ASTR 105
The Solar System

This THURSDAY 10/08: First Group Project Covering Lectures 2 - 12
• The orbital period of the Moon is 29.5 days, and its distance from Earth is 238,900 miles. What is the mass of the Earth?

\[ P^2 = \frac{4\pi^2}{GM} a^3 \rightarrow \text{solve for } M \]

• The New Horizon spacecraft will take 9 years to travel to Pluto (D=7.5x10^9 km). What is its average speed?

\[ V = \frac{D}{\text{time}} \]

• Uranus’s orbit lasts 84 years. If you live at its South pole, for roughly how long would you see continuous day light?

About 42 years

• List at least 2 differences between Pluto and the other solar planets. What feature did astronomers agree upon as a way to differentiate a ‘planet’ from a ‘dwarf planet’?

Composition, orbital inclination, \textit{neighborhood not cleared}
Solar Nebula:

- **SPINNING**
  - Conservation of angular momentum
- **HOT**
  - Collapse $\Rightarrow$ compression
- **DISK**
  - Collisions force common motions
More Support for the Nebular Theory

- Plenty of disks around other stars
- New planetary systems forming?
At this point, we are going to skip the details about forming the star

[This topic is part of AST 101]
Four Challenges for a Solar System Formation Theory

1. Orderly motions ✓
2. Two kinds of planets
3. Two kinds of small bodies
4. Exceptions to the rules
Building the Planets

• Let’s look at the four main ingredients

<table>
<thead>
<tr>
<th>Materials in the Solar Nebula</th>
<th>Metals</th>
<th>Rocks</th>
<th>Hydrogen Compounds</th>
<th>Light Gases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examples</td>
<td>iron, nickel, aluminum</td>
<td>various minerals</td>
<td>water (H₂O) methane (CH₄) ammonia (NH₃)</td>
<td>hydrogen, helium (do not condense in nebula)</td>
</tr>
<tr>
<td>Typical Condensation Temperature</td>
<td>1,000–1,600 K</td>
<td>500–1,300 K</td>
<td>&lt;150 K</td>
<td></td>
</tr>
</tbody>
</table>
At 400K, what exists in solid form?

A. Metals
B. Rocks
C. Hydrogen Compounds
D. Metals & Rocks
E. Metals, Rocks, and Hydrogen compounds
At 400K, what exists in solid form?

A. Metals
B. Rocks
C. Hydrogen Compounds
D. Metals & Rocks
E. Metals, Rocks, and Hydrogen compounds
At 50K, what exists in solid form?

A. Metals
B. Rocks
C. Hydrogen Compounds
D. Metals & Rocks
E. Metals, Rocks, and Hydrogen compounds
At 50K, what exists in solid form?

A. Metals
B. Rocks
C. Hydrogen Compounds
D. Metals & Rocks
E. Metals, Rocks, and Hydrogen compounds
Inside the frost line, rocks and metals condense, hydrogen compounds stay gaseous.

Beyond the frost line, rocks, metals, and hydrogen compounds condense.

**Condensation**
- The formation of solid/liquid particles from a gas

**This is first step to forming planets**
What is the frost line?

A. The layer in a planet’s atmosphere where temperatures are cold enough for ice to form.
B. The time during the solar system formation that ices formed
C. The distance from the Sun in the solar system where the Dwarf Planets reside
D. The distance in the solar system where ice can begin to form
E. The distance from the Earth where water is no longer able to be liquid
What is the frost line?

A. The layer in a planet’s atmosphere where temperatures are cold enough for ice to form.
B. The time during the solar system formation that ices formed
C. The distance from the Sun in the solar system where the Dwarf Planets reside
D. The distance in the solar system where ice can begin to form
E. The distance from the Earth where water is no longer able to be liquid
Next step: Turning planet seeds into planetesimals

- **Accretion**
  - Small objects gather together to make larger objects
- **The big get bigger**
  - like a snowball
- **REALLY big planetesimals (>10-20 \( M_{\text{Earth}} \)) gravitationally capture hydrogen & helium and become GIANTS**
  - Objects outside the frost line had ices (hydrogen compounds) available
Hydrogen envelopes over cores of some form of rock, metal and hydrogen compounds
Large moons of jovian planets form from their own mini-nebular disk.
Why 2 Types of Planets?

- Cosmic Abundance of Elements
- Temperature Drops Farther from Sun
  - Inside the frost line
    - Small amounts of rock & metal = small terrestrial planets
  - Outside the frost line
    - Rocks, metals, AND ices condense
    - Giant snowballs have enough gravity to capture H/He = Giant Gas Planets (jovian planets)
Four Challenges for a Solar System Formation Theory

1. Orderly motions ✓
2. Two kinds of planets ✓
3. Two kinds of small bodies
4. Exceptions to the rules
Remember the amount of building material present in the early solar system (0.6% rocks/metals, 1.4% ices, 98% gas). How would things look if there had been a lot of rocks/metals (1.5%) but only a small amount of hydrogen compounds (0.1%) and a smaller amount of gas (10%)?

A. Large rocky planets close to the Sun, few small icy/gaseous planets in the outer solar system
B. Gas giant planets with rock/metal cores close, gas giant planets with rock/metal/icy cores far
C. Gas giant planets close, large terrestrial planets far (planet compositions the same).
D. No different than it is now
Remember the amount of building material present in the early solar system (0.6% rocks/metals, 1.4% ices, 98% gas). How would things look if there had been a lot of rocks/metals (1.5%) but only a small amount of hydrogen compounds (0.1%) and a smaller amount of gas (10%)?

A. Large rocky planets close to the Sun, few small icy/gaseous planets in the outer solar system
B. Gas giant planets with rock/metal cores close, gas giant planets with rock/metal/icy cores far
C. Gas giant planets close, large terrestrial planets far (planet compositions the same).
D. No different than it is now
What happens to the gas?

Young stars go through a phase of very strong solar winds

- Blows away gas
- Leaves anything solid
  - planets, moons, asteroids, comets, etc.
Origin of the Asteroids

- Leftover **rocky** planetesimals which did not accrete onto a planet are **asteroids**.
- Most were shepherded into the **asteroid belt** between Mars & Jupiter.
  - Jupiter’s gravity prevented a planet from forming there.
Leftover icy planetesimals are comets.

- Planetesimals beyond Neptune’s orbit stayed in the ecliptic plane in the Kuiper belt.
- Planetesimals among jovian planets ‘flung out’ in all directions into the Oort cloud.
Four Challenges for a Solar System Formation Theory

1. Orderly motions ✓
2. Two kinds of planets ✓
3. Two kinds of small bodies ✓
4. Exceptions to the rules
Four Challenges for a Solar System Formation Theory

1. Orderly motions ✓
2. Two kinds of planets ✓
3. Two kinds of small bodies ✓
4. Exceptions to the rules
After the solar wind cleared all the gas out, there was still lots of planetesimals roaming around.

- Collisions were frequent
  - This was known as the period of heavy bombardment.

Collapse, Condensation, Accretion, Gas Capture, Solar Wind Clearing, Heavy Bombardment
Origin of Earth’s Water & Atmosphere

- Bombardment by asteroids brings us ‘the good stuff’ from beyond the frost line!
  - Water may have come to Earth by way of icy planetesimals from outer solar system
Formation of the Moon (Giant Impact Hypothesis)

- Earth was struck by a Mars-sized planetesimal
- Part of Earth’s outer layers was ejected
- This re-accreted into the Moon.
A Bad Day for Earth?

- Earth was struck by a Mars-sized planetesimal
- Part of Earth’s outer layers was ejected
- This re-accreted into the Moon.
- This explains why the Moon:
  - orbits in same direction as Earth rotates
  - Has a lower density than Earth
  - Has little/no easily-vaporized ingredients (water)
Clicker Question

Which of the following is not a line of evidence supporting the hypothesis that our Moon formed as a result of a giant impact?

A. The Moon has a much smaller proportion of easily vaporized materials than Earth.
B. The Moon’s average density suggests it is made of rock much more like that of the Earth’s outer layers than that of Earth as a whole.
C. The Pacific Ocean appears to contain a large crater – probably the one made by the giant impact.
D. Computer simulations show that the Moon could really have formed in this way.
Which of the following is not a line of evidence supporting the hypothesis that our Moon formed as a result of a giant impact?

A. The Moon has a much smaller proportion of easily vaporized materials than Earth.
B. The Moon’s average density suggests it is made of rock much more like that of the Earth’s outer layers than that of Earth as a whole.
C. The Pacific Ocean appears to contain a large crater – probably the one made by the giant impact.
D. Computer simulations show that the Moon could really have formed in this way.
Heavy bombardment *could* have also knocked Uranus on its side and caused Venus to spin backwards.
Captured Moons

- Unusual moons of some planets probably are captured planetesimals
  - Also explains screwy orbits
Four Challenges for a Solar System Formation Theory

1. Orderly motions ✓
2. Two kinds of planets ✓
3. Two kinds of small bodies ✓
4. Exceptions to the rules ✓
Clicker Question

How would the solar system be different if the solar nebula had been cooler, with a temperature half its actual value?

A. Jovian planets would have formed closer to Sun
B. There would be no asteroids
C. There would be no comets
D. Terrestrial planets would be larger
E. Jovian and Terrestrial planets would switch places
How would the solar system be different if the solar nebula had been cooler, with a temperature half its actual value?

A. Jovian planets would have formed closer to Sun
B. There would be no asteroids
C. There would be no comets
D. Terrestrial planets would be larger
E. Jovian and Terrestrial planets would switch places
WHEN did this all happen?
What could we look at to date the age of the solar system?

• Earth?
  - Ø Most of Earth’s surface has been recycled over the years

• Moon?
  - Ø Formed AFTER the initial formation of the Earth

• Small Solar System Bodies?
  - These are the remnants from the original formation processes
Oldest Solar System Rocks

- The oldest dated moon rocks, have ages between 4.4 - 4.5 billion years
- Meteorites dated to be between 4.53 and 4.58 billion years old

4.55 BY to ~1% accuracy
Stages of Solar System Formation

Collapse

Condensation

Accretion
- Gas Capture

Solar Wind Clearing

Heavy Bombardment