Planet Formation:
Evolution of The Solar Nebula

Evolution of the Solar Nebula

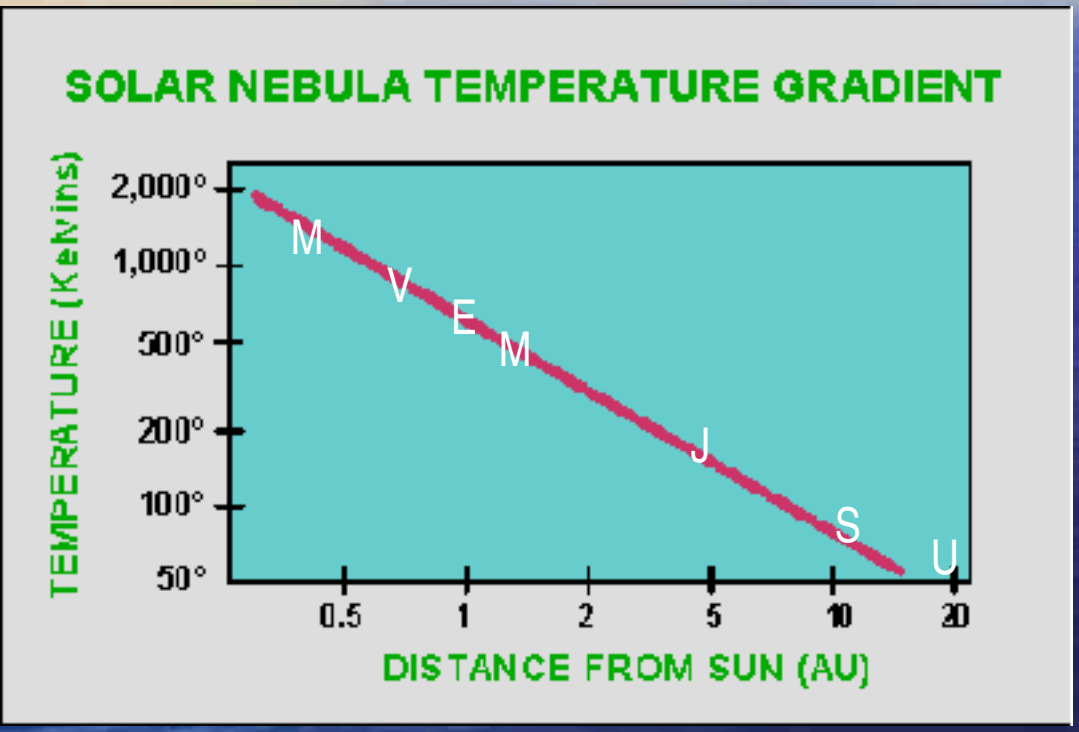
1. Nebula collapses into a disk.
   - Causes nebula to warm up
   - Temperatures near the Sun reach 2000 K

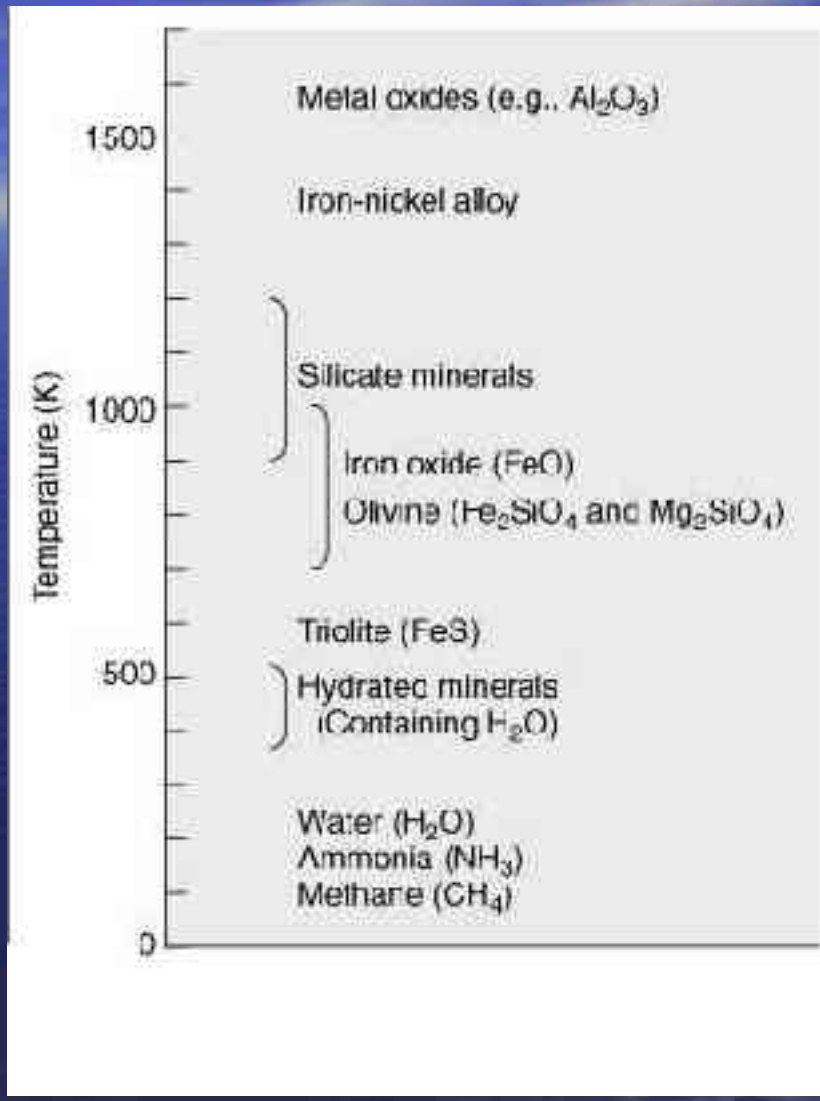
Evolution of the Solar Nebula

1. Collapse into a disk.
2. Collapse Vaporizes almost all material.
   - Inner nebula is almost totally gaseous

Evolution of the Solar Nebula

1. Collapse into a disk.
2. Collapse Vaporizes almost all material.
3. High-T elements condense
   - Cooling of the gas allows condensation of molecules
   - Temperature gradient in the disk
     - Warmer near sun: silicate rich (rocky) inner planets
     - Cooler away from sun: volatile rich (gaseous) outer planets


SOLAR NEBULA TEMPERATURE GRADIENT
TEMPERATURE (Kelvins)
2,000°
1,000°
500°
200°
100°
50°
M
V
E
M
J
S
U
0.5
1
2
5
10
20
DISTANCE FROM SUN (AU)


Temperature (K)
1500
1000
500
0
Metal oxides (e.g., Al_2O_3)
Iron-nickel alloy
Silicate minerals
Iron oxide (FeO)
Olivine (Fe_2SiO_4 and Mg_2SiO_4)
Troilite (FeS)
Hydrated minerals
(Containing H_2O)
Water (H_2O)
Ammonia (NH_3)
Methane (CH_4)

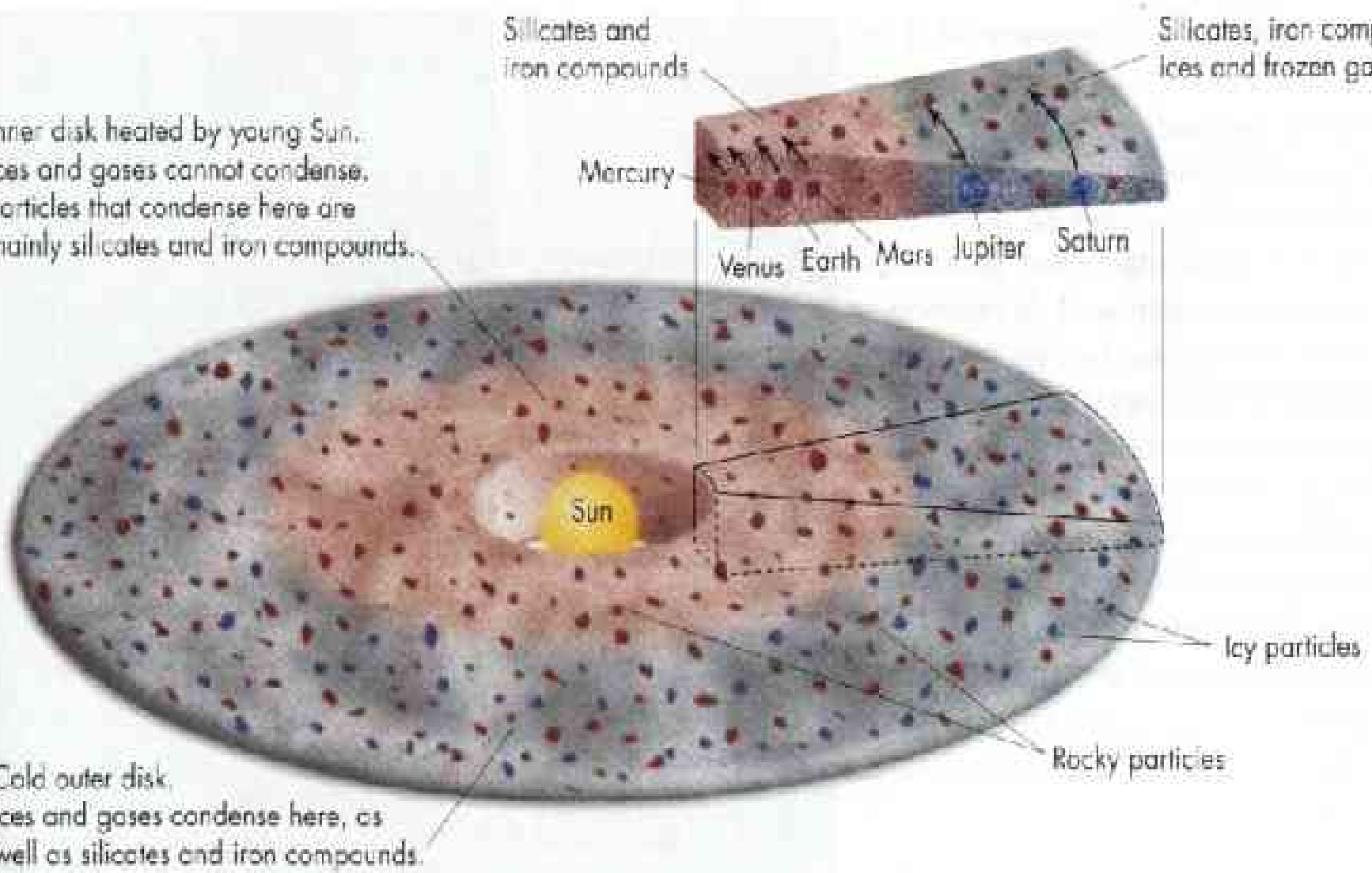


FIGURE OV4.6

Heat from the young Sun prevented ice from condensing in the inner parts of the Solar Nebula. The planetesimals—and ultimately the planets—that formed there are therefore composed mainly of rock and iron.

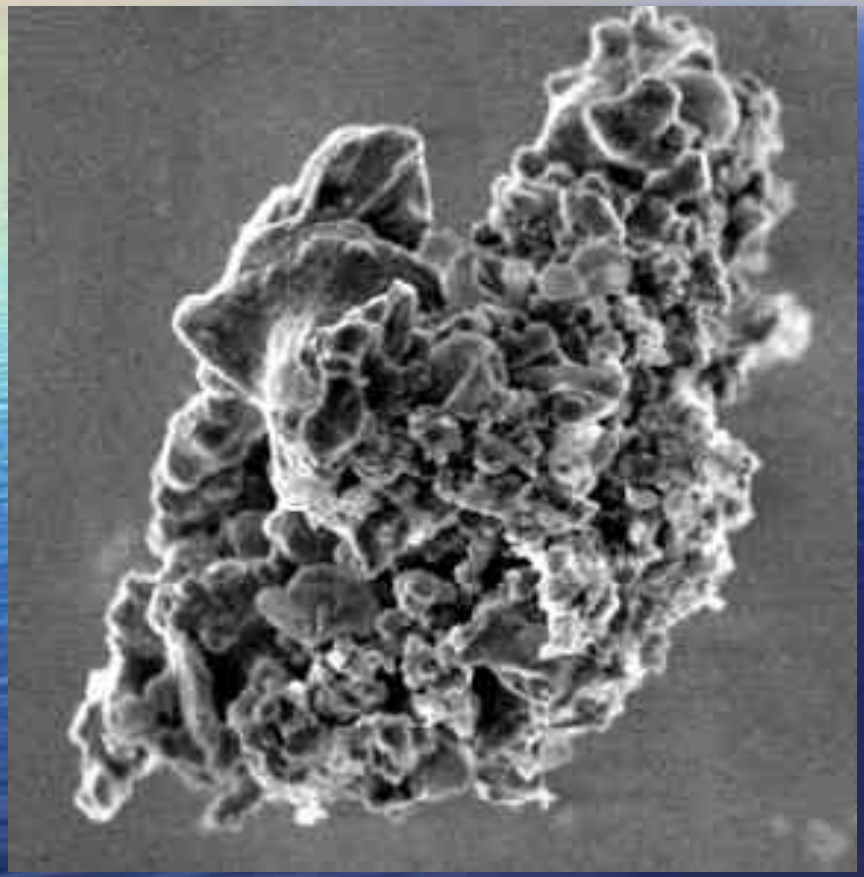
Evolution of the Solar Nebula

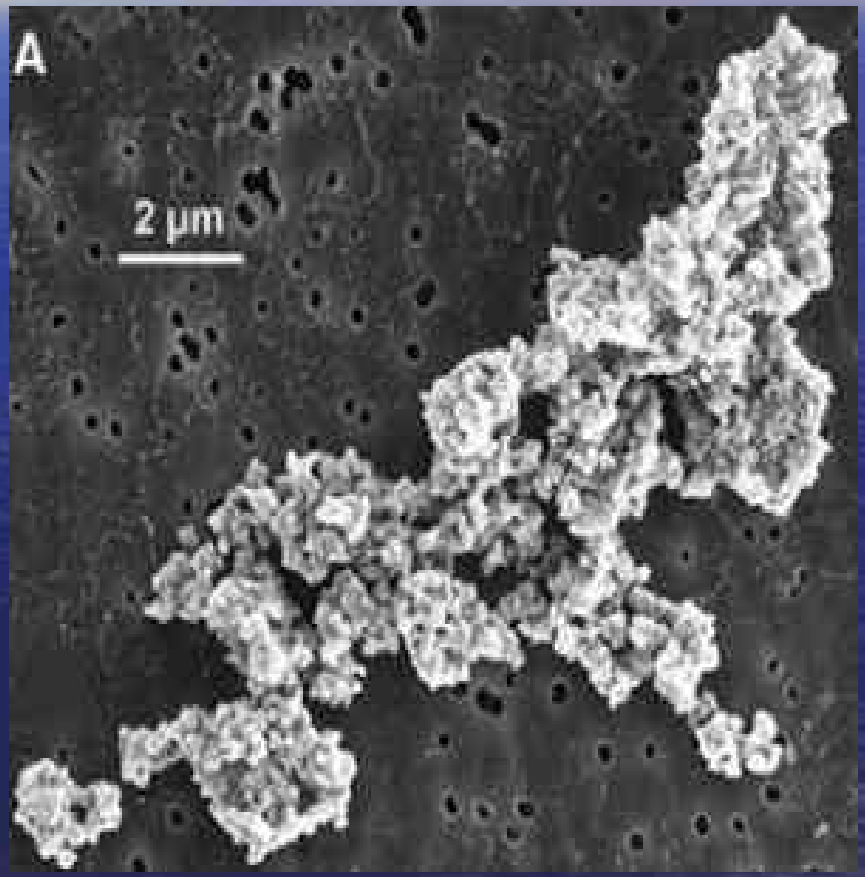
1. Collapse into a disk.
2. Collapse Vaporizes almost all material.
3. High-T elements condense
4. Low velocity collisions cause adhesion of Particles
   - Process produces fewer numbers of larger bodies:

     1 mm → 1 cm → 1 km, in ~10^3 years, at 1 AU

     (this happens slower at greater distances from the sun)

Interplanetary Dust Particles





They stick together because they are “fluffy”

Evolution of the Solar Nebula

1. Collapse into a disk.
2. Collapse Vaporizes almost all material.
3. High-T elements condense
4. Low-V Collisions → Adhesion of Particles
5. Gravity takes over & Planetesimals form
   - When the collision process creates larger aggregates, gravitational forces begin to dominate accretion

     1km → 1000 km, with M ~ $0.01M_{earth}$
   - Runaway Growth Process: larger bodies accrete faster than smaller bodies
   - By time t ~ 10^5 years, few hundred protoplanets in the Terrestrial Zone

Evolution of the Solar Nebula

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5. Gravity takes over & Planetesimals form
6. Planetesimals accrete to form planets
   - As planetesimals become larger, impacts become rarer and more violent
   - Protoplanets are heated by collisions
     - differentiation

Satellite Formation: Accretionary Disks

Mini Solar Systems

Large satellites of Jupiter, Saturn and Neptune

Galilean Moons, Jupiter

Satellite Formation: Captured Satellites

- Phobos & Deimos (Mars)
- Some of the outer satellites of the gas giants

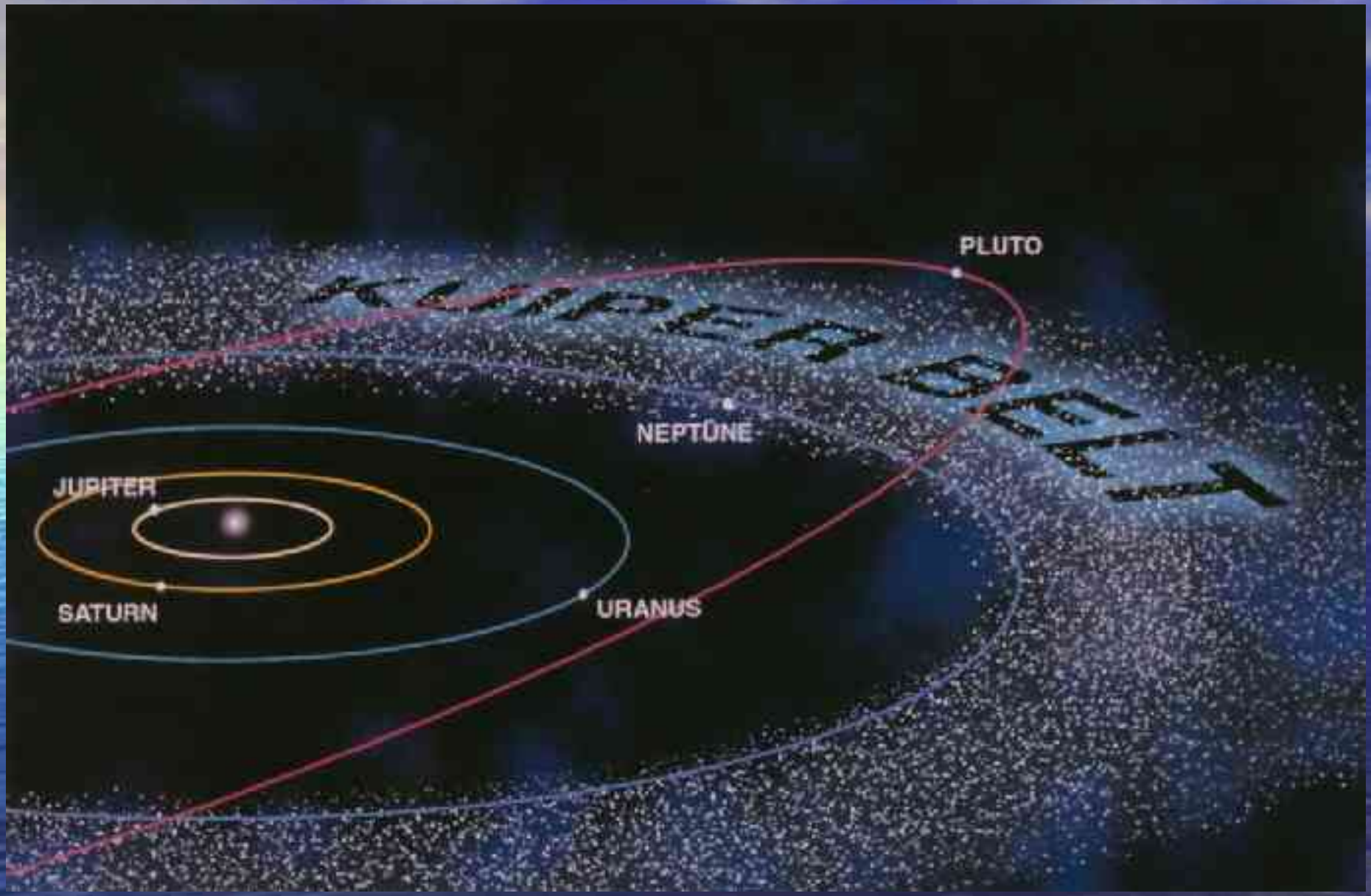
Satellite Formation: Catastrophic Collision

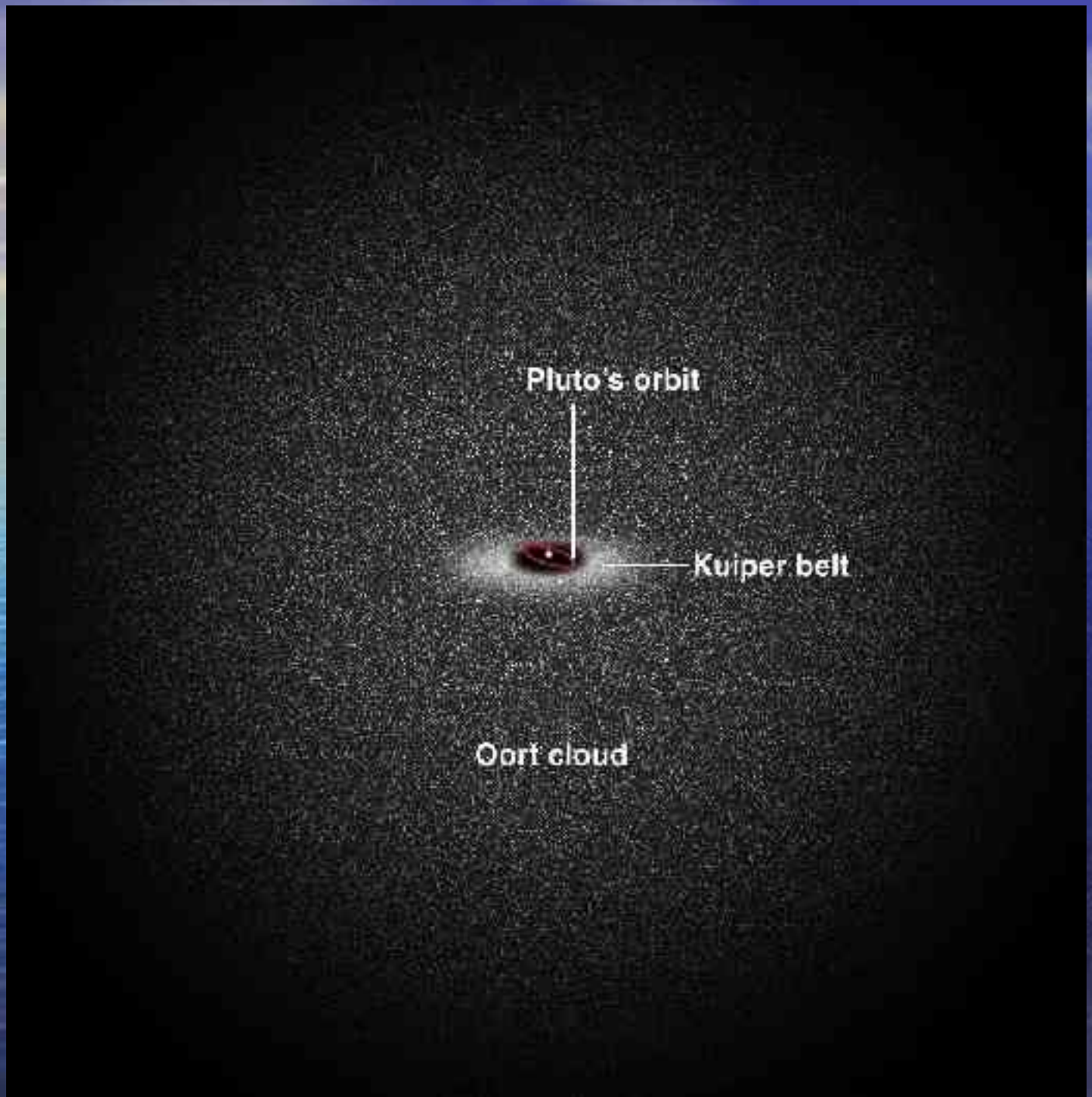
Formation of Earth's moon by collision with a Mars-size object

Happened after Earth differentiated

Satellite Formation

- Asteroid Belt :
  - Gravitational perturbations prevent the asteroids from accreting into a planet.
- Giant planets have perturbed many icy planetesimals to the edge of the Solar System
  - Kuiper Belt (source of short period comets)
  - Oort Cloud (long period comets)


PLUTO
NEPTUNE
JUPITER
SATURN
URANUS


Pluto's orbit
Kuiper belt
Oort cloud

Ring Formation

- Particles that were unable to form a Satellite
- Satellite Breakup
  - Due to tidal forces
  - Due to Impact

Titius-Bode Rule

$a_n = 0.4 + (2^n \times 0.3)$, where $n = -\infty, 0,1,2,3,\ldots$

a_n = distance to the planet in Astronomical Units (AU)

Planet	Calculation	Predicted Distance	Actual Distance
Mercury	0.4 + 0 · 0.3	0.4	0.39
Venus	0.4 + 1 · 0.3	0.7	0.72
Earth	0.4 + 2 · 0.3	1.0	1.00
Mars	0.4 + 4 · 0.3	1.6	1.52
Asteroids	0.4 + 8 · 0.3	2.8	2.77
Jupiter	0.4 + 16 · 0.3	5.2	5.20
Saturn	0.4 + 32 · 0.3	10.0	9.54
Uranus	0.4 + 64 · 0.3	19.6	19.19
Neptune	0.4 + 128 · 0.3	38.8	30.07
Pluto			39.4