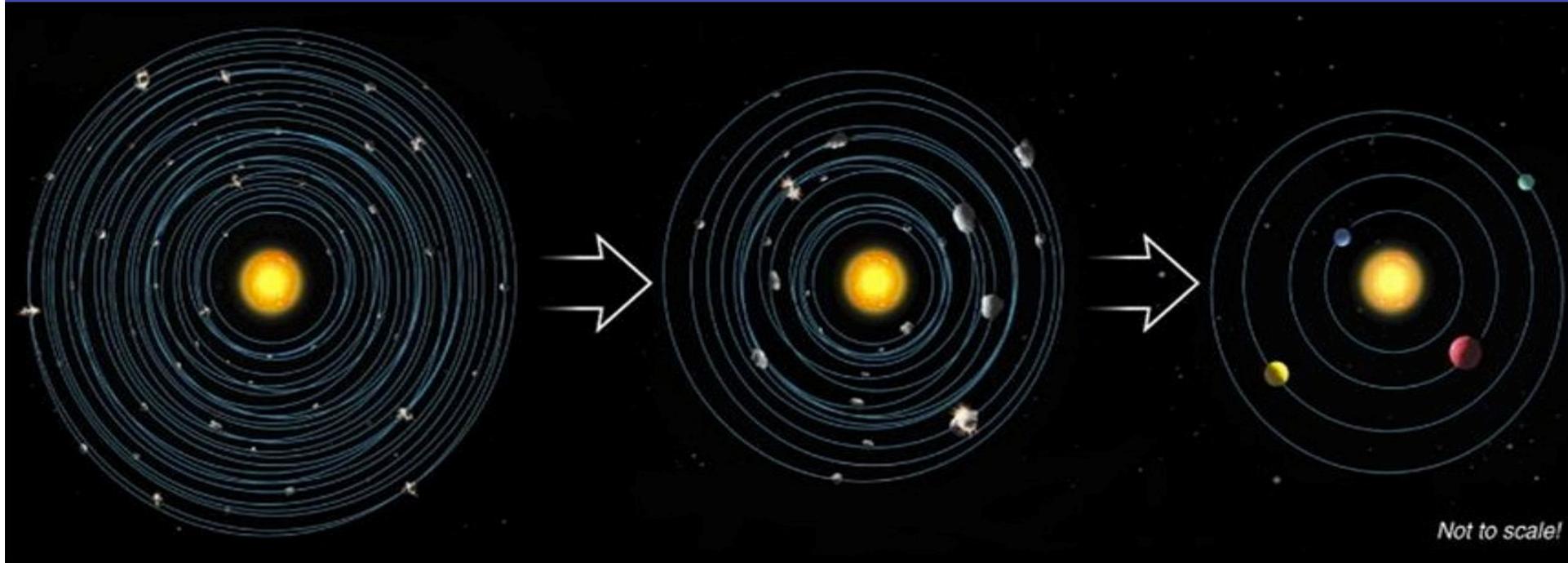
Coefficient of restitution =

$$v_{\text{rebound}} / v_{\text{impact}}$$

(accretion only proceeds when

$$v_{\text{rebound}} < v_{\text{escape}})$$

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

STEPS:

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COLLAPSE**



**ROTATING
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CONDENSATION



ACCRETION

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