This evening’s announcements

Homework 4 assignment sheet available at entry, due Wednesday, March 19.

Quiz 4 is graded and available at entry.

Corrections for extra credit are due with homework.

The next Brooks Observatory session for this class will be next week, Mon. – Thu., starting at 8:30 PM, not 7:30 PM as originally announced.
Jovian planets, satellites, rings

Jupiter vital statistics

- Diameter: 11 Earths
- Mass: 300 Earths (1/1000 Sun; contains about 70% of planetary mass)
- Rotation period about 10 hours, equatorial speed 28,000 mph
Density 1.2 grams per cubic centimeter

- Implies mostly made of hydrogen & helium
- Similarity to density of water is accidental
- Internal material is highly compressed by planet’s strong gravitational pull, with density at center above 25 grams per cubic centimeter
- Density progressively smaller toward outside, tiny fraction of a gram per cubic centimeter in atmosphere
Telescopic view: nothing but clouds

- Striped appearance caused by rapid rotation stretching clouds out
- Strong cyclonic, anticyclonic storms
- Dramatic changes observed by *Hubble Space Telescope* in early 2007
Best information about atmosphere is from *Galileo* entry probe, Dec. 1995

- Fell in for 61 minutes, then stopped transmitting
- Reached depth 90 miles, temperature approximately $300^\circ$ F, pressure 24 atmospheres

- Main findings
  - Composition, temperature, pressure of atmosphere through which it fell
  - First direct sampling of helium abundance (difficult to measure from the spectrum)
  - High winds far below visible cloud tops
Atmospheric composition

- Hydrogen
- Helium
- Methane (CH₄), ammonia (NH₃), other hydrogen-rich compounds
- Counting by elements, composition is similar to that of Sun: 90% of atoms are hydrogen, 10% are helium, all other elements present in small traces
Infrared radiation from Jupiter

Jupiter emits more energy than it receives from the Sun — it is an independent source of infrared thermal radiation.
Why its heat source is more visible from the outside than Earth’s

- Jupiter’s interior is much hotter
- Jupiter made of fluids rather than rock; moving fluid in the interior carries heat to the exterior.
Why is Jupiter so hot inside?

- Radioactivity is not important here; not enough radioactive substances
- Unlike the Earth, Jupiter formed hot

Probable formation process

- Solid body accretion built up planet to about 10 or more Earth masses, rock and ices
- Then, its gravity became strong enough to attract gas, mostly hydrogen and helium
- It grew very large & massive
- Gravitational contraction & heating
## Comparison of the jovian planets

<table>
<thead>
<tr>
<th>Planet</th>
<th>Mass (Earth = 1)</th>
<th>Radius (Earth = 1)</th>
<th>Bulk density (grams per c.c.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jupiter</td>
<td>320</td>
<td>11.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Saturn</td>
<td>90</td>
<td>9.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Uranus</td>
<td>14</td>
<td>4.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Neptune</td>
<td>17</td>
<td>3.9</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Saturn is almost as large in size as Jupiter in spite of much smaller mass

- Hence its low density
- Weaker gravitational pull, therefore less compressed
• Similar composition despite lower density

Uranus & Neptune

• Larger density in spite of smaller masses, less gravitational compression

• Implies larger content of rocky material

• Reason: similar formation process, but less gas available at formation?
Appearance of jovian planets

**Saturn**: cloud layers located deeper in atmosphere, therefore less visible than Jupiter’s

**Uranus, Neptune**

- Cloud layers likewise deeper in atmosphere, less visible than Jupiter’s
- Blue color caused by methane, which absorbs red light
The Galilean Satellites of Jupiter

Jupiter’s largest satellites, discovered by Galileo

One is bigger than Mercury, and the other 3 are bigger than the Moon.

In order of increasing distance from Jupiter:

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Density (grams per c.c.)</th>
<th>Likely composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Io</td>
<td>3.5</td>
<td>Rock</td>
</tr>
<tr>
<td>Europa</td>
<td>3.3</td>
<td>Rock</td>
</tr>
<tr>
<td>Ganymede</td>
<td>1.9</td>
<td>Half rock, half ice</td>
</tr>
<tr>
<td>Callisto</td>
<td>1.8</td>
<td>Half rock, half ice</td>
</tr>
</tbody>
</table>

265
A “miniature solar system” with density decreasing going away from the heat source in the center.

Evidence that Jupiter was indeed hot at formation:

- Galilean satellites formed by solid-body accretion.
- Close to Jupiter (at Io), only rocks and metals could condense.
- Farther away, more and more ices in the mix, so lower-density bodies formed.
Callisto

Cratered surface

Light/dark contrast implies mixture of ice & rock

Impact basin; heavily cratered, unmodified surface

Oldest, most heavily cratered surface in solar system, no signs of any resurfacing

But Galileo discovered lack of small craters; also erosion features implying evaporation of ices
Ganymede

The largest of the four

Two types of terrain

• Dark, heavily cratered, like Callisto

• Lighter, grooves and cracks, few craters; a younger, modified surface; some kind of crustal plate motion
Europa

Bright, icy surface with only small height differences

Few impact craters, implying recent resurfacing

*Galileo* closeup views suggest large-scale *ice floes*

*Ridges* resemble sea-floor spreading centers on earth

Structure of satellite: icy crust atop mobile subsurface layer

- Semi-fluid ice layer?

- Or subsurface ocean? Past or present?
Io

Active volcanoes; plumes

Enough material ejected to cover surface completely every million years

Most volcanic body known in solar system

Heat source?

Io, Europa, Ganymede show surface activity indicating warm interior
Reason for heating:

Jupiter

Io

Europa

(Size & shape exaggerated for clarity)
• Jupiter’s gravitational pull weaker on satellite’s far side than on its near side (tide, same as between Earth and Moon)

• Causes satellite to be elongated in shape

• Other satellite’s gravity causes small changes in this distorted shape: squeezing & unsqueezing

• Frictional heating

• A similar process heats Europa, but less strongly because it is farther from Jupiter.
Saturn’s satellite Enceladus¹

Ice-covered body with density 1.2 grams per cubic centimeter

Parts of surface are crater-covered, parts are highly modified.

“Tiger stripe” terrain near south pole has active water ice “geysers.”

A liquid water source is conjectured.

Last week, Cassini flew through the plumes to sample the ejected material. Results of analysis are to come.

¹ Pronounced like “en-salad-us,” not like “enchilada.”
Saturn’s satellite Titan

Second largest satellite in solar system, after Ganymede; Saturn’s only large satellite

Bulk density is 1.9 grams per cubic centimeter; suggests ice & rock bulk composition
Atmosphere

- Opaque in visible light because of haze & clouds
- Composition mostly nitrogen (N$_2$)
- Methane (CH$_4$) can exist as solid, liquid, or gas (similar to water on Earth)
- Other substances: various hydrocarbons
- A recent discovery: propane (C$_3$H$_8$) in upper atmosphere