Announcements

- HW #4 handed out today; due Tues Nov 13
- Midterms will be returned on Tues
- Observing tonight → 9:00pm on the roof of Sterling Hall.
Compare and contrast....
Giant Planets – issues

- Basics
  - Interior structure (is there something solid?)
    - Sources of heat
    - Magnetic fields
  - Composition – deviations from solar?
  - Atmospheric physics
    - What accounts for the colors?
- Can the giant planet systems be considered “mini-solar systems?”
  - Ring systems
  - Extensive satellite systems
- Cool Moons
  - Io, Europa, Titan, Triton
- Formation
  - How long does it take to form a gas giant?
  - How did they get there?
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How do you measure the chemical composition of a giant planet?
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- **Spectroscopy** → largely IR, some optical, some radio
  - CO$_2$ absorbs at 4.3μm, 15μm
  - CH$_4$ at 3.3μm, 7.7μm, and numerous optical lines
  - NH$_3$

- **Occultation**
  - Planet comes between Earth and star; atmosphere absorbs light → radiative transfer!!!!
Giant Planets – Composition

- How ‘bout going there?
- Cassini (Saturn), New Horizons (Jupiter)
- Galileo Probe – Jupiter (December 1995)
  - Descended for ~57 mins
  - Final depth ~600 km, pressure ~24 bar
  - Measures composition, ρ, T, wind speed, P
- Results from Galileo (see table 4–5)
  - “All” H,He
    - He underabundant in atmosphere
    - CH₄ more abundant in U+N by factor of 10
# Atmospheric Compositions

<table>
<thead>
<tr>
<th></th>
<th>Sun</th>
<th>Jup</th>
<th>Sat</th>
<th>Ura</th>
<th>Nep</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>84</td>
<td>86.4</td>
<td>97</td>
<td>83</td>
<td>79</td>
</tr>
<tr>
<td>He</td>
<td>16</td>
<td>13.6</td>
<td>3</td>
<td>15</td>
<td>18</td>
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<tr>
<td>H₂O</td>
<td>0.15</td>
<td>0.1</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.07</td>
<td>0.21</td>
<td>0.2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>NH₃</td>
<td>0.02</td>
<td>0.07</td>
<td>0.03</td>
<td>-</td>
<td>-</td>
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<tr>
<td>H₂S</td>
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<td>0.008</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C/H</td>
<td>1</td>
<td>2.9</td>
<td>3</td>
<td>30-40</td>
<td>30-40</td>
</tr>
</tbody>
</table>
What’s an atmosphere?

- What do you call the atmosphere of a gas ball?
- H₂O in atmospheres
  - Via mid-IR spectroscopy → H₂O in all giant planets
  - 10x overabundant (over theory) → accretion?
- Atmospheric/interior structure/composition
  - Stratosphere (P < 1 bar) H₂O, NH₃, CH₄
  - Troposphere (1 bar) → clouds of NH₃, NH₄SH, H₂O
  - 10⁴ > P > 100 bar → cloud deck of SiO₂, CO, N₂
  - P ~ 10⁴ → H₂
  - P ~ 10⁶ → metallic H
Physical Processes in the Atmospheres of the Giant Planets

- Upper layers of atmosphere
  - Convection to P ~ 100mbar
  - T increases above this → why?
  - Highest, thinnest → charged particles trapped in B field

- Condensation
  - J+S → Hydrated molecules (H₂O, H₂S, NH₄SH)
  - U+N → CH₄ → so why are these planets blue??
  - What accounts for the bands of color on J, S??
More Physical Processes

- Define some equation of state for H, He mixture....

\[ T = T(P), \ P = P(\rho) \rightarrow \rho(R) \]

- Assume hydrostatic equilibrium \( \rightarrow \) conclude the interior is nearly completely convective!!!
  - What are the conditions for convection?
Convective Interiors

- What does convection do?
What does convection do?

- Stirs things up → affects chemistry
- Source of mechanical energy → drives eddies in outer layers of atmosphere
- Lightning → Galileo satellite detected lightning in Jovian cloud structures
Special Note – Volatiles

- Volatiles must be trapped in a solid (e.g. ice)
- At high T, volatiles remain gaseous
Volatile must be trapped in a solid (e.g. ice)

At high T, volatiles remain gaseous

Galileo – Ar, Kr, Ne 2x more abundant than predicted by solar nebula model → implies formation in cold region (T < 75K)
- Ar, N₂ at T < 30K
- Ne at T < 17K → way beyond Pluto!!!!
- how’d this stuff get incorporated into Jupiter????
Structure of Giant Planets

- What happens to common molecules at ridiculous pressures?
- What kind of deformations occur with a spinning ball of gas?
- Are there solid cores in the centers of the giant planets?
Is Jupiter the biggest “planet” possible?
- $\sim 80M_J \rightarrow$ w/out H fusion = brown dwarf
- Probably have D fusion
What’s a planet?

The diagram shows the relationship between the radius and mass of exoplanets, with different markers indicating specific planets and regions labeled as H+He, H2, Water ice, and Olivine.
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What is the basic behavior of H?
- T(1 bar) $\rightarrow$ 165K (J), 135K (S), 76K (U), 50K (N)
- $10^5$ bar $\rightarrow$ hot liquid
- 1Mbar $\rightarrow$ 10,000 km $\rightarrow$ liquid metallic H
  - Fantastic conductor $\rightarrow$ B-field
Giant Planets
Comparison of the Giant Planets

![Graph showing the comparison of giant planets in terms of temperature and pressure. The graph includes lines for gaseous hydrogen, liquid metallic hydrogen, brown dwarf, and solid metallic hydrogen. Points for Jupiter, Saturn, Neptune, and Uranus are marked. The triangular area represents the region where helium rainout might occur.]
Structure of the Giant Planets

Uranus
- ~70 K 100 kPa
- ~2000 K 10 GPa
- ~8000 K 800 GPa
- Mixed with rocks?
- Rocks?

Neptune
- ~70 K 160 kPa
- ~2000 K 10 GPa
- ~8000 K 800 GPa

Jupiter
- 15000–21000 K 4000 GPa
- Ices + Rocks core?

Saturn
- 5650–6100 K 200 GPa
- Metallic H (Y~0.20?)
- Iahomogeneous?

Molecular H₂ (Y~0.23)

Metallic H (Y~0.27)
A few specific studies

- Benedetti et al 1999 Science 286 100 → What is the fate of methane under conditions in Neptune’s interior?
- Anallotto et al 1997 Science 275 1288 → more on methane in Neptune, Uranus
- Cavazzoni et al 1999 Science 283 44 → How do NH₃ and H₂O behave at high P, T?