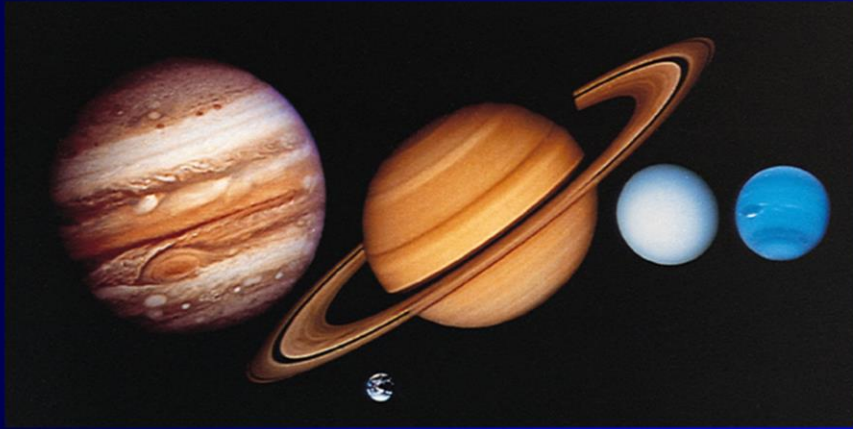


# The Jovian Planets



# The Jovian (Jupiter-like) Planets

Much larger and more massive than terrestrial planets



Much larger and much more massive than the terrestrial planets, although not necessarily as dense

Composed mostly of H, He, and H compounds

No solid surface

Fast rotation rates, therefore Slightly squished in nature

Many moons

- Over 100 combined

- Captured asteroids and comets

- Some similar to terrestrial planets

All have rings

# The Jovian Planets

Low density

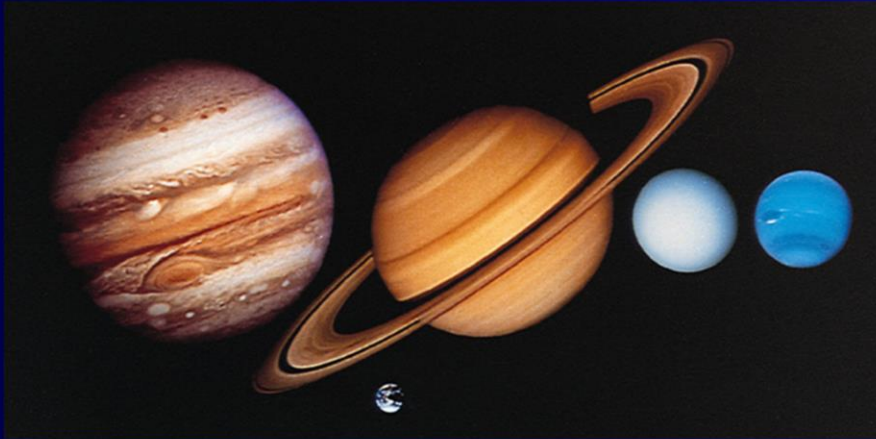
Composition: H, He, H compounds

No solid surface

Though it is possible that the stuff at the center of Uranus & Neptune are solid... hard to say for sure.

# Jovian Atmospheres

Colors are caused by different chemicals in the clouds



Different colors caused by different chemicals condensing into clouds (these are *trace* amounts)

White-yellow: Ammonia ( $\text{NH}_3$ )

Blue-green: Methane ( $\text{CH}_4$ )

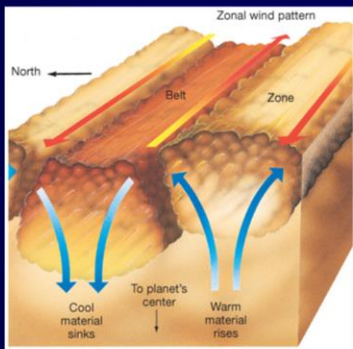
White: Water ( $\text{H}_2\text{O}$ )

Brown-rust: Ammonium Hydrosulfide ( $\text{NH}_4\text{SH}$ )

Atmosphere temperature and condensation points for each chemical explain planet colors

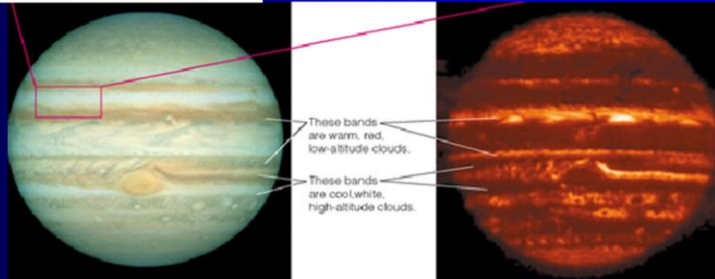
Uranus and Neptune are cold enough to form methane clouds which absorb red light and reflect blue light

# Jupiter's Atmosphere



Banding is caused by strong convection

Bands alternate hot and cold



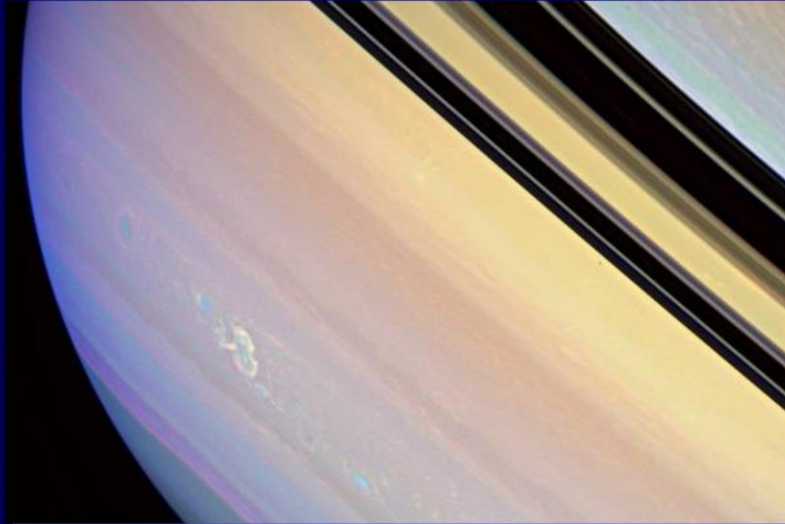
Severe winds within the troposphere, 300 miles an hour as measured by Galileo probe

Bands and zones created by strong convection

The great red spot is a giant hurricane – 2.5 times the diameter of Earth! It's been going on for over 400 years now.

Note: Jupiter (and Saturn and Neptune) actually emits more light than it receives!! This is because it's still undergoing gravitational contraction.

# Saturn



Saturn has intense lightning storms

Saturn isn't as dense as Jupiter because it has less gravity

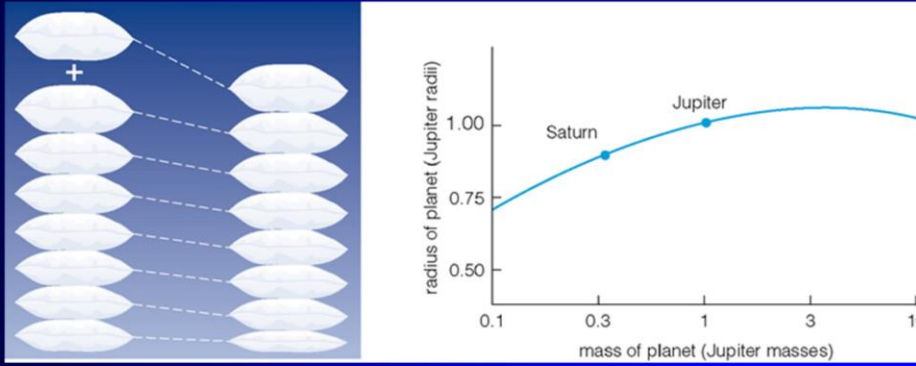
Also, its clouds are thicker due to less gravity; they get compressed less at the altitude that clouds form.

Like Jupiter, Saturn also emits more light than it receives; probably because He droplets are still condensing and raining down (sort of like differentiation, in a way)

Saturn has powerful lightning storms, ten thousand times stronger than on Earth, that occur in huge, deep thunderstorms columns nearly as large as the entire Earth. The storms occasionally boil up to the planet's visible surface.

# Sizes of the Gas Giants

Jupiter has three times the mass of Saturn



But is only slightly larger


Jupiter has 3 times the mass of Saturn but it is not much larger

Increasing the mass doesn't really increase the size because the added weight compresses the planet more

Jupiter is about as big as planets can get

Increasing Jupiter's mass would actually shrink the size

## Uranus' Axis



- Polar axis is in the ecliptic
- No banding or clouds
- Odd weather due to axis tilt
- Blue because of methane

Uranus' rotation axis tilt leads to extreme seasons

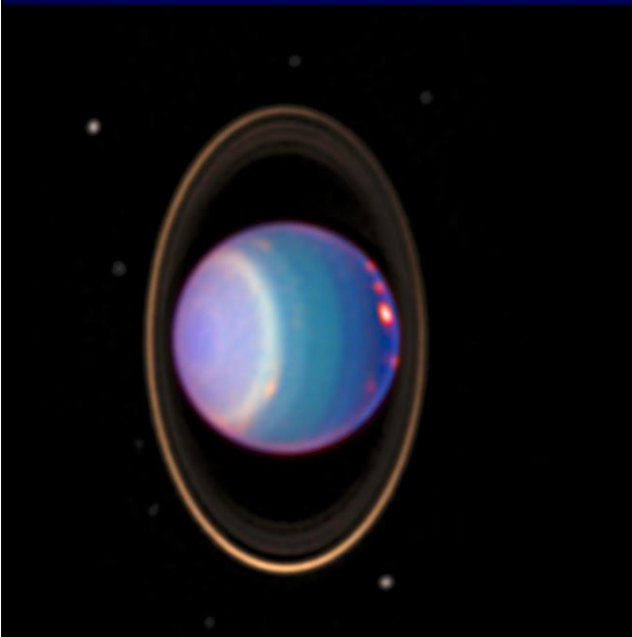
No storms

No clouds or banded structure seen in 1986 when N pole facing Sun

HST saw storms in 1998, perhaps because the S hemisphere is warming up

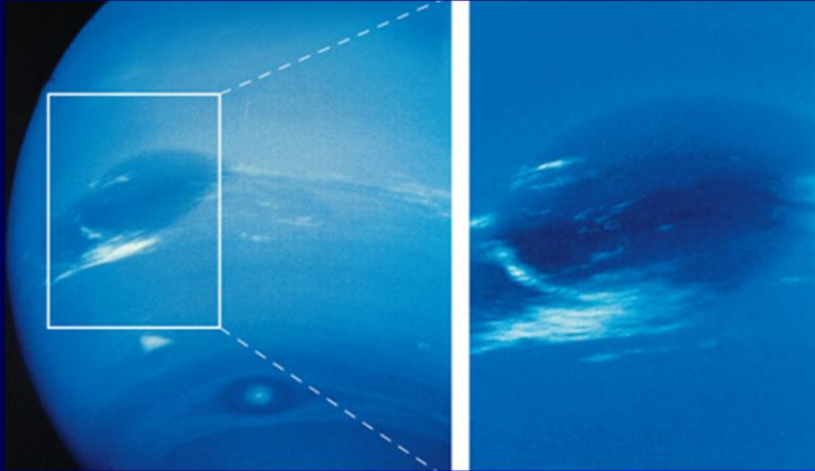


# Uranus



But in the  
IR, we do  
see storms  
and bands!

# Neptune



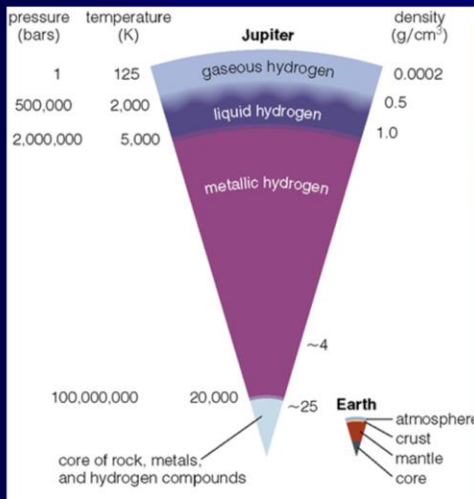
Interestingly, the Great Dark Spot has disappeared!

Neptune's winds go the wrong way around – opposite its rotation!

They're also really fast, at 2,000km/h!

**Neptune also emits more light than it receives... we don't know why, as it does not appear to be contracting still. Maybe the methane insulates it?**

# Jupiter's Interior



No real 'surface'

Gaseous atmosphere

Liquid and metallic hydrogen interior

Earth sized core

*Temperature, density, and pressure all increase with depth*

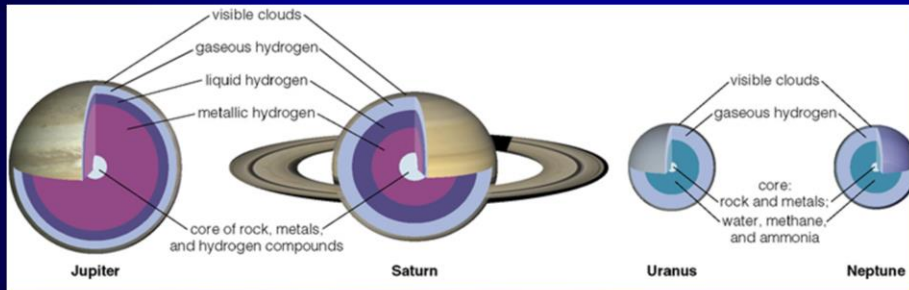
Jupiter's core is slightly larger than the Earth, but 10 times as massive and 5 times as dense due to the intense pressure from the material stacked on top of it

Metallic Hydrogen

Hydrogen molecules share the same electrons

# Other Interiors

Jupiter and Saturn are very similar



Uranus and Neptune are similar

The cores of all Jovian planets appear roughly the same

Composition: rock, metal, hydrogen compounds

Small rocky cores were probably the seeds of accretion (~10 times as massive as Earth)

Uranus and Neptune captured less matter from the solar nebula than Jupiter and Saturn

Accretion of planetesimals took longer

Had less time before material was cleared out by the solar wind

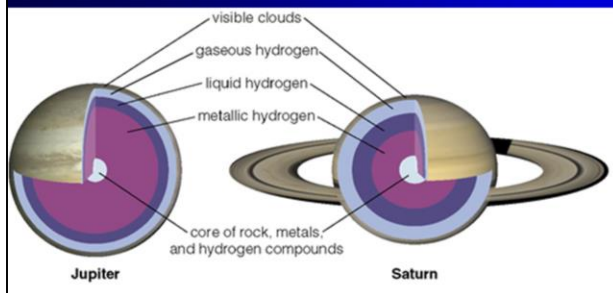
Only Jupiter and Saturn have metallic hydrogen

Jupiter, Saturn, and Neptune emit more light than they receive from the sun: Jupiter is still contracting; Saturn is still differentiating (see next slide); not sure what's going on with Neptune and Uranus.

# Other Interiors

Saturn is different in that it:

- Has thicker clouds
- Has a thicker liquid hydrogen layer
- Has a smaller metallic hydrogen layer
- Has a larger core (but not more massive)

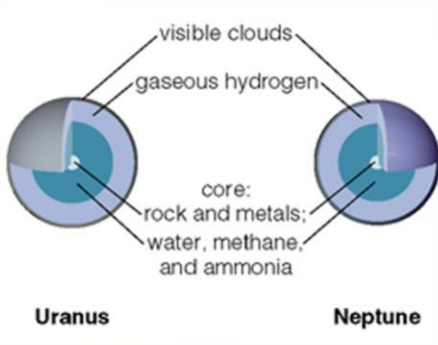


*because it has less gravity*

Saturn also has hydrogen "rain" → still differentiating

Jupiter, Saturn, and Neptune emit more light than they receive from the sun. Jupiter is still contracting; Saturn is still differentiating (see next slide); not sure what's going on with Neptune and Uranus.

# Other Interiors



**Uranus and Neptune**

- No liquid hydrogen
- Differentiated cores
- Much smaller than Jupiter & Saturn

*Why? Slower accretion → captures less H*

- Cores about the same size as Jupiter & Saturn

The cores of all Jovian planets appear roughly the same

Composition: rock, metal, hydrogen compounds

Small rocky cores were probably the seeds of accretion (~10 times as massive as Earth)

Uranus and Neptune captured less matter from the solar nebula than Jupiter and Saturn

Accretion of planetesimals took longer

Had less time before material was cleared out by the solar wind

Only Jupiter and Saturn have metallic hydrogen

Jupiter, Saturn, and Neptune emit more light than they receive from the sun.

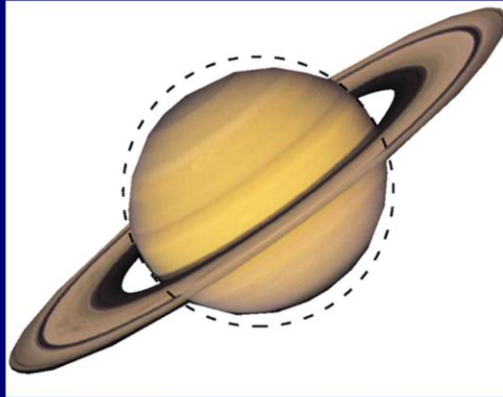
## Rotation

Jupiter: 9h 50m

Uranus: 16h 34m

Saturn: 10h 19m

Neptune: 17h 17m



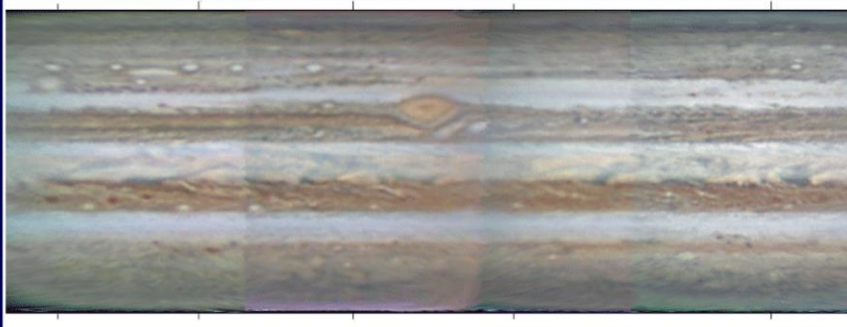
High rotation rates cause them to be *oblate*

Just like pre-solar nebula spin into a disk... rapidly rotating planets spin (slightly) into a disk

Jupiter completes one rotation in 9.8 hours. Saturn 10.23 hours

# Rotation

## *Differential Rotation*



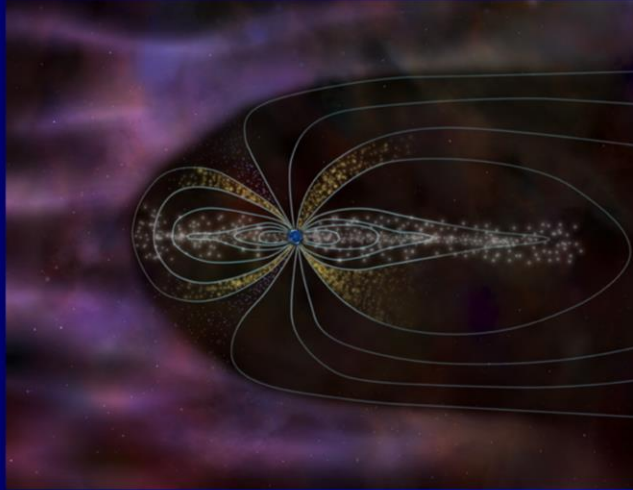
Means different parts rotate slower/faster

Jupiter has some pretty fast winds



# Jupiter's Magnetic Field

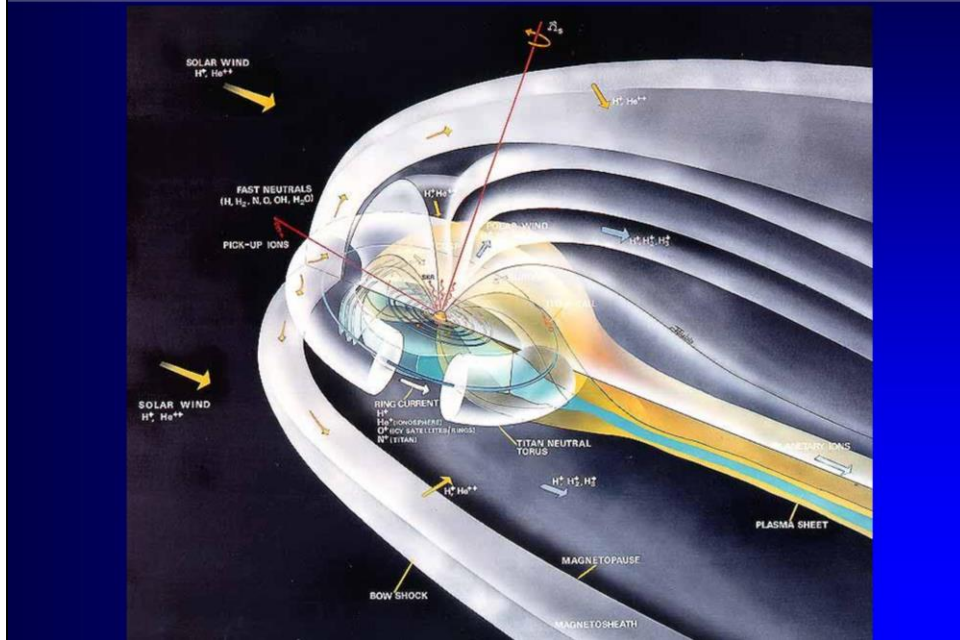
## Magnetic Fields



Plasma sheet in the plane of Jupiter's orbit, due to ions that are trapped by the magnetic field. Io (and Europa a little) put out atoms into the Jovian environment. Neutral ones get trapped in a torus around the moon; ions often make it to Jupiter causing the aurora.

Jupiter's magnetic field is VERY strong, due to the spinning metallic hydrogen at its center.

# Saturn's Magnetic Field

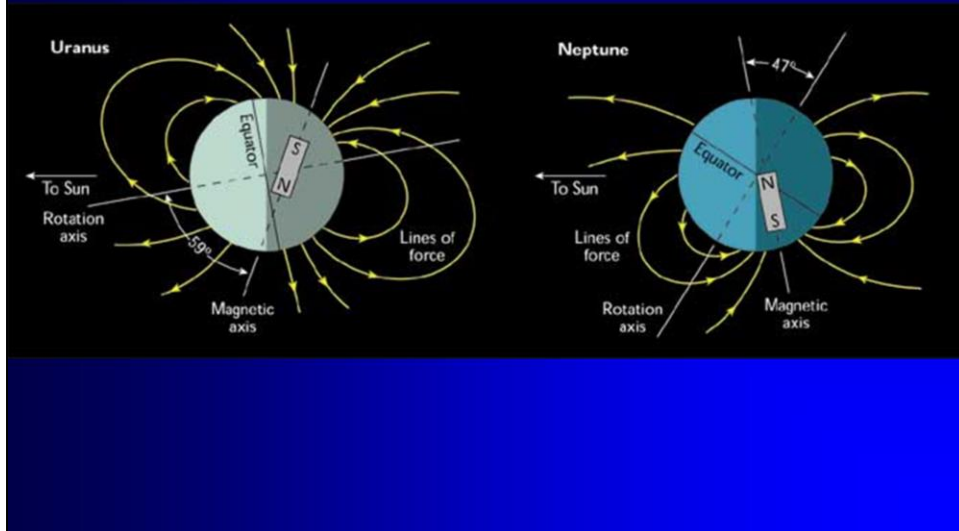


Saturn's magnetic field is similar to Jupiter's. There is a neutral torus around Titan, a plasma sheet, etc.

It was expected that a large amount of neutral Nitrogen would escape from Titan's atmosphere; we don't see that though. So is less Nitrogen escaping than expected, or is it somehow being removed? We don't know yet, but we're trying to find out!

Uranus and Neptune have smaller magnetic fields.

# Uranus & Neptune



Uranus and Neptune have weird magnetic fields. Neither are aligned with the spin axis. With Uranus, the extreme tilt and strange seasons likely come into play. Neither of the magnetic field axes pass through the center of the planet. Since there is not a metallic hydrogen core, the process of generating the magnetic fields is poorly understood; it's entirely possible that it's generated at higher altitudes, such as in the water-ammonia ocean at the center.

# Saturn's Rings

Saturn's rings are made of small particles

From large rocks to grains of dust



Easily visible through a telescope

Consist of many small particles

From large rocks to tiny dust grains

Mostly made of water ice

The brighter rings consist of more material, so they reflect more light.

Darker rings have less material

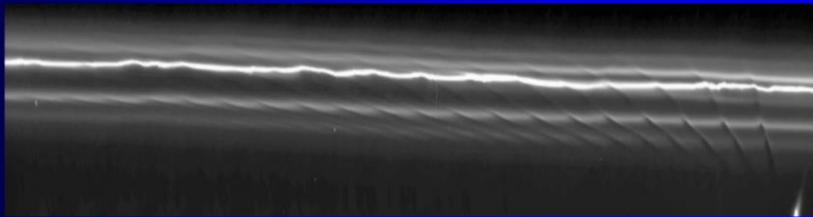
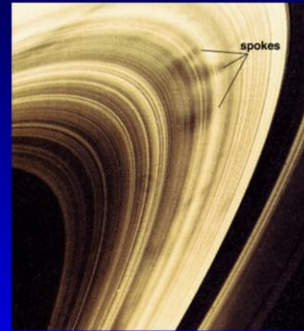
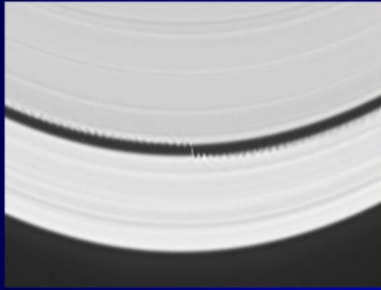
Very thin due to constant collisions

A few meters thick, 270,000 km in dia.

Invisible when viewed edge on

Your book notes that the rings are pretty young and so must be replenished. In fact, we DO see moons being ground apart, and even reforming, in the rings.

# Saturn's Rings



Aside from the rings, we see gaps and ripples

Gravitational interaction with moons inside the rings push particles into specific orbits

clear gaps

Interaction with larger, distant moons can clear gaps and form ripples.

Dark patches called 'spokes' appear and disappear but origin is unknown

Perhaps they might be particles of dust drawn out by Saturn's magnetic field

Origin of rings is probably a moon destroyed by tidal forces

## Clicker: Planetary Atmospheres

Jovian planets have HUGE hydrogen atmospheres because

- A. they have massive cores and are cold
- B. they have massive cores and are warm
- C. they have no cores and are cold
- D. they have no cores and are warm

A

It's cold where Jupiter forms. And, the jovian cores are BIG.

So, hydrogen isn't moving very fast. It doesn't exceed the escape velocity.

## Clicker: Planetary Atmospheres

Terrestrial planets have no hydrogen in their atmospheres because

- A. Hydrogen is light and terrestrial planets are warm.
- B. The Sun blows the hydrogen away.
- C. There was very little hydrogen in the disk when the Earth formed.
- D. All of the hydrogen got fused inside the Sun.

A.

It's too warm here, and terrestrial planets aren't very massive. So, hydrogen exceeds the escape velocity.

## Clicker: Jovian Interiors

Jupiter and the other jovian planets are sometimes called "gas giants." In what sense is this term misleading?

- A. They are not in any sense "giants."
- B. They actually contain relatively little material in a gaseous state.
- C. The materials they are made of are not the kinds of thing we usually think of as gases.
- D. Actually, it's a great description, because these worlds are big and gaseous throughout.

A.

It's too warm here, and terrestrial planets aren't very massive. So, hydrogen exceeds the escape velocity.



## Clicker: Jovian Interiors


Uranus and Neptune are smaller than Jupiter and Saturn because:

- A. Colder gas has less gravity and could not form such large balls
- B. The size differences are random coincidence.
- C. Particles were more spread out so accretion took longer & couldn't form before the solar wind started
- D. Only rock and metal could condense at the distances of Uranus and Neptune.

A.

It's too warm here, and terrestrial planets aren't very massive.  
So, hydrogen exceeds the escape velocity.

# Exoplanets



One of NASA's goals is to investigate the possibility of life on other worlds

The question is... will it be obvious?

**What are the things that life needs to exist?**

**Are each of these *necessary*, or can we get around them somehow?**

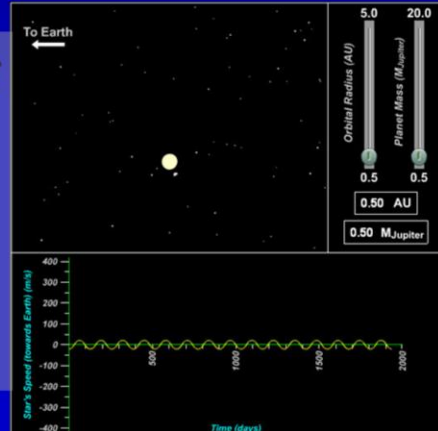
**If we want to find life, where should we look?**

# Detecting Exoplanets

*Exoplanets* are planets that orbit a star that is not the Sun

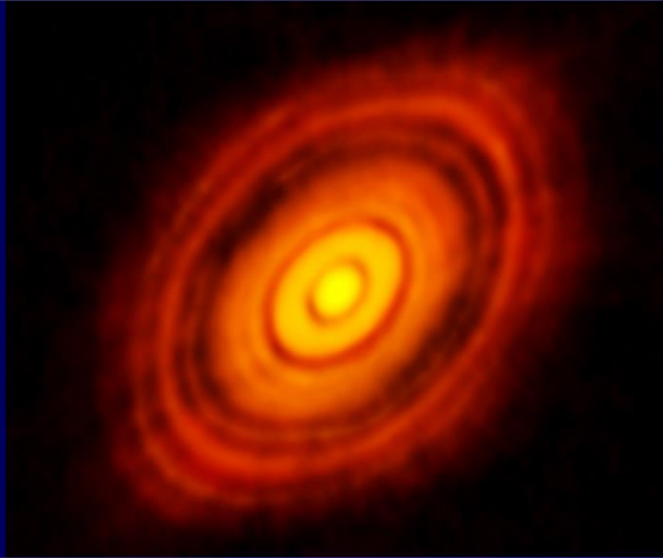
*Methods of detecting:*

- *Stellar “wobble” (astrometry)\**
- *Direct detection\**
- *Doppler shift*
- *Transits*



Mostly, we can only see the effect that they have on their parent stars. Really big planets (Like the size of Jupiter) can cause a significant wobble in the star... but this can be hard because it's best if they are far from their star, which makes the wobble take a long time. Best for nearby stars, and only works in rare cases. The GAIA mission that the European Space Agency (ESA) is running is currently working on doing this accurately.

# Direct Detection

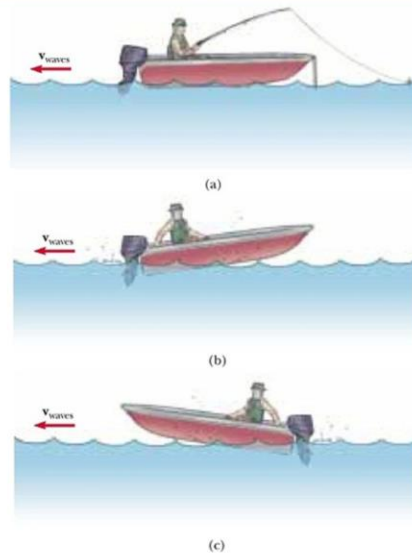


Only a few found... but maybe more soon!

It's VERY HARD to detect extra solar planets directly. Rare cases only....

As the Alma telescope comes online this will become easier – but most likely will focus on the planetary systems already detected. This is a *protoplanetary* disk, one of the first ones imaged! Look at those gaps! Just like we predicted!

# Light: Doppler shift



**Figure 17.9** (a) Waves moving toward a stationary boat. The waves travel to the left, and their source is far to the right of the boat, out of the frame of the drawing. (b) The boat moving toward the wave source. (c) The boat moving away from the wave source.

We can detect that wobble through the **Doppler Effect**.

The absorption lines in the star shift back and forth as the star wobbles first away from us and then towards us.

So let's talk about Doppler shift (we will need it for other things as well).

If you think about waves on a lake, the water waves move at a constant rate

When you move **TOWARDS** the waves, the frequency with which you get hit in the head **INCREASES**

When you move **AWAY** from the waves, the frequency with which you get hit in the head **DECREASES**

Another analogy:

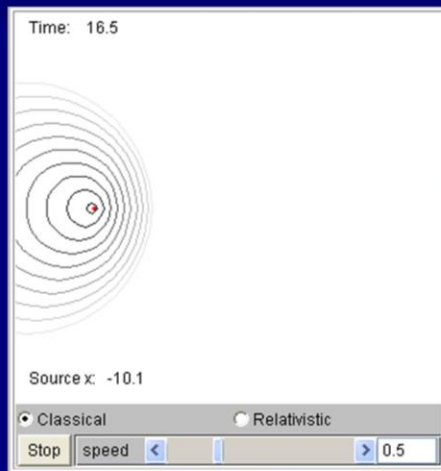
A baseball machine shoots baseballs at a constant rate...

When you run **TOWARDS** the machine, the frequency with which you get hit in the head **INCREASES**

When you run **AWAY** from the machine, the frequency with which you get hit in the head **DECREASES**

**It doesn't matter if it's the machine moving (the thing generating the waves) or if you're moving; it's the RELATIVE velocity that matters.**

# Light: Doppler shift



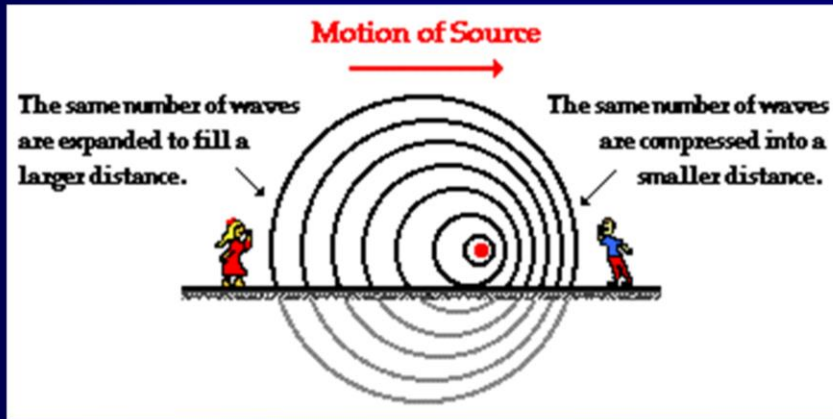
Notice in this example the people are stationary and the wave source is moving, as opposed to the boat/baseball examples.

Either one could be the case, the end result is the same.

(In fact, Newton says that you can't really tell which is moving unless one is *accelerating*. If velocities are constant than each one can claim it is stationary and the other is moving.)

[http://www.fisica.uniud.it/~deangeli/applets/Multimedia/Waves\\_java/Doppler/doppler.htm](http://www.fisica.uniud.it/~deangeli/applets/Multimedia/Waves_java/Doppler/doppler.htm)

# Light: Doppler shift



The person on the left sees a longer wavelength (redder light)

The person on the right sees a shorter wavelength (bluer light)

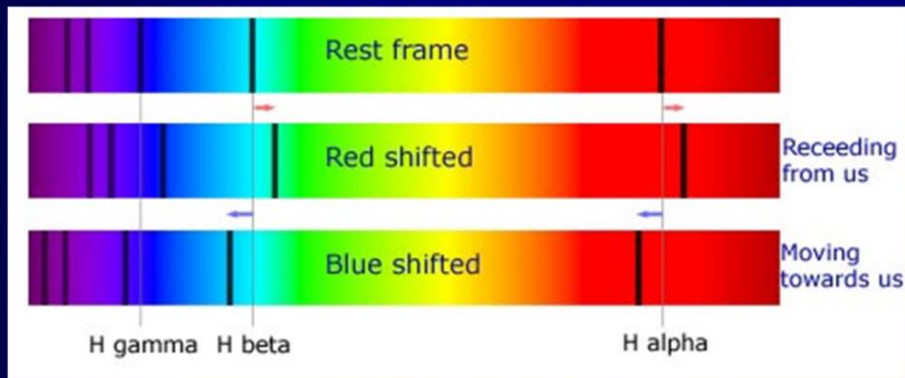
Redder/bluer are relative to the source's emitted light (the source sees itself at rest/not in motion so emits like it were stationary).

Image from The Physics Classroom:

<http://www.physicsclassroom.com/class/sound/Lesson-3/The-Doppler-Effect-and-Shock-Waves>



# Light: Doppler shift



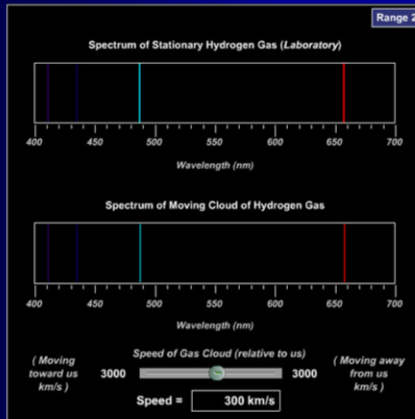
In terms of spectra, this is what we see.

Image from

[http://www.atnf.csiro.au/outreach/education/senior/astrophysics/spectra\\_info.html](http://www.atnf.csiro.au/outreach/education/senior/astrophysics/spectra_info.html)

# Measuring Velocity

If we know the REST wavelength  
of an emission line...



$$\frac{\Delta\lambda}{\lambda_{rest}} = \frac{v}{c}$$

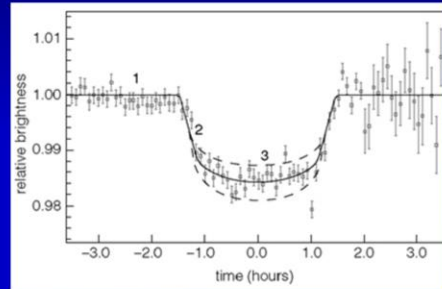
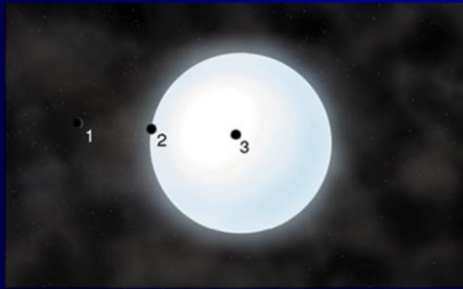
if we know the REST (not moving toward or away from us) wavelength we can calculate the VELOCITY...

[file:///U:/Astro/Powerpoints/CP\\_InteractiveFigs/IF\\_5.22\\_doppler\\_shift\\_emission\\_line.html](file:///U:/Astro/Powerpoints/CP_InteractiveFigs/IF_5.22_doppler_shift_emission_line.html)

[file:///U:/Astro/Powerpoints/CP\\_InteractiveFigs/IF\\_5.23\\_star\\_motion\\_doppler\\_effect.html](file:///U:/Astro/Powerpoints/CP_InteractiveFigs/IF_5.23_star_motion_doppler_effect.html)

# Detecting Exoplanets

Transits can be detected by the light curve



The transiting planet blocks some of the starlight

We can also, if we are very lucky and happen to see a planetary system aligned juuust right, see the starlight dim slightly as the planet passes in front of it.

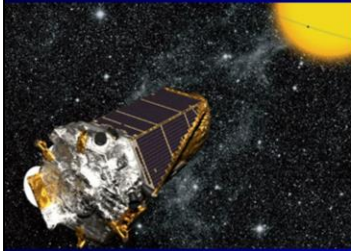
This method favors big planets close to the star.

Show:

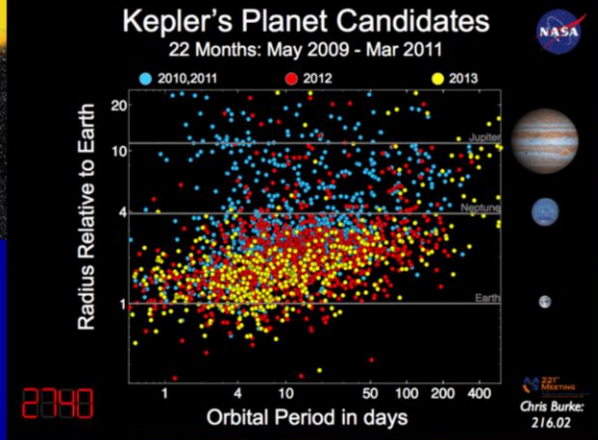
file:///U:/Astro/Powerpoints/CP\_InteractiveFigs/IF\_13.5\_planetary\_transits.html

# Detecting Exoplanets

## Kepler Space Telescope



Confirmed:  
1030  
Candidates:  
4696



These are only the ones that have more than one transit seen, and only from Kepler data. There are others detected as well (not just with Kepler) as well.

# Life...

