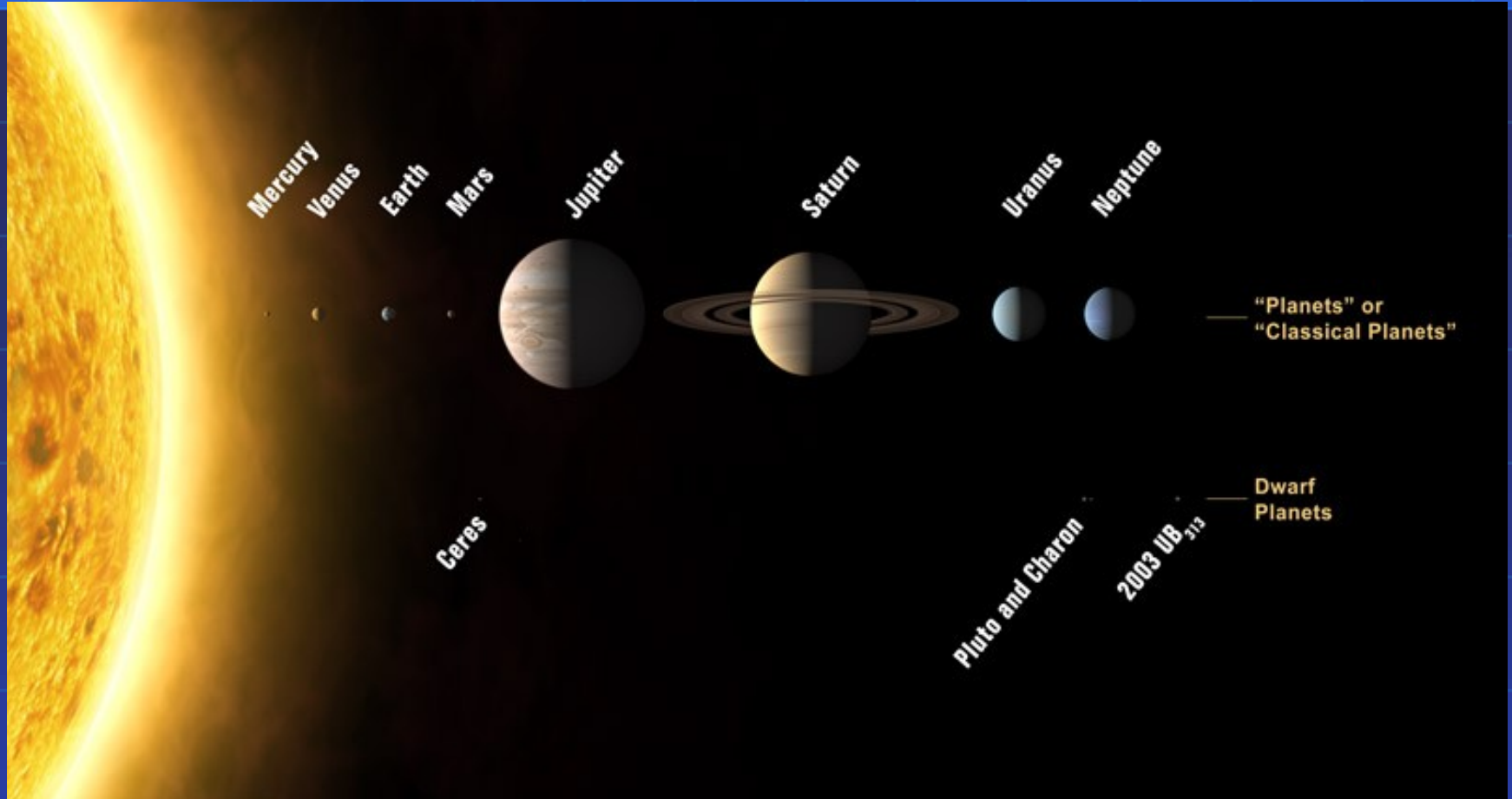


Making Our Solar System: Planetary Formation and Evolution

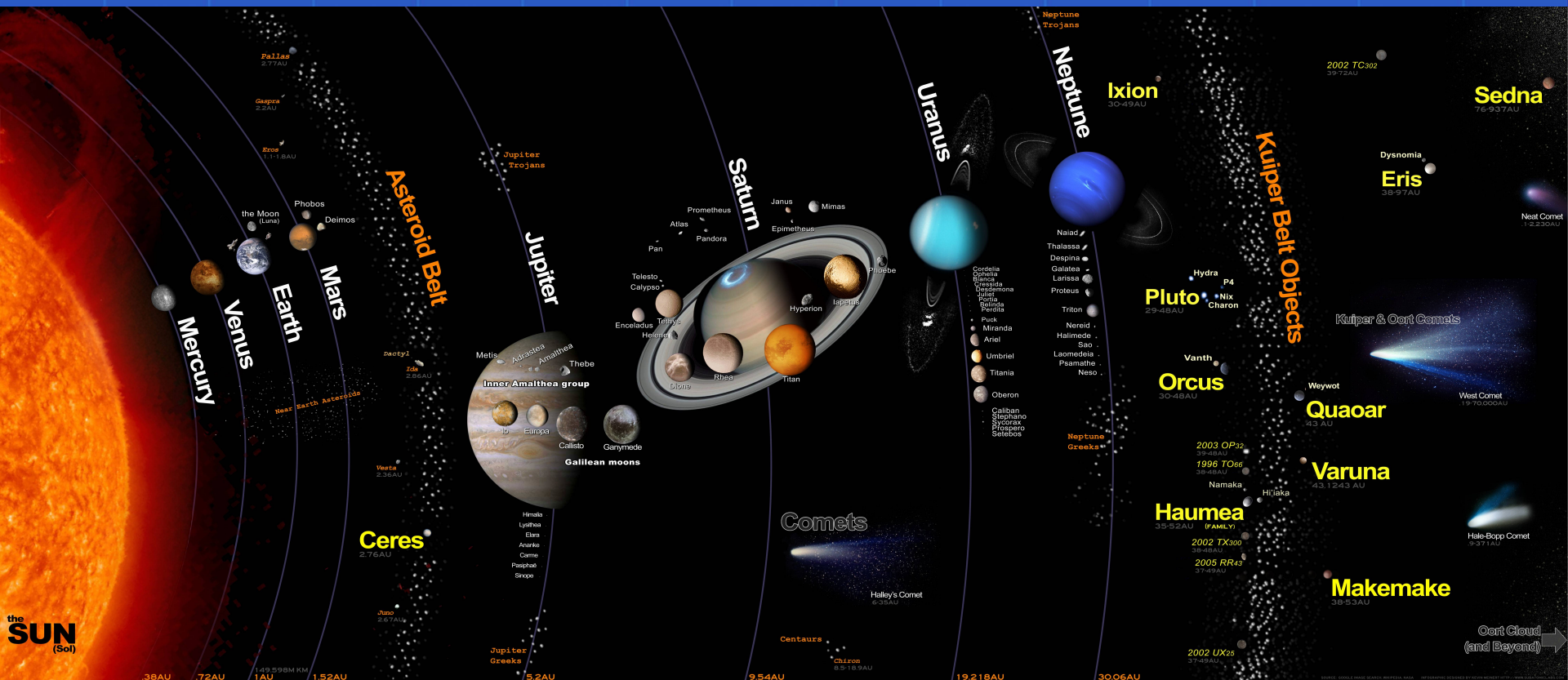


Dr. Michelle Kirchoff

**With help from Dr. Bill Bottke & Dr. Julien Salmon
Southwest Research Institute, Boulder, CO**



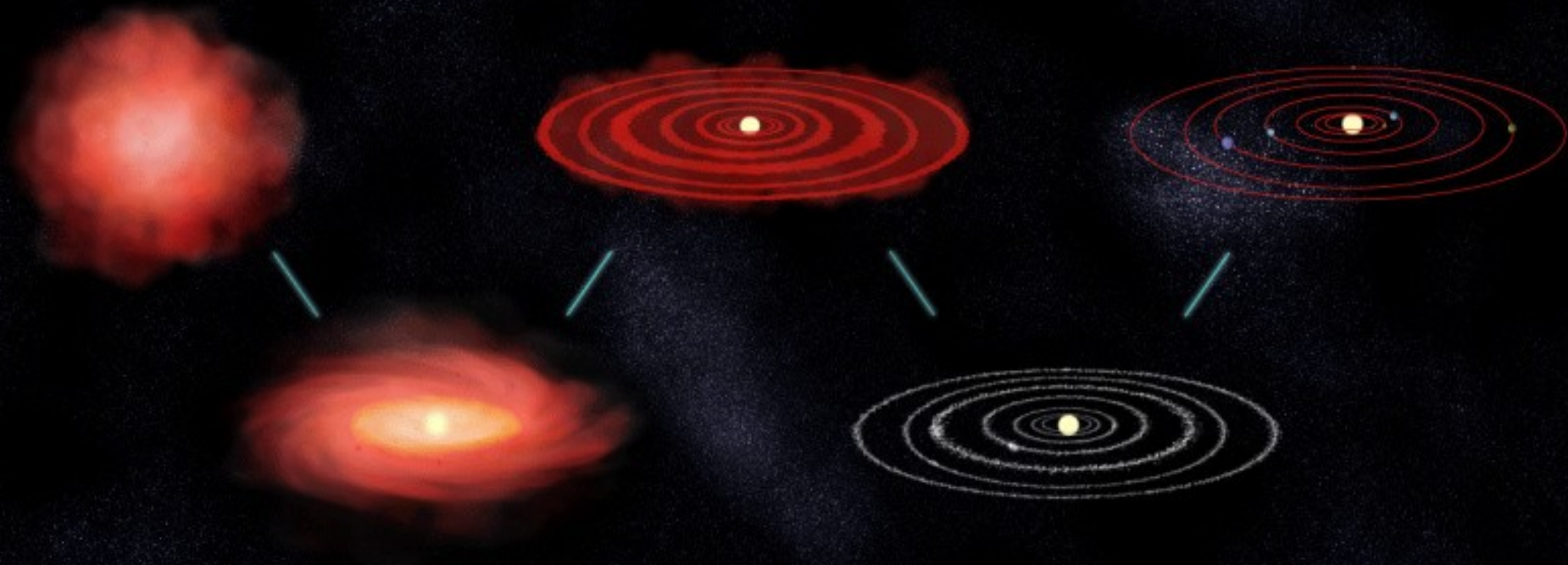
Important Observations



1. Current locations of the planets
2. Some planets made of rock, others made of gas
3. Characteristics of asteroids and comets
4. Many planets have moons

Our Story Begins...

The Nebular Model of Planet Formation



SOLAR SYSTEM FORMATION

1. Cloud Collapse

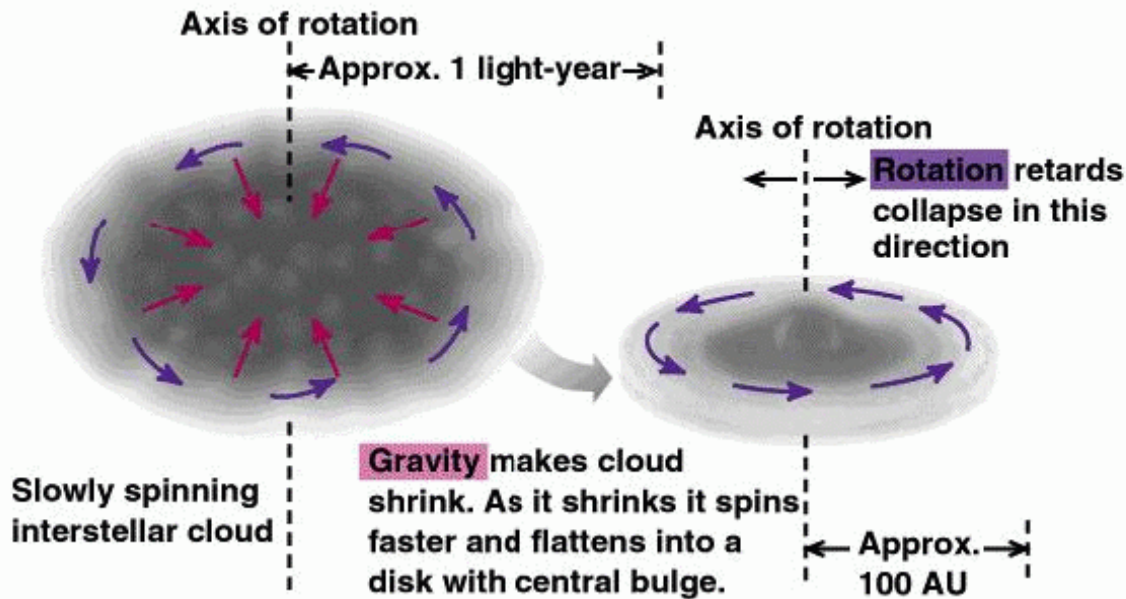


■ A huge cloud of interstellar gas and dust collapses.

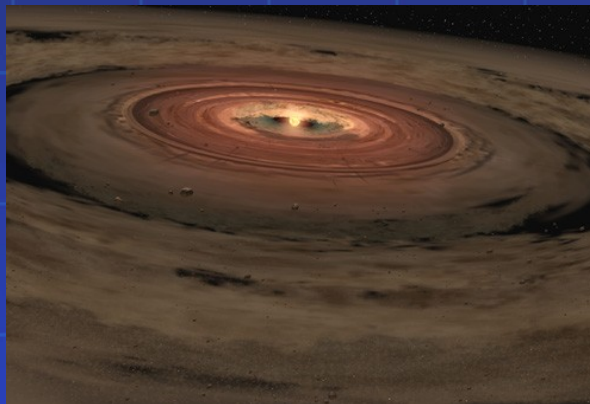
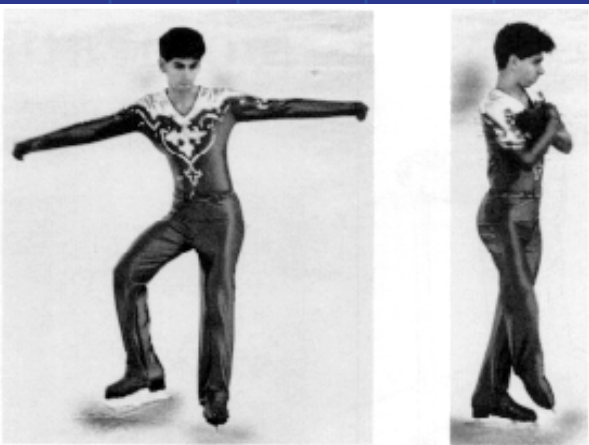
- The clouds are usually light years across!
- The collapse may be triggered by a supernova.



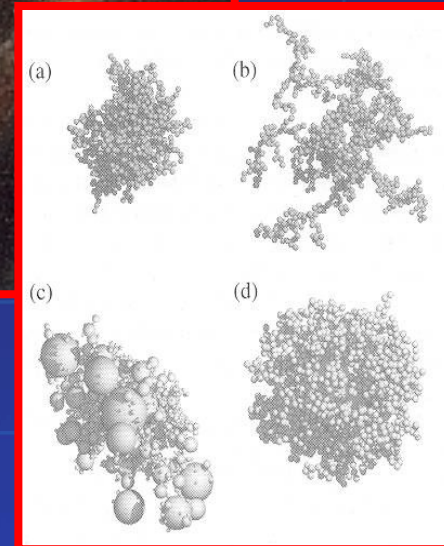
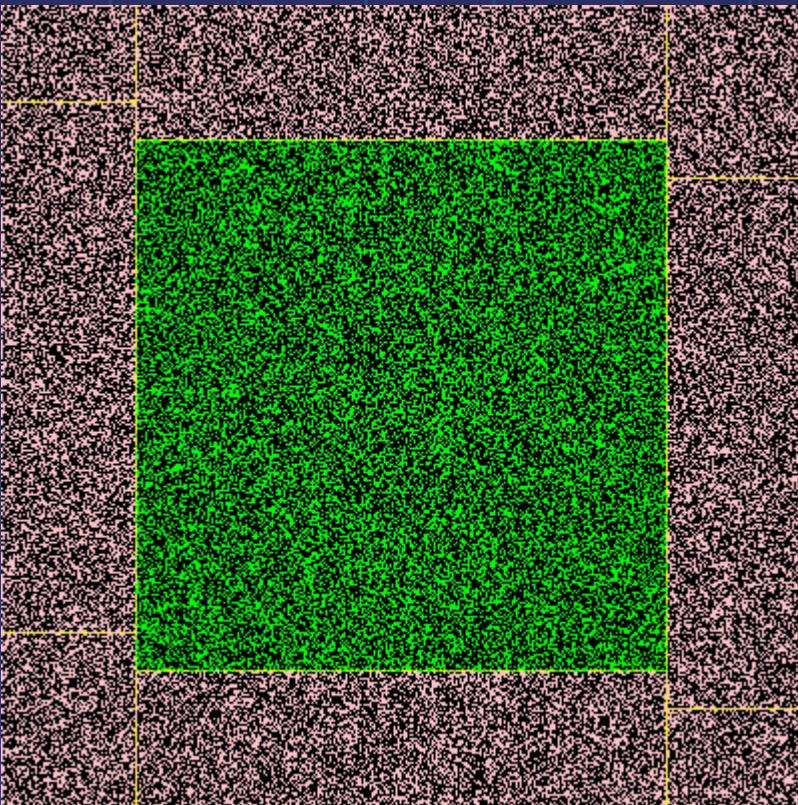
2. Formation of Protoplanetary Disk



- Gravity causes cloud to flatten.
- Conservation of angular momentum causes it to spin faster.
- Gas/dust disk forms around growing star.

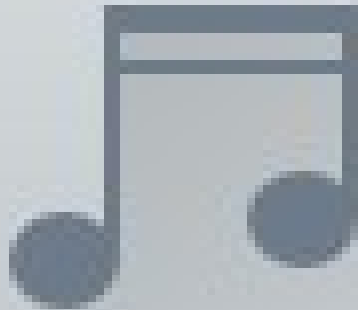


3. Growth of Planetesimals



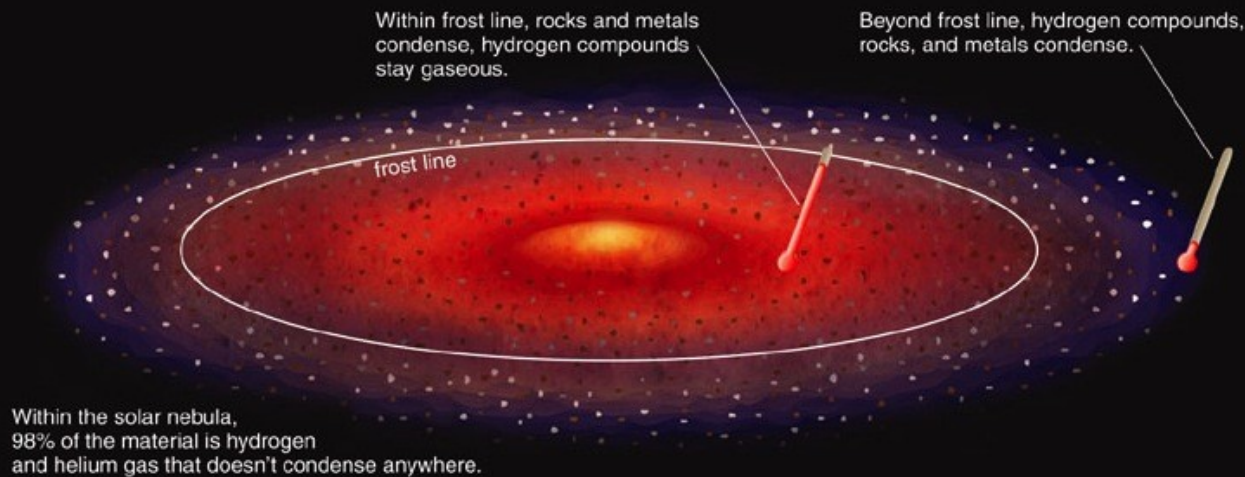
- Gravity causes dust to collect into larger planetesimals (asteroid- or comet-like bodies).

4. Collisions Make Large Bodies!

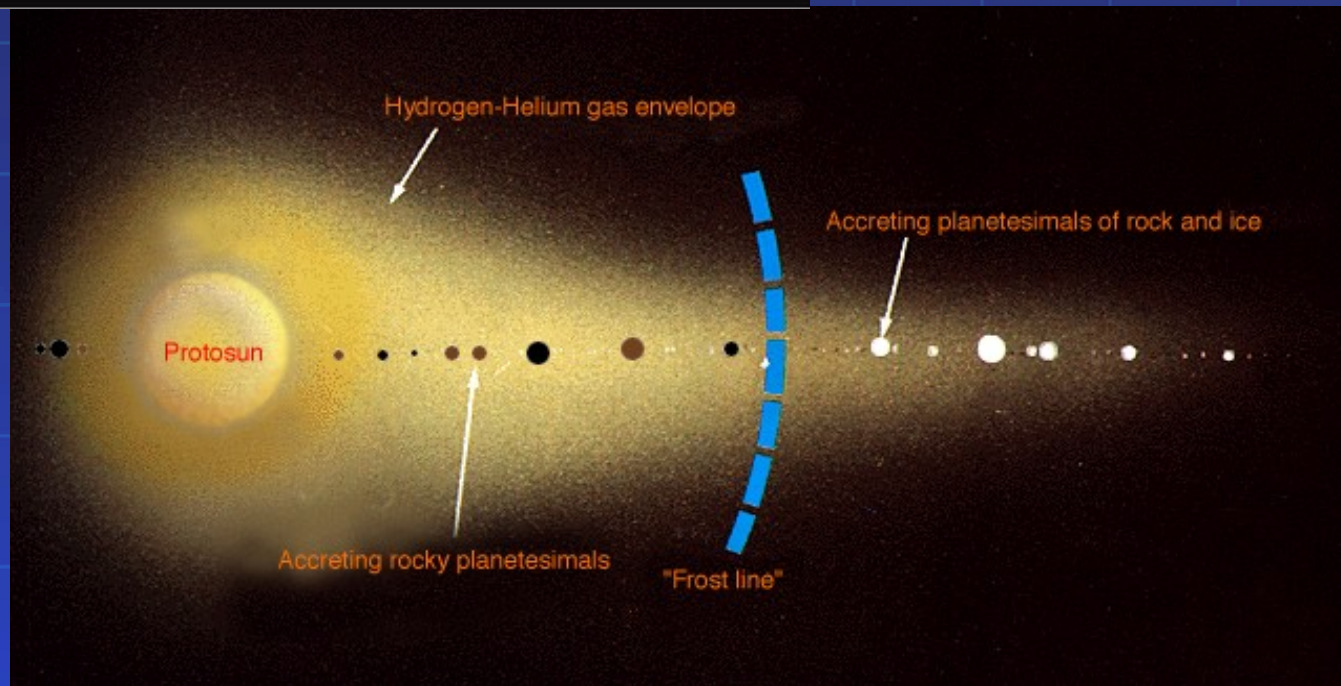


- The planetesimals collide and form larger bodies. Over time, they grow into Moon/Mars-sized protoplanets.

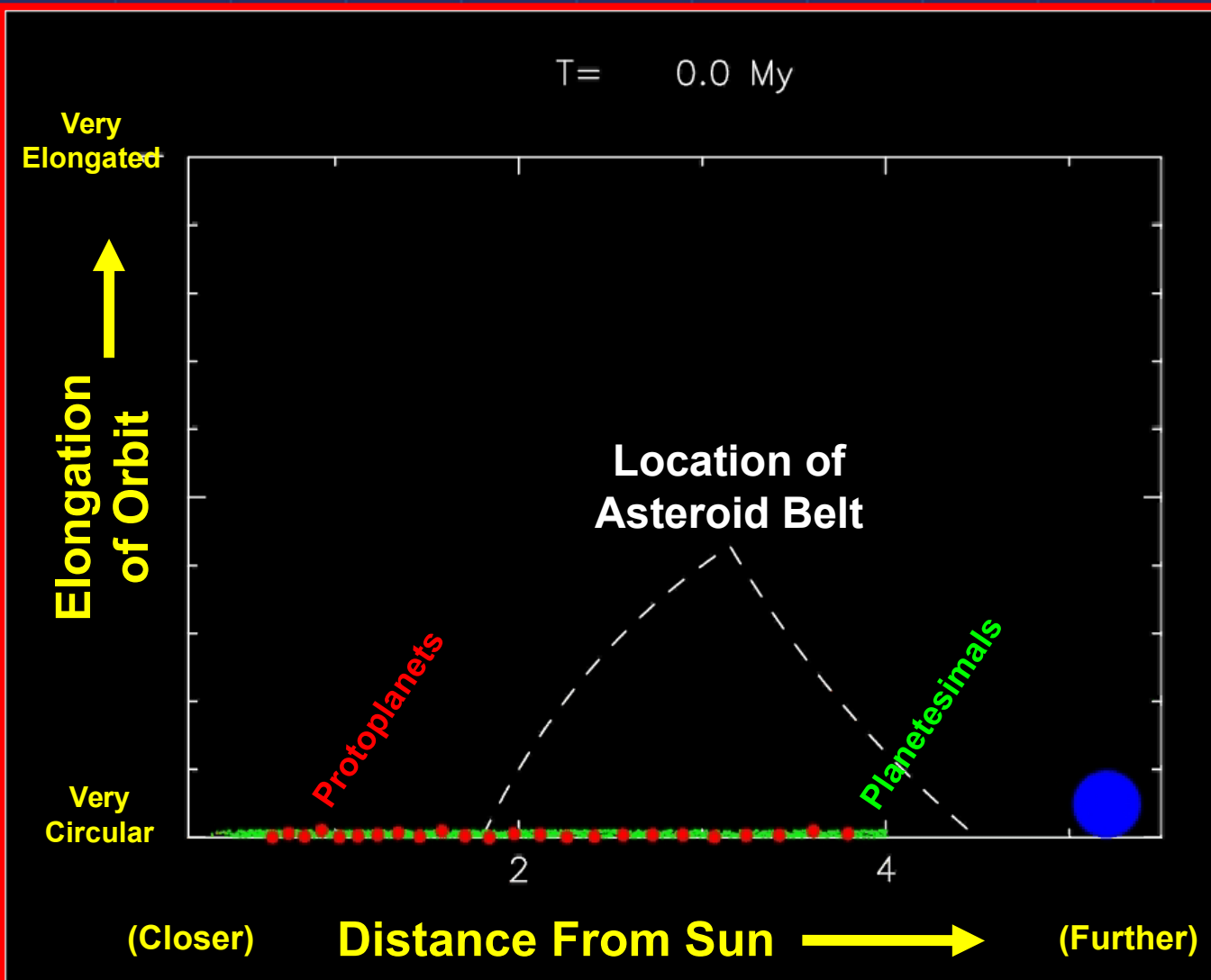
5. Planet Formation



Protoplanets closer to the Sun are made of rocky materials; farther away are made of icy materials.



5. Planet Formation: Inner Solar System



■ Sea of bodies:

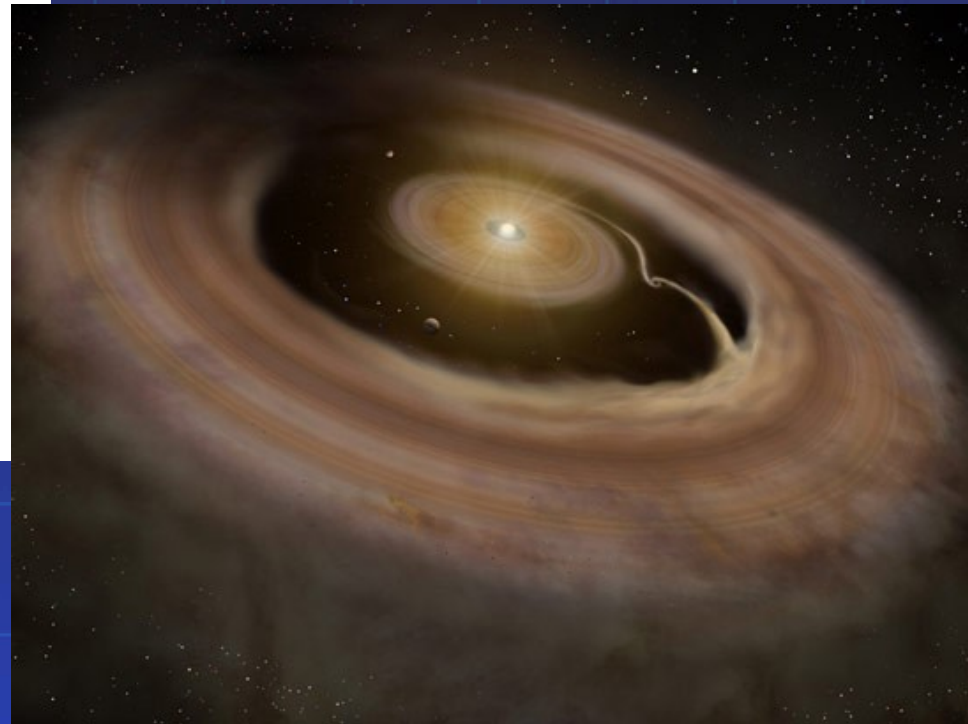
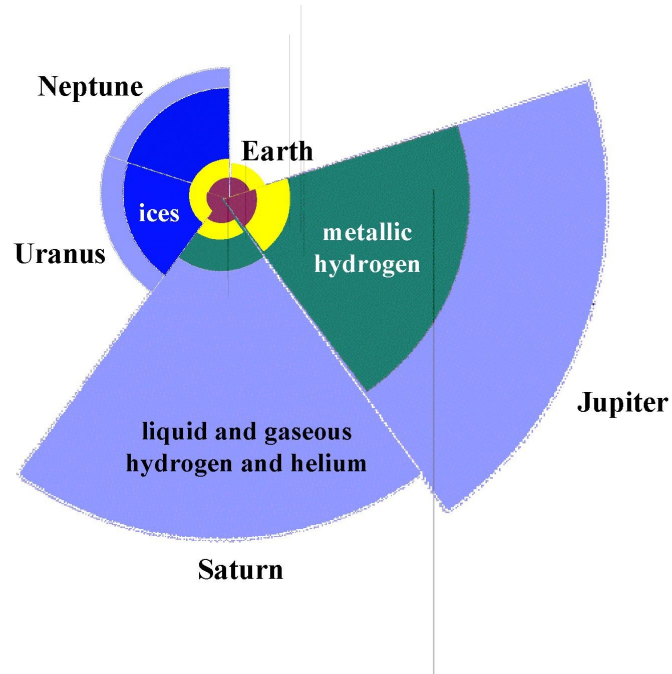
- Moon to Mars-sized bodies
- Smaller planetesimals.

5. Planet Formation: Inner Solar System



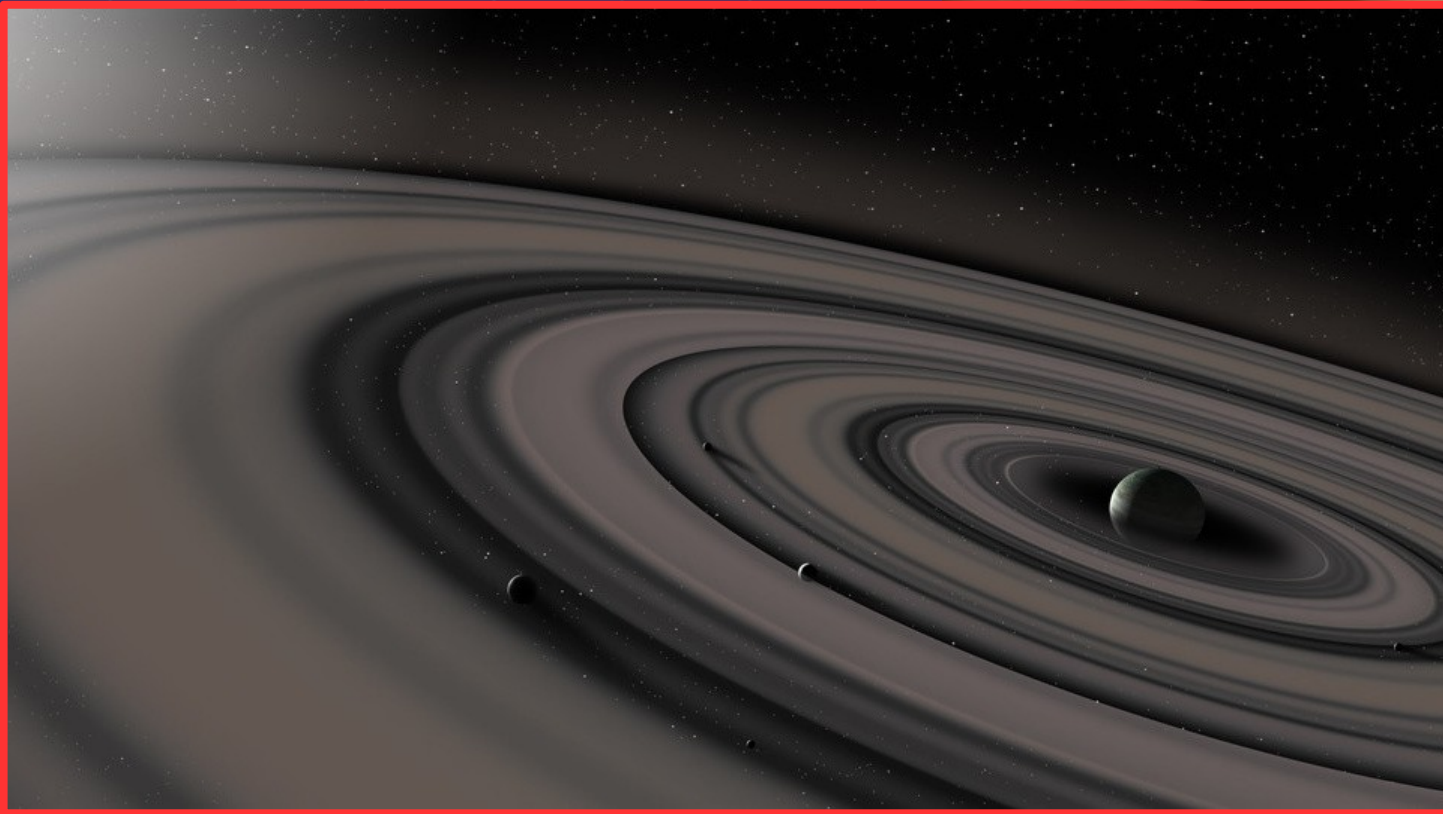
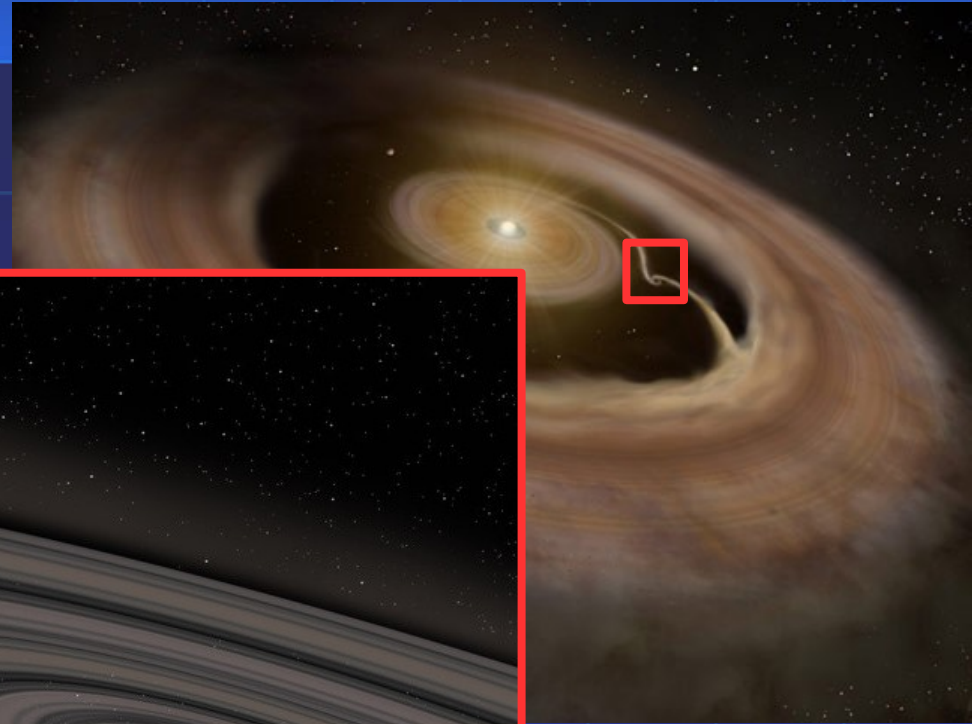
- **Sea of bodies:**
 - Moon to Mars-sized bodies
 - Smaller planetesimals.
- **Collisions create planets!**
- **Some bodies are left behind in the asteroid belt.**

5. Planet Formation: Outer Solar System



- Some protoplanets are large enough to capture lots of gas from disk. This is where the gas giants come from!

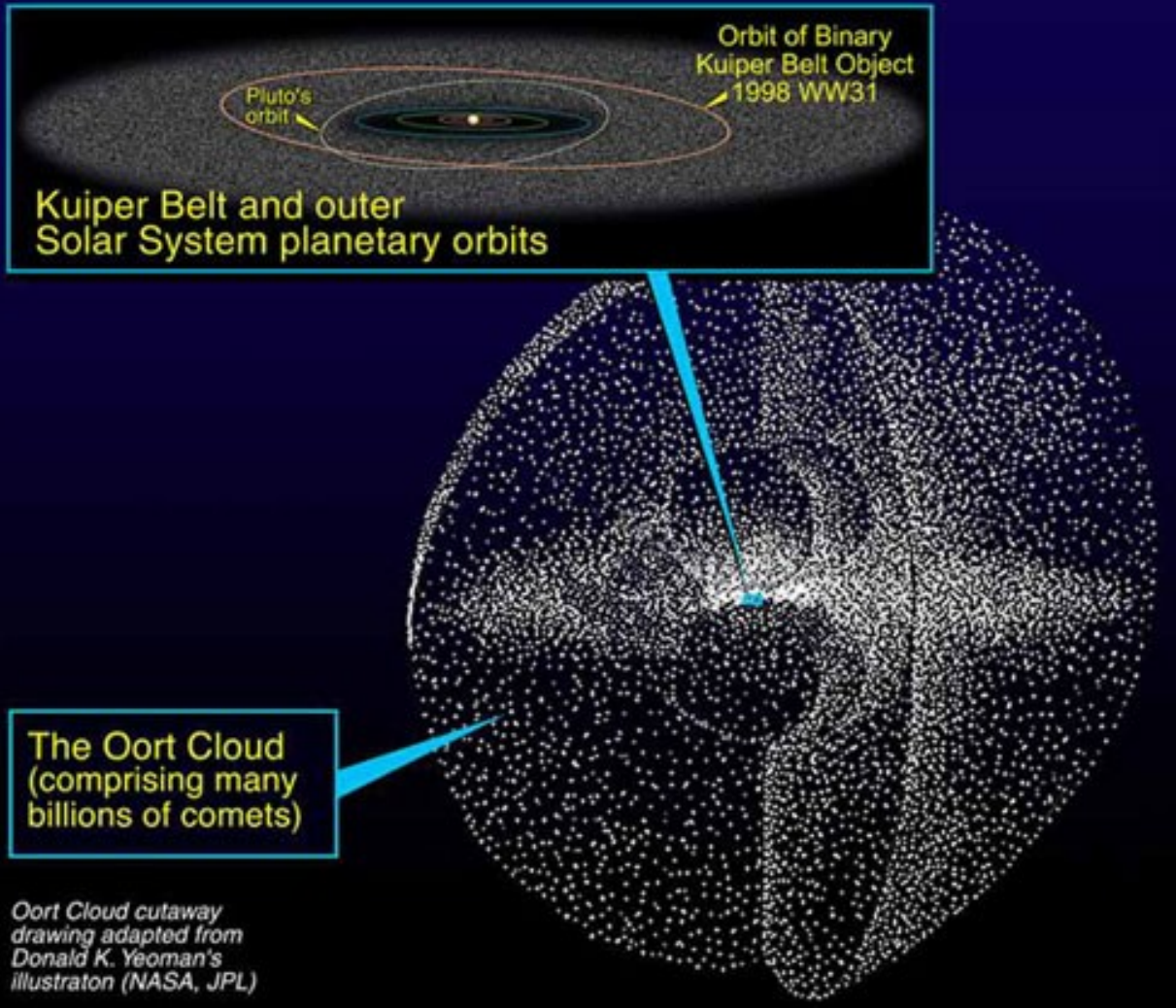
5. Planet Formation: Outer Solar System



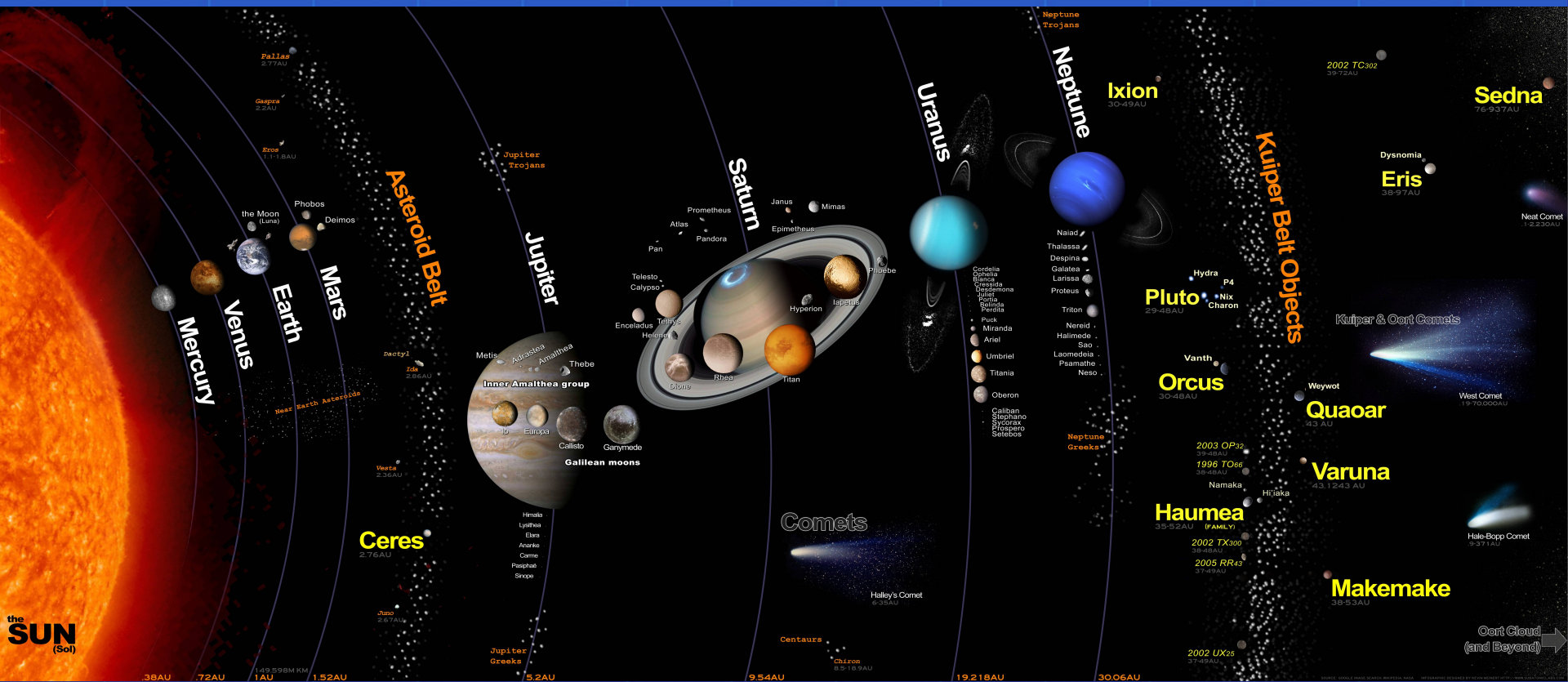
- This “circumplanetary” disk could also explain the satellites of the giant planets

The Kuiper Belt and Oort Cloud

- Regions where our comets come from.



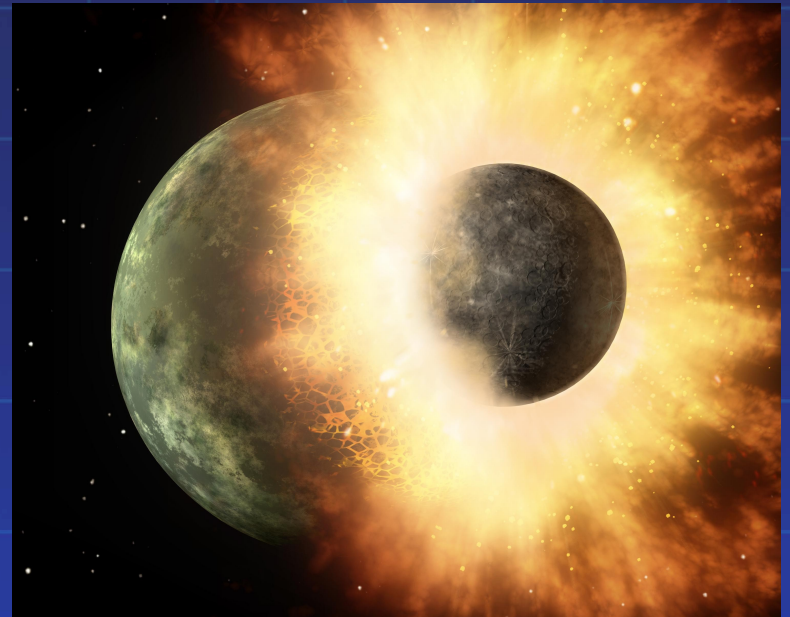
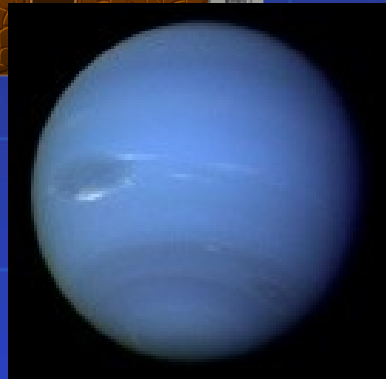
Important Observations



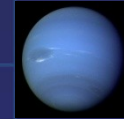
1. Current locations of the planets – **Sort of**
2. Some planets made of rock, others made of gas – **Yes!**
3. Characteristics of asteroids and comets – **Sort of**
4. Many planets have moons – **Sort of**

Our Story Continues...

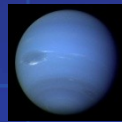
Moving planets, large collisions, oh my!



Modified Solar System Formation Model

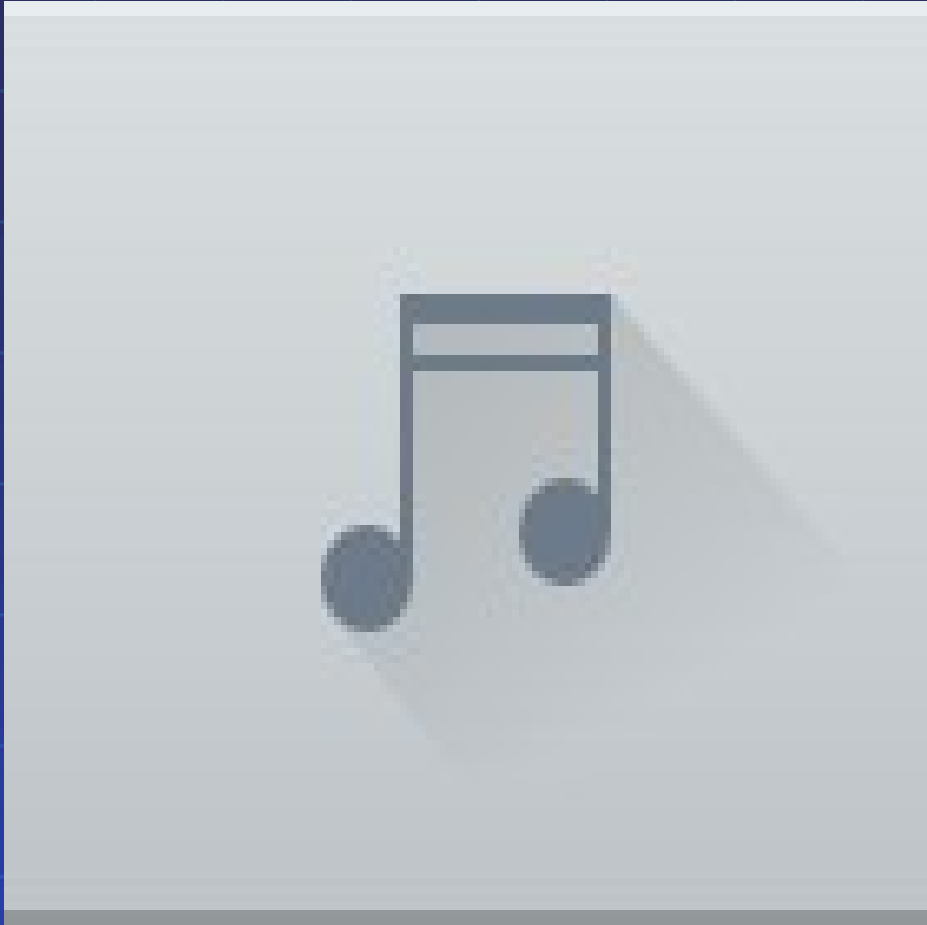


- **Old view.** Gas giants/comets formed near present locations (5-30 AU) and reached current orbits ~4.5 Gy ago.



- **New view.** Gas giants formed in more compact configuration (5-15 AU). Massive comet population existed between 15-30 AU.

Destabilizing the Outer Solar System: The “Nice” Model



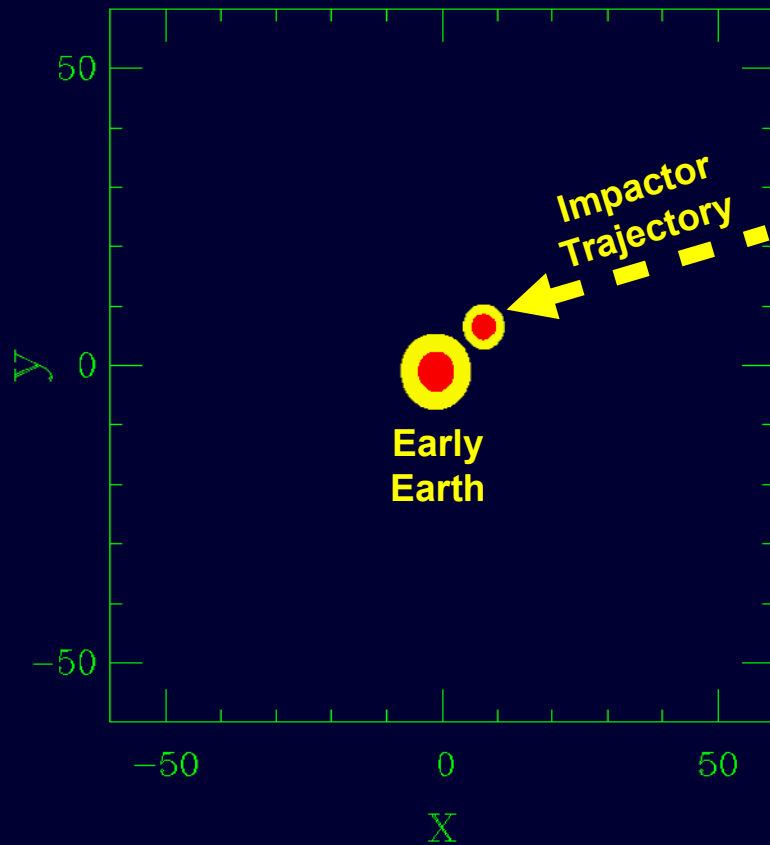
Watch what happens after 850 My!



Explains the orbits of giant planets and depleted
Kuiper belt & Asteroid belt

Tsiganis et al. (2005); Morbidelli et al. (2005); Gomes et al. (2005)

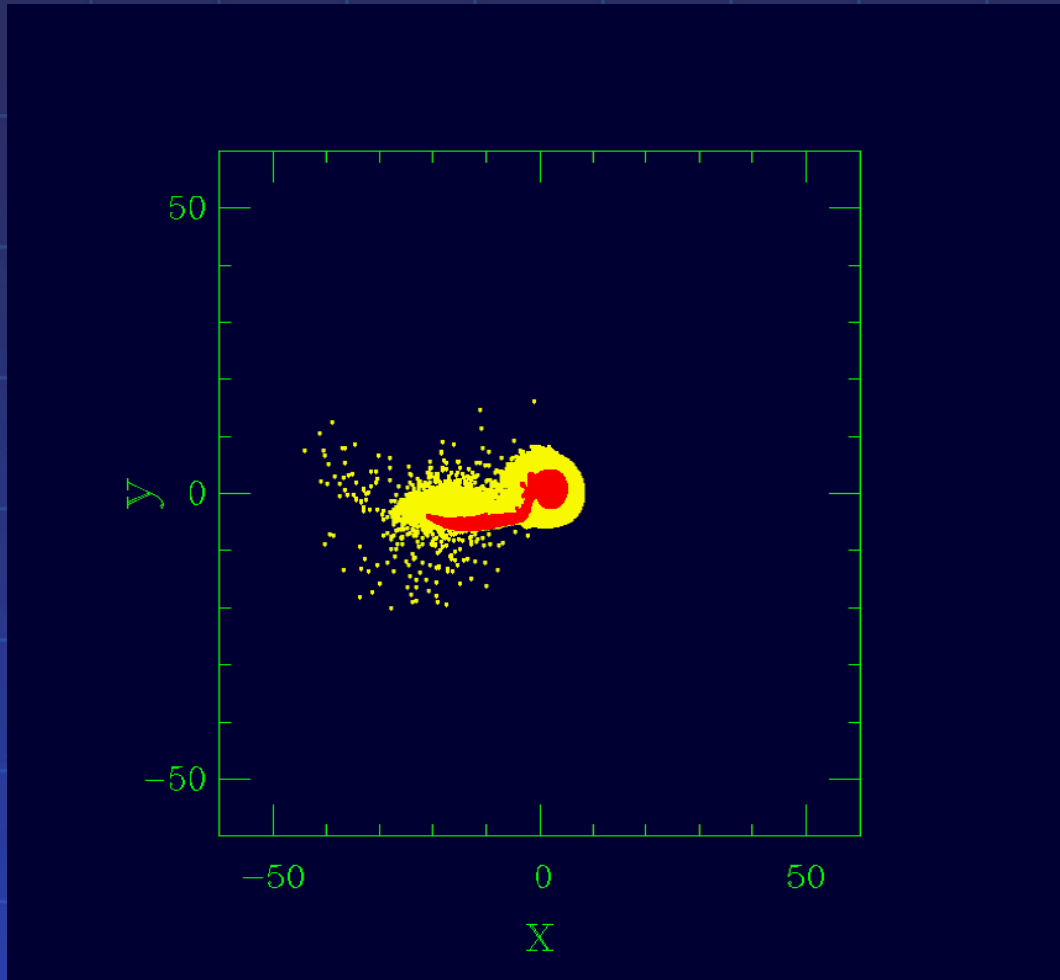
Giant Impact Model of Moon Formation



- Mars-sized body hits Earth and forms Moon from debris disk.

Iron core vs. stony mantle

Giant Impact Model of Moon Formation



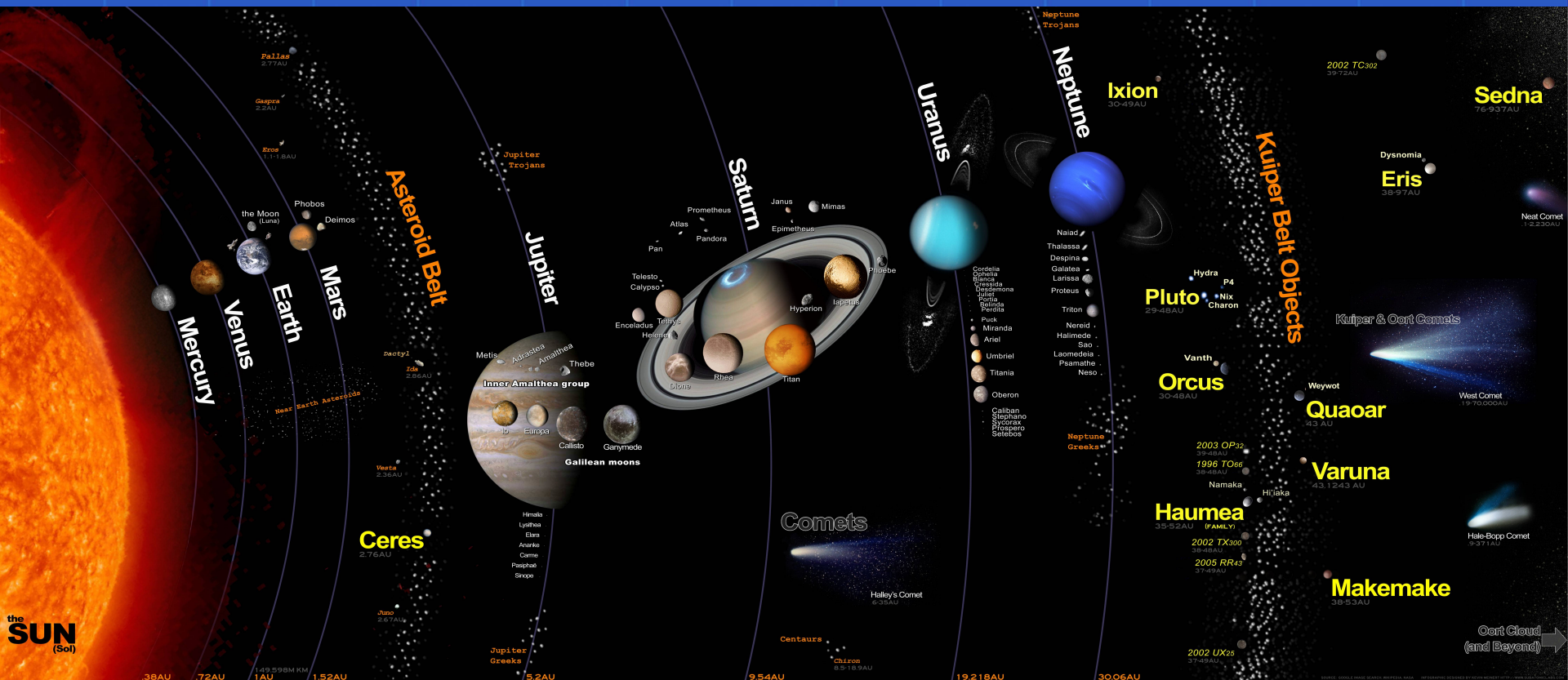
- **Mars-sized body hits Earth and forms Moon from debris disk.**
- **This model explains:**
 - Large Moon!
 - High Earth/Moon angular momentum.
 - Lack of iron in Moon.

Further Implications



- **Small moons can be captured during migration**
- **Planet properties affected by final large impacts**
 - Tilt of planet's axis (north pole), its rotation rate, whether it had a moon.

Important Observations



1. Current locations of the planets – **Yes!**
2. Some planets made of rock, others made of gas – **Yes!**
3. Characteristics of asteroids and comets – **Yes!**
4. Many planets have moons – **Yes!**

What Do We Still Need to Learn?

- Location and size of Mars still a mystery
- Details of growing planetesimals and accretion
- Details of forming “natural” satellites
- Details of satellite capture
- Why do other solar systems look so different?
- ??

Thank You!

Questions?