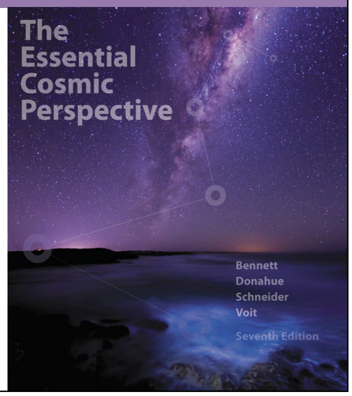
Lecture Outline

## Chapter 8: Jovian Planet Systems





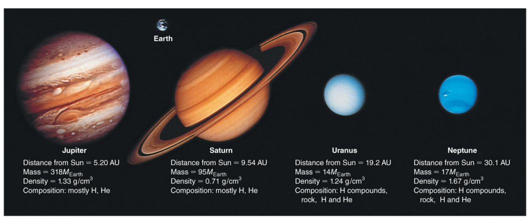

## 8.1 A Different Kind of Planet

Our goals for learning:

- What are jovian planets made of?
- What is the weather like on jovian planets?



## What are jovian planets made of?






## Jovian Planet Composition

- Jupiter and Saturn
  - Mostly H and He gas
- Uranus and Neptune
  - Mostly hydrogen compounds: water ($H_2O$), methane ($CH_4$), ammonia ($NH_3$)
  - Some H, He, and rock



## Jovian Planet Formation

- Beyond the frost line, planetesimals could accumulate ICE.
- Hydrogen compounds are more abundant than rock/metal so jovian planets got bigger and acquired H/He atmospheres.



## Jovian Planet Formation

- The jovian cores are very similar: ~ mass of 10 Earths
- The jovian planets differ in the amount of H/He gas accumulated.

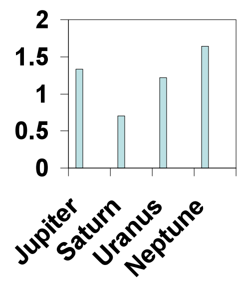
Why did that amount differ?

## Differences in Jovian Planet Formation

- TIMING: The planet that forms earliest captures the most hydrogen and helium gas. Capture ceases after the first solar wind blows the leftover gas away.
- LOCATION: The planet that forms in a *denser* part of the nebula forms its core first.



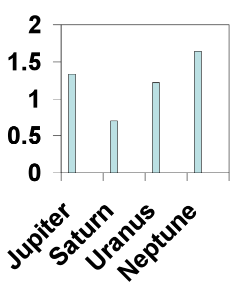
## Density Differences




- Uranus and Neptune are denser than Saturn because they have less H/He, proportionately.



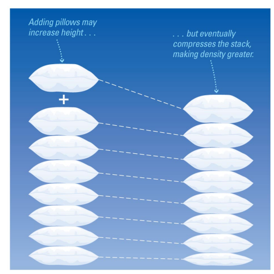
## Density Differences




- But that explanation doesn't work for Jupiter.



## Sizes of Jovian Planets

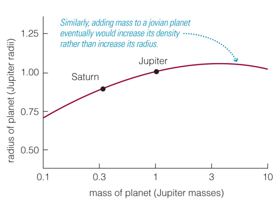



a Adding pillows to a stack may increase its height at first but eventually compresses the stack, making its density greater.

- Adding mass to a jovian planet compresses the underlying gas layers.



## Sizes of Jovian Planets




b This graph shows how radius depends on mass for a hydrogen/helium planet. Notice that Jupiter is only slightly larger in radius than Saturn, despite being three times as massive. Gravitational compression of a planet much more massive than Jupiter would actually make its radius smaller.

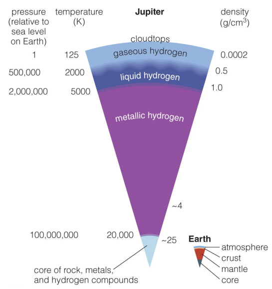
- Greater compression is why Jupiter is not much larger than Saturn, even though it is three times more massive.
- Jovian planets with even more mass can be smaller than Jupiter.



## Interiors of Jovian Planets

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

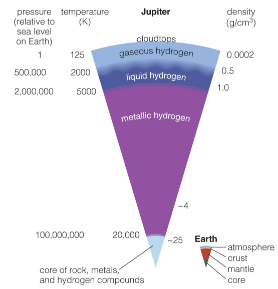
## Inside Jupiter




- High pressure inside of Jupiter causes the phase of hydrogen to change with depth.
- Hydrogen acts like a metal at great depths because its electrons move freely.



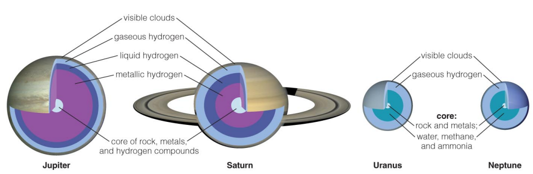
## Inside Jupiter




- The core is thought to be made of rock, metals, and hydrogen compounds.
- The core is about the same size as Earth but 10 times as massive.



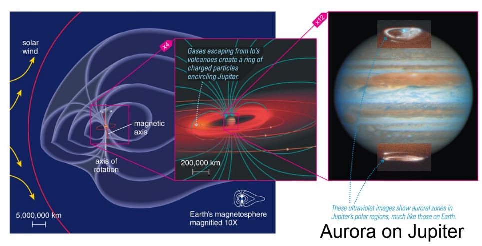
## Comparing Jovian Interiors




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



## Jupiter's Magnetosphere

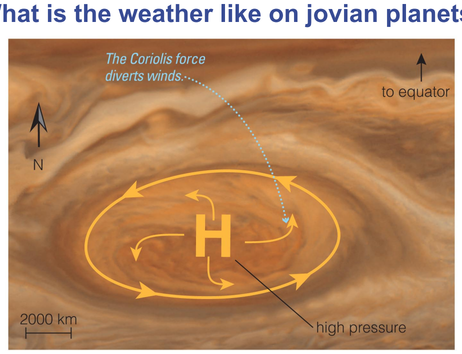



Aurora on Jupiter

- Jupiter's strong magnetic field gives it an enormous magnetosphere.
- Gases escaping Io feed the donut-shaped Io torus.

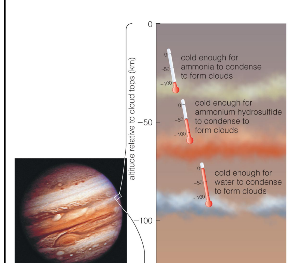


## What is the weather like on jovian planets?






## Jupiter's Atmosphere



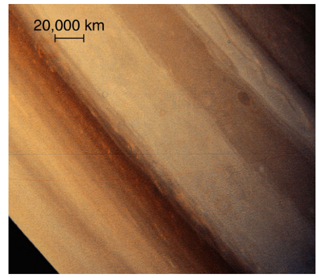

- Hydrogen compounds in Jupiter form clouds.
- Different cloud layers correspond to freezing points of different hydrogen compounds.
- Other jovian planets have similar cloud layers.

## Jupiter's Colors


- Ammonium sulfide clouds ($NH_4SH$) reflect red/brown.
- Ammonia, the highest, coldest layer, reflects white.



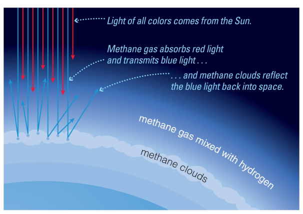
## Saturn's Colors




- Saturn's layers are similar but are deeper in and farther from the Sun—more subdued.



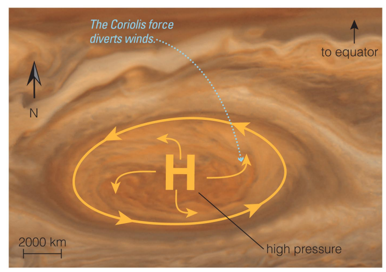
## Methane on Uranus and Neptune




- Methane gas on Neptune and Uranus absorbs red light but transmits blue light.
- Blue light reflects off methane clouds, making those planets look blue.



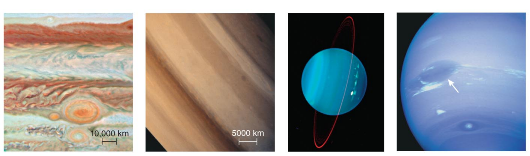
## Jupiter's Great Red Spot




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



## Weather on Jovian Planets




**a** This Hubble Space Telescope image shows Jupiter's southern hemisphere with the Great Red Spot, "Baby Red" (to its left), and "Red Jr." (below). Baby Red was torn apart by the Great Red Spot a few days later.

**b** Saturn's atmosphere, photographed by *Voyager 1*. Its banded appearance is very similar to that of Jupiter, but it has even faster winds.

**c** This infrared image of Uranus from the Keck Telescope shows several storms (the bright blotches) and Uranus's thin rings (red).

**d** Neptune's atmosphere, viewed from *Voyager 2*, shows bands and occasional strong storms. The large storm (white arrow) was called the Great Dark Spot.

- All the jovian planets have strong winds and storms.



## What have we learned?

- What are jovian planets made of?
  - Jupiter and Saturn are mostly made of H and He gas.
  - Uranus and Neptune are mostly made of H compounds.
  - They have 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 the colors of jovian planets.
  - All have strong storms and winds.



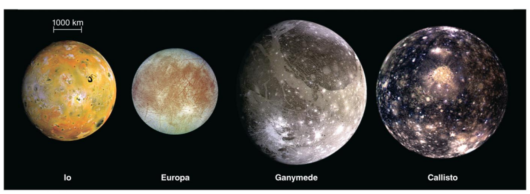
## 8.2 A Wealth of Worlds: Satellites of Ice and Rock

Our goals for learning:

- What kinds of moons orbit the jovian planets?
- Why are Jupiter's Galilean moons geologically active?
- What geological activity do we see on Titan and other moons?
- Why are jovian planet moons more geologically active than small rocky planets?



## What kinds of moons orbit the jovian planets?



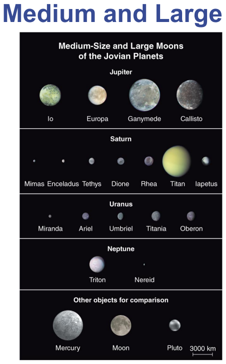



## Sizes of Moons

- Small moons (< 300 km)
  - No geological activity
- Medium-sized moons (300–1500 km)
  - Geological activity in past
- Large moons (> 1500 km)
  - Ongoing geological activity



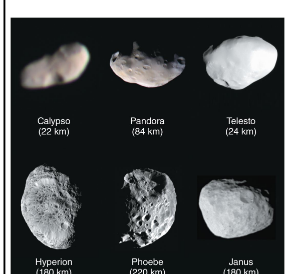
## Medium and Large Moons




- 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

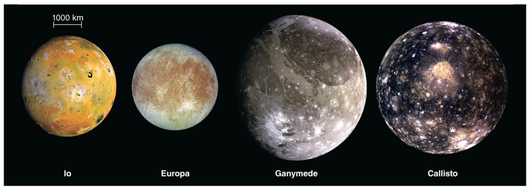


## Small Moons



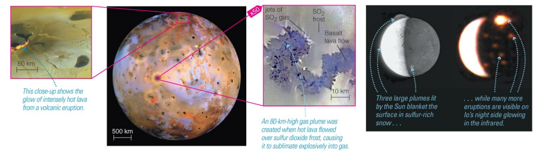

- Far more numerous than the medium and large moons
- Not enough gravity to be spherical: "potato-shaped"

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






## Io's Volcanic Activity



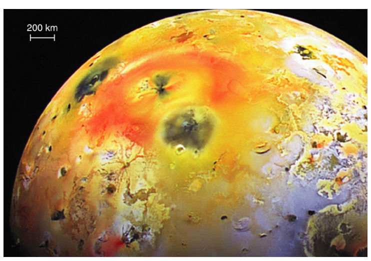

**a** Most of the black, brown, and red spots on Io's surface are recently active volcanic features. White and yellow areas are sulfur dioxide ($SO_2$) and sulfur deposits, respectively, from volcanic gases. (Photographs from the *Galileo* spacecraft; some colors slightly enhanced or altered.)

**b** Two views of Io's volcanoes taken by *New Horizons* on its way to Pluto.

- Io is the most volcanically active body in the solar system, but why?



## Io's Volcanoes



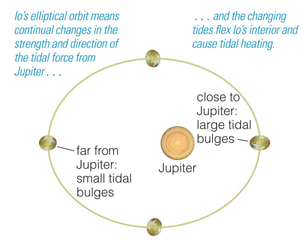

- Volcanic eruptions continue to change Io's surface.

PLAY Io Volcanoes IR



## Tidal Heating

Io is squished and stretched as it orbits Jupiter.



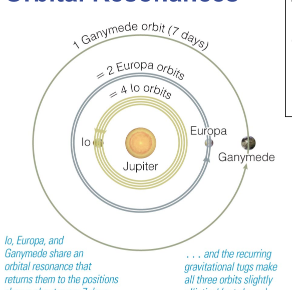

**a** Tidal heating arises because Io's elliptical orbit (exaggerated in this diagram) causes varying tides.

But why is its orbit so elliptical?



## Orbital Resonances

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

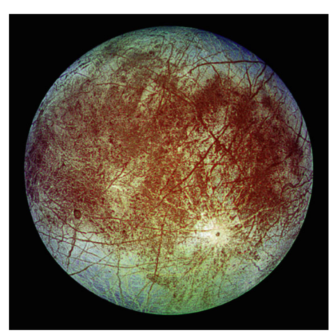



**b** Io's orbit is elliptical because of the orbital resonance Io shares with Europa and Ganymede.

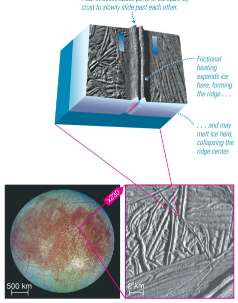
Every seven days, these three moons line up.



## Europa's Ocean: Waterworld?



## Tidal stresses crack Europa's surface ice

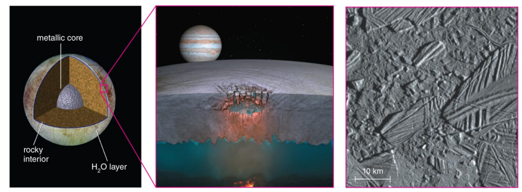



Europa's surface appears heavily cracked even from a distance.

Close-up photos show double-ridged cracks, best explained by an icy crust moving upon a soft or liquid layer below.



## Europa's interior also warmed by tidal heating



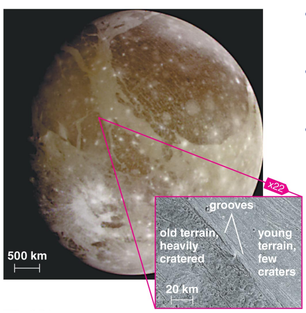

Europa may have a 100-km-thick ocean under an icy crust.

Rising plumes of warm water may sometimes create lakes within the ice, causing the crust above to crack . . .

. . . explaining surface terrain that looks like a jumble of icebergs suspended in a place where liquid or slushy water froze.



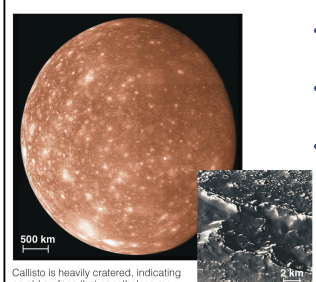
## Ganymede




- Largest moon in the solar system
- Clear evidence of geological activity
- Tidal heating plus heat from radio-active decay?



## Callisto




Callisto is heavily cratered, indicating an old surface that nonetheless may hide a deeply buried ocean.

Close-up photo shows a dark powder overlaying the low areas of the surface.

- "Classic" cratered iceball
- No tidal heating, no orbital resonances
- But it has magnetic field!?



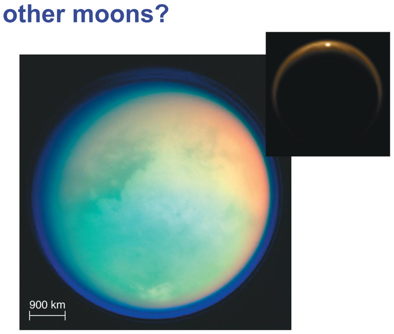
## Thought Question

How does Io get heated by Jupiter?

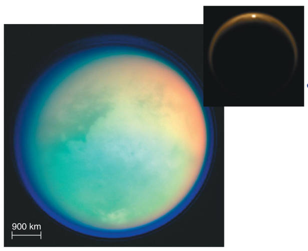
A. Auroras
B. Infrared light
C. Jupiter pulls harder on one side than the other
D. Volcanoes



## What geological activity do we see on Titan and other moons?



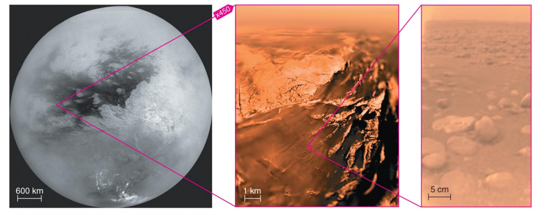
## Titan's Atmosphere




- Titan is the only moon in the solar system that has a thick atmosphere.
- It consists mostly of nitrogen with some argon, methane, and ethane.



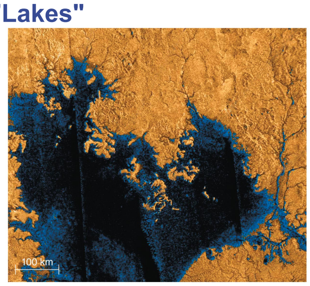
## Titan's Surface




- The *Huygens* probe provided a first look at Titan's surface in early 2005.
- It had liquid methane, "rocks" made of ice.



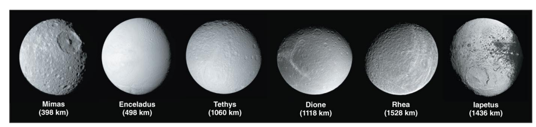
## Titan's "Lakes"




- Radar imaging of Titan's surface has revealed dark, smooth regions that may be lakes of liquid methane.



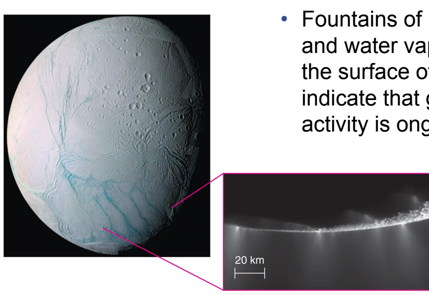
## Medium Moons of Saturn




- Almost all show evidence of past volcanism and/or tectonics.



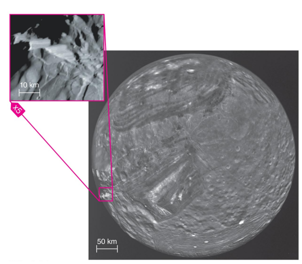
## Ongoing Activity on Enceladus




- Fountains of ice particles and water vapor from the surface of Enceladus indicate that geological activity is ongoing.

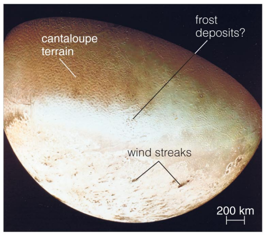


## Medium Moons of Uranus

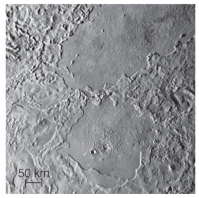



- Varying amounts of geological activity occur.
- Moon Miranda has large tectonic features and few craters (episode of tidal heating in past?).

## Neptune's Moon Triton



Triton's southern hemisphere as seen by *Voyager 2*.

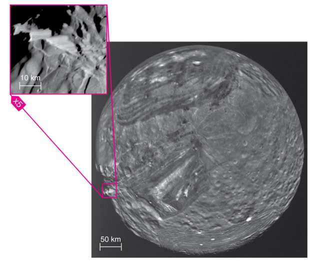


This close-up shows lava-filled impact basins similar to the lunar maria, but the lava was water or slush rather than molten rock.

- Similar to Pluto, but larger
- Evidence for past geological activity

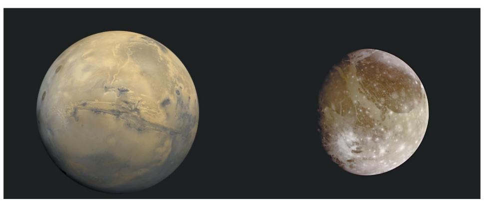


## Why are jovian planet moons more geologically active than small rocky planets?






## Rocky Planets vs. Icy Moons



- Rock melts at higher temperatures.
- Only large rocky planets have enough heat for activity.

- Ice melts at lower temperatures.
- Tidal heating can melt internal ice, driving activity.



## What have we learned?

- What kinds of moons orbit the jovian planets?
  - Moons of many sizes
  - Level of geological activity depends on size.
- Why are Jupiter's Galilean moons geologically active?
  - Tidal heating drives activity, leading to Io's volcanoes and ice geology on other moons.



## What have we learned?

- What geological activity do we see on Titan and other moons?
  - Titan is the only moon with a thick atmosphere.
  - Many other icy moons show signs of geological activity.
- Why are jovian planet moons more geologically active than small rocky planets?
  - Ice melts and deforms at lower temperatures, enabling tidal heating to drive activity.

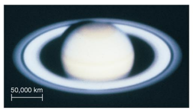


## 8.3 Jovian Planet Rings

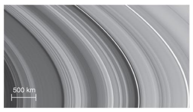
Our goals for learning:

- What are Saturn's rings like?
- Why do the jovian planets have rings?

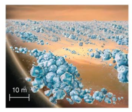
## What are Saturn's rings like?




**a** This Earth-based telescopic view of Saturn makes the rings look like large, concentric sheets. The dark gap within the rings is called the *Cassini division*.




**b** This image of Saturn's rings from the *Cassini* spacecraft reveals many individual rings separated by narrow gaps.




**c** Artist's conception of particles in a ring system. Particles clump together because of gravity, but small random velocities cause collisions that break them up.

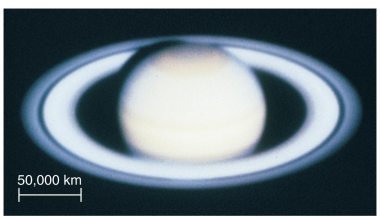


## What are Saturn's rings like?

- They are made up of numerous, tiny individual particles.
- They orbit over Saturn's equator.
- They are very thin.



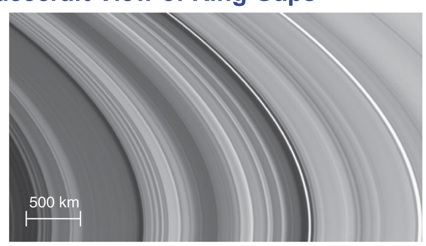
## Earth-Based View




**a** This Earth-based telescopic view of Saturn makes the rings look like large, concentric sheets. The dark gap within the rings is called the *Cassini division*.



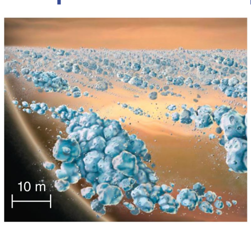
## Spacecraft View of Ring Gaps




**b** This image of Saturn's rings from the *Cassini* spacecraft reveals many individual rings separated by narrow gaps.



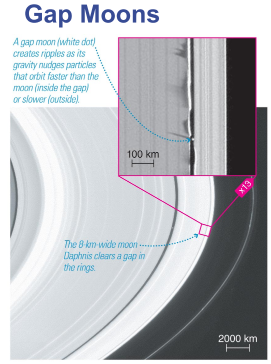
## Artist's Conception of Close-Up




**c** Artist's conception of particles in a ring system. Particles clump together because of gravity, but small random velocities cause collisions that break them up.

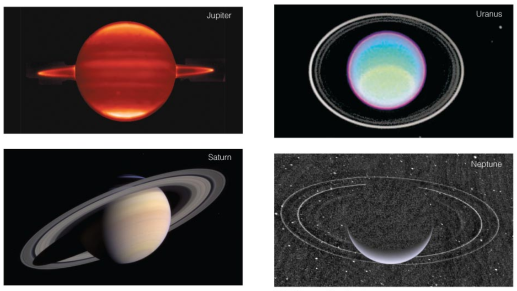


## Gap Moons




- Some small moons create gaps within rings.

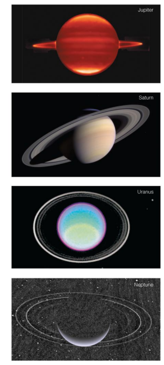
## Why do the jovian planets have rings?






## Jovian Ring Systems

- All four jovian planets have ring systems.
- Others have ring particles that are smaller and darker than Saturn's.





## Why do the jovian planets have rings?

- They formed from dust created in impacts on moons orbiting those planets.

How do we know this?

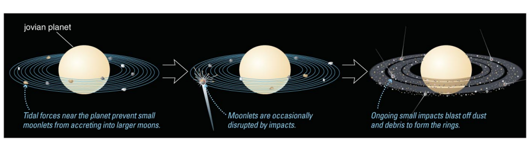


## How do we know?

- Rings aren't leftover from planet formation because the particles are too small to have survived this long.
- There must be a continuous replacement of tiny particles.
- The most likely source is impacts with the jovian moons.



## Ring Formation




- Jovian planets all have rings because they possess many small moons close-in.
- Impacts on these moons are random.
- Saturn's incredible rings may be an "accident" of our time.



## What have we learned?

- What are Saturn's rings like?
  - They are made up of countless individual ice particles.
  - They are extremely thin with many gaps.
- Why do the jovian planets have rings?
  - Ring systems of other jovian planets are much fainter with smaller, darker, less numerous particles.
  - Ring particles are probably debris from moons.