Homework

by Tuesday, 27 JAN
read/look through Chapter 1: 19 pages

by Thursday, 29 JAN
choose 1 topic for project
and turn in first page of 2 papers
Solar System Formation I
Clues to Solar System Formation

Internal Motion Clues

Internal Bodies Clues

External Clues
Internal Motion Clues to S.S. Formation

1. planetary orbits are roughly circular
2. planets are isolated
3. planetary orbits are roughly coplanar
4. planetary orbits are prograde (all)
5. moons’ orbits are prograde
6. … but not all
7. planetary rotations are prograde
8. … but not all
9. cometary orbits have high $a$, $e$, $i$
10. many moons are tidally locked and/or in resonance

**PAPER TOPIC: Where is the Oort Cloud anyway?**
Internal Bodies Clues to S.S. Formation

11. Sun contains 99.8% of Solar System mass
12. chondritic meteorites are $4.56 \pm 0.01$ Gyr old (Pb isotopes)
13. planet types/compositions depend on location (beware Moon)
14. planetary atmospheres contain ice fractions dependent on temp
15. all planets, large moons/asteroids differentiated (were warm)
16. meteorites have mineralogical differences, rapid heating/cooling
17. rapid impact cratering widespread, past far more than today’s rate
18. asteroids old, size distribution implies collisional evol ($0.05 \, M_{\text{moon}}$)
19. 98% of angular momentum resides in planet orbits
20. TNOs and Oort comets old and unevolved

PAPER TOPIC: How does the Kuiper Belt fit into S.S. origin?
External Clues to S.S. Formation

21. clouds of gas/dust observed

22. proplyds observed at very young ages --- a few million years

23. T Tauri stars observed

24. substantial disks observed at 10-100 million years

25. no disks seen (yet) past ~ 1 billion years

26. planets and planetary systems now detected

PAPER TOPIC: What’s the latest on disk statistics with age?
Formation Scenarios

1. CAPTURE  free floaters, planet theft

2. COLLISION  passing star, Sun fragmented

3. CONDENSATION  nebular hypothesis
Condensation to a Solar System

I. molecular cloud core \(\text{before } t = 0\)

II. freefall collapse \(t = 0.1 \text{ to } 1 \text{ Myr}\)

III. protostar / disk evolution \(t \sim 1 \text{ to } 10+ \text{ Myr}\)

IV. baby star / clearing / planet building \(t \sim 100 \text{ Myr}\)

V. evolution of Solar System \(t > 100 \text{ Myr}\)
1. Clouds of gas & dust collapse under gravity

2. Disk of gas and dust left over around new star.

3. Comets & asteroids form

Where do planets come from?

10,000 yr

100,000 yr

10 Myr

100 Myr
I. Molecular Cloud Core

T ~ 10-30 K

primarily H₂ and He, traced by CO, CN, OH, HCN, H₂O, etc.

Jeans mass is minimum mass for collapse:

\[ M_J \sim (kT/G \mu m)^{3/2} \rho^{-1/2} \]

assumes thermal pressure only (no turbulence, rotation, mag fields)

key attribute is density

shock mechanism is needed to start the process …

invoke hot star outflows, supernovae, spiral density waves
II. Freefall Collapse

0.1 to 1 Myr

timescale for collapse, \( t_{\text{ff}} \sim \rho^{-1/2} \) (inside-out collapse)

fragmentation may occur if cloud rotating … multiple star system

contraction by a factor of 1000X is likely

angular momentum problem results in disk formation
III. Protostar / Disk Evolution

1 to 1000 Myr (mass-dependent)

vertical collapse of disk

protostar stage occurs when infrared radiation trapped

magnetic braking of protostar when gas becomes ionized

viscous torques move material in and out

chemical evolution
Differentiation in Solar Nebula

![Diagram showing temperature vs. distance from the Sun, illustrating the differentiation process in the solar nebula.](image-url)
Disk Condensation Chemistry

Sun reflects initial elemental composition of disk

but … chemistry happens

disk changes composition over time

composition changes with distance from Sun
Disk Condensation Chemistry

*** assumes chemical equilibrium, low pressures of solar nebula ***

2000K      pretty much everything vaporized
1400K      Fe and Ni form an alloy
1300K      magnesium silicates (Mg/Si/O)
1200K      feldspars (Ca/Na/K/Al/Si/O)
700K 1 AU  carbon form transition CO $\rightarrow$ CH$_4$ (beware Pluto … solneb not eq)
500K      iron oxide (FeO), olivines/pyroxenes (Mg/Fe/Si/O)
[ 373K 2 AU H$_2$O liquid ]
300K      nitrogen form transition N$_2$ $\rightarrow$ NH$_3$ (beware Triton … solneb not eq)
[ 273K H$_2$O ice    ]
180K 3 AU  pure H$_2$O ice (hydrated silicates at warmer temps)
120K 4 AU  ammonia clathrate (NH$_3$ $\cdot$ H$_2$O)
[  77K N$_2$ liquid  ]
70K       methane clathrate (CH$_4$ $\cdot$ 6H$_2$O)
40K       CH$_4$ and Ar ices
25K       CO and N$_2$ ices

*** disequilibrium chemistry is norm beyond several AU ***
# Ices/Liquids in the Solar System

Phase transitions at one atmosphere pressure while cooling:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Substance</th>
<th>Object (Temperature)</th>
</tr>
</thead>
<tbody>
<tr>
<td>373K</td>
<td>H₂O liquid</td>
<td>Earth (hot)</td>
</tr>
<tr>
<td>273K</td>
<td>H₂O ice</td>
<td>Mars (hot)</td>
</tr>
<tr>
<td>240K</td>
<td>NH₃ liquid</td>
<td>Mars (cold)</td>
</tr>
<tr>
<td>195K</td>
<td>NH₃ ice</td>
<td>Earth (cold)</td>
</tr>
<tr>
<td>194K</td>
<td>CO₂ ice</td>
<td>Enceladus</td>
</tr>
<tr>
<td>186K</td>
<td>CO₂ ice</td>
<td>Jupiter</td>
</tr>
<tr>
<td>124K</td>
<td>CH₄ liquid</td>
<td>Saturn</td>
</tr>
<tr>
<td>90K</td>
<td>CH₄ ice</td>
<td></td>
</tr>
<tr>
<td>77K</td>
<td>N₂ liquid</td>
<td>Enceladus</td>
</tr>
<tr>
<td>63K</td>
<td>N₂ ice</td>
<td>Uranus, Neptune</td>
</tr>
<tr>
<td>72K</td>
<td></td>
<td>Pluto</td>
</tr>
<tr>
<td>59K</td>
<td></td>
<td>Triton</td>
</tr>
<tr>
<td>45K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>38K</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Solar System Explorers 2015

Rules:
1. Goal is roughly once each week (Thursdays).
2. You will know the topic a week in advance.
3. You will draw a mini-Mars each week. You will answer in order of your mini-Mars value. The value on your mini-Mars determines the number of points you can earn that round: 1-5 earns 3 points, 6-10 earns 4 points, 11-15 earns 5 points.
4. You may not re-use or re-attempt an answer already mentioned. Be careful not to effectively repeat an answer already given.
5. You must be clear in your answer, and I will be the final judge of whether points will be awarded. Partial points may be awarded.
6. Results will be posted on the course website.

This game is for learning (and fun), NOT for bickering, backstabbing, and/or browbeating … but it does affect your grade.
Describe something you have already learned in this course that you did not know previously.