



# *SECRETS OF THE SOLAR SYSTEM*

## *S<sup>3</sup>-04*

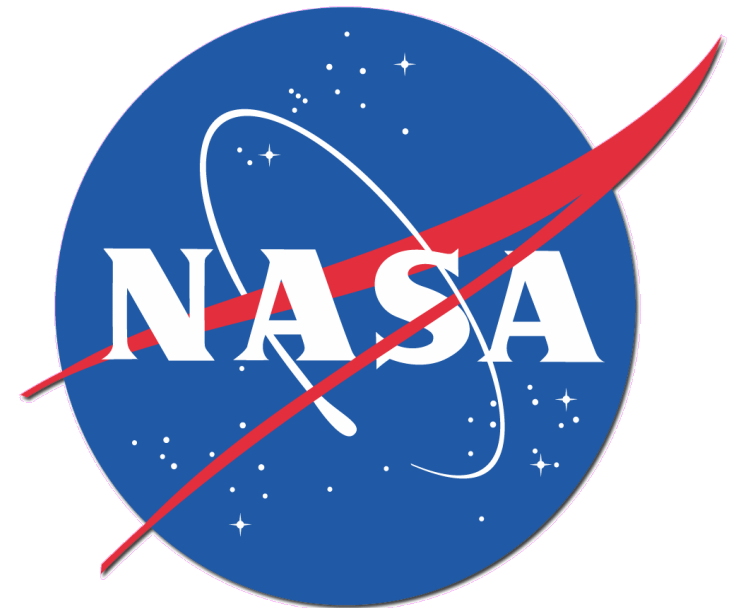
*Wladimir (Wlad) Lyra*  
*Brian Levine*

*AMNH After-School Program*

AMERICAN  
MUSEUM OF  
NATURAL  
HISTORY

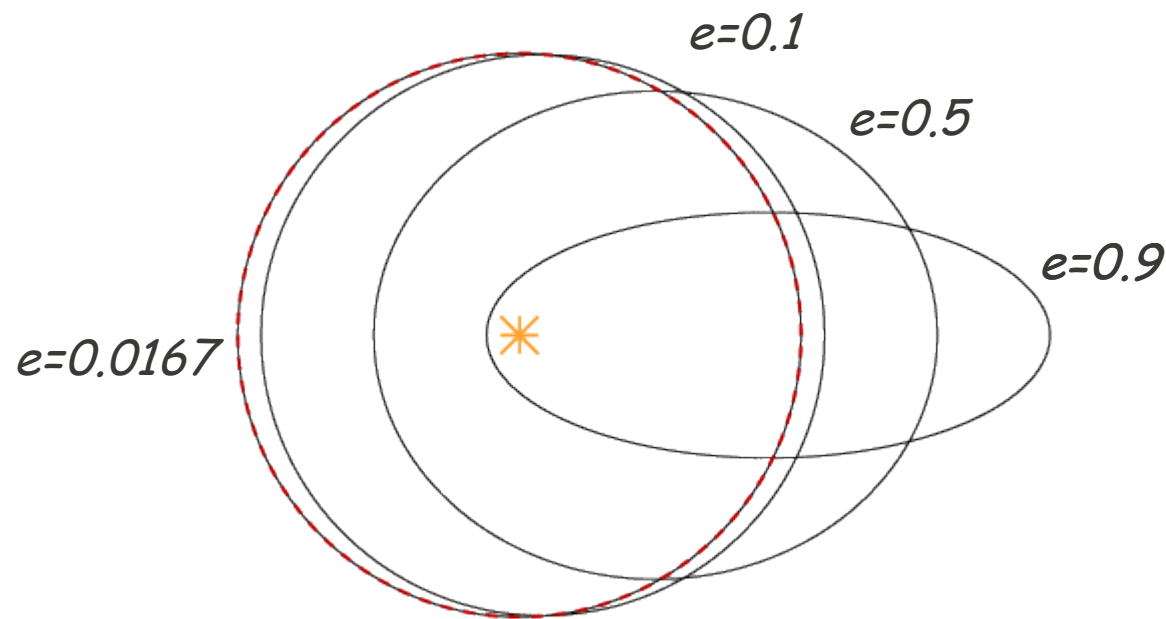


**This class is brought to you by funding provided by NASA, and is part of the AMNH After-School Program and Science Research Mentoring Program. The material contained in this course is based upon work supported by NASA under grant award Number NNX09AL36G. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of NASA.**



# From Last Class

Seasons on Earth are **NOT** because of eccentricity



Earth's eccentricity of 0.0167  
makes its orbit pretty much a circle

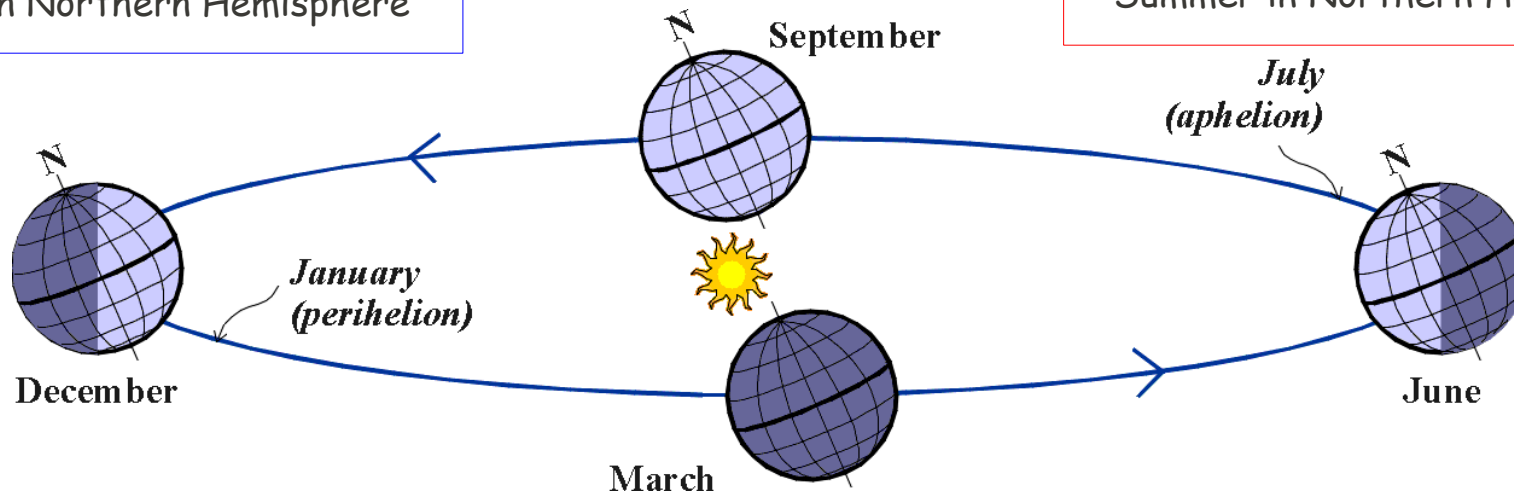
# From Last Class

## December solstice

Summer in Southern Hemisphere  
Winter in Northern Hemisphere

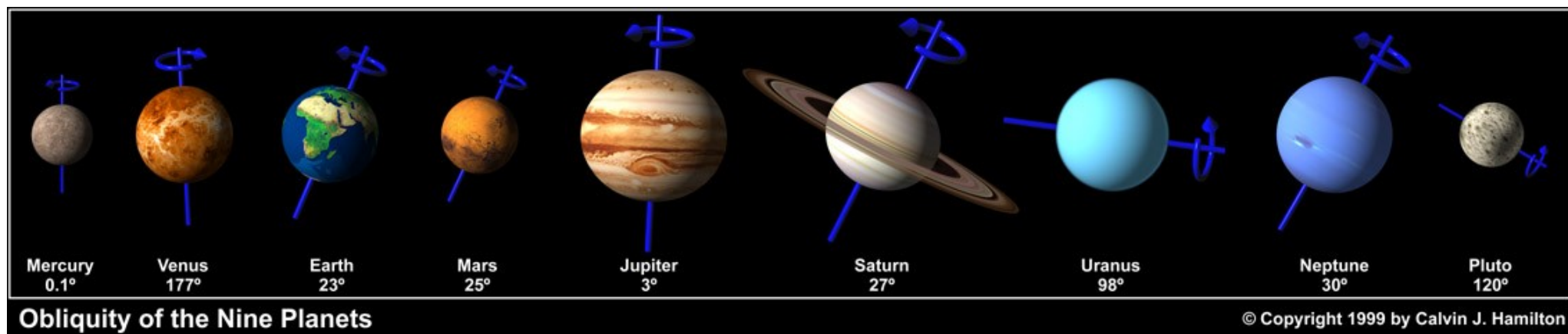
## June solstice

Winter in Southern Hemisphere  
Summer in Northern Hemisphere



Earth's tilt defines the seasons

A very eccentric planet would have  
**"eccentricity seasons"** in addition to **"tilt seasons"**,  
but NOT Earth, whose orbit is very close to CIRCULAR!



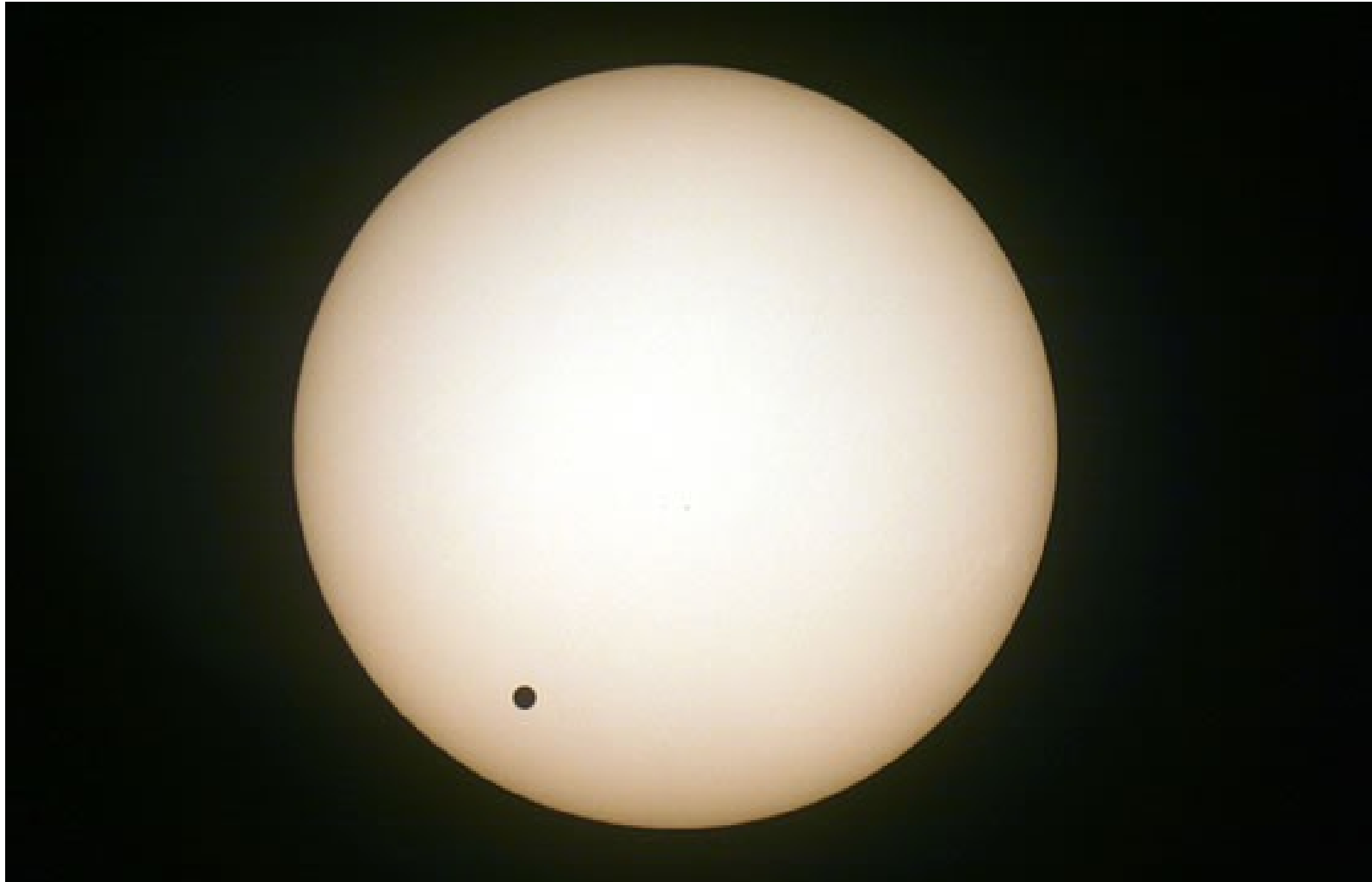
Measure the period (in yr),  
get the distances (in AU)!

Planet	Orbital Period (yr)	Distance (AU)
Mercury	0.241	0.39
Venus	0.615	0.72
Earth	1.000	1.00
Mars	1.881	1.52
Jupiter	11.68	5.2
Saturn	29.46	9.5
Uranus	84.32	19.2
Neptune	164.8	30.1

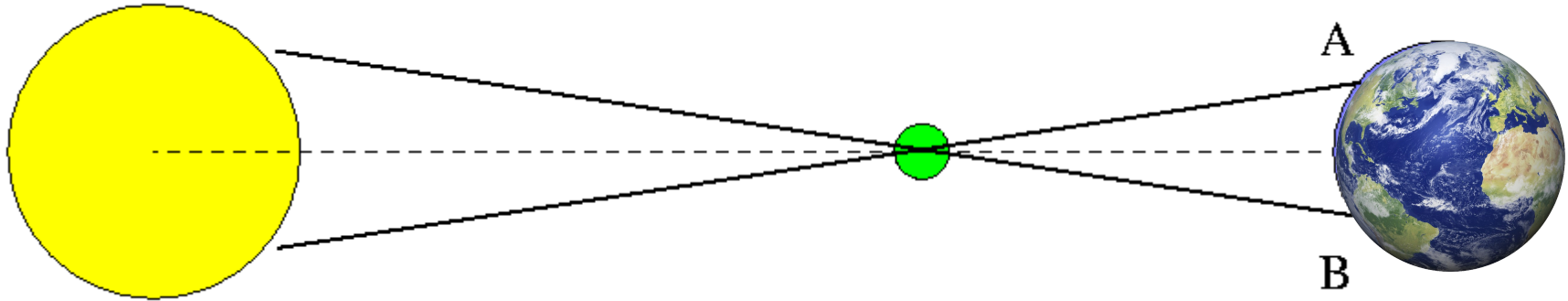
Kepler 3<sup>rd</sup> Law

$$T_{yr}^2 = r_{AU}^3$$

# Transit of Venus



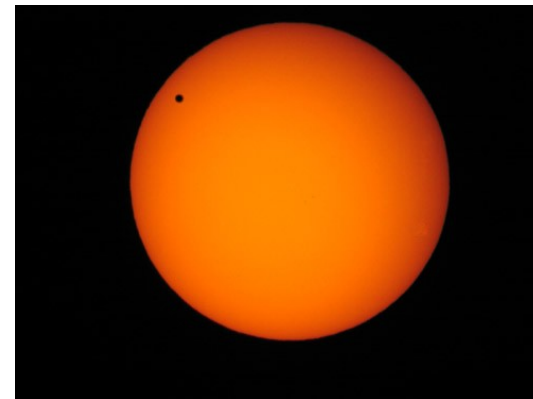
# Transit of Venus



View from A

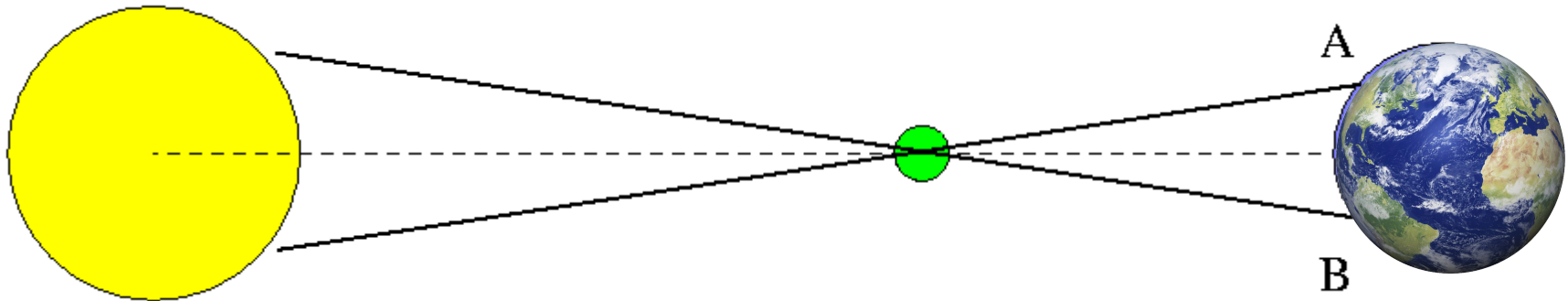


View from B

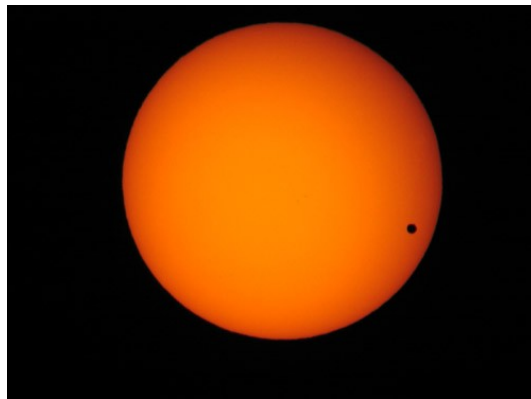




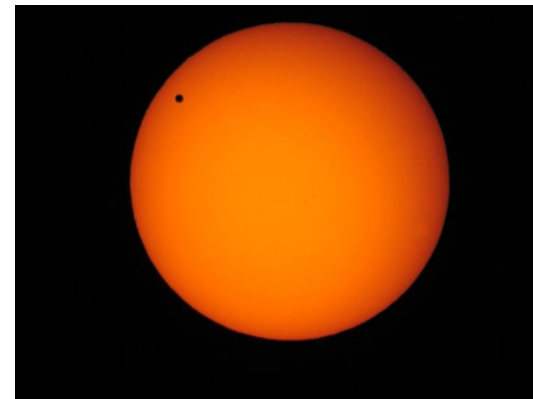
# Transit of Venus



View from A

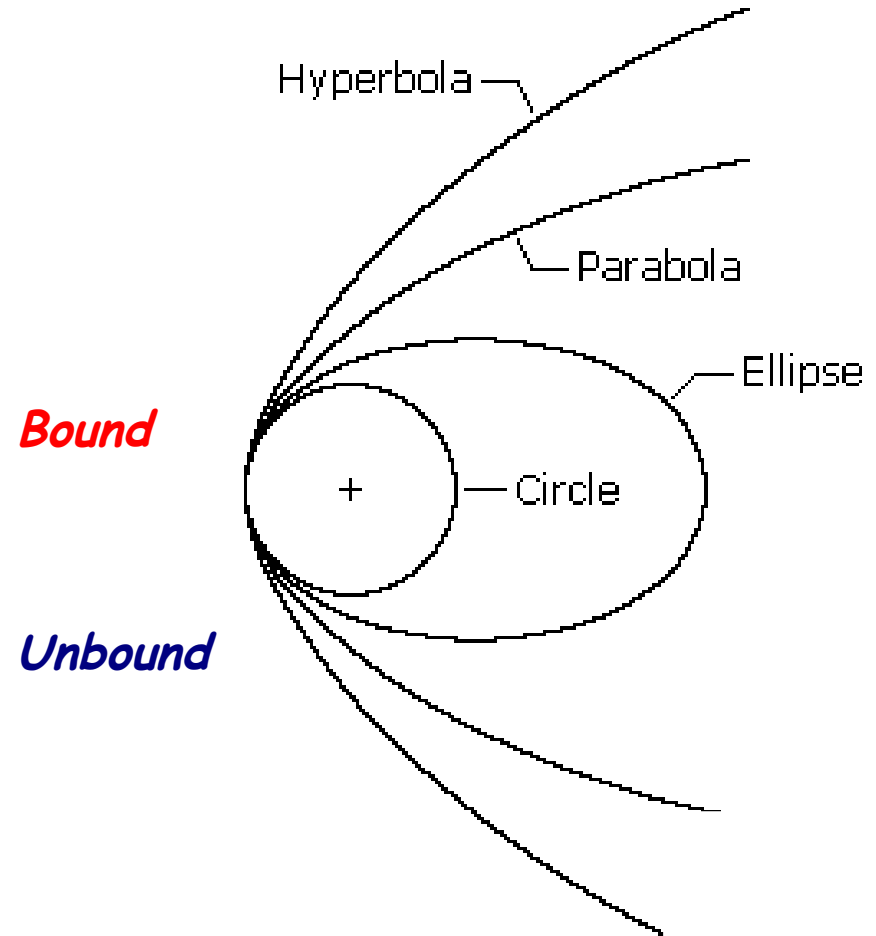


View from B



# Types of orbit

Orbit Type	Eccentricity	Energy
Circle	$e = 0$	$E = E_{\min}$
Ellipse	$0 < e < 1$	$E_{\min} < E < 0$
Parabola	$e = 1$	$E = 0$
Hyperbola	$e > 1$	$E > 0$



# Outline

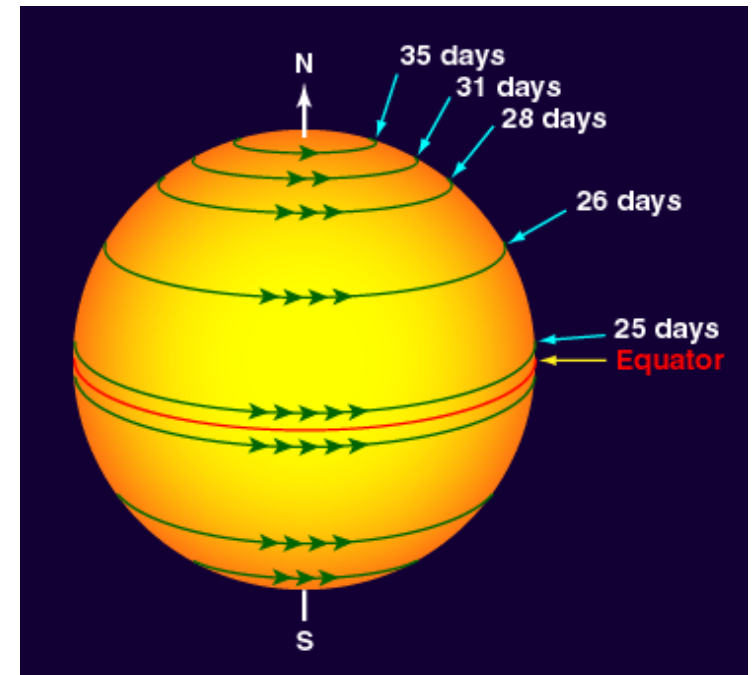
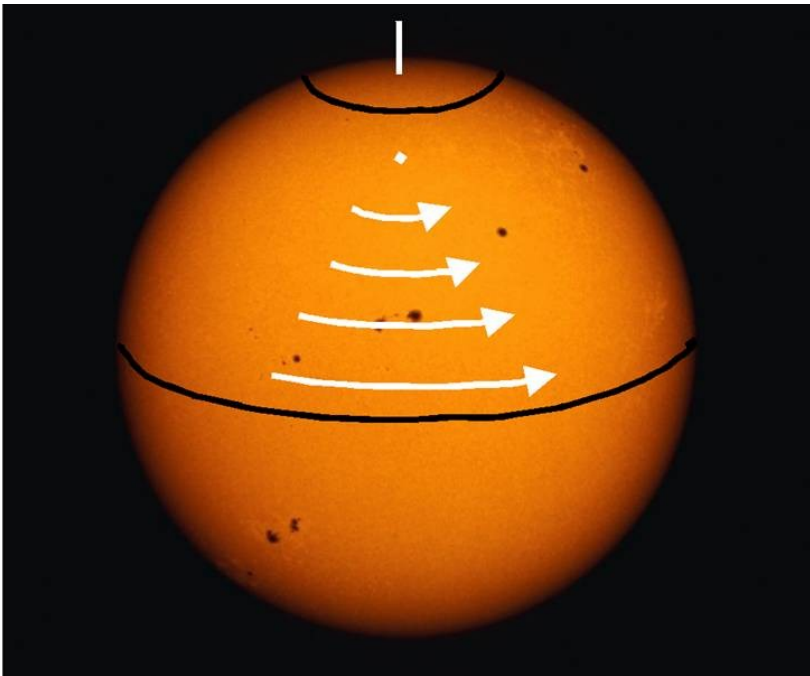
The Sun

Giant Planets

- Interiors
- Atmospheres

# Differential Rotation

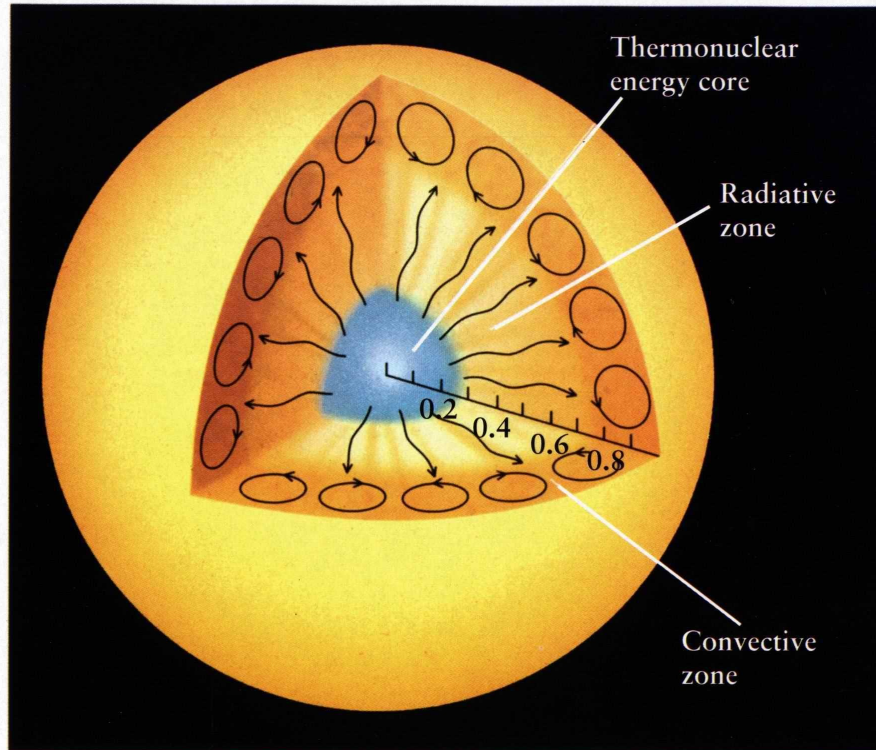
The equator spins faster than the poles



As any gaseous body, the Sun displays differential rotation.

25 days at the equator  
35 days at the poles

# Solar Structure



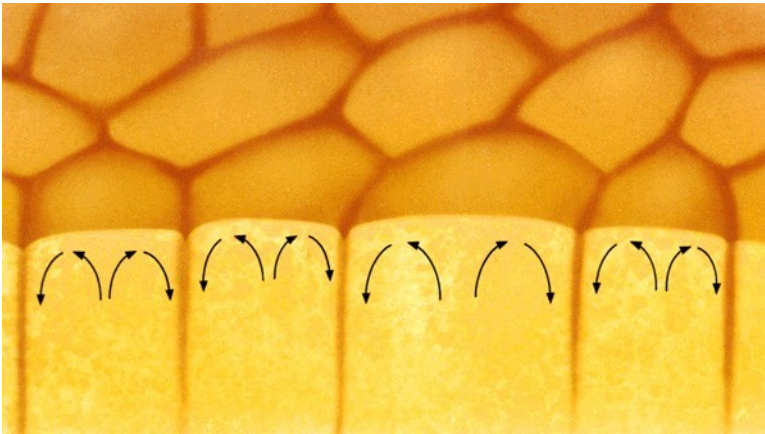
In the interior,  
heat is transported by **radiation**  
(without transport of mass).

Near the surface,  
heat is transported by **convection**  
(with transport of mass).

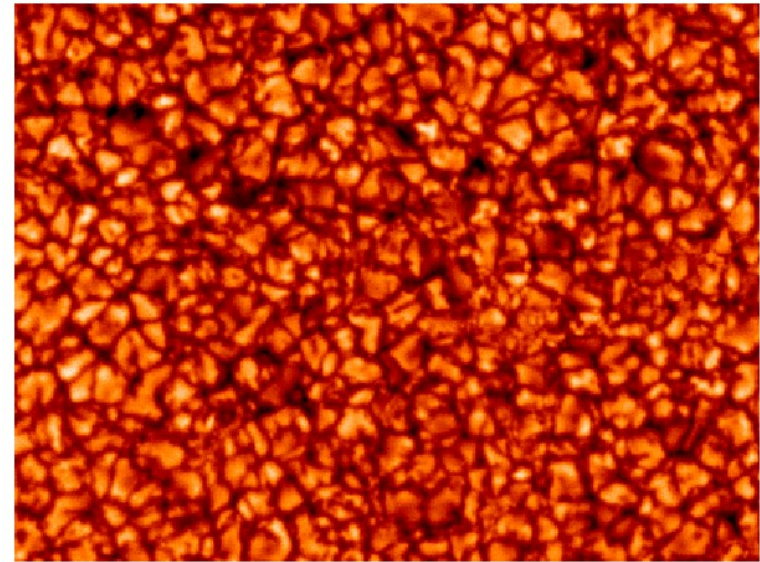
The Sun displays a  
**radiative zone**  
**in the interior**

And a  
**convective zone**  
**near the surface**

# Granulation



Convective cells



Close-up of the surface of the Sun





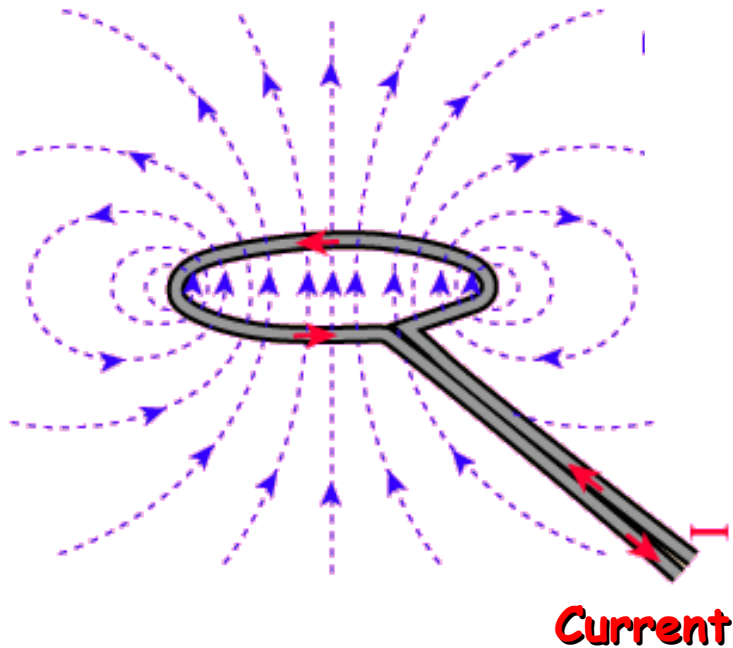
# Magnetic Fields

Masses produce gravitational fields

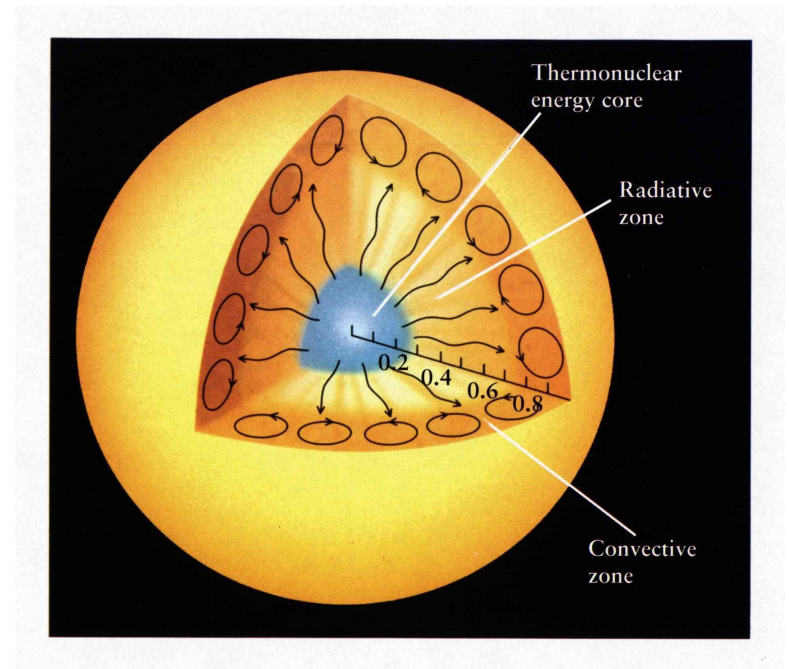
Static charges produce electric fields

**Moving charges** produce **magnetic fields**

**Magnetic Field  
produced by current**



The sun is a ball of ionized gas

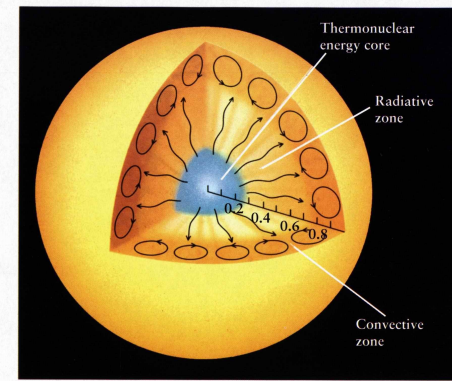
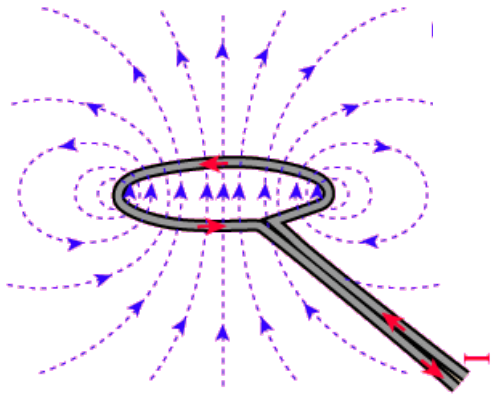


A convective cell is a current loop

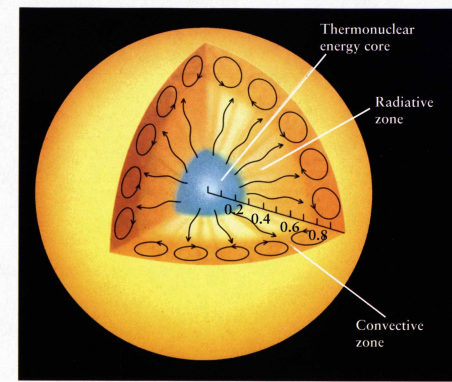
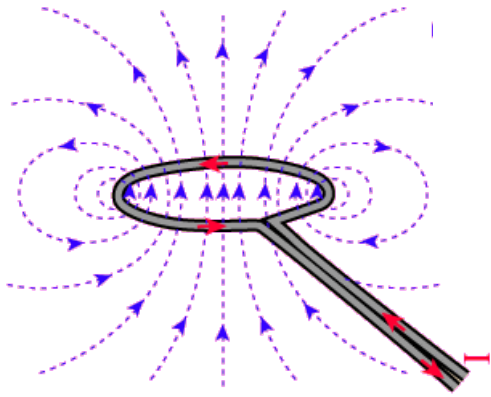
We should expect **magnetic fields**  
associated with **convection**



# Magnetic Fields

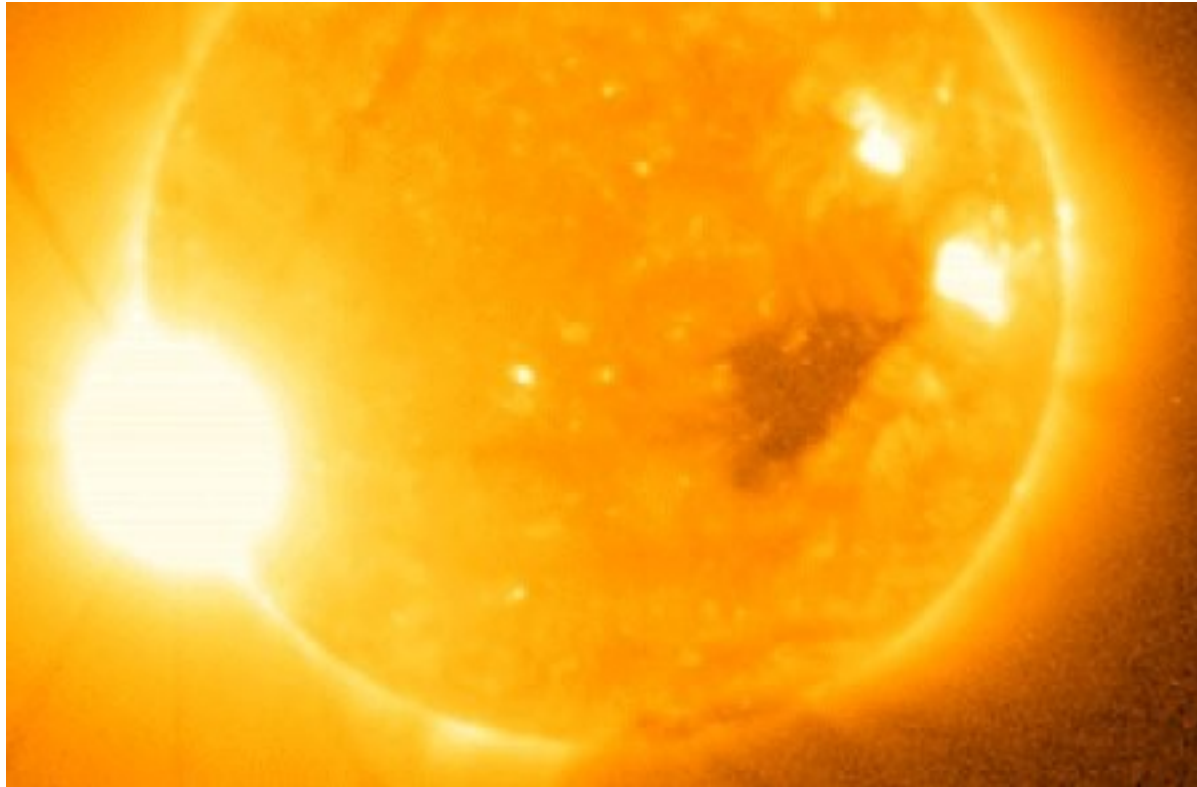


# Magnetic Fields



# Solar Flares

The most powerful explosions in the solar system ( $\sim 10^{32}$  ergs)

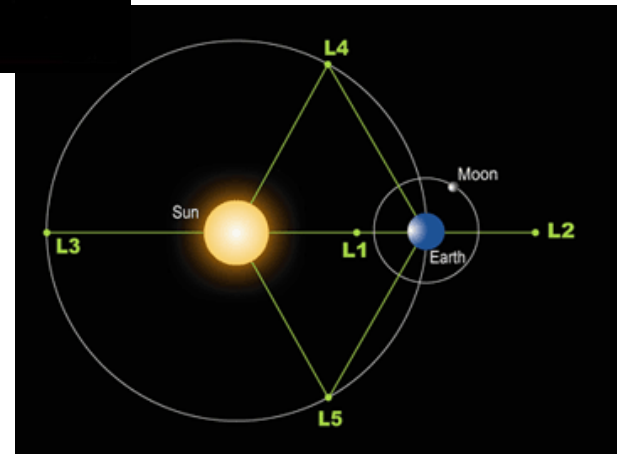
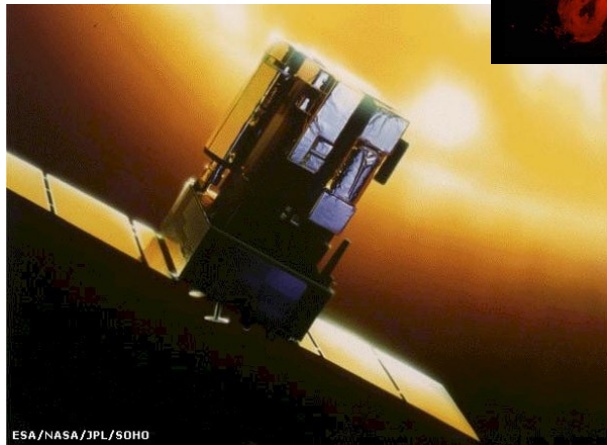
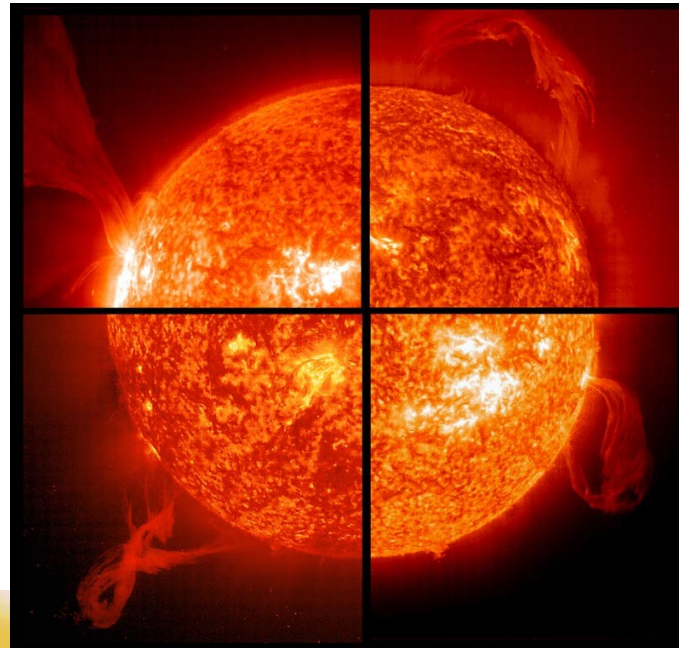


Flares are **explosions** on the surface of the Sun  
powered by **magnetic reconnection**



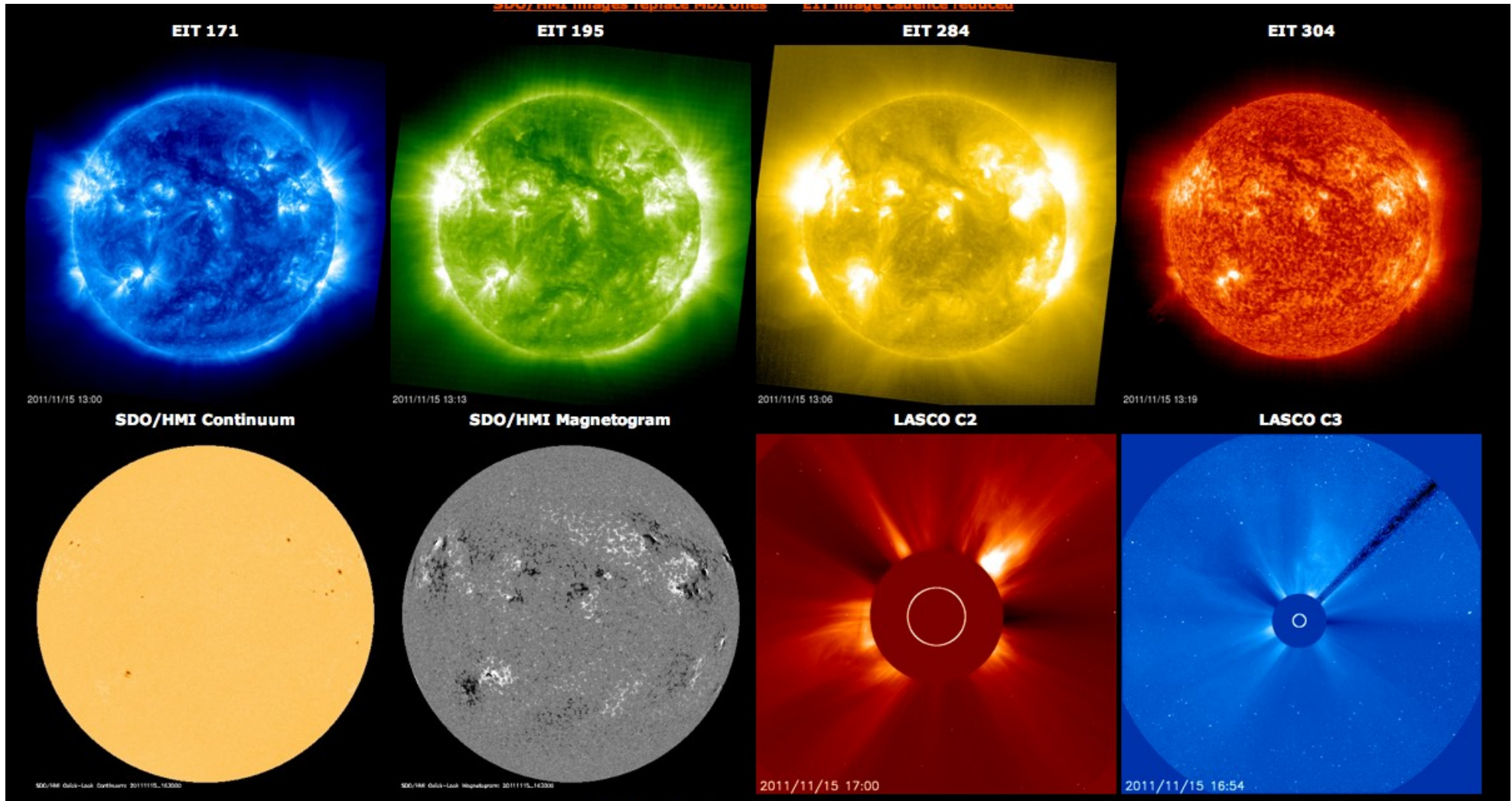
# Solar Observation Satellites

Solar and Heliospheric Observatory (SOHO - ESA/NASA)



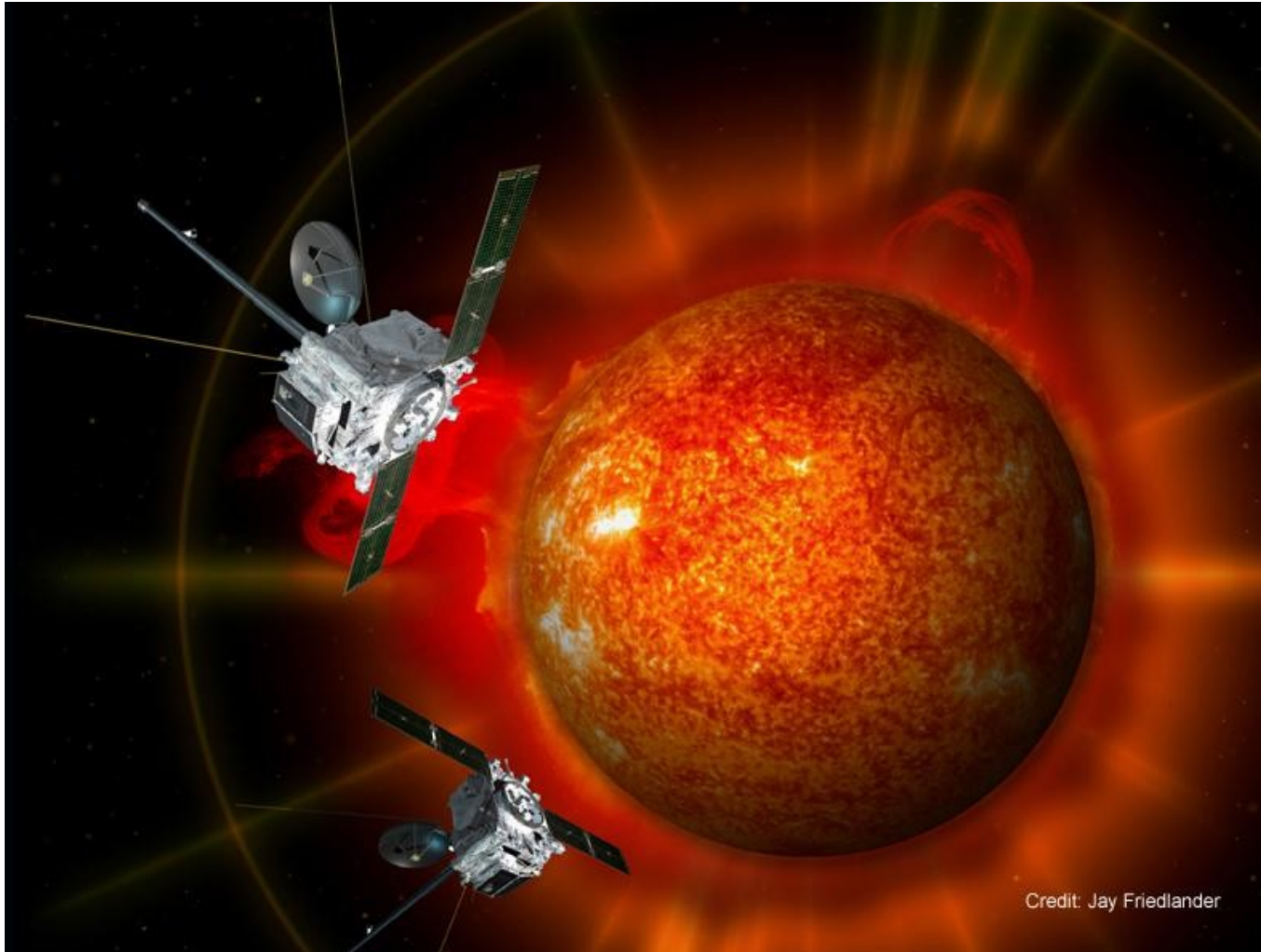


# Solar Observation



# Solar Observation Satellites

Solar-Terrestrial Relations Observatory (STEREO - NASA)



# Solar Observation Satellites

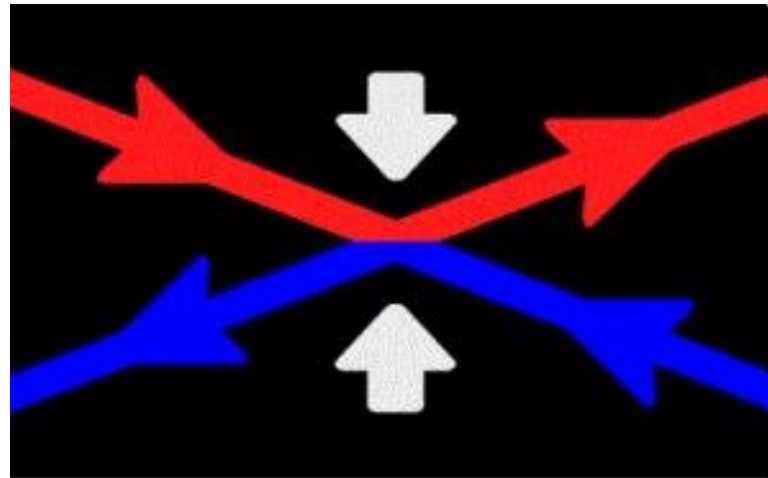
Solar-Terrestrial Relations Observatory (STEREO - NASA)





# Magnetic Reconnection

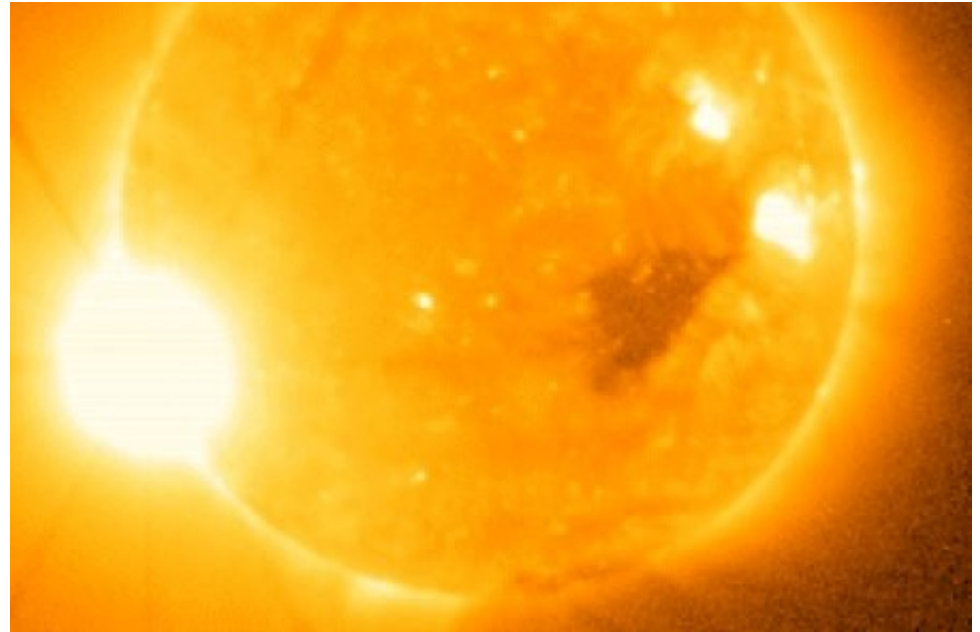
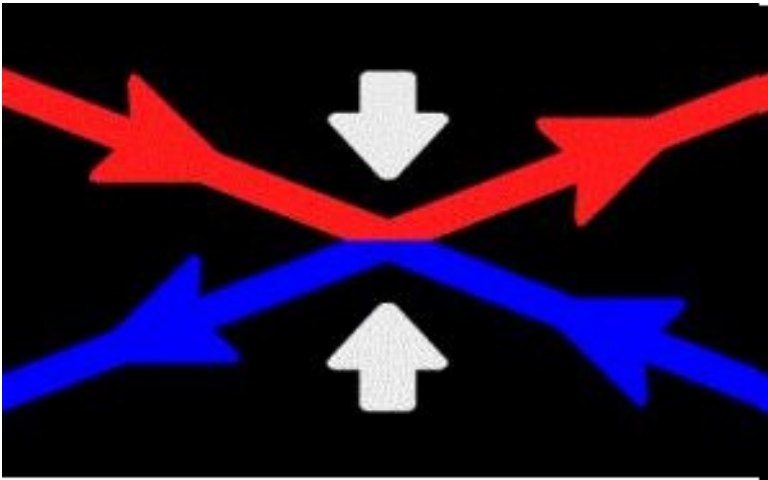
Get two field lines of opposite polarity together...



... and you have the magnetic equivalent of a short circuit

# Magnetic Reconnection

Magnetic Field lines store energy

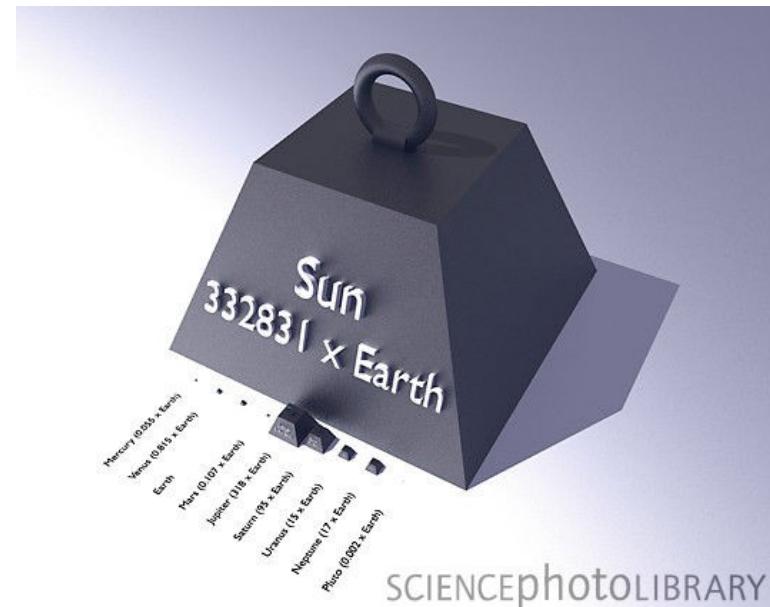
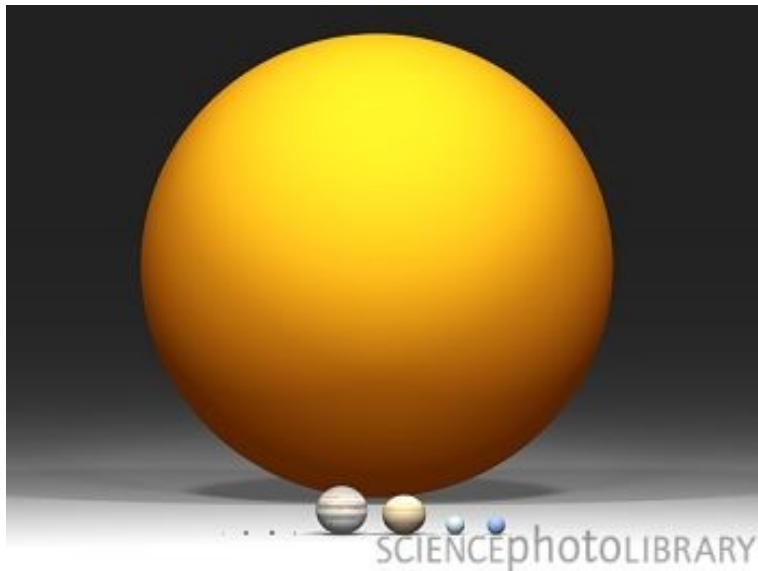


Upon cancellation, the energy is explosively released

*Activity*

# The Sun

The Sun is by far the dominant object of the Solar System

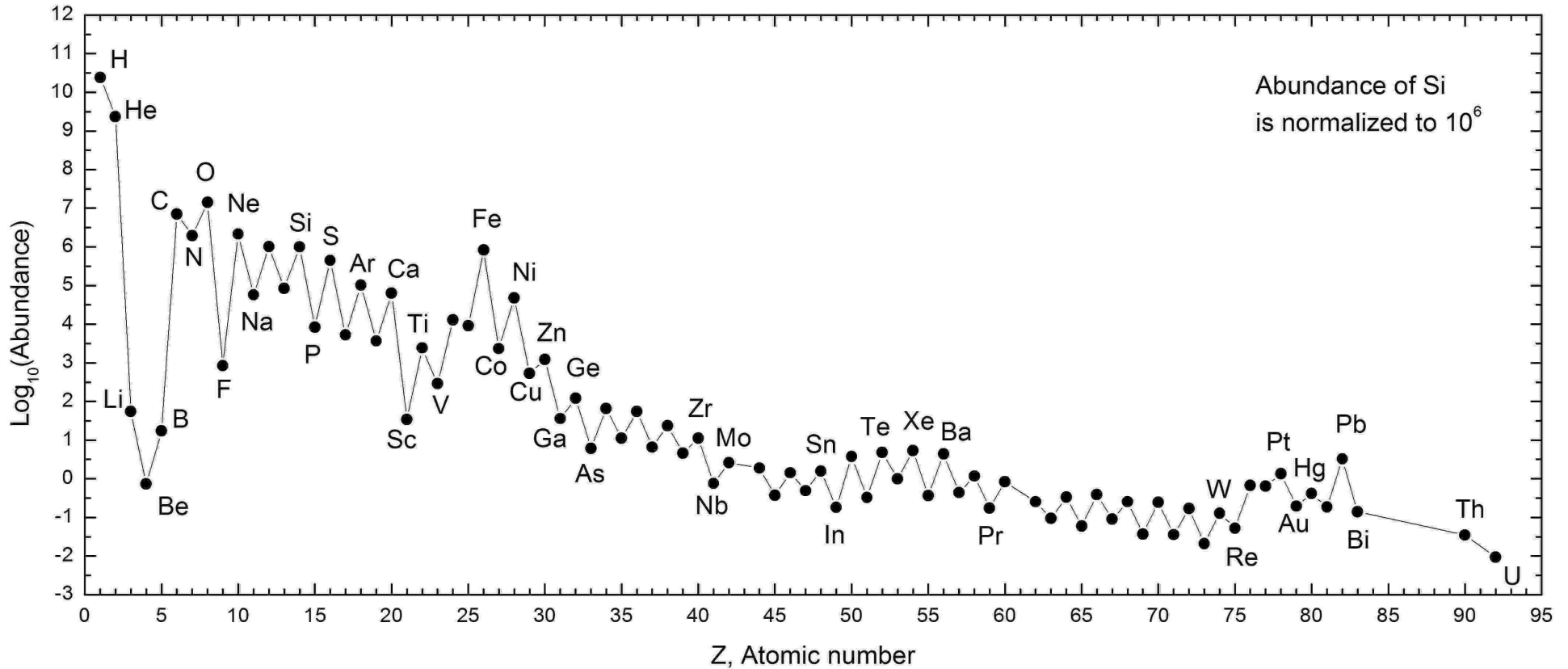


Jupiter has more than twice the mass of all planets combined.  
And the Sun is more than 1000x more massive than Jupiter.

The Sun accounts for 99.9% of the mass of the solar system

# Chemical Composition

## The chemical composition of the Sun



Most abundant elements, in order:

H (71%) He (27%)

O (1.04%) C (0.46%)

Ne (0.13%) Fe (0.11%) N (0.1%)

Si (0.06%), Mg (0.05%), S (0.04%)

# What will the chemistry of the mixture be?

H (71%)  
He (27%)

O (1.04%)  
C (0.46%)  
Ne (0.13%)  
Fe (0.11%)  
N (0.1%)  
Si (0.06%)

*Volatiles*

*Refractory*

## What will the chemistry of the mixture be?

H H H H H He H  
H O H H  
H C  
H H H H H H H H H H H He H  
H H H H H H H H H H H He H  
H H H H He H H H H H H H H H O H  
H H H H H O H Ne H H H H  
H H H H H H H H H H H H H He H  
H H H H H H H H H H H H H He H H H H O H H H H H H H H H H H H H H H H He  
H H H H H H H H O H H H H H H H He H H H H H H H H H H H H H H H H H H  
H He H H H  
H H H H H H H H H H H H H H H H He H H H H H H G H H H H H H H H H H H H H  
H H H H H H H H H H H H H H H H H He H H H H H H H H H H H H H H H H H H  
H H H He H H H H He H N H H H  
H He H H H H H H  
O He H H  
H  
H H O H H H H H H H H H H H H C H H H H H H H H H H H He H H H H H H H  
H  
H H H O H H H H H H He H H He H H H H H H H H H H H H H H Fe H H H  
H H

## What will the chemistry of the mixture be?

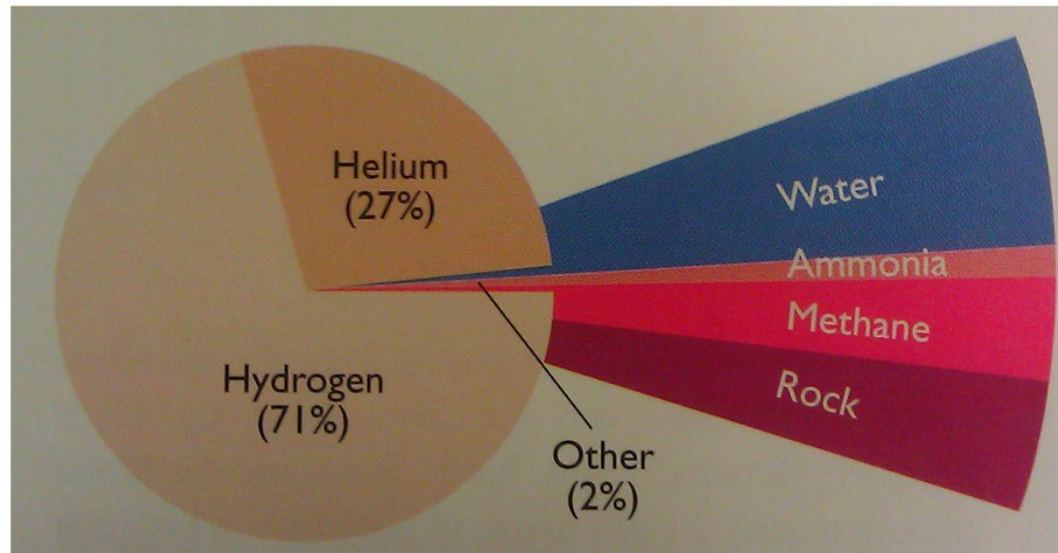
[illegible]



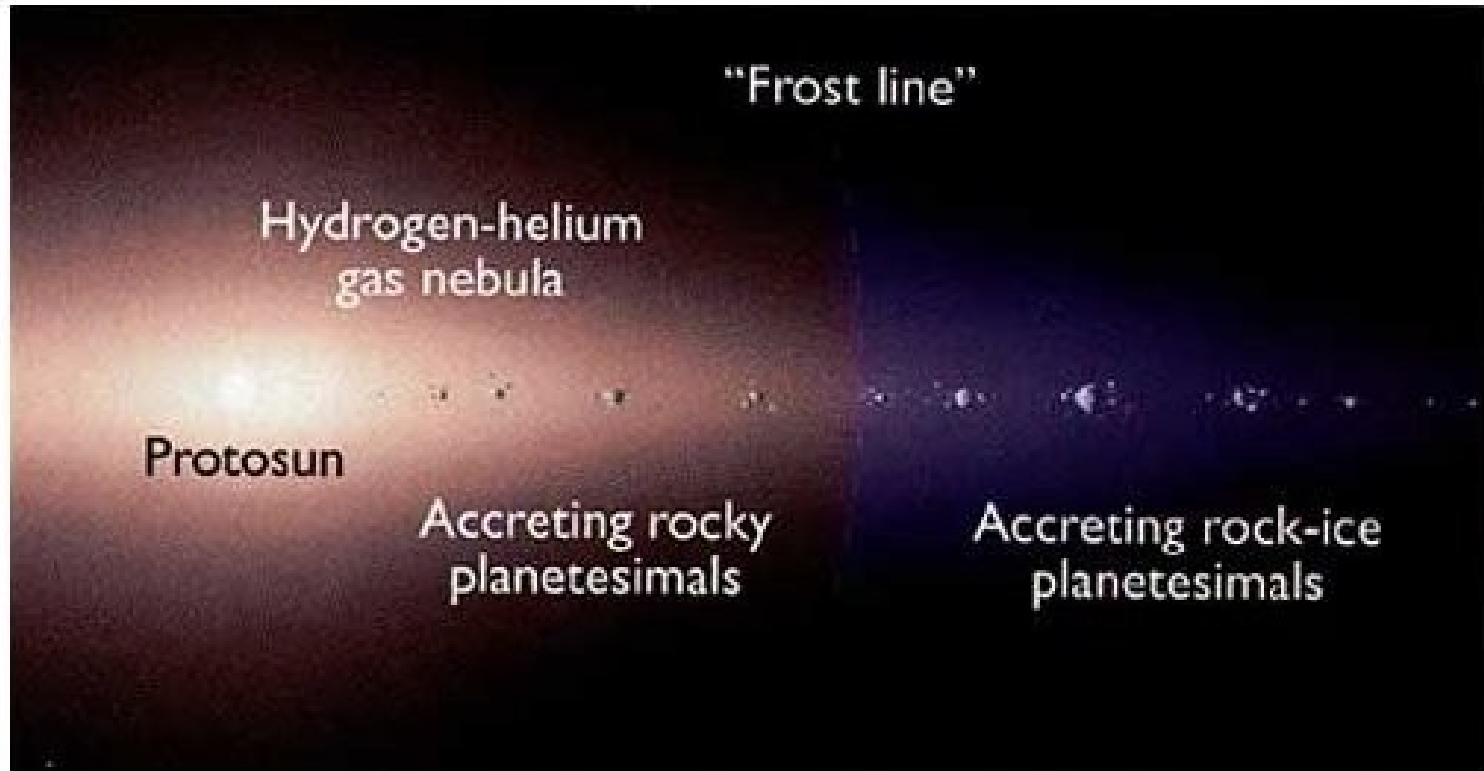
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$H_2$  He  
 $H_2O$  - Water  
 $CH_4$  - Methane  
Ne  
 $NH_3$  - Ammonia  
Fe, Si - Rocks (metals and silicates)



# The Snowline



Volatiles in gas phase

Volatiles in solid phase

Colder than  $\sim 150\text{K}$ , the volatiles ( $\text{H}_2\text{O}$ ,  $\text{CH}_4$ ,  $\text{NH}_3$ )

condense into **ices**.

# Classes of planets

## Rocky Planets

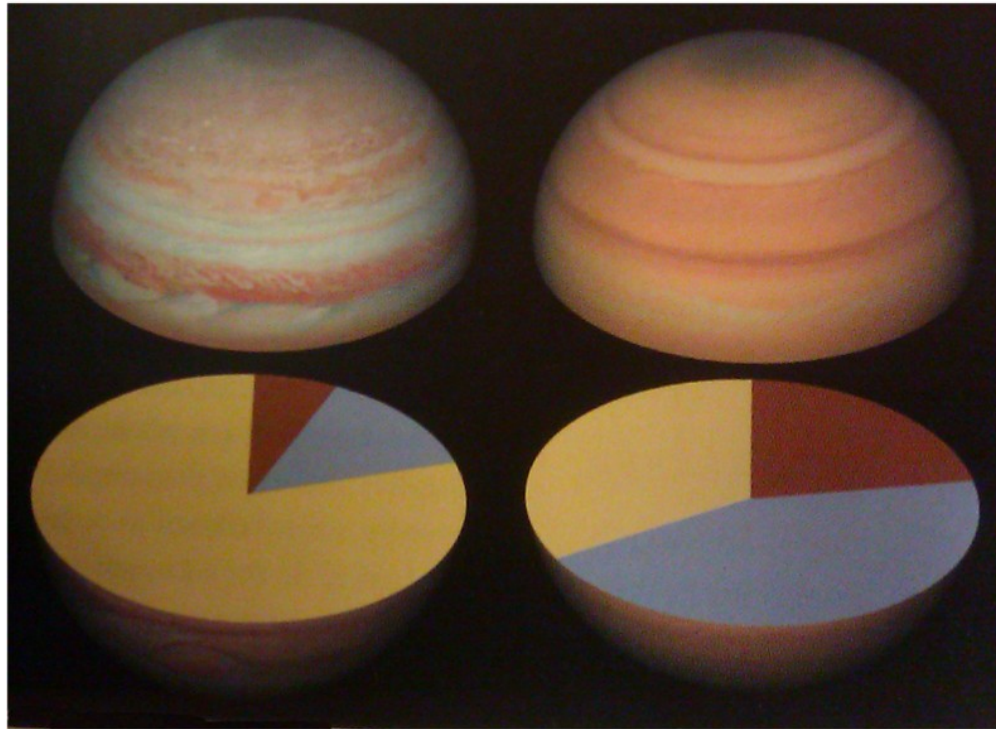
Earth



## Gas Giants

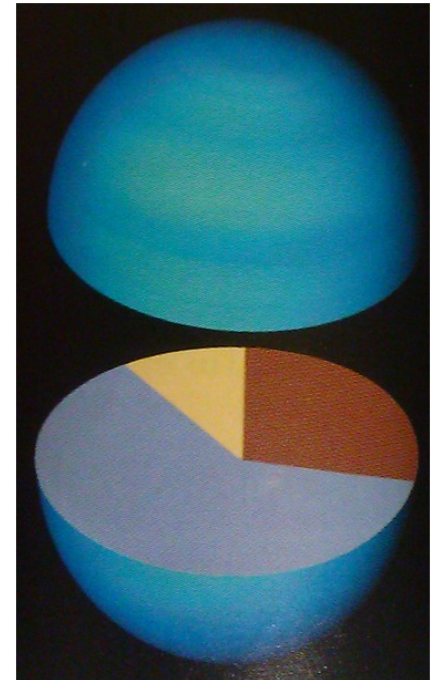
Jupiter

Saturn



## Ice Giants

Uranus/Neptune



Rock

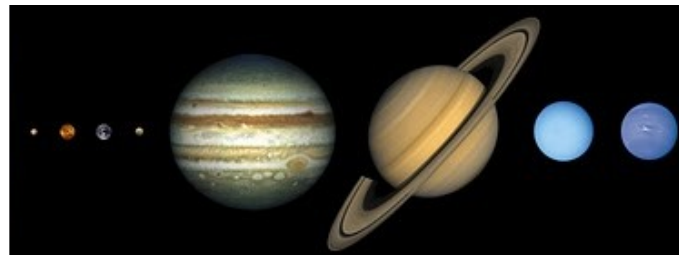
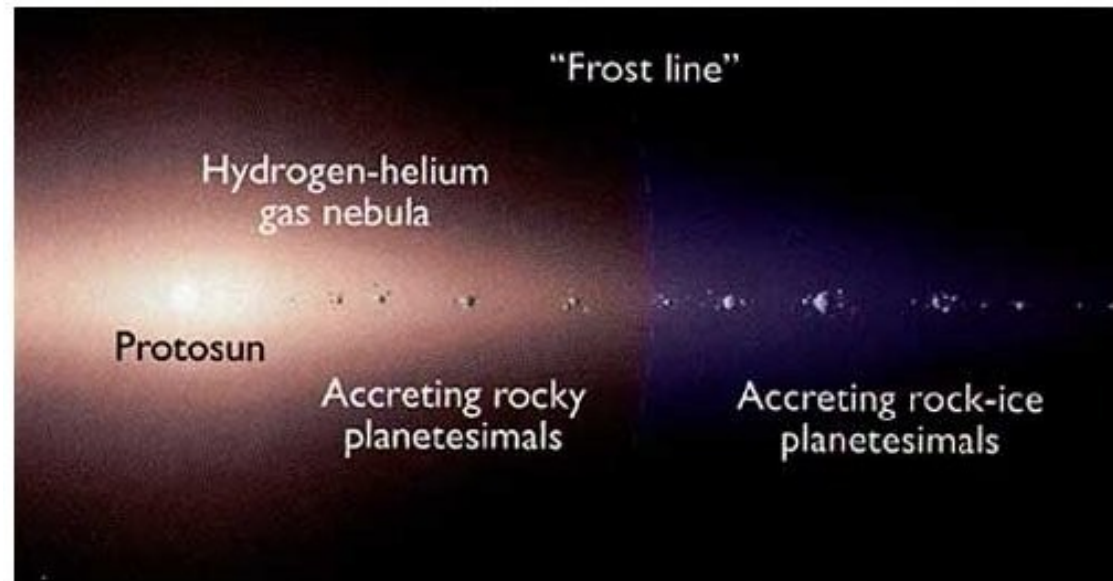


Gas



Ice

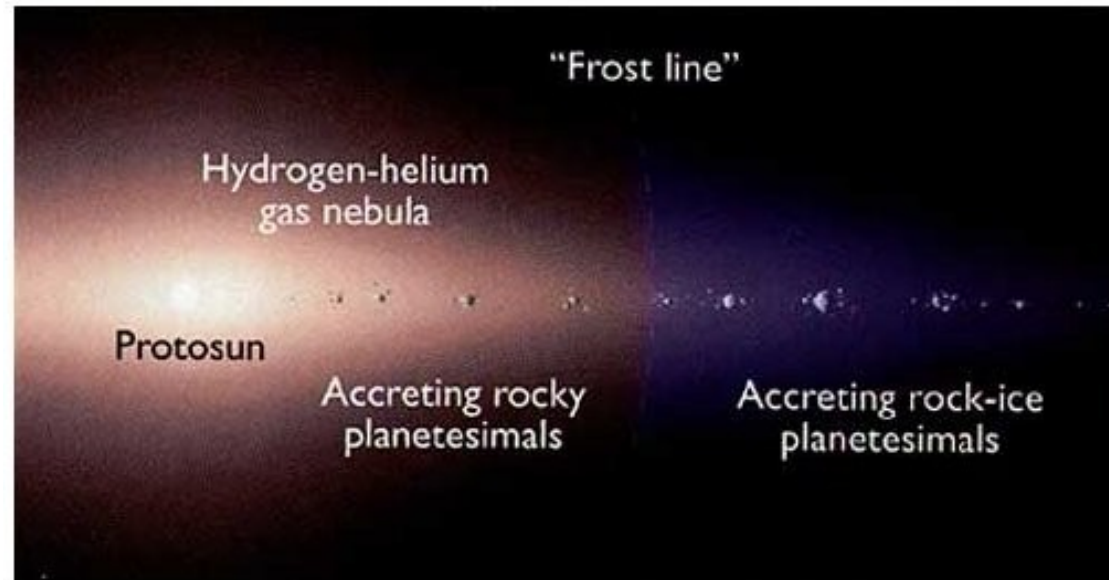
# Formation



# Formation

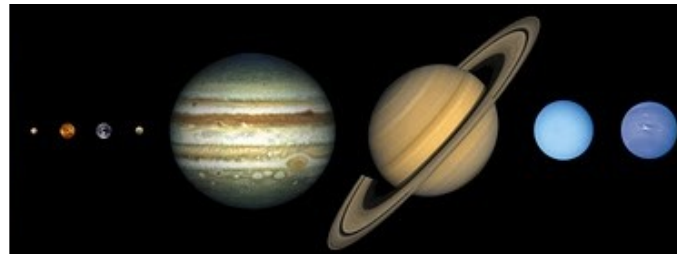
## Inward of snowline

Accreting  
rocky cores  
(small)



## Outward of snowline

Ice comes to aid!  
Growing big  
icy/rocky cores.

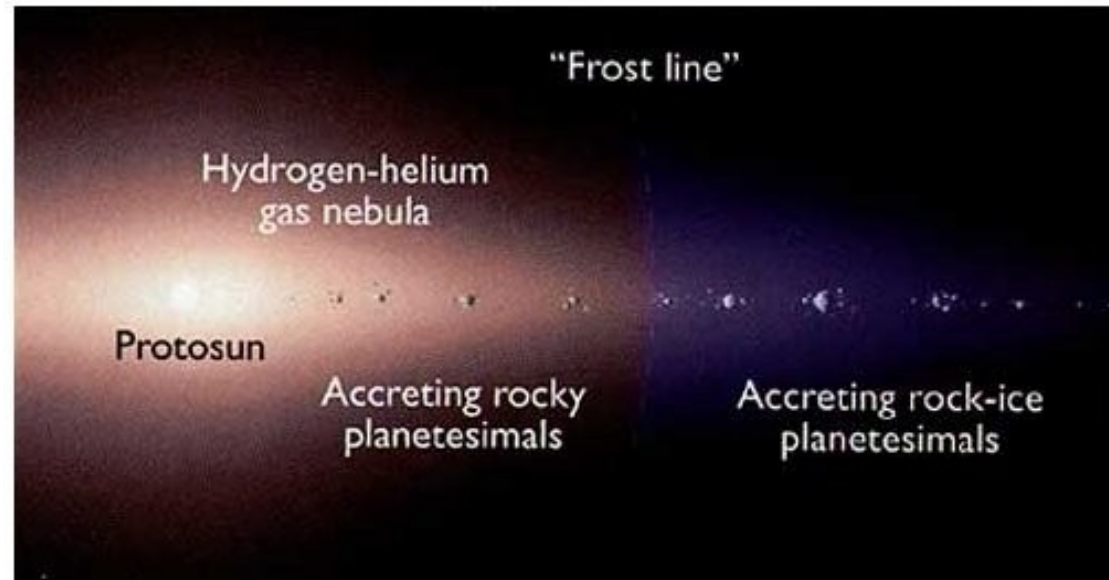




# Formation

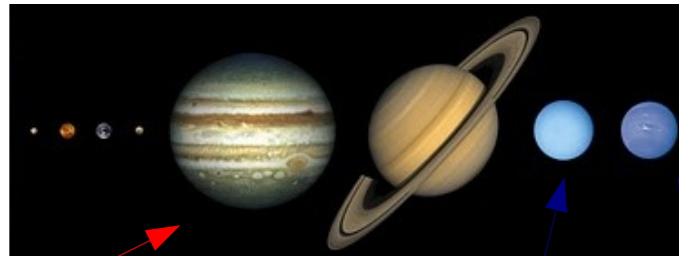
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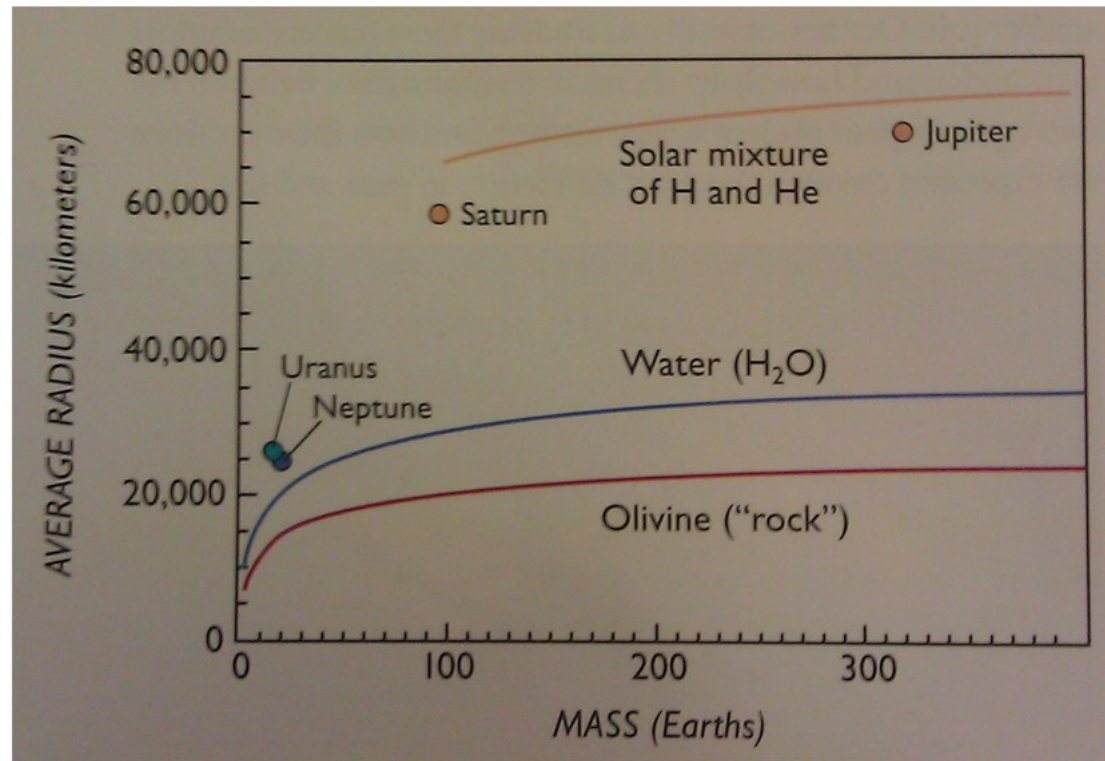
These guys got so big  
they started accreting  
gas from the nebula!

These ones never did.  
They are just the icy/rocky cores.

# Gas Giants



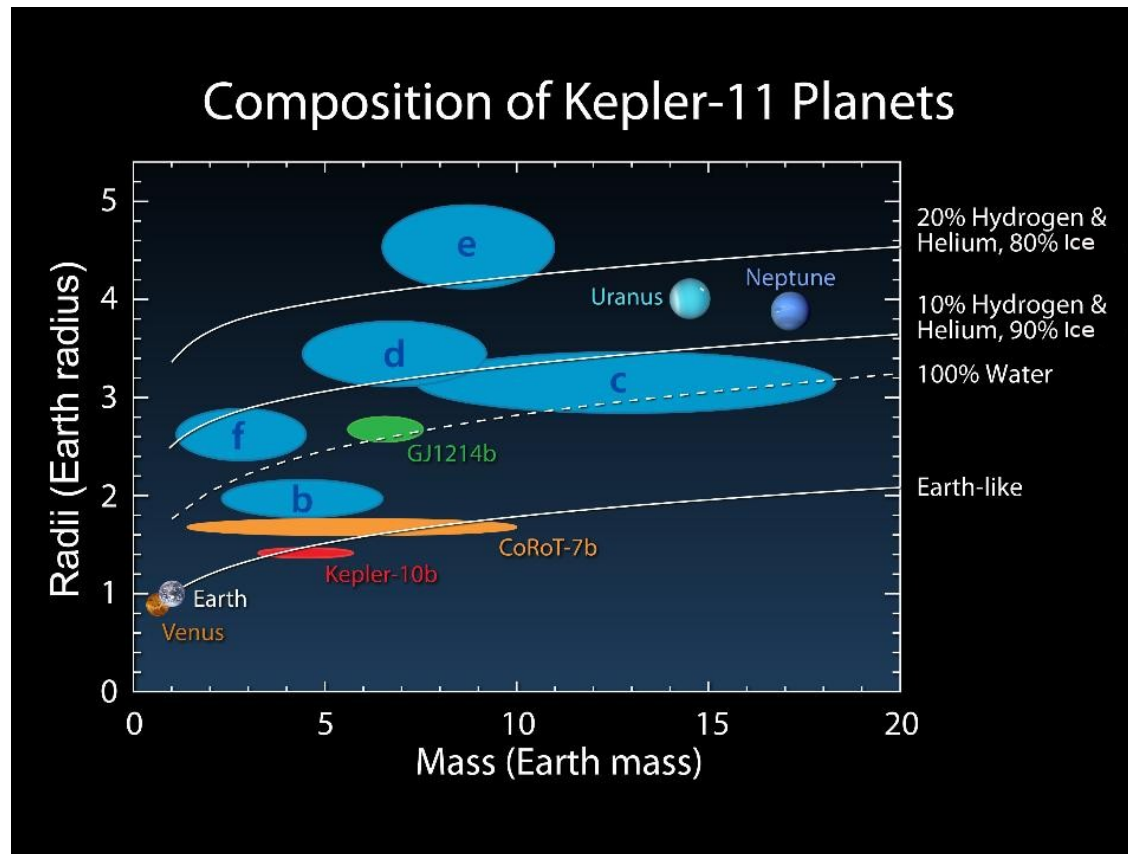
# Mass-Radius Diagram



Measure mass and radius  
Plot prediction curves from models  
Estimate the gas/ice/rock proportions!

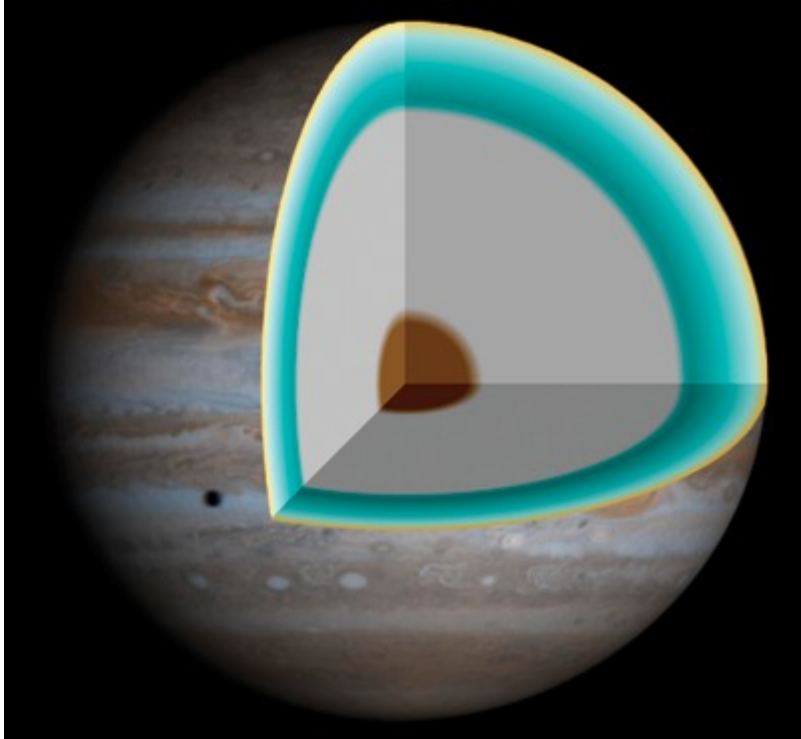


# Mass-Radius Diagram



Very useful when applied to exoplanets!

# Interior of Jupiter



Pressure = weight/area

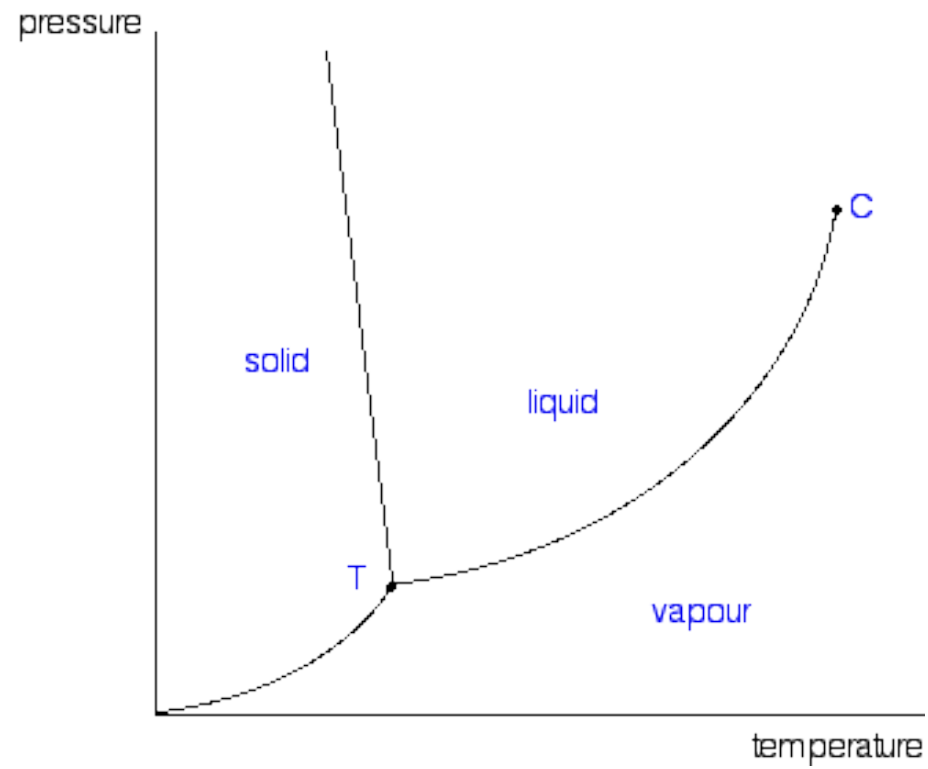
Pressure at center

**70 million atmospheres**

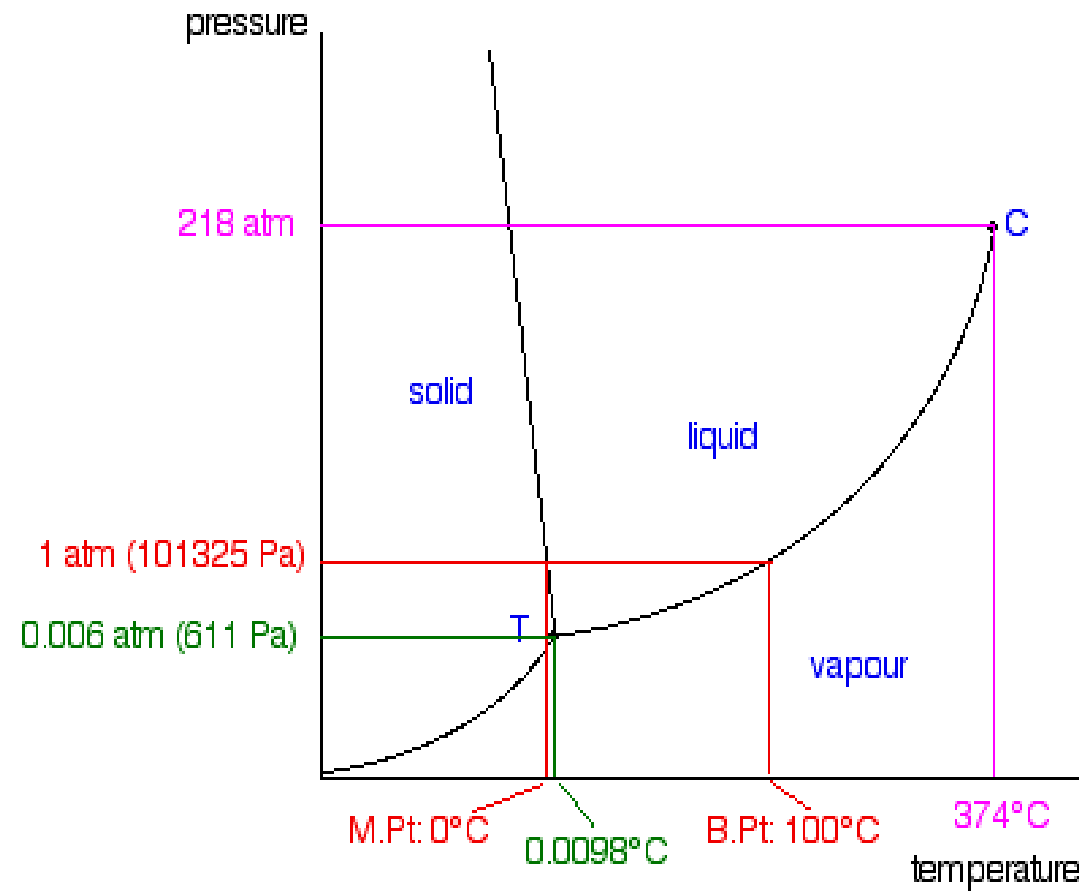
Temperature at center

**17.000 K**

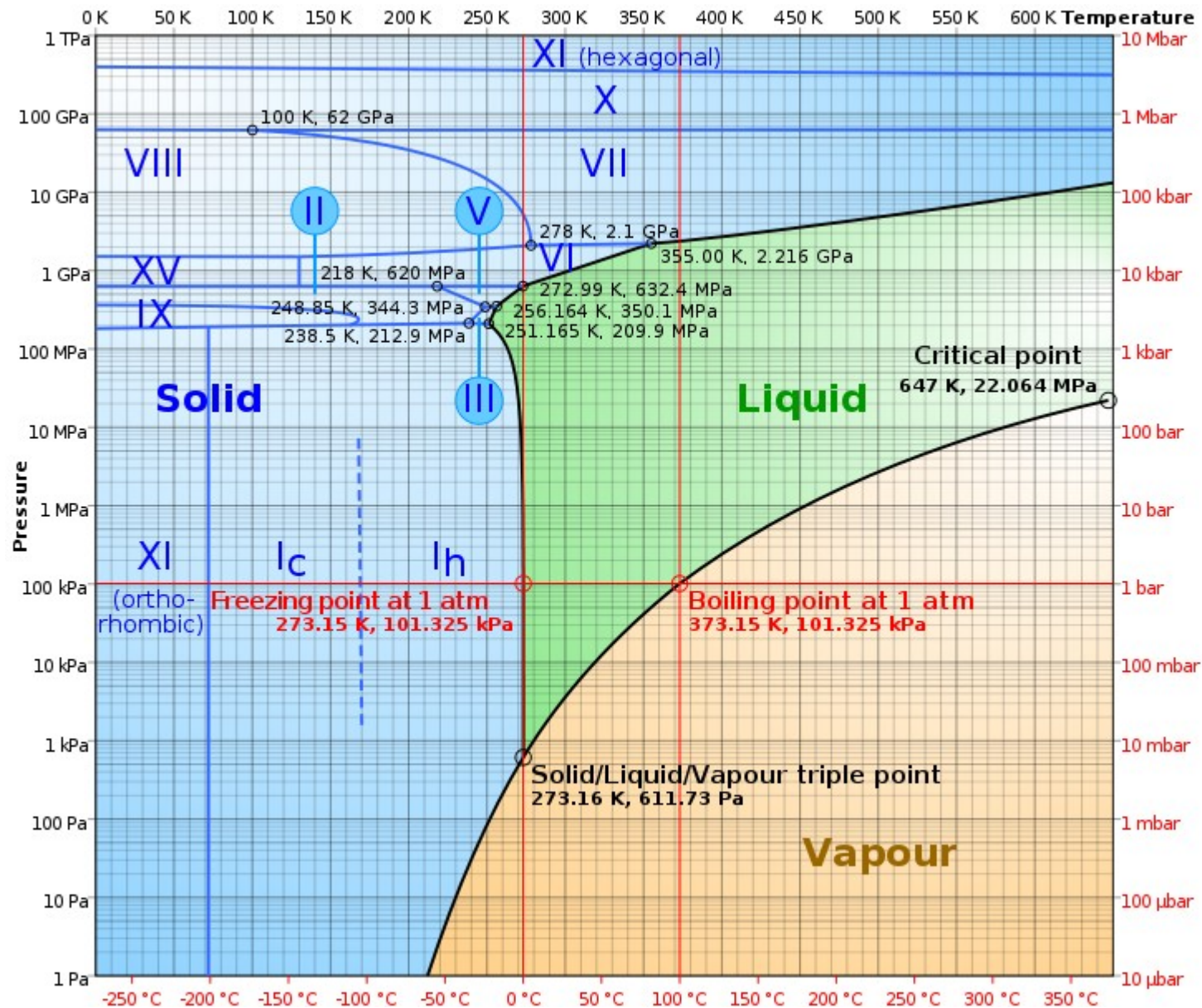
# Phase diagram



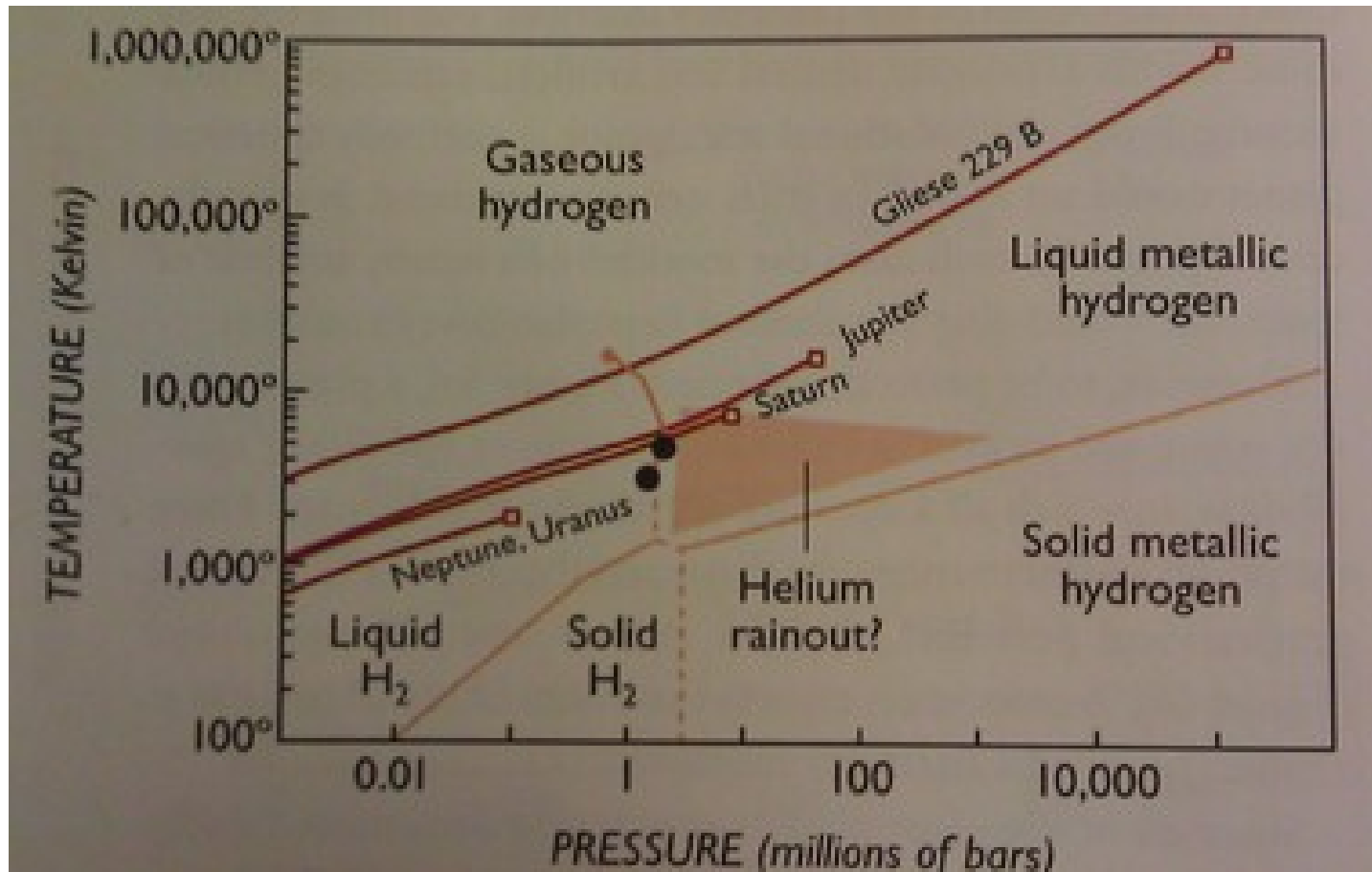
# Phase diagram



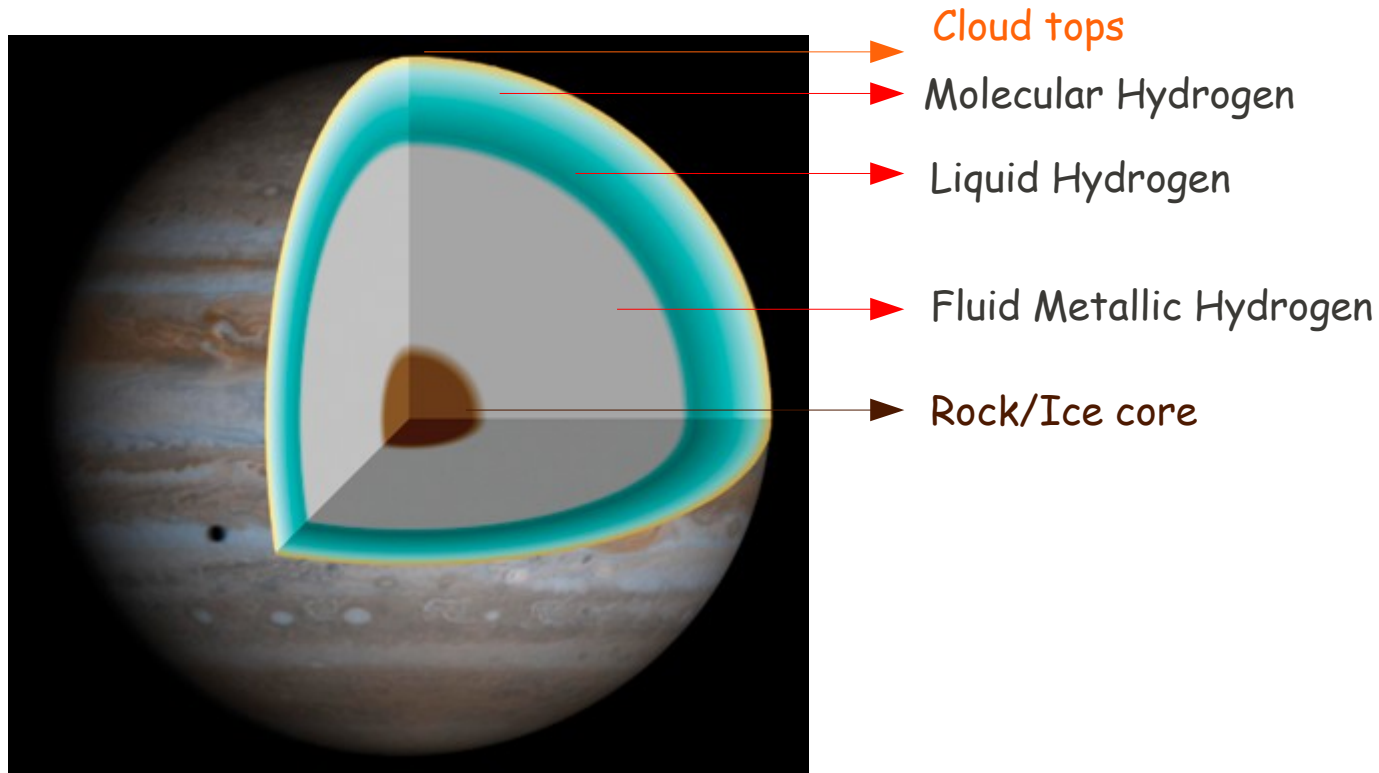
# A lot more happens at high pressures



# Hydrogen under pressure



# Interior of Jupiter

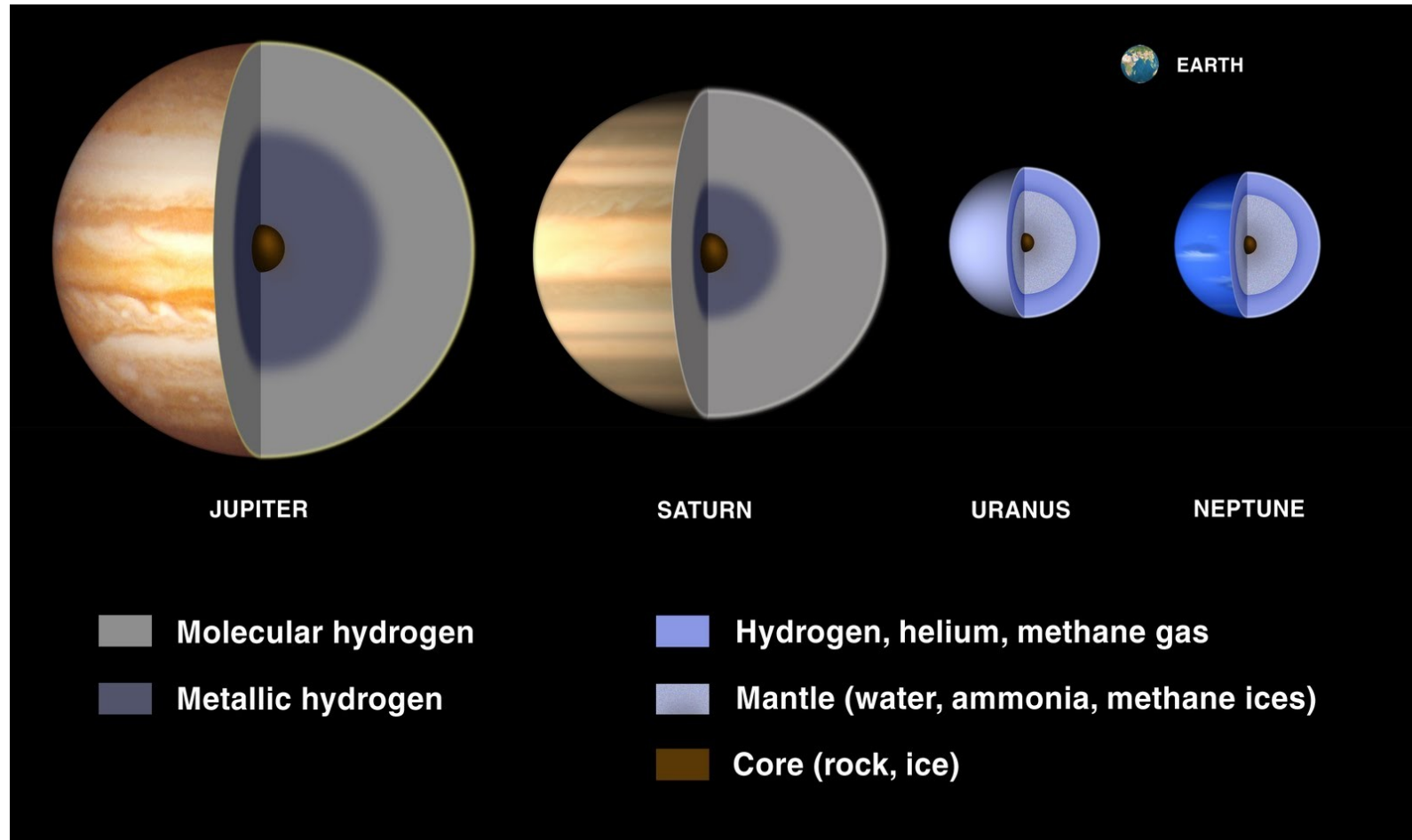


Pressure = weight/area

Pressure at center  
**70 million atmospheres**

Temperature at center  
**17.000 K**

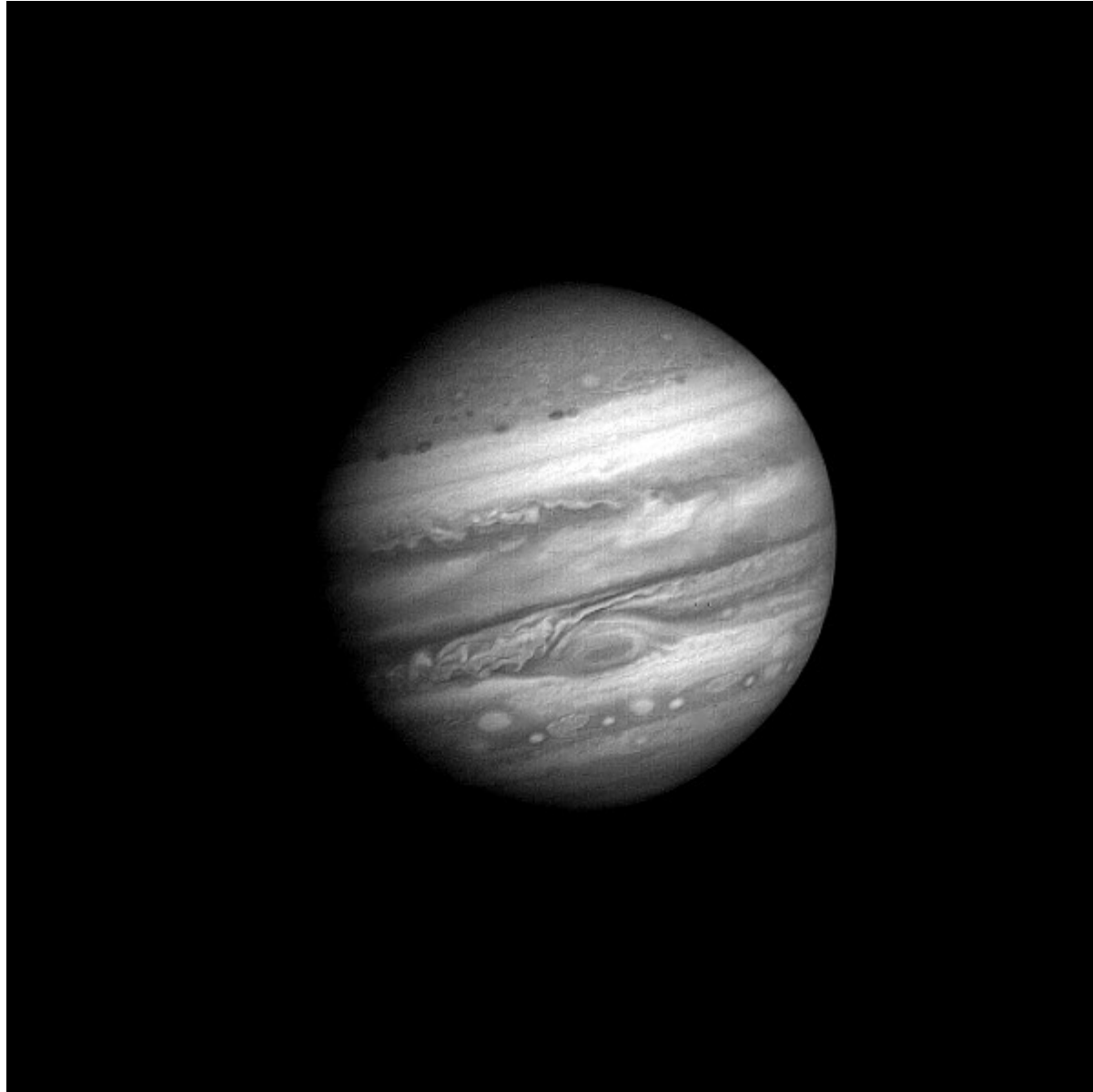
# Interior of the giant planets



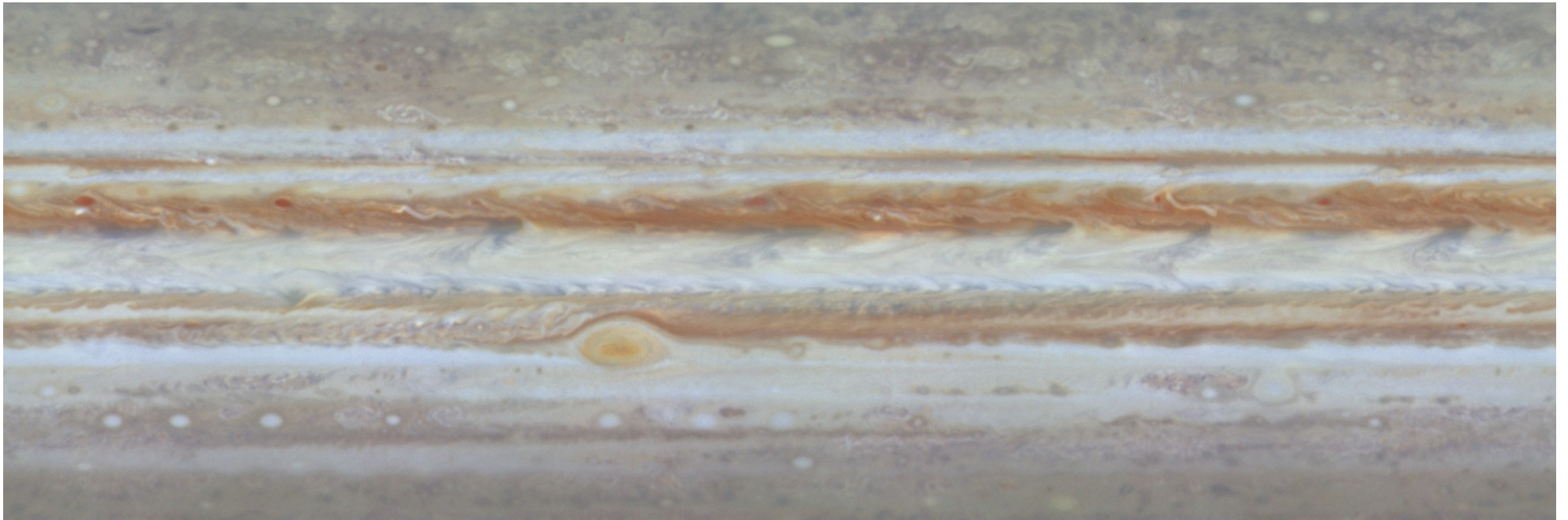


*Activity*

# Atmospheres of the Giant Planets



# Atmospheres of the Giant Planets

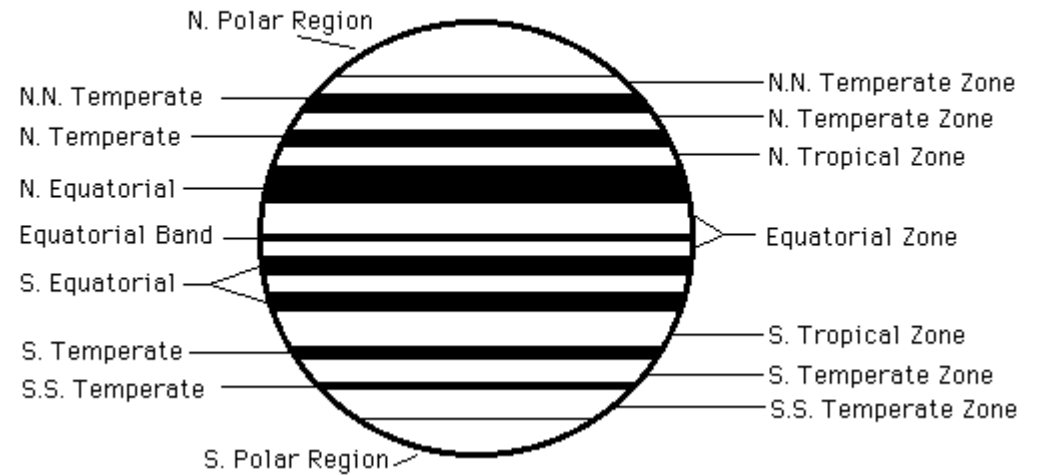


# Atmospheres of the Giant Planets



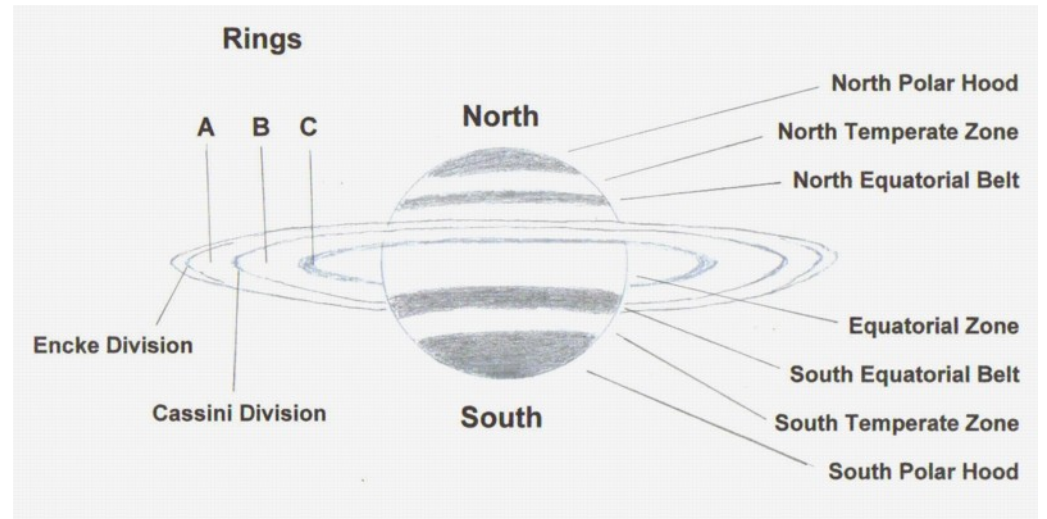
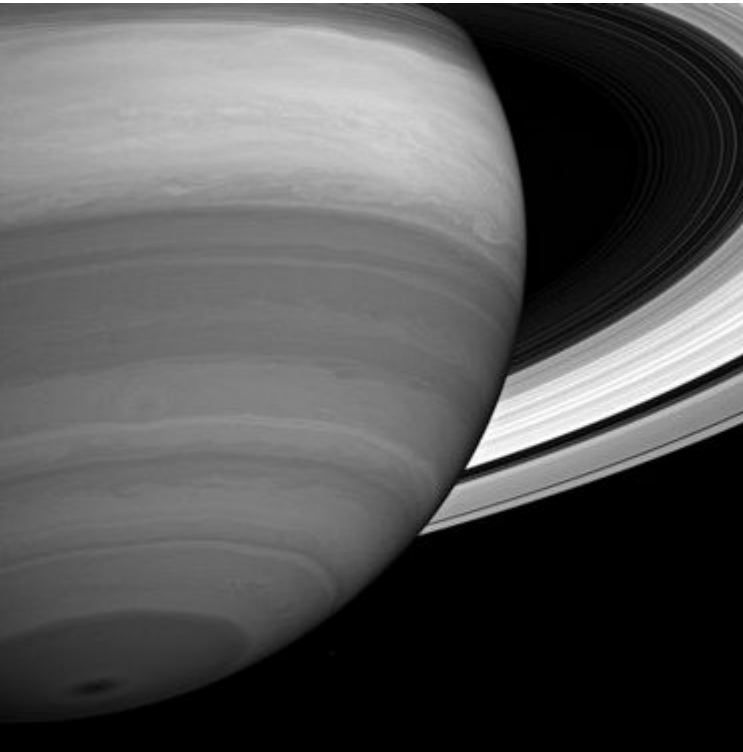
## DARK BELTS

## BRIGHT ZONES



Bands and Storms

# Atmospheres of the Giant Planets

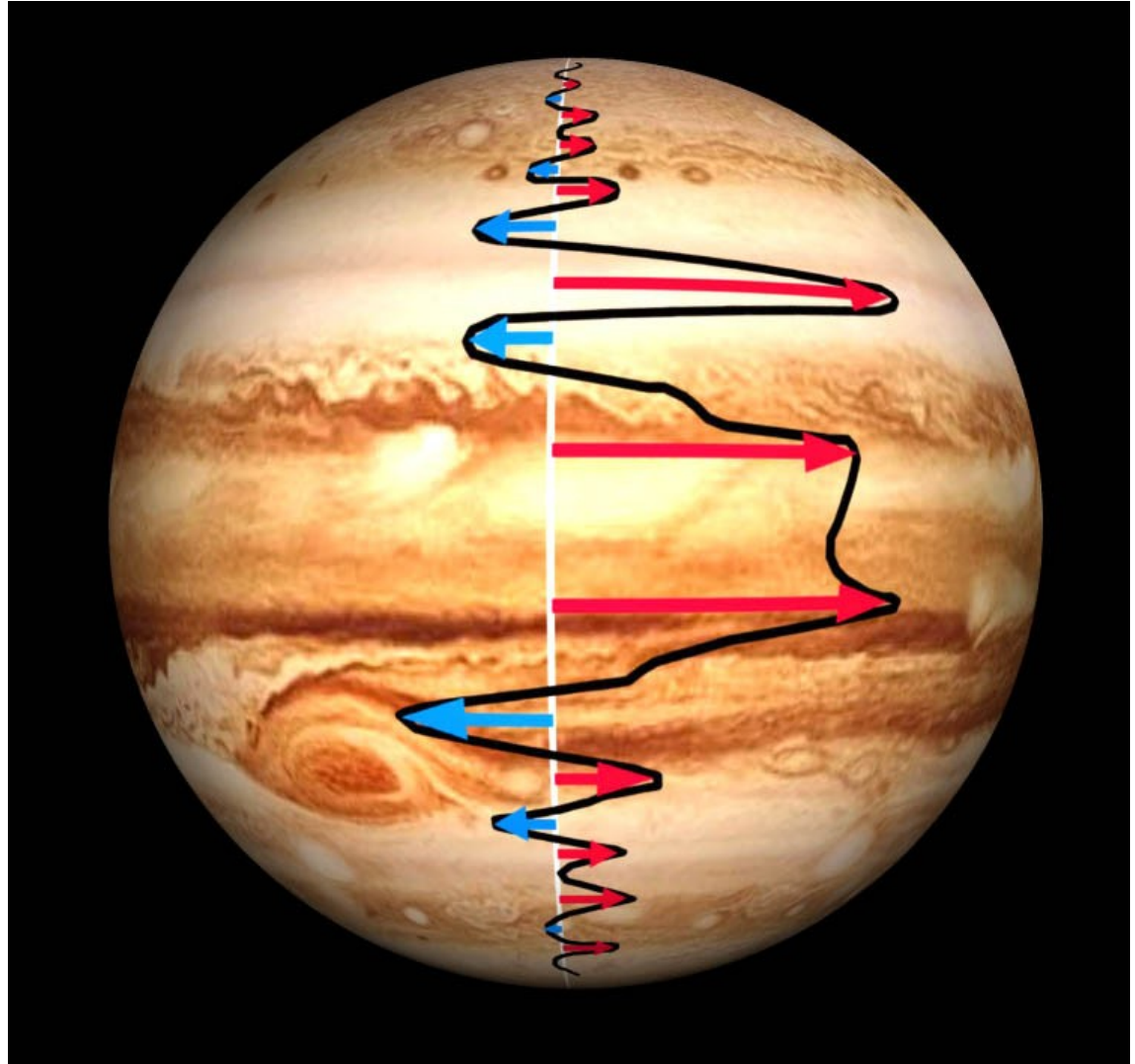


Bands and Storms

# Atmospheres of the Giant Planets

## Bands and Zones

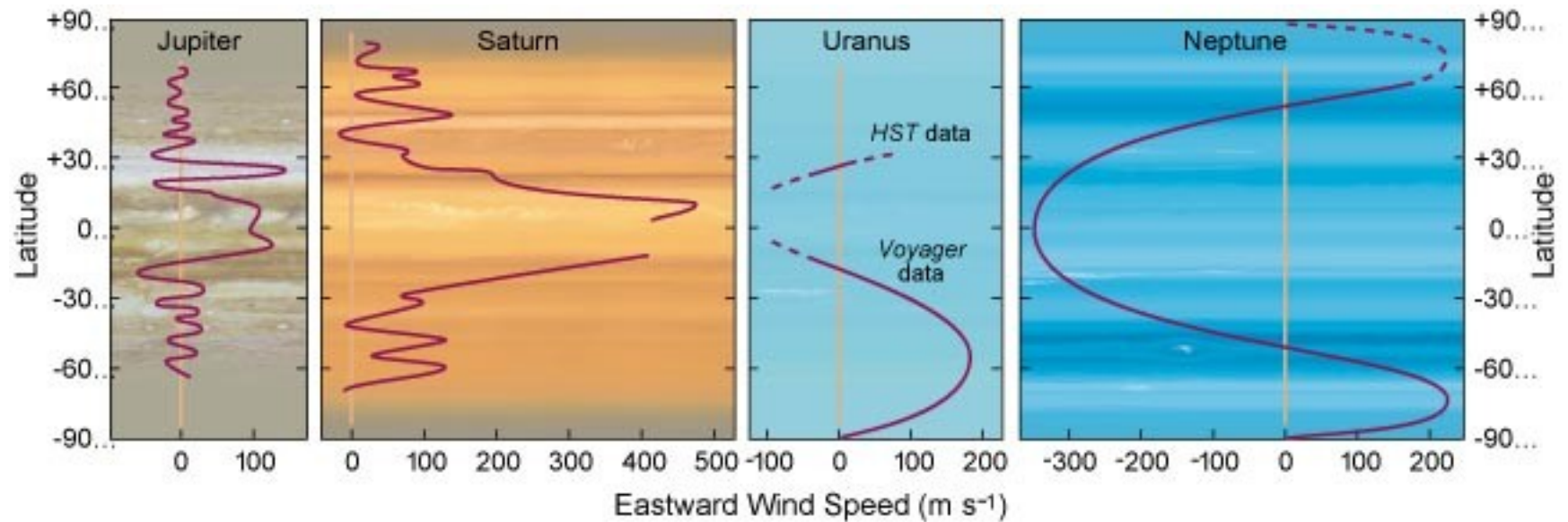
Large scale winds  
of alternate direction





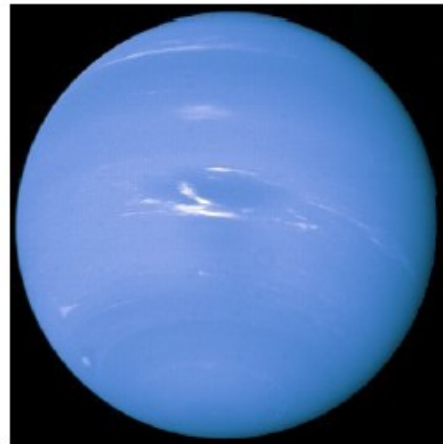
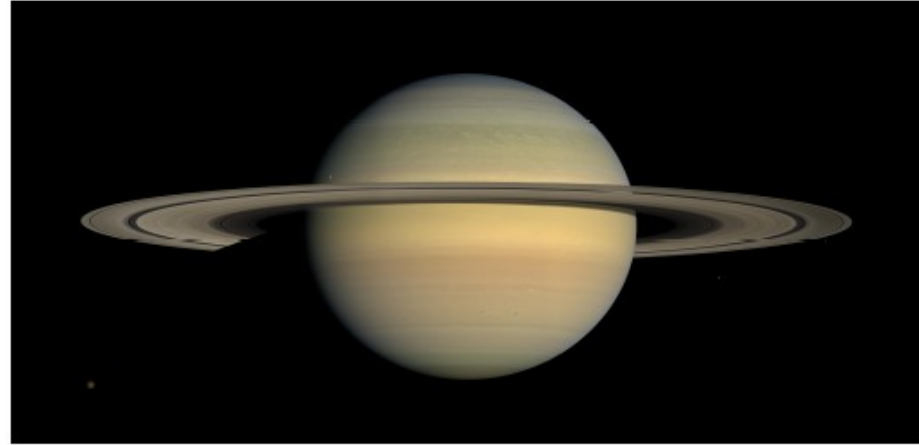
# Atmospheres of the Giant Planets

## Wind Speeds





# Clouds of the Giant Planets



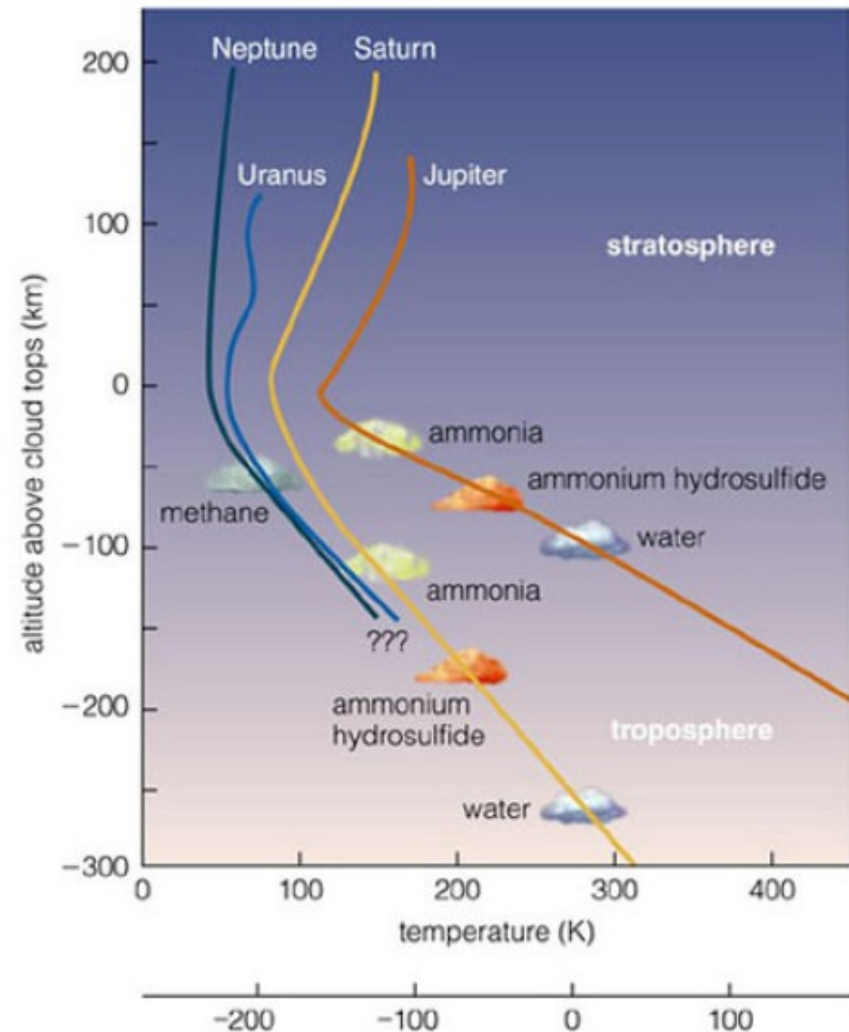
# Molecules condense at different temperatures

## Atmospheric Temperatures

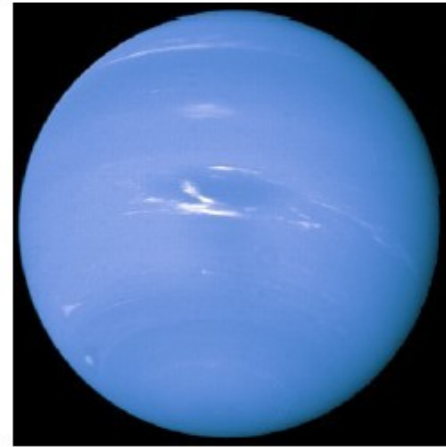
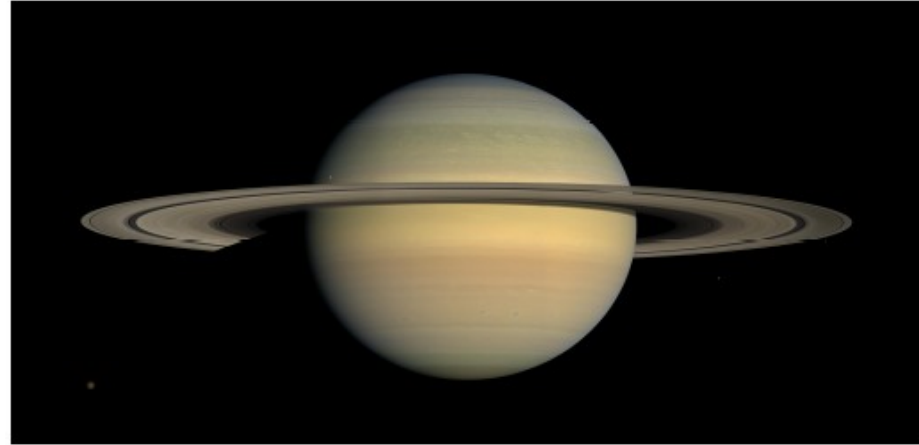
$\text{H}_2\text{O}$  ~300K

$\text{NH}_3$  ~140K

$\text{CH}_4$  ~80K

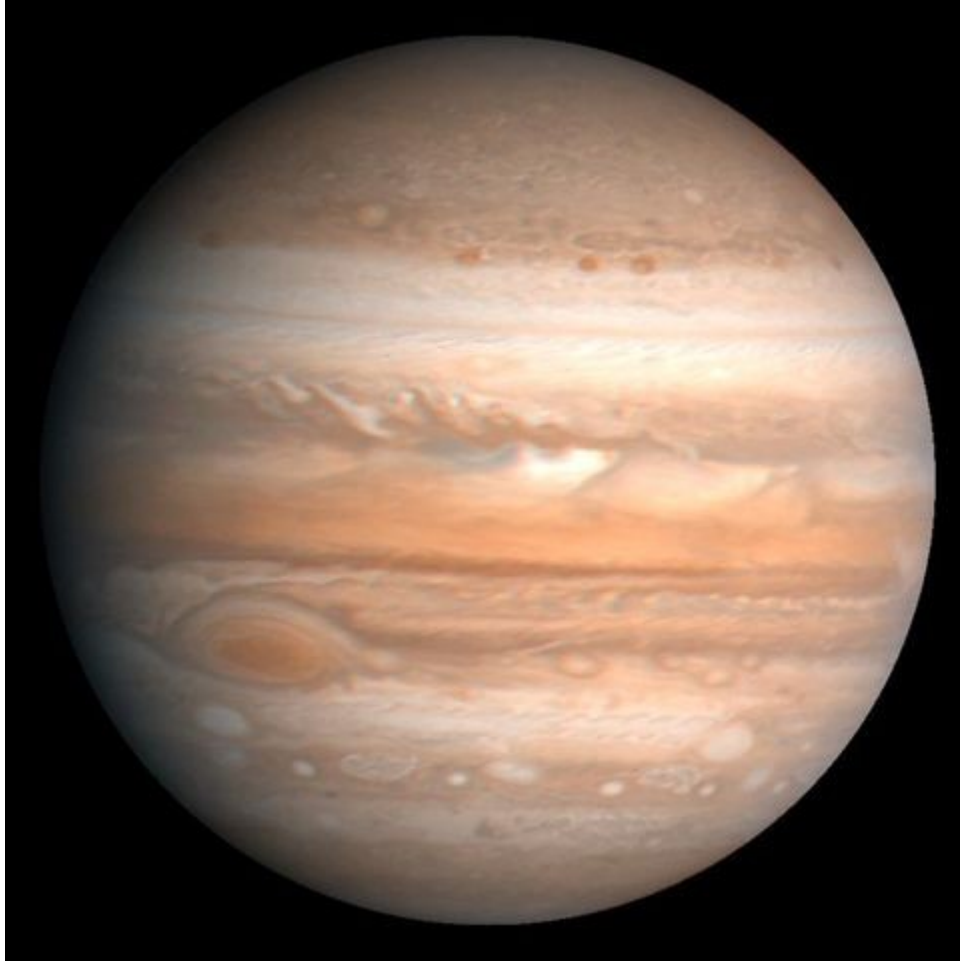


# Ammonia and Methane Clouds



Jupiter and Saturn have **ammonia clouds**  
Colder Uranus and Neptune have **methane clouds**

# Clouds of Jupiter



Bright *Zones*

Dark *Belts*

Dark brown color:  
compounds of sulfur (S) and phosphorus (P)

Bright zones:  
High ammonia clouds  
shielding brown stuff below

# Clouds of Jupiter

Bright *Zones*

Dark *Belts*

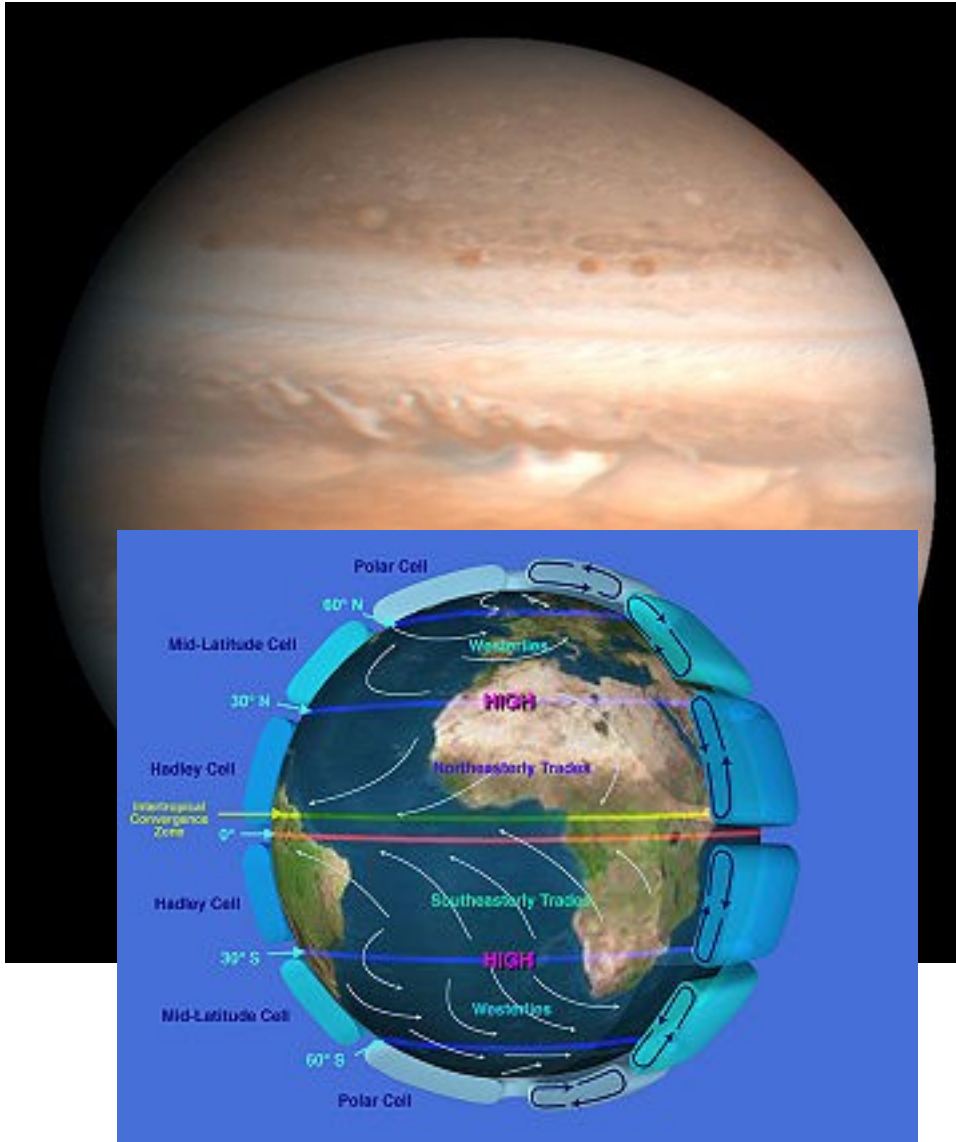
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High ammonia clouds  
shielding brown stuff below

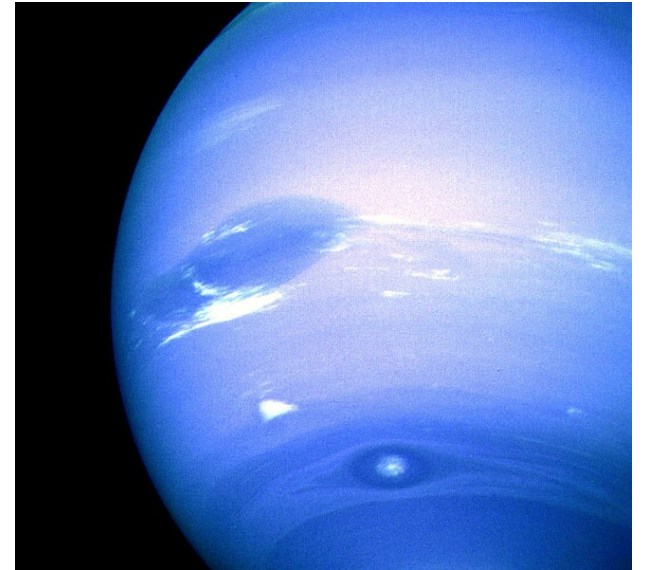
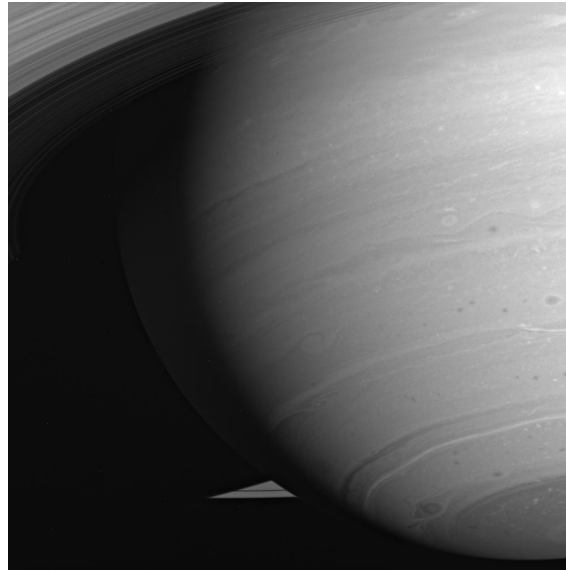
In Jupiter

Hot gas rises, **cools**,  
ammonia condenses -> **Zones**.

Cold air sinks, **heats**,  
little ammonia - > **Belts**.



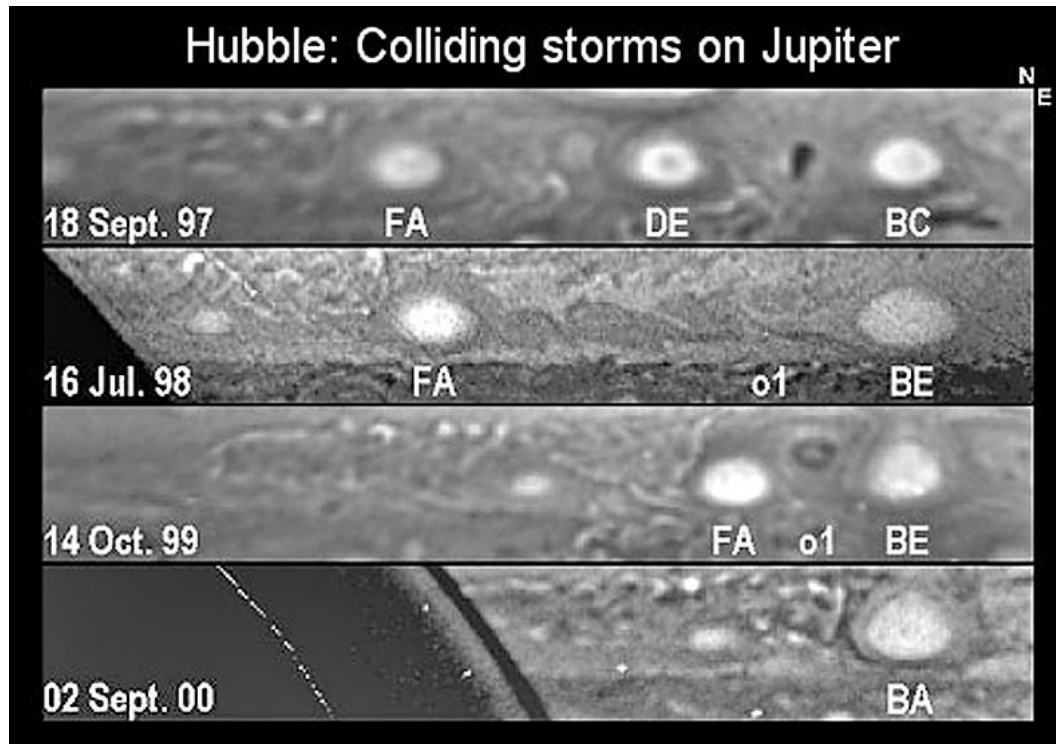
# Atmospheres of the Giant Planets



*Storms !!*



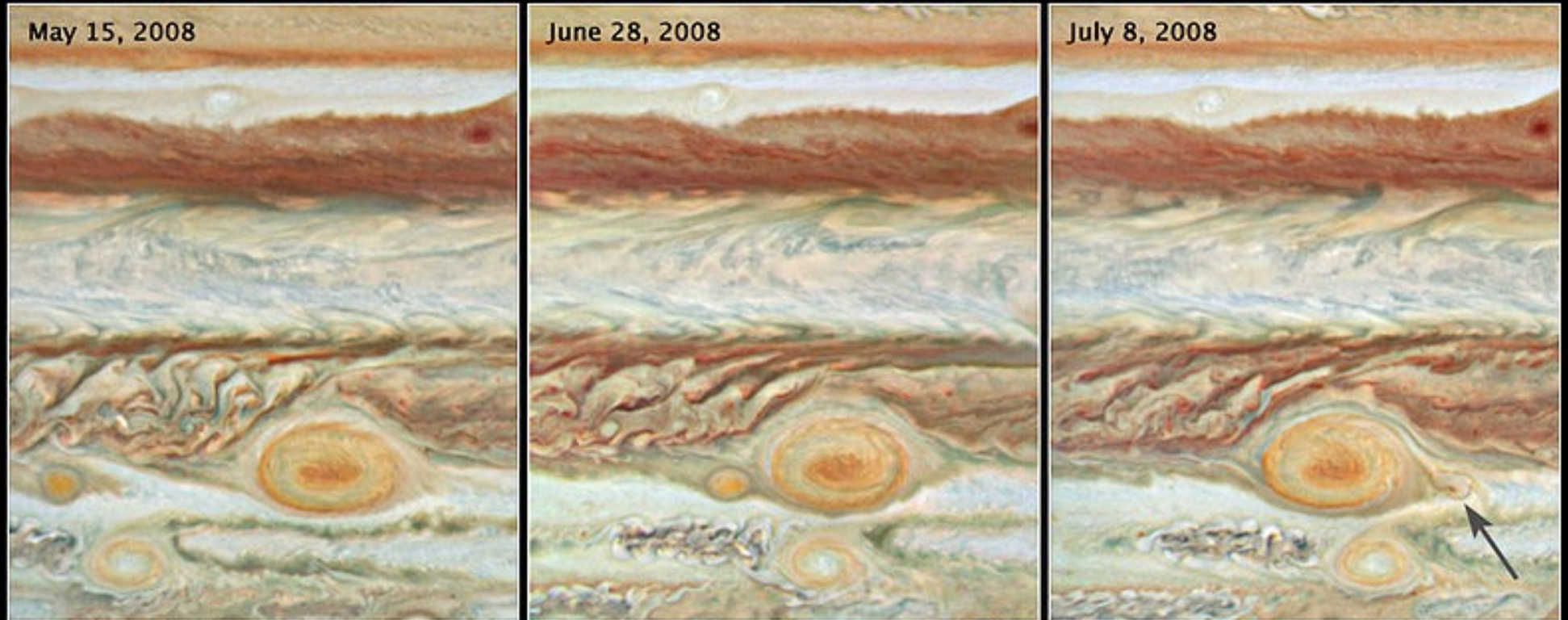
# Merging Storms





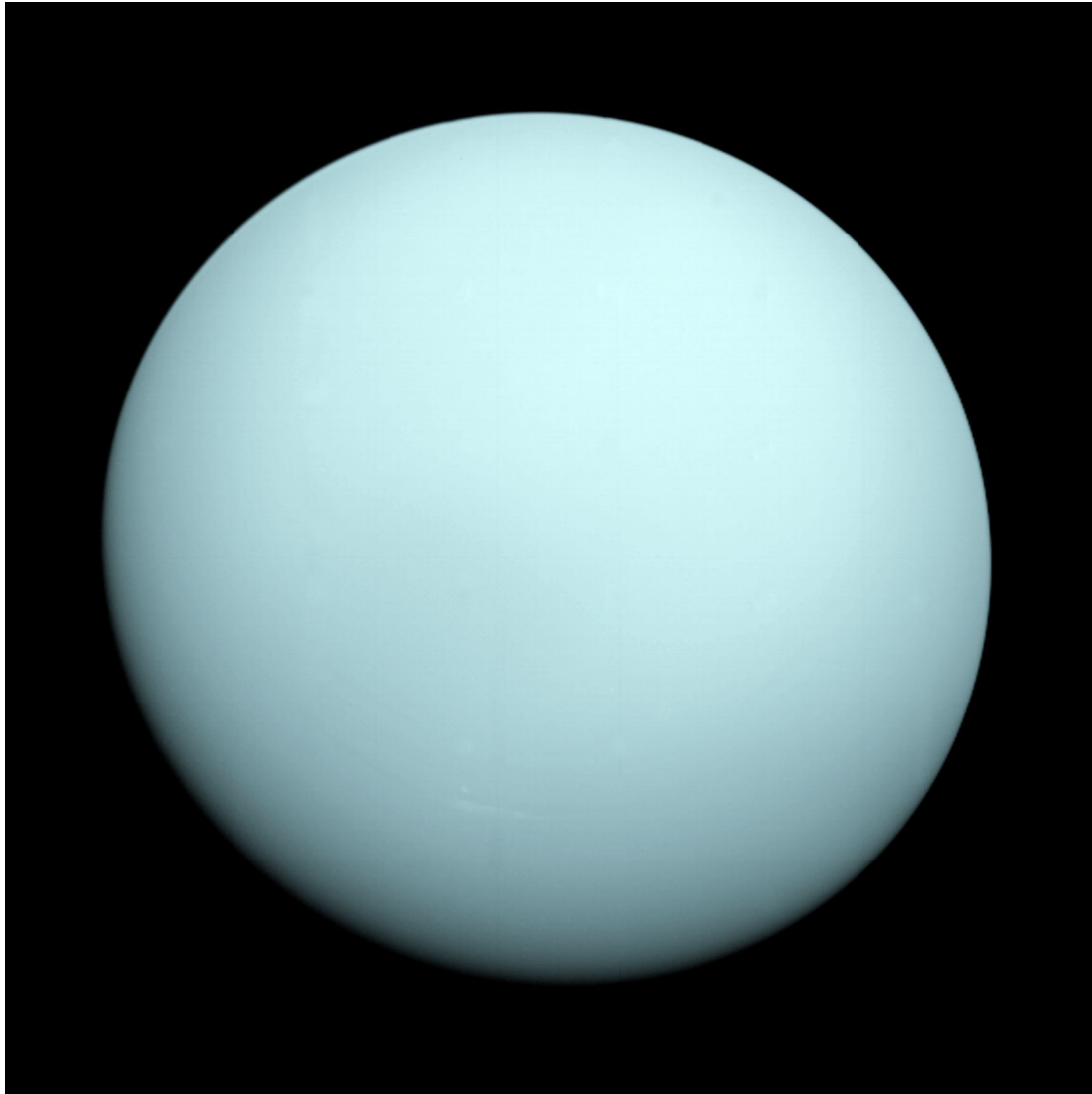
# Jupiter's Red Spots

Jupiter's Red Spots ▪ *Hubble Space Telescope* WFPC2



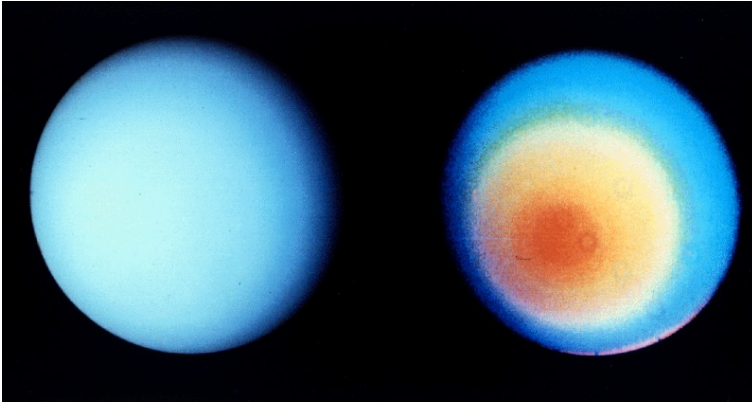
NASA, ESA, and A. Simon-Miller (NASA Goddard Space Flight Center) ▪ STScI-PRC08-27

# Uranus

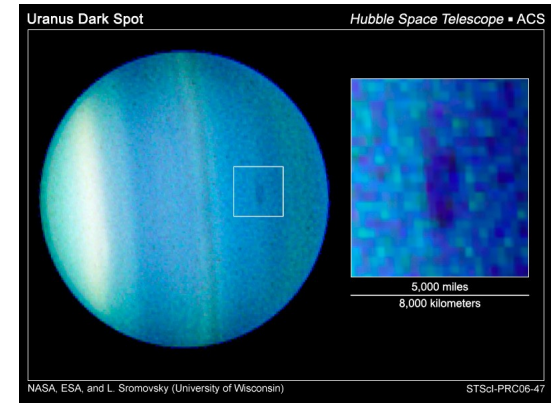


*Featureless...*

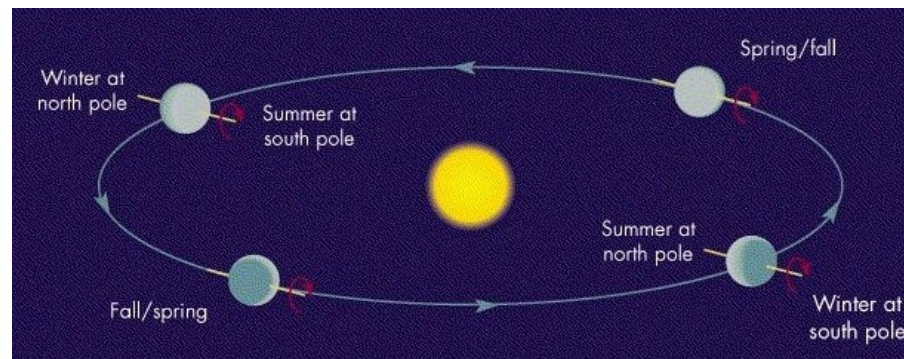
# Not quite featureless...



Uranus in false color: *Bands !*



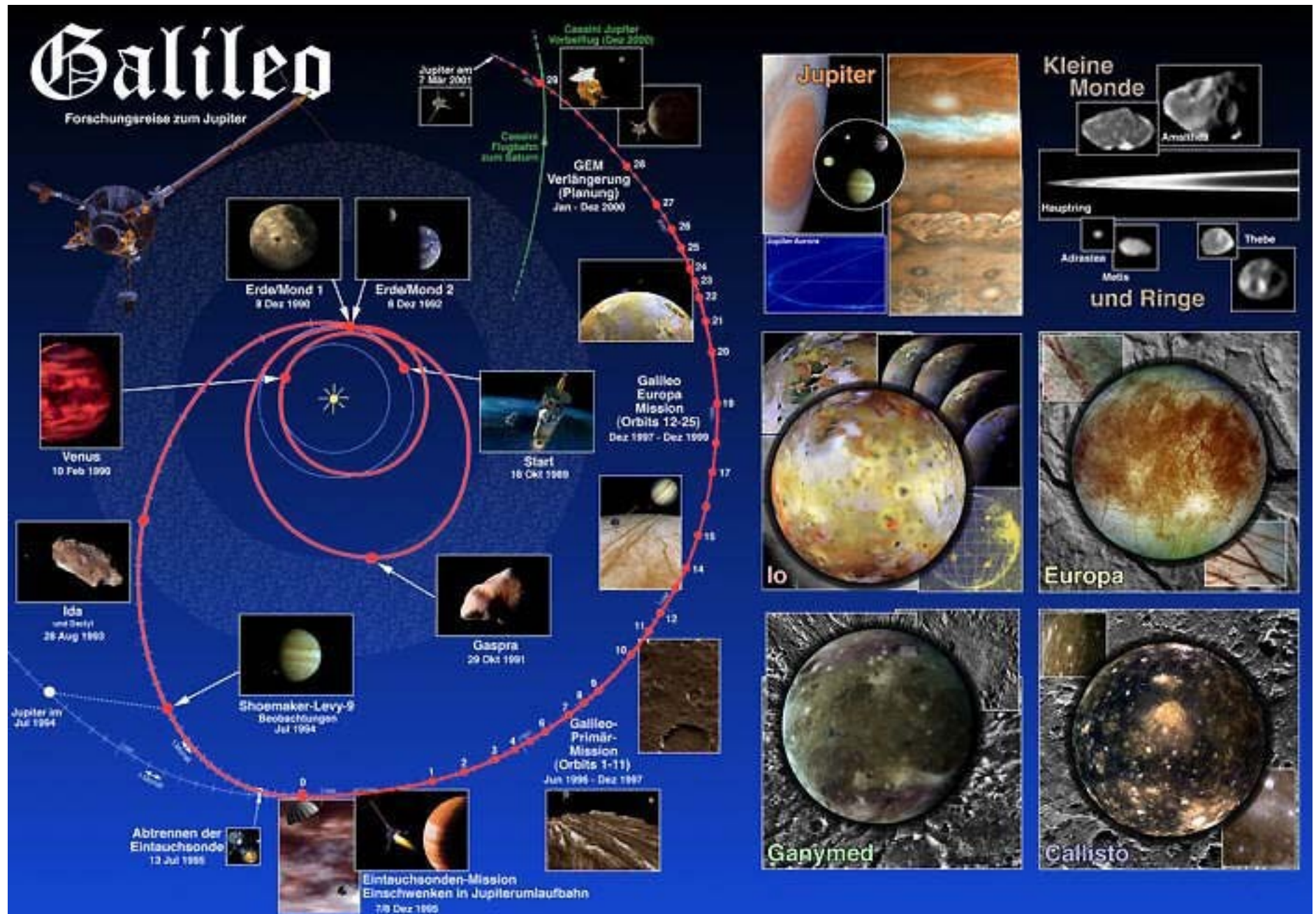
Recently seen by Hubble: *Storms !*



Due to the extreme axial tilt,  
weather in Uranus may be **highly seasonal**,  
being more Neptune-like in the equinoxes.

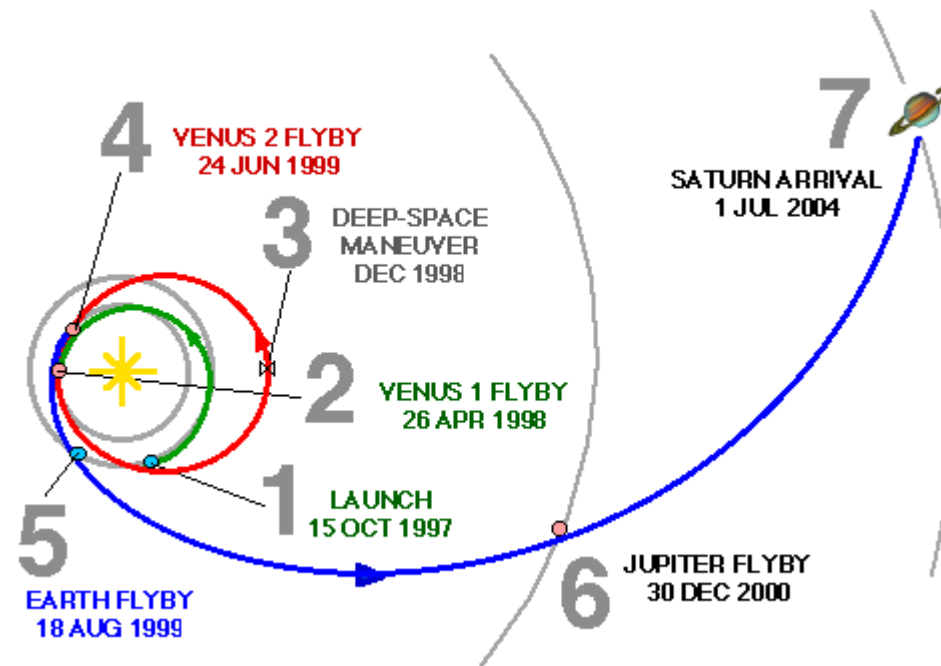
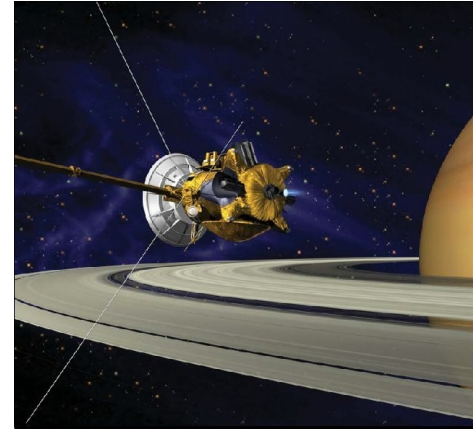


# Mission to Jupiter: Galileo





# Mission to Saturn: Cassini





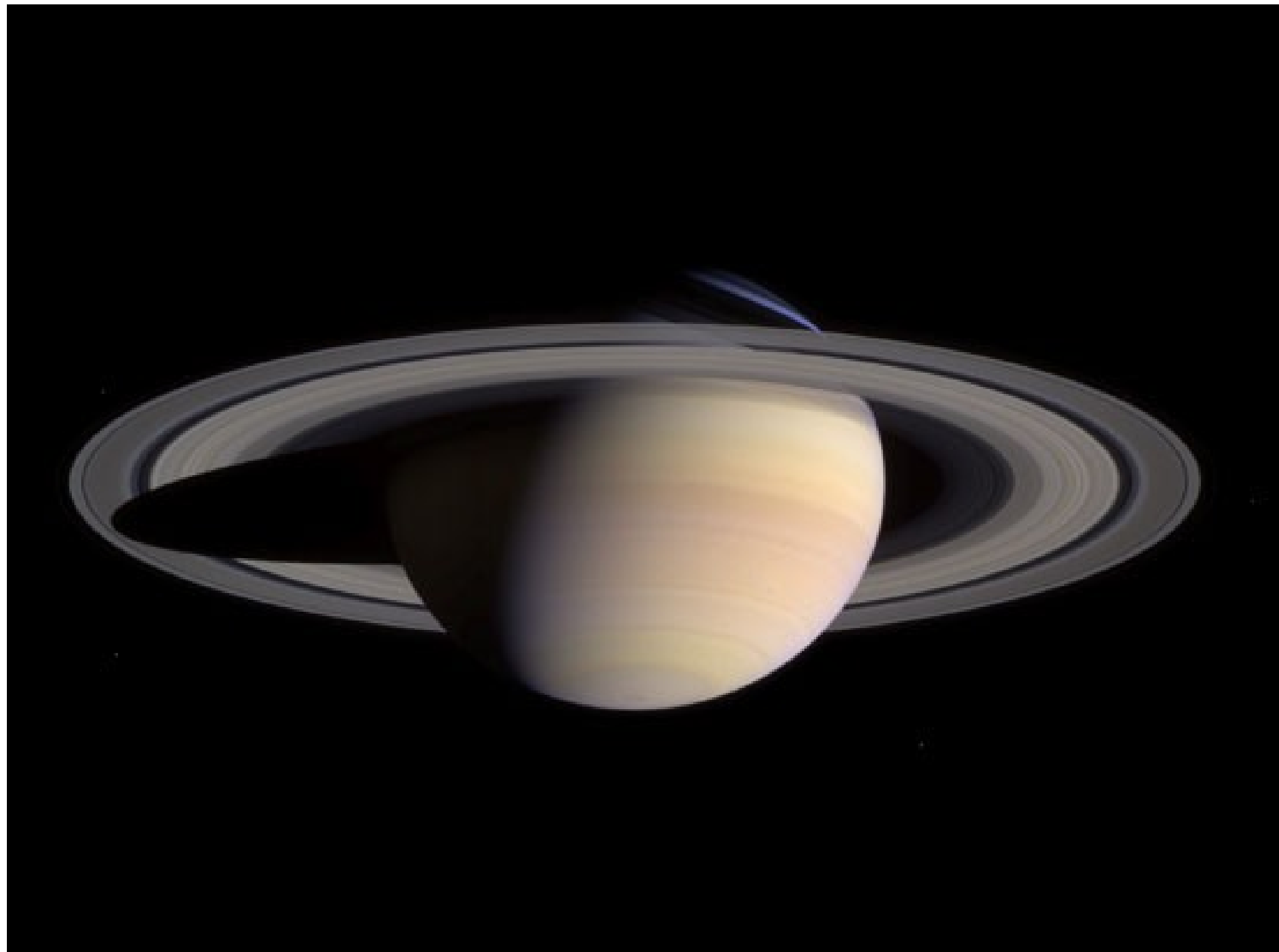


# IO WITH JUPITER BACKDROP

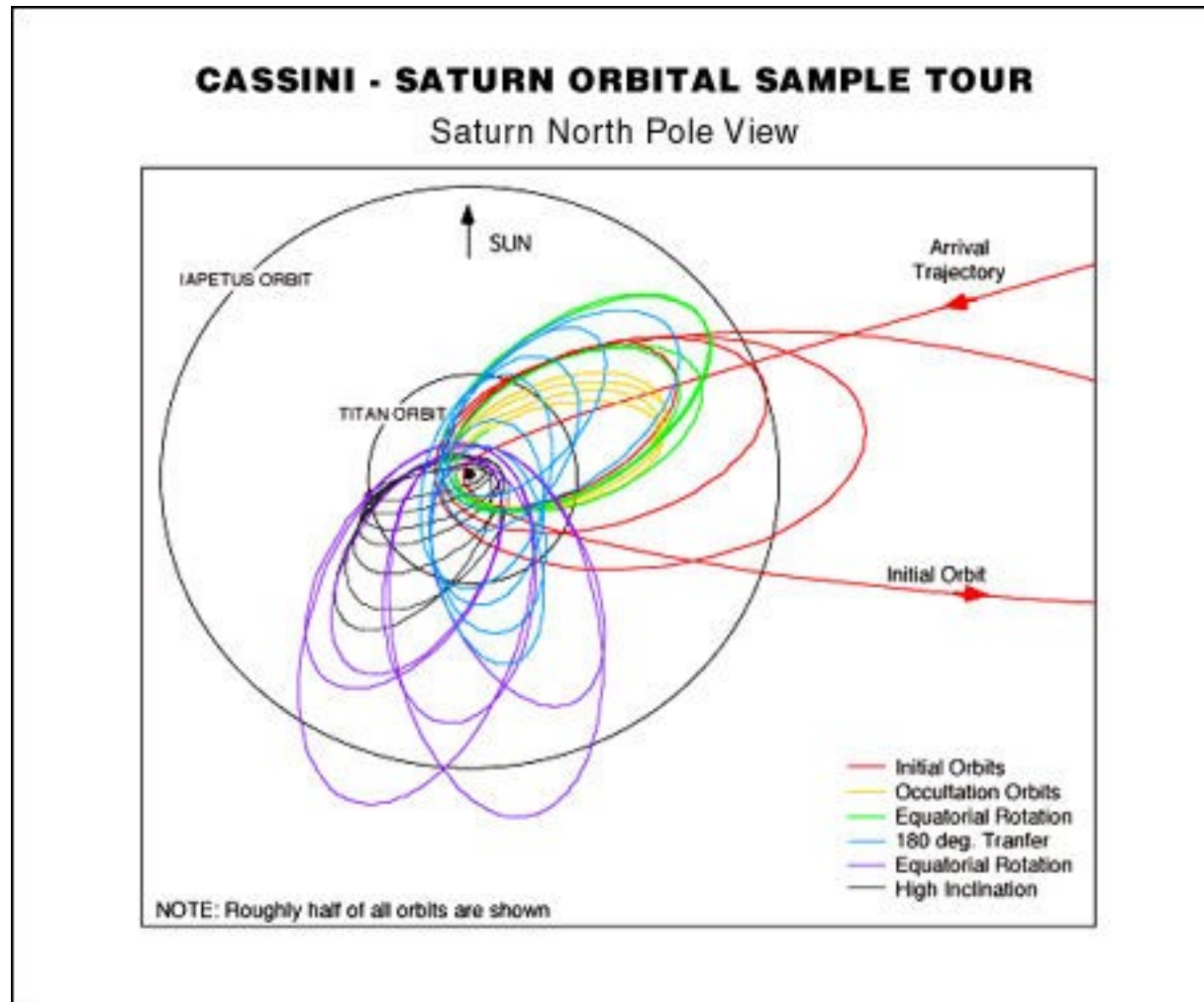
YEAR: 2001  
MISSION: CASSINI  
TARGET: JUPITER / IO

The moon Io captured against Jupiter and crossing into  
Jupiter's night side.





# Cassini orbiting Saturn



# Ringshine

