Planet Formation

10/30/2009
Opening Discussion

- http://www.youtube.com/watch?v=yOAl0enE7kI
- Have you seen anything interesting in the news?
- What did we talk about last class?
Where We Left Off

- Protostar surrounded by a disk of material.
- The structure of the disk explains much of the orderly motions in our Solar System.
  - The orbits of the planets have to all go in the same direction as the Sun spins.
  - The rotations of the planets will tend to also go this direction as the greater amount of material on the outside has more angular momentum.
  - The giant planets should also have their own disks around them that form their moons.
Contents of the Disk

- The disk is mostly hydrogen and helium. About 98% by mass.
- The other 2% is a combination of metals, rocks, and hydrogen compounds.

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<thead>
<tr>
<th></th>
<th>Metals</th>
<th>Rocks</th>
<th>H Compounds</th>
<th>H and He</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condensation Temp</td>
<td>1000-1600K</td>
<td>500-1300K</td>
<td>&lt;150K</td>
<td>Never</td>
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<tr>
<td>Relative Abundance</td>
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Within the solar nebula, 98% of the material is hydrogen and helium gas that doesn’t condense anywhere.

Within frost line, rocks and metals condense, hydrogen compounds stay gaseous.

Beyond frost line, hydrogen compounds, rocks, and metals condense.
Safronov Model

• The standard model of planet formation was developed by Victor Safronov who envisioned flakes of material sticking to one another to form larger pieces which continue to grow through a process called accretion.

• Depending on distance from the Sun and disk temperature more or less material would condense and the accretion process would progress differently.

• Much work has been done on this model to work out various details. It works very well for the terrestrial planets.
Runaway and Oligarchic Growth

- Early during accretion, bodies only grow based on their cross-section. Once they get large enough their gravity starts to pull things toward them and their growth rates increase.

- This leads to runaway growth where the first body to reach a certain size “wins” because it starts to grow even faster.

- Bodies can only sweep up material that it within a certain range so you get oligarchic growth where a few bodies reach the size of protoplanets and have little left to accrete.
Final Stages

- This leaves us with a few bodies between the size of the Moon and Mars.
- Over time they perturb one another and the orbits begin to intersect.
- After a period of violent collisions, you are left with a set of final planets.
Jovian Planets

• Nothing we have discussed so far involves hydrogen and helium gas. Since the Jovian planets are made mostly of these materials we need another step for them.

• Under the standard model, once an embryo reaches about 10 Earth masses, it can hold onto the gas in the nebula. This enhances growth that leads to a runaway process that is stopped only when material is exhausted.

• There are problems with this model. There is evidence that Jupiter formed very quickly. Also, measurements of core sizes don't agree well.
Giant Instability Model

- An alternative model is that proposed by Alan Boss where gravitational instabilities lead to collapse of regions of the disk.
- This requires that the disk have a sufficient density and/or be sufficiently cold. It isn't clear if disks meet these criteria. Simulations can't currently produce stable protoplanets.
- If this did happen it could form Jupiter and Saturn very quickly (less than 1 million years). It would also agree better with core measurements.
Nice Model

- The core accretion model has gained additional support from the development of the Nice model which explains many other features of the solar system.
  - Uranus and Neptune form closer in.
  - Outer Solar System goes through rapid evolution after about a half billion years when Jupiter and Saturn cross 2:1 resonance.
  - Fallout includes late, heavy bombardment.
Solar Wind

- In the end, the Sun begins to fuse and develops a strong solar wind that blows away the solar nebula.
- This would terminate the growth of the giant planets and signals other changes in the dynamics of the early solar system that we haven't really talked about.
The Sun's Rotation

- The early Sun should have been spinning very fast, being at the center of the collapse.
- The current Sun spins quite slowly, about once each month.
- Magnetic field transfers angular momentum to gas which is then blown away.
Minute Essay

- Do you have a laptop that you could bring to class for course evaluations at the end of the semester?
- Remember to turn in assignment #3 before you leave.