#### **Test 3 Result (Section 1)**

#### **Grade Histogram Column Statistics for: Test3** Count: [0.00, 5.00) 86 Average: [5.00, 10.00) 36.4 [10.00, 15.00) Median: [15.00, 20.00) 37.5 원 [ 20.00, 25.00 ) 명 민 ( 25.00, 30.00 ) 민 ( 30.00, 35.00 ) Maximum: 50.0 Minimum: 14.0 [ 35.00, 40.00] Standard Deviation: [40.00, 45.00) 7.89 [45.00, 50.00) [50.00] 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27

Frequency

#### **Test 3 Result (Section 2)**

#### **Column Statistics for: Test3**

Count: **113** Average: **37.3** Median: **38.0** Maximum: **49.0** Minimum: **19.0** Standard Deviation: **6.91** 





#### Face on Mars!?

#### Elephant on Mars?!





#### 1976 Viking Orbiter



#### Chapter 11 Jovian Planet Systems



#### 11.1 A Different Kind of Planet

#### Our goals for learning:

- Are jovian planets all alike?
- What are jovian planets like on the inside?
- What is the weather like on jovian planets?
- Do jovian planets have magnetospheres like Earth's?

#### **Exploration of Jovian Planets**

- Scientists established the value of AU only in 1760s, so only then the immense sizes of Jupiter and Saturn were recognized.
- Uranus and Neptune were discovered in 1781 and 1846, so they were unknown during the Copernican revolution.
- Pioneer 10 & 11: Jupiter and Saturn in 1970s
- *Voyager 1 & 2*
- *Galileo*: Jupiter, 1995-2003
- Cassini: Saturn, 2004
- New Horizons: Jupiter, 2007

#### Are jovian planets all alike?



- The terrestrial planets grew only through accretion of solid planetesimals containing rock and metal, which were quite rare in the solar nebula. So the terrestrial planets never grew massive enough for their gravity to hold much of H & He.
- On the other hand, the jovian planets grew from **ice-rich planetesimals**, which were much more abundant --- differences in composition comes from the amount of H & He gas that they captured.

## **Jovian Planet Composition**

- Jupiter and Saturn
  - Mostly H and He gas
- Uranus and Neptune
  - Mostly hydrogen compounds: water (H<sub>2</sub>O), methane (CH<sub>4</sub>), ammonia (NH<sub>3</sub>); heavier than just H & He gas
  - Some H, He, and rock

# What are jovian planets like on the inside?



Combination of theoretical models and laboratory experiments tells us the inner structure.

#### **Interiors of Jovian Planets**

- No solid surface.
- Layers under high pressure and temperatures.
- Cores (~10 Earth masses) made of hydrogen compounds, metals & rock
- The layers are different for the different planets. WHY?

### **Inside Jupiter**



- High pressures inside Jupiter cause phase of hydrogen to change with depth
- Hydrogen acts like a **metal** at great depths because its electrons move freely
- Core is thought to be made of rock, metals, and hydrogen compounds
- Core is about same size as Earth but 10 times as massive

## **Comparing Jovian Interiors**



- Models suggest cores of jovian planets have similar composition
- Lower pressures inside Uranus and Neptune mean no metallic hydrogen

#### **Jupiter's Internal Heat**



- Jupiter radiates
  twice as much
  energy it receives
  from Sun
- Energy probably comes from slow
   contraction of interior (releasing gravitational potential energy)

#### Internal Heat of Other Planets

- Saturn also radiates twice as much energy it receives from Sun, but Saturn's mass is too small for it to be generating this heat by contraction like Jupiter.
- Energy probably comes from **differentiation** (helium rain) in Saturn.
- Uranus emits virtually no excess heat.
- Neptune emits nearly twice as much energy as it receives, but the source of that energy remains mysterious



#### What is the structure of Jupiter like?

- A. Rocky core, thin atmosphere
- B. Rocky core, thick atmosphere
- C. Gaseous on the outside, then liquid hydrogen, more dense metallic hydrogen, rocky core
- D. Gaseous on the outside, then liquid hydrogen, then helium, then the other elements



#### How does the energy Jupiter radiates back to space compare to the energy from the Sun that falls on it?

- A. Jupiter gives off more than it receives
- B. Jupiter gives off about as much as it receives
- C. Jupiter gives off less than it receives



# How do astronomers think Jupiter generates internal heat?

- A. Fusion
- **B.** Chemical reactions
- C. Friction due to its fast rotation
- D. Shrinking and releasing gravitational potential energy

# What is the weather like on jovian planets?



#### Jupiter's Atmosphere



- Jupiter has a similar temperature structure to the Earth atmosphere.
- Temperature rises in troposphere because of greenhouse effect -- leads to convection --> clouds
- Hydrogen compounds in Jupiter form clouds
- Different cloud layers correspond to freezing points of different hydrogen compounds

### **Jovian Planet Atmospheres**



- Other jovian planets have cloud layers similar to Jupiter's
- Atmospheres get progressively cooler with increasing distance from the Sun
- Saturn's clouds are vertically more separated because of weaker gravity than Jupiter.

## Jupiter's colors



- Different compounds make clouds of different colors
- Ammonium sulfide clouds (NH<sub>4</sub>SH) reflect red/brown -- but could be from as-yetunidentified compounds
- Ammonia, the highest, coldest layer, reflects white.

#### Saturn's colors



- Saturn's layers are similar, but deeper in.
- Less light penetrates to the depths of the clouds, and the reflected light is obscured by the atmosphere above them.

#### Methane on Uranus and Neptune

.....Light of all colors comes from the Sun.

Methane gas absorbs red light • and transmits blue light . . .

methane gas mixed with hydroger

- Methane gas of Neptune and Uranus absorb red light but transmit blue light
- Blue light reflects
   off methane clouds,
   making those planes
   look blue

#### **Global Winds and Storms on Jupiter**

- Jupiter has planetwide circulation cells like Earth.
- Solar heat causes equatorial air to expand and spill towards the poles.
- the **Coriolis effect** splits the large equator-topole circulation cells into smaller cells ----Jupiter rotates much faster than Earth ---- split into many alternating bands of rising and falling air.

#### **Jupiter's Bands**

White ammonia clouds form where air rises

Between white clouds we see deeper reddish clouds of ammonium hydrosulfide Coriolis effect changes N-S flow to E-W winds

Warmer red bands (lower altitiude clouds) are brighter in IR



#### Jupiter's Great Red Spot



- A storm twice as wide as Earth
- Has existed for at least 3 centuries

• Smaller storms -- brown ovals are low-pressure storms, and white ovals are high-pressure storms topped with ammonia clouds

#### Weather on Jovian Planets



- All the jovian planets have strong winds and storms
- Saturn's wind is even faster than Jupiter's.
- Saturn may have seasons because of axis tilt.
- Neptune has the "Great Dark Spot", similar to Jupiter's Great Red Spot. Disappeared within 6 yrs.

#### Jupiter's Magnetosphere



- Jupiter's strong magnetic field (x20,000 stronger than Earth's) gives it an enormous magnetosphere
- Gases escaping *Io* feed the donut-shaped *Io torus*

### **Other Magnetospheres**



All the jovian planets have substantial **magnetospheres**, but Jupiter's is largest by far

- The size of
  magnetosphere also
  depends on the strength
  of solar wind -- less
  effect of solar wind on
  Uranus and Neptune
- Magnetic fields of Uranus and Neptune are not aligned with the rotation axis - a mystery.



Jupiter does *not* have a large metal core like the Earth. How can it have a magnetic field?

- a) The magnetic field is left over from when Jupiter accreted
- b) Its magnetic field comes from the Sun
- c) It has metallic hydrogen inside, which circulates and makes a magnetic field
- d) That's why its magnetic field is weak

#### What have we learned?

- Are jovian planets all alike?
  - Jupiter and Saturn are mostly H and He gas
  - Uranus and Nepture are mostly H compounds
- What are jovian planets like on the inside?
  - Layered interiors with very high pressure and cores made of rock, metals, and hydrogen compounds
  - Very high pressure in Jupiter and Saturn can produce metallic hydrogen

#### What have we learned?

- What is the weather like on jovian planets?
  - Multiple cloud layers determine colors of jovian planets
  - All have strong storms and winds
- Do jovian planets have magnetospheres like Earth's?
  - All have substantial magnetospheres
  - Jupiter's is largest by far

#### **11.2 Satellites of Ice and Rock**

Our goals for learning:

- What kinds of **moons** orbit jovian planets?
- Why are Jupiter's **Galilean moons** so geologically active?
- What is remarkable about **Titan** and other major moons of the outer solar system?
- Why are small icy moons more geologically active than small rocky planets?

# What kinds of moons orbit the jovian planets?



#### **Sizes of Moons**

- Small moons (< 300 km)</li>
  No geological activity
- Medium-sized moons (300-1,500 km)
   Geological activity in past
- Large moons (> 1,500 km)
   Ongoing geological activity



## Medium & Large Moons

- Enough self-gravity to be spherical
- Have substantial amounts of **ice**.
- Formed in orbit around jovian planets.
- Circular orbits in same direction as planet rotation.

## Small Moons



- Far more numerous than the medium and large moons.
- Not enough gravity to be spherical: "potato-shaped"
- Captured asteroids or comets, so orbits do not follow usual patterns.

# Why are Jupiter's Galilean moons so geologically active?



#### **Io's Volcanic Activity**



- Io is the most **volcanically active** body in the solar system, but why?
- Red color: sulfur, White: sulfur dioxide.



### Orbital Resonances

The tugs add up over time, making all 3 orbits elliptical.



#### **Io's Volcanoes**



- Volcanic eruptions continue to change Io's surface
- Eruptions are so frequent that they have buried most impact craters.
- Sulfur and sulfur dioxide (SO2) are outgassed up to 100s of km.
- Supplies ionized gas to the Io torus and Jupiter's magnetosphere.
- It must be quite hot inside -- tidal heating.