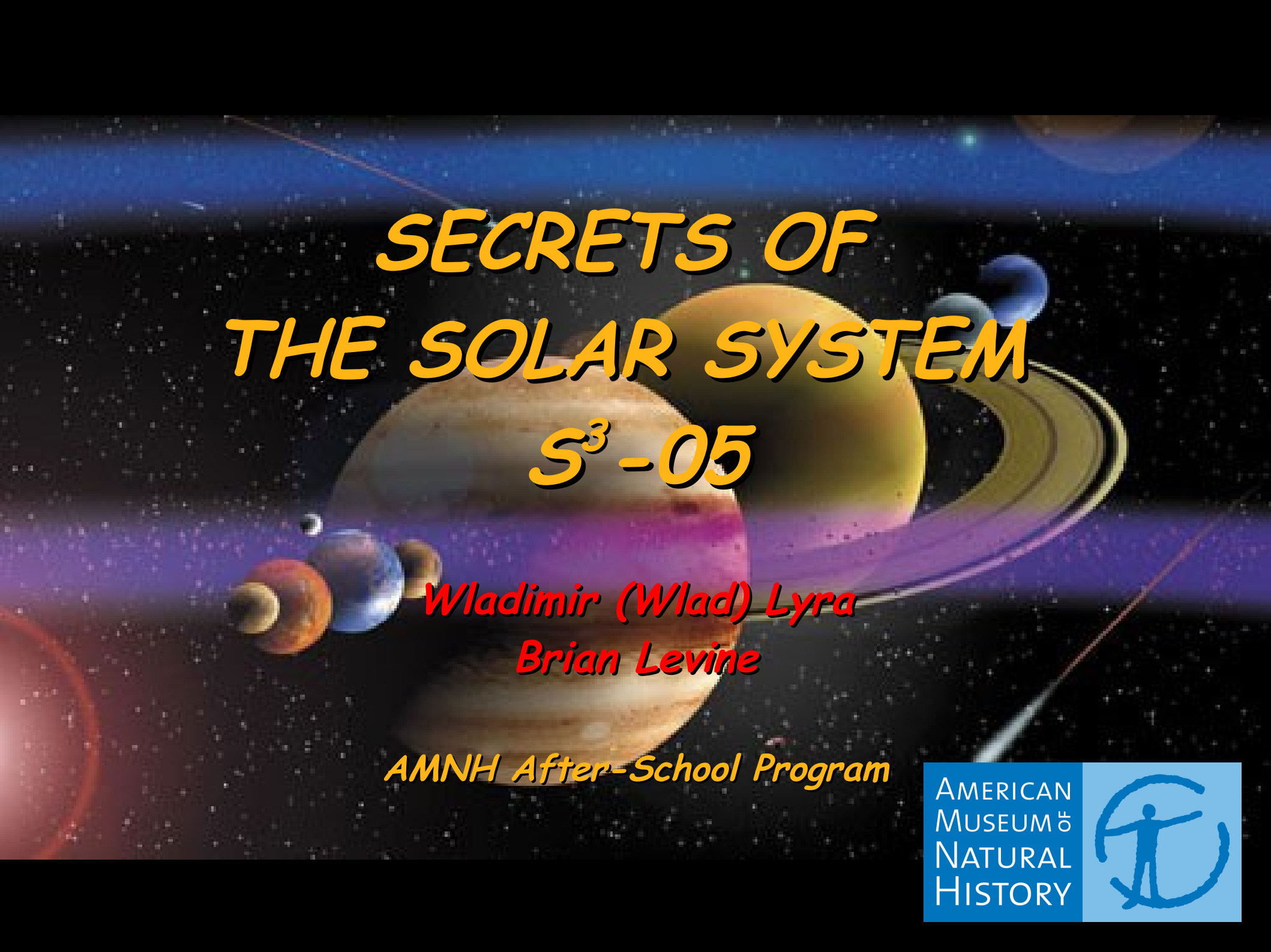


SECRETS OF THE SOLAR SYSTEM

S^3-05

Wladimir (Wlad) Lyra

Brian Levine

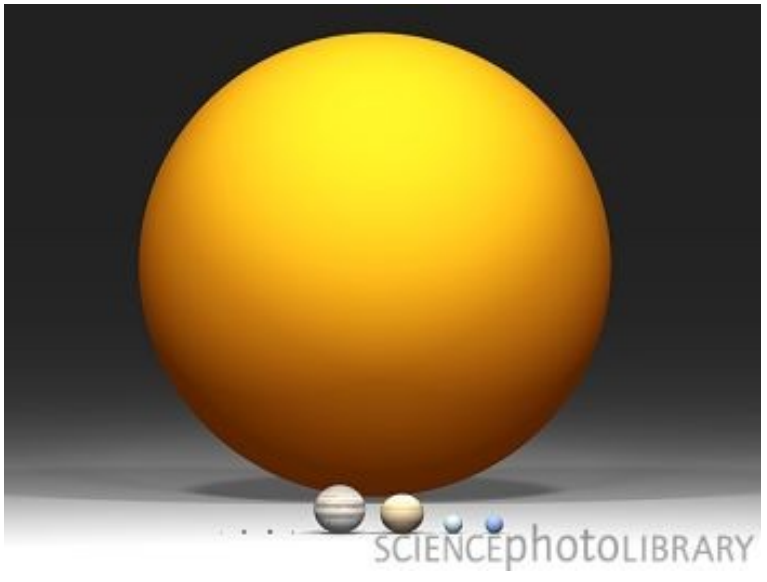
AMNH After-School Program

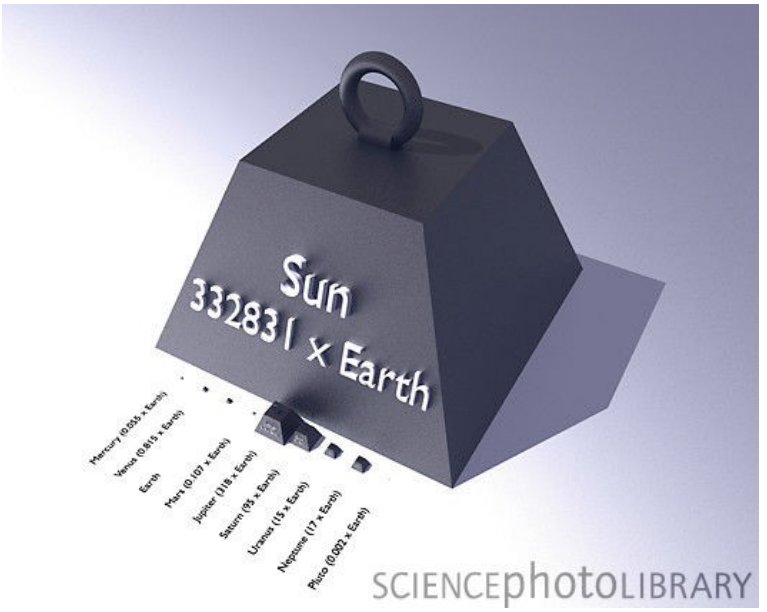
American Museum of Natural History

From last class

The Sun

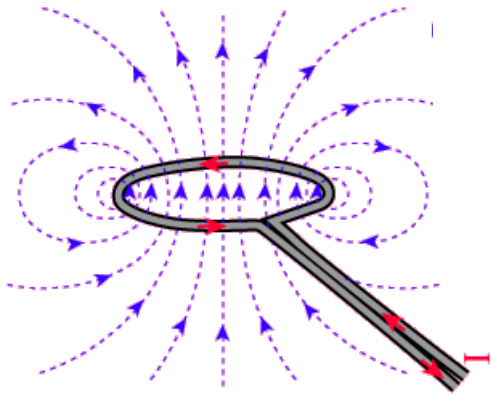
The Sun is by far the dominant object of the Solar System



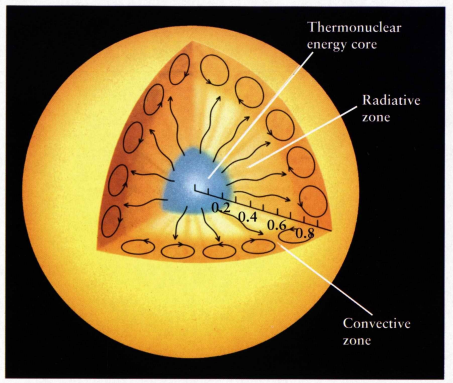


Jupiter has more than twice the mass of all planets combined.
And the Sun is more than 1000x more massive than Jupiter.

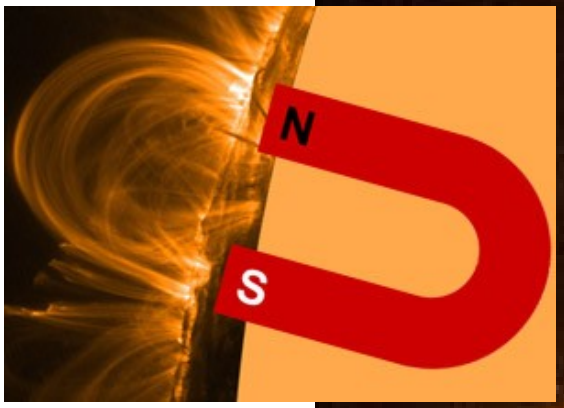
The Sun accounts for 99.9% of the mass of the solar system



From last class



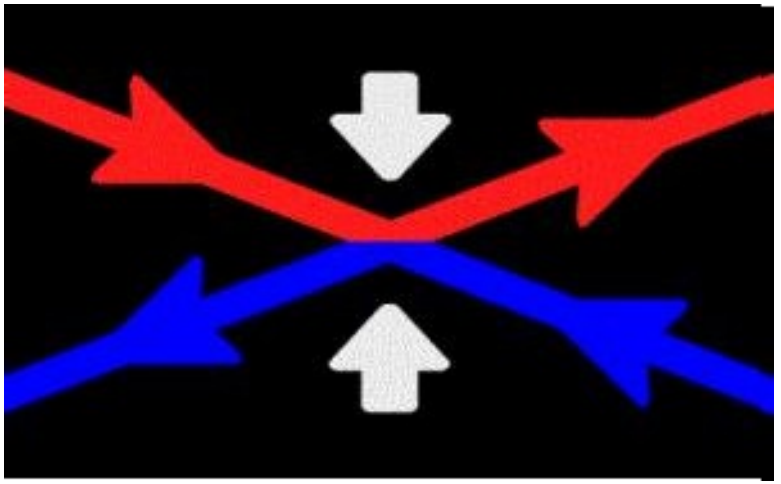
Magnetic Fields

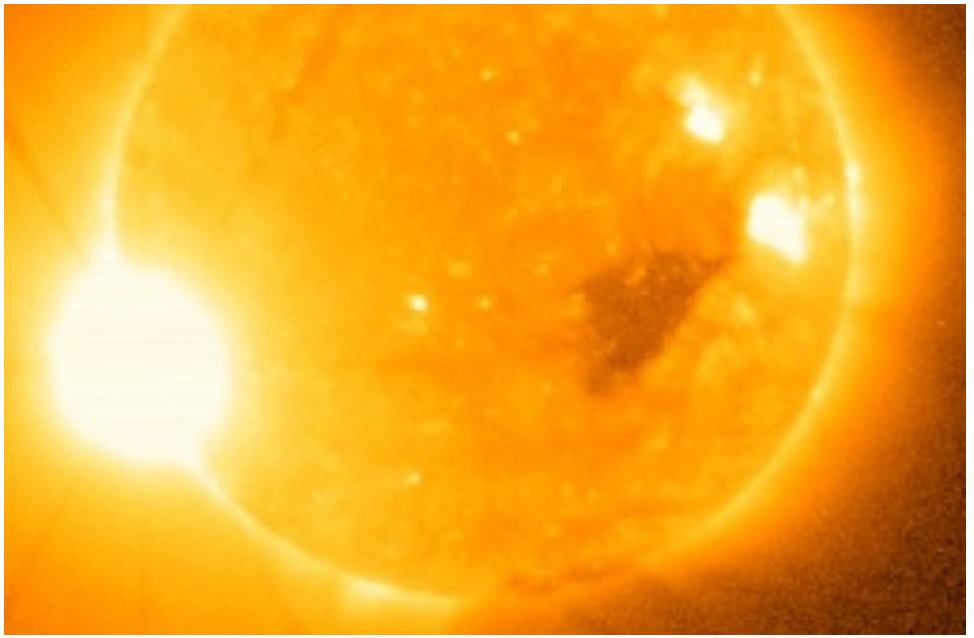


From last class

Magnetic Reconnection

Magnetic Field lines store energy



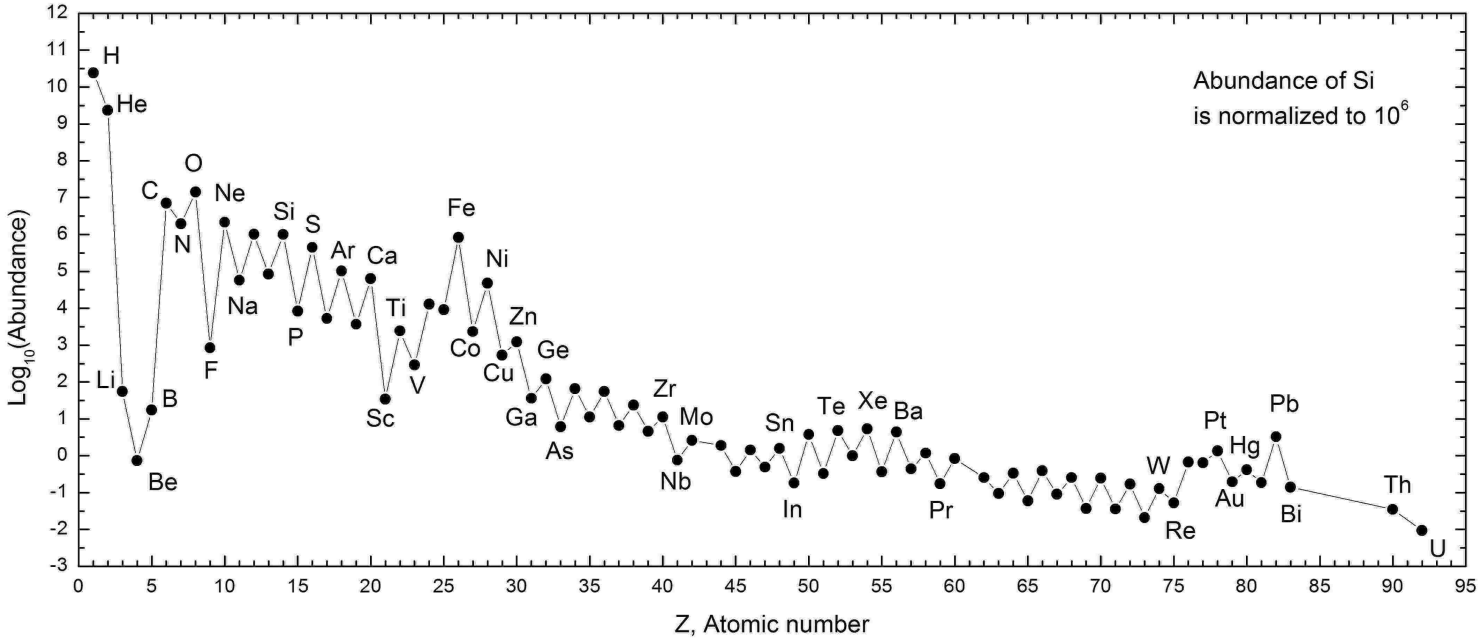


Upon cancellation, the energy is explosively released

From last class

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%)

From last class

Chemistry

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 H H H H H He 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 O 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 H C
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 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 H H
H H H He H H H H 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 O H H H H H H H H H H H H H H H H H H H H Ne 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 H H H H H H H H He H H H O H H H H H H H H H H H H H H He
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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 He H H H H H C H H H H H H H H H H H H
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 H H He 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 C 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 He H H H H He H H H H H H H H H HH H H H H H H N 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
O H H H H H H H H H H H H O 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 H H H H H H H H H H H H H
H H O H H H H H H H H H H C H H H H H H H H He H H H H H H H
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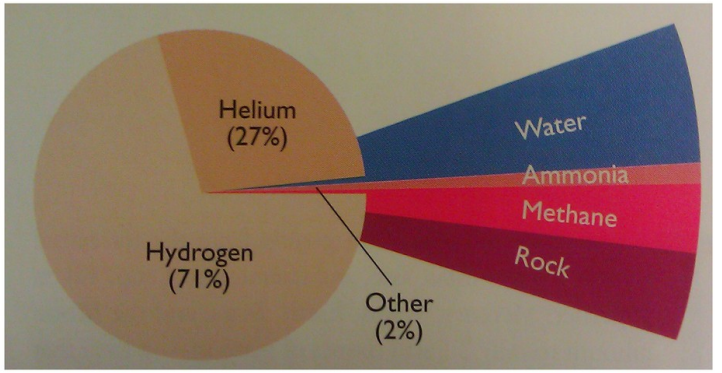


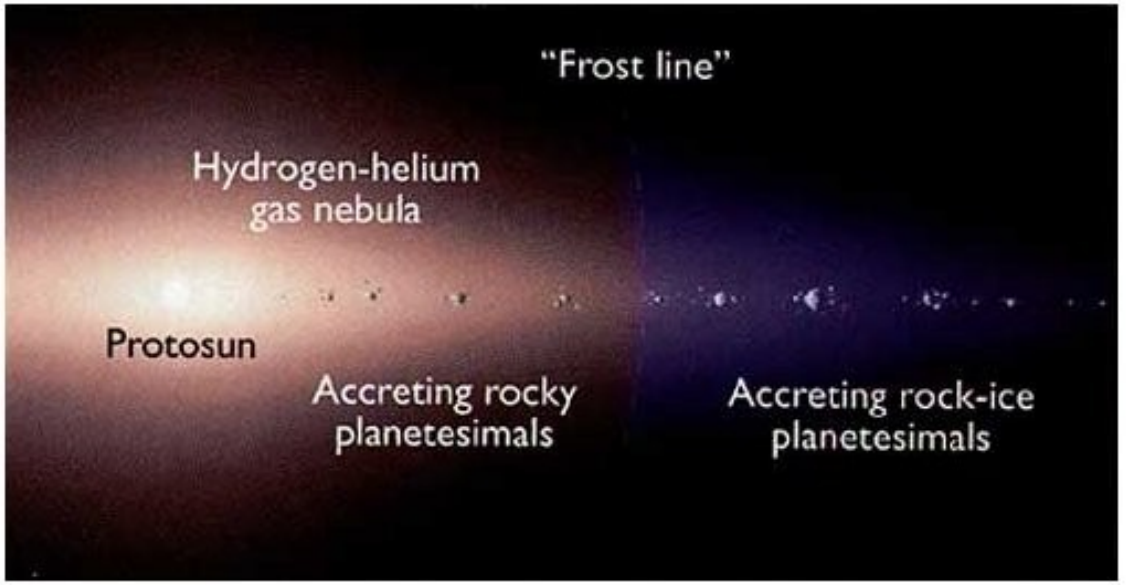
H_2 He	Gas
H_2O CH_4 NH_3	Ices
Fe, Si	Rock

From last class

Formation

Inward of snowline

Accreting rocky cores (small)



Outward of snowline

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

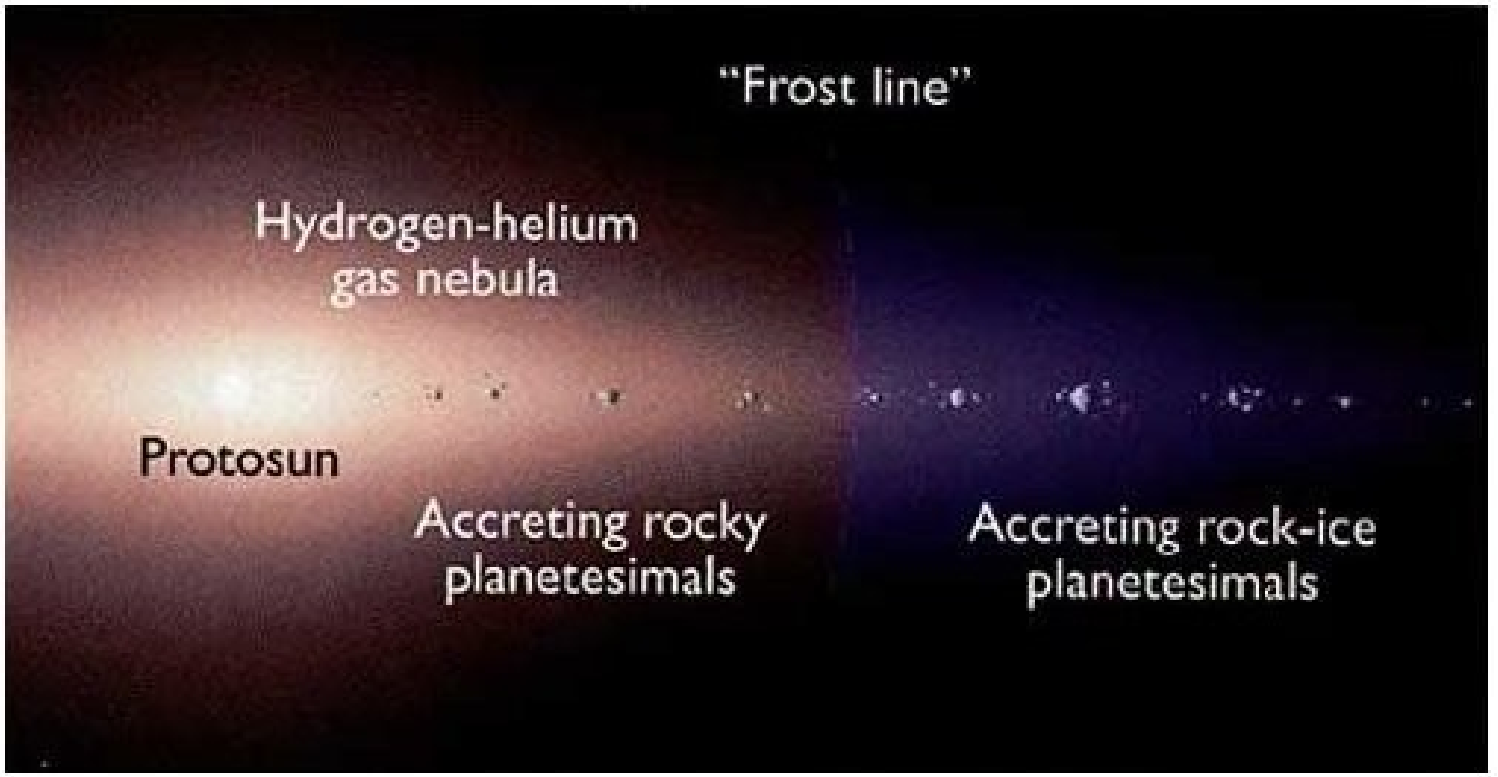
Outline

Classes of Planets

Giant Planets

- Interiors
- Atmospheres
- Rings

The Snowline



Volatiles in gas phase

Volatiles in solid phase

Colder than ~150K, the volatiles (H_2O, CH_4, NH_3)

condense into ***ices***.

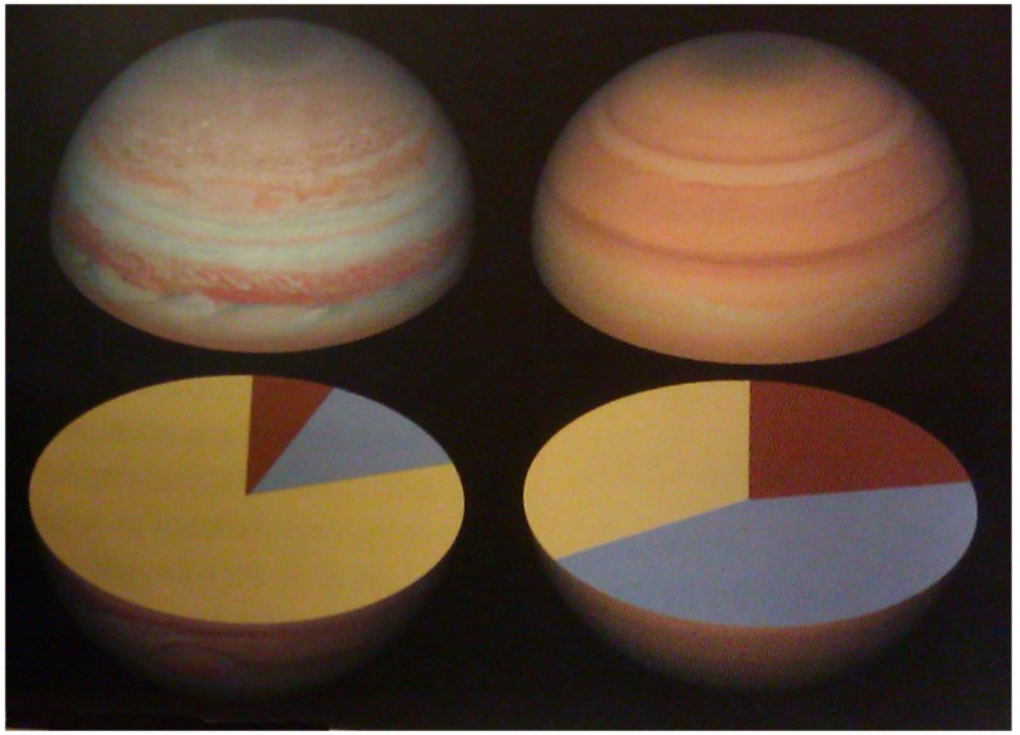
Classes of planets

Rocky Planets

Earth

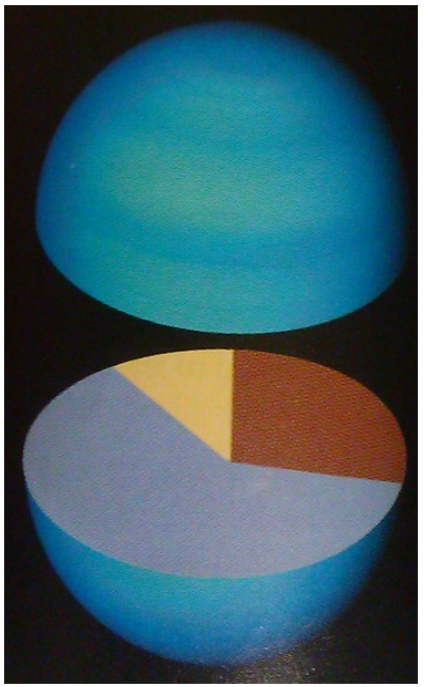
Gas Giants

Jupiter Saturn



Ice Giants

Uranus/Neptune

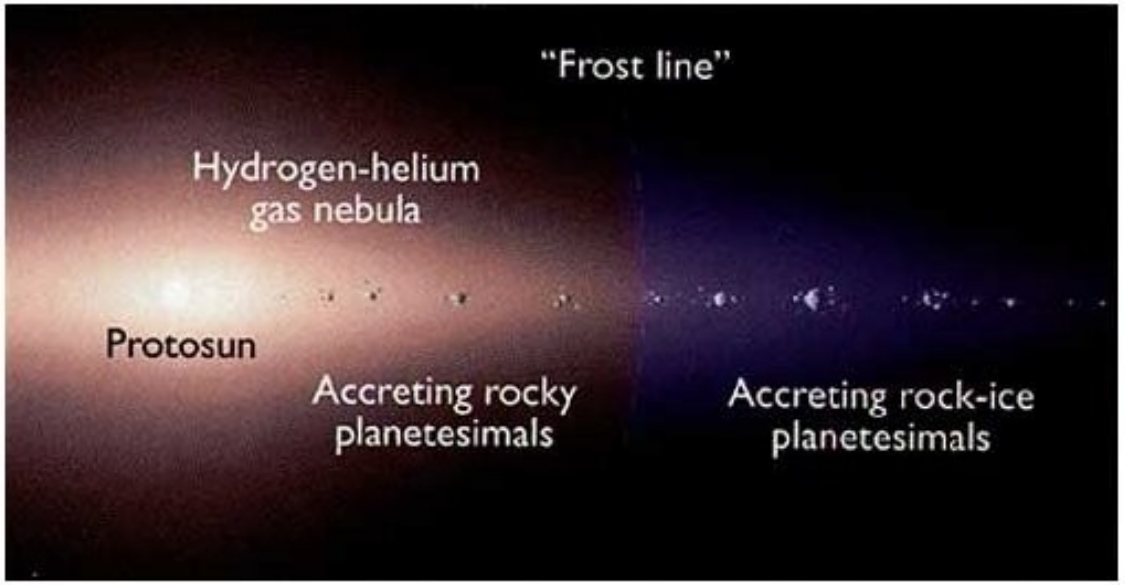


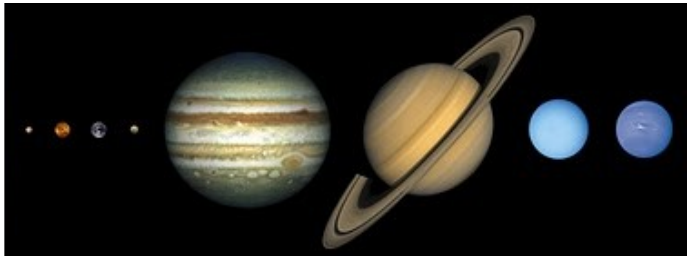
Rock

Gas

Ice

Formation

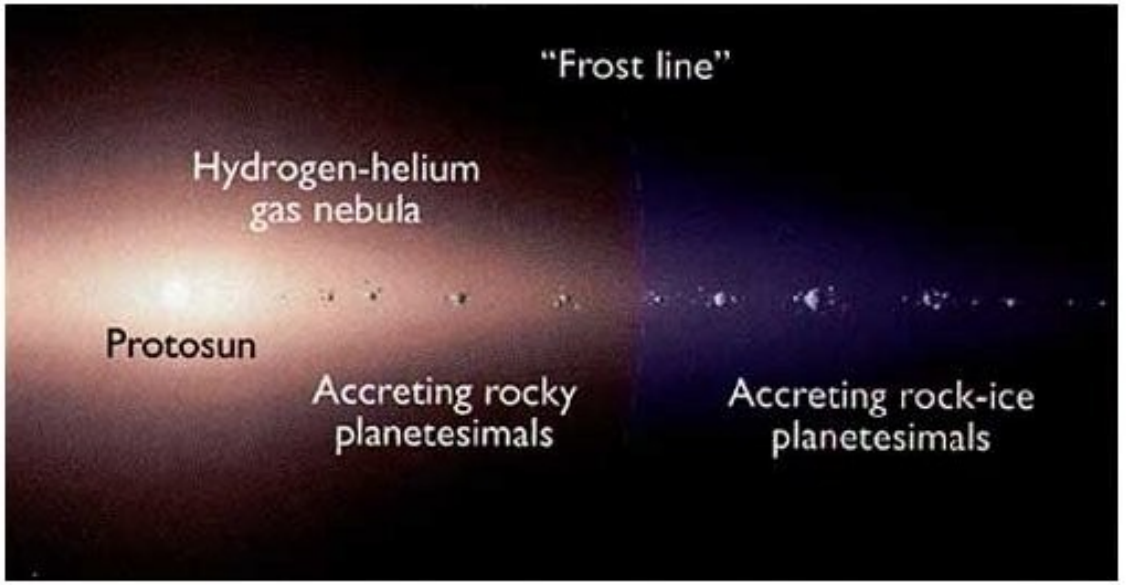

"Frost line"
Hydrogen-helium
gas nebula
Protosun
Accreting rocky
planetesimals
Accreting rock-ice
planetesimals

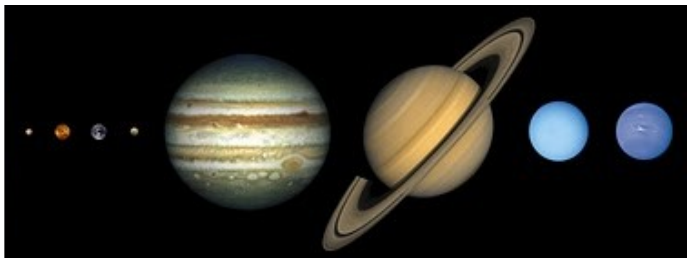


Formation

Inward of snowline

Accreting rocky cores (small)





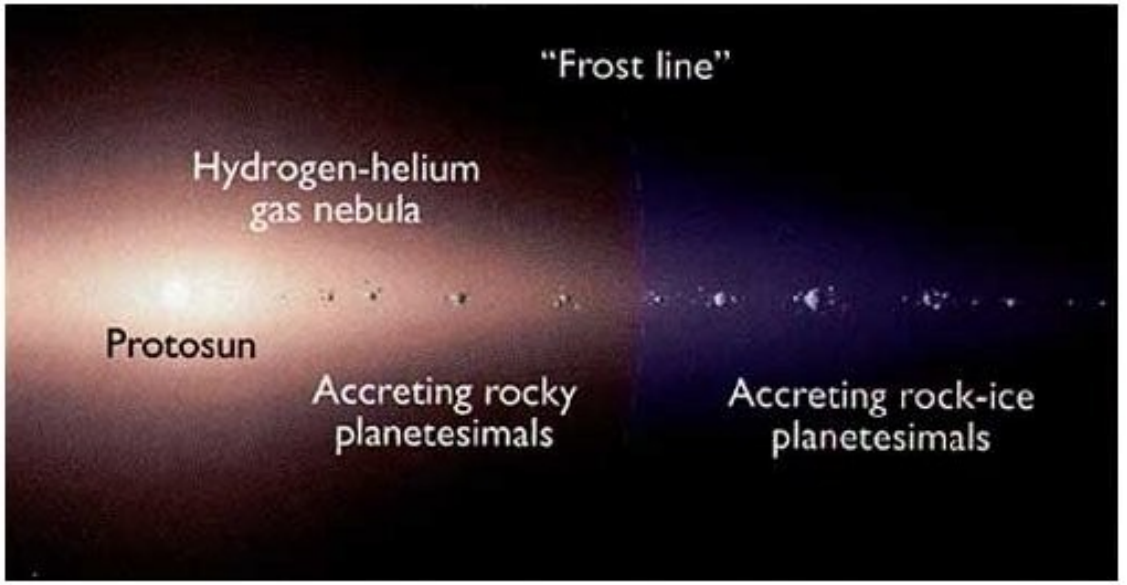
Outward of snowline

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

Formation

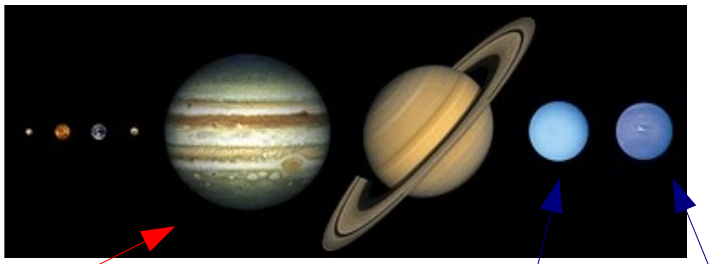
Inward of snowline

Accreting rocky cores (small)



Outward of snowline

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



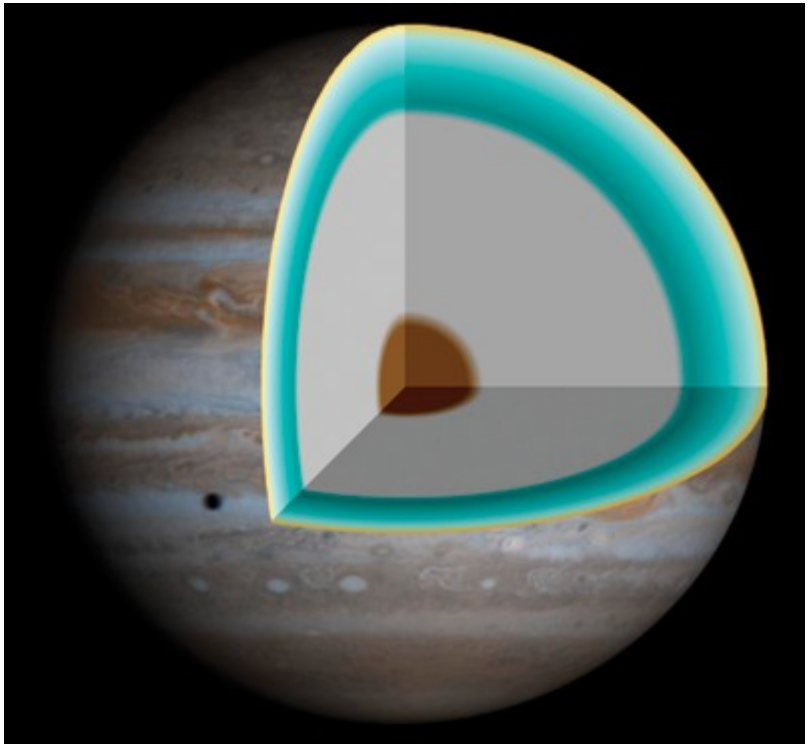
These guys got so big they started accreting gas from the nebula!

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

Gas Giants

Activity

Interior of Jupiter

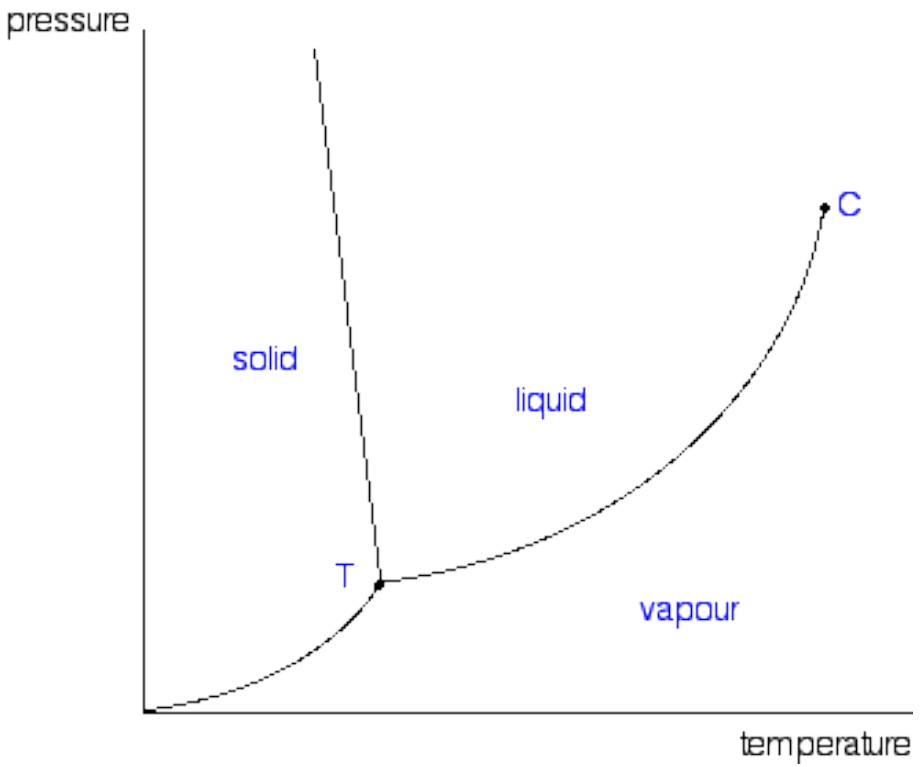


Pressure = weight/area

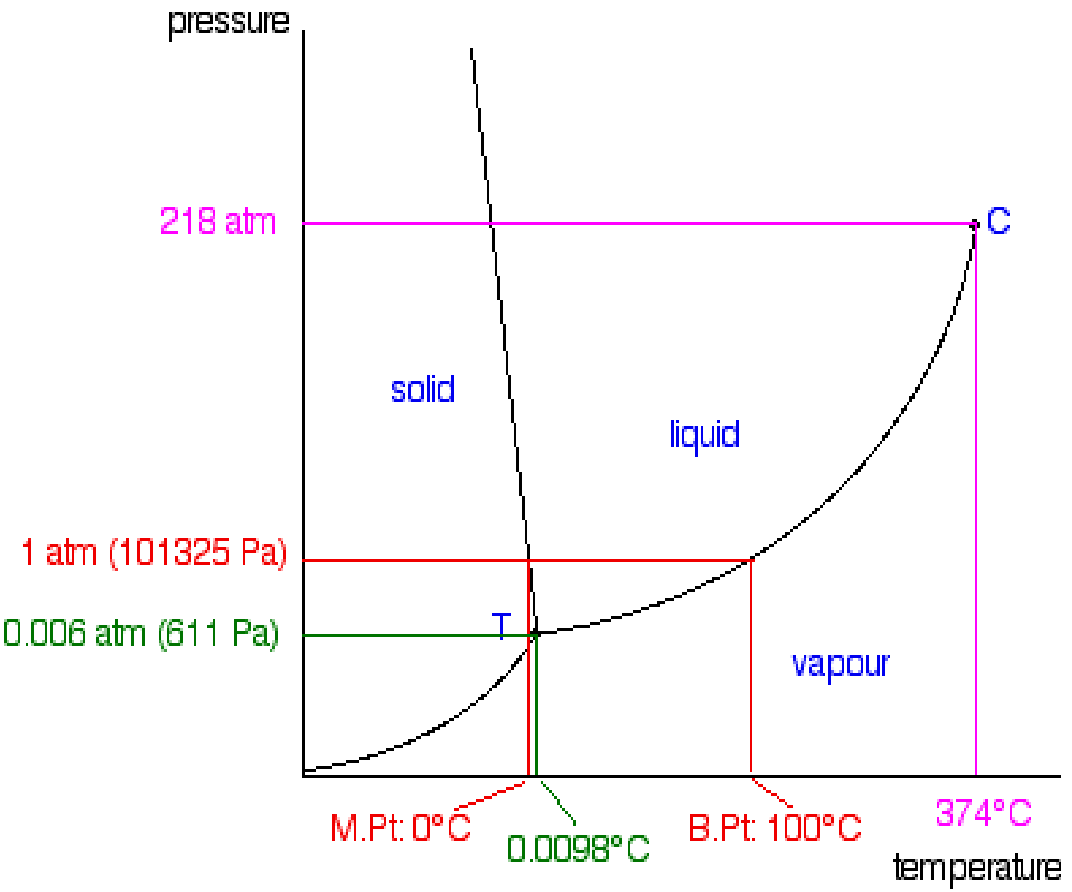
Pressure at center
70 million atmospheres

Temperature at center
17.000 K

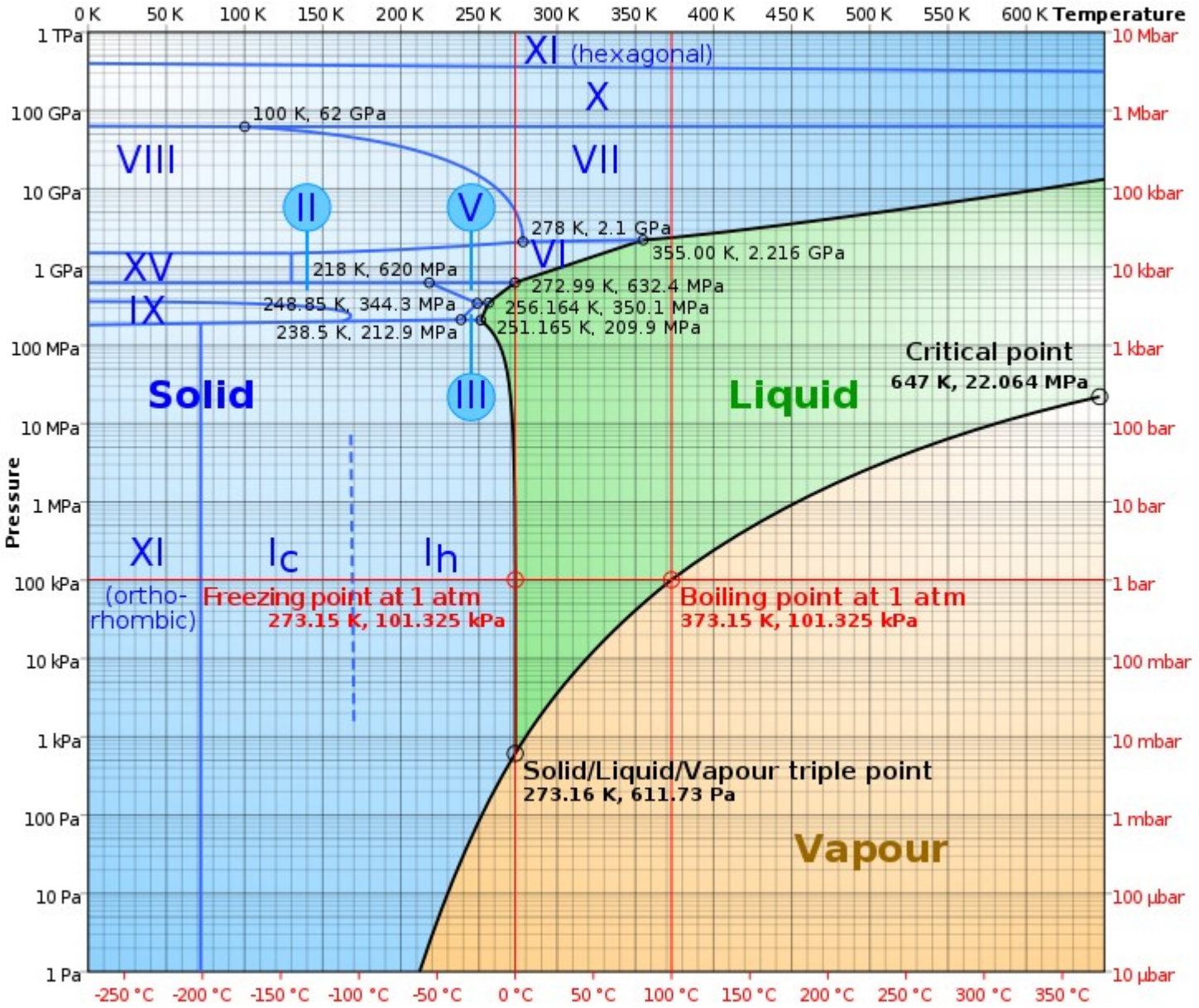
Phase diagram



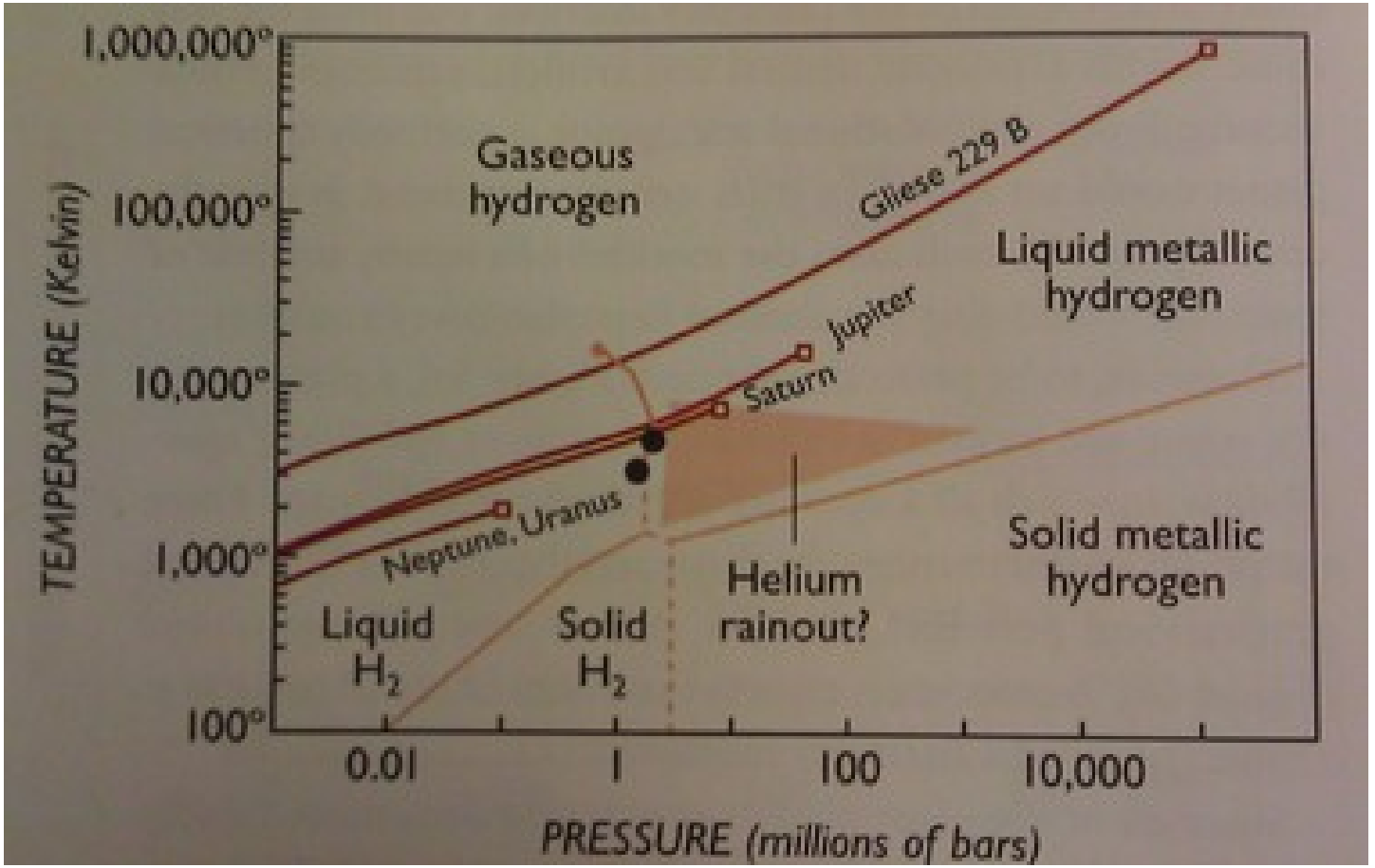
Phase diagram



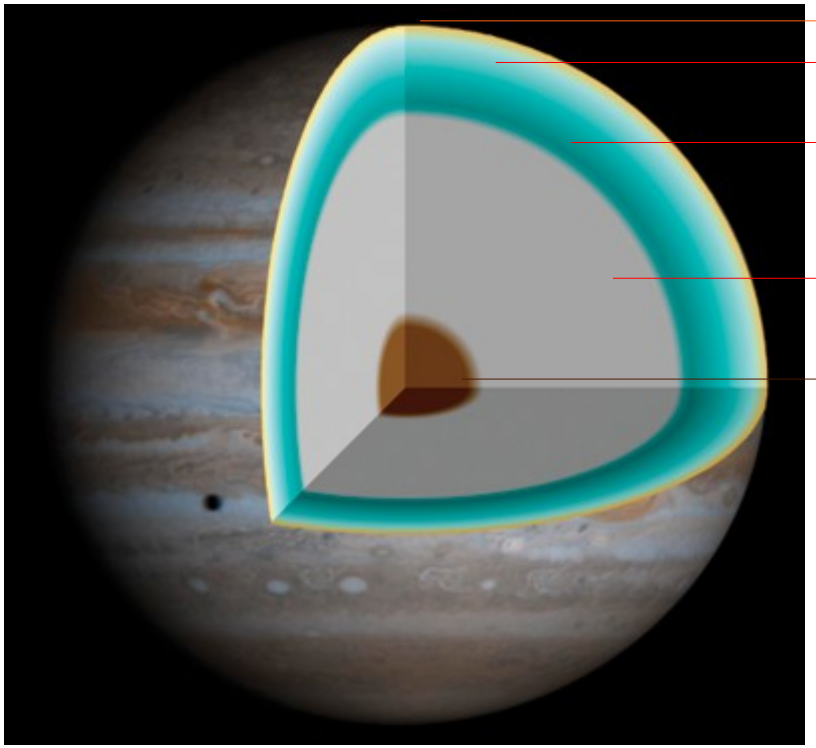
A lot more happens at high pressures



Hydrogen under pressure



Interior of Jupiter

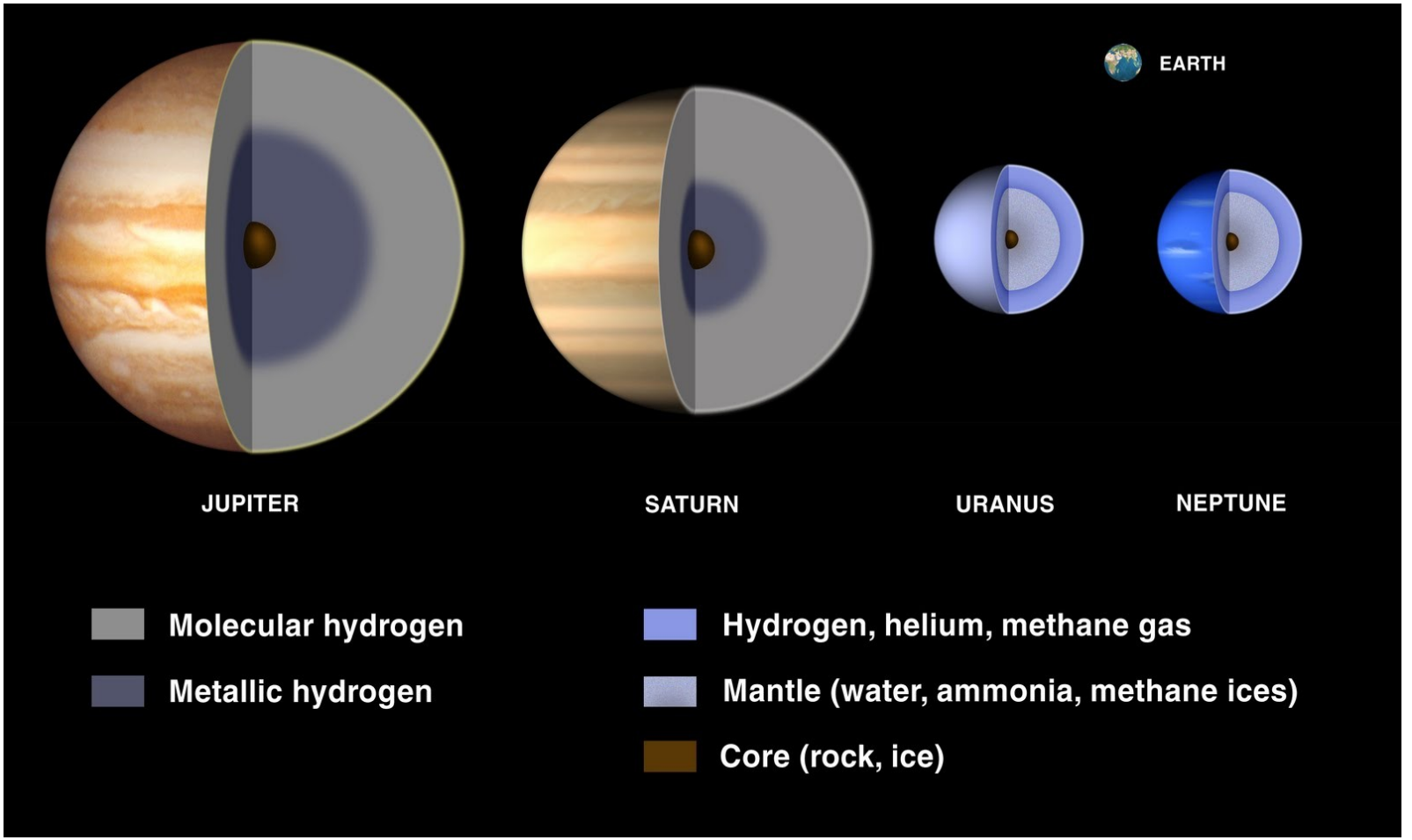


Pressure = weight/area

Pressure at center
70 million atmospheres

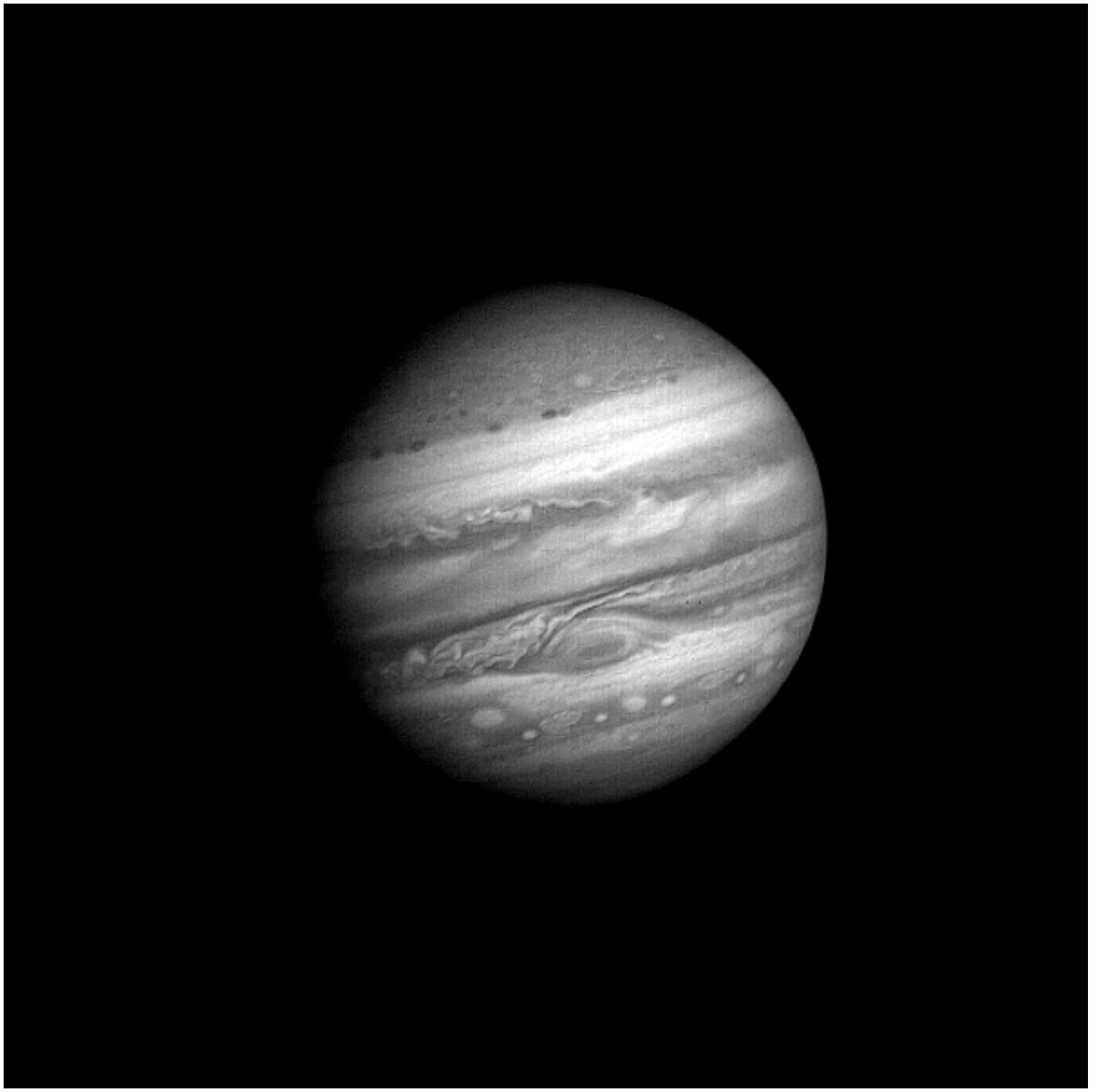
Temperature at center
17.000 K

Interior of the giant planets

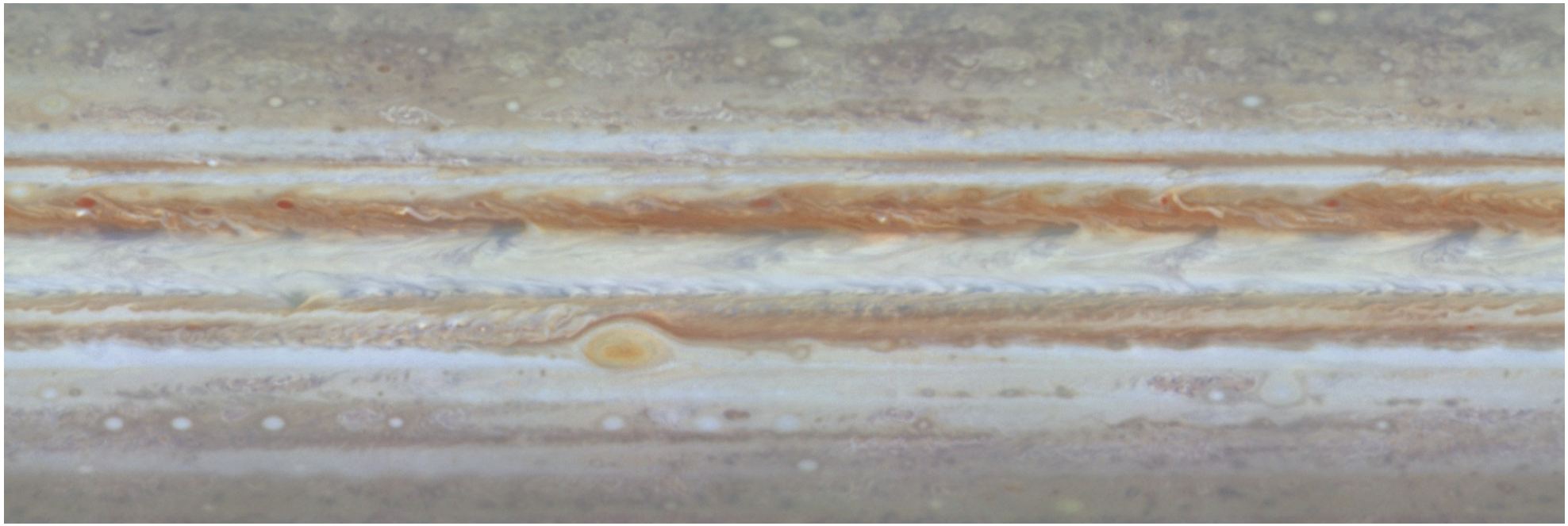


Activity

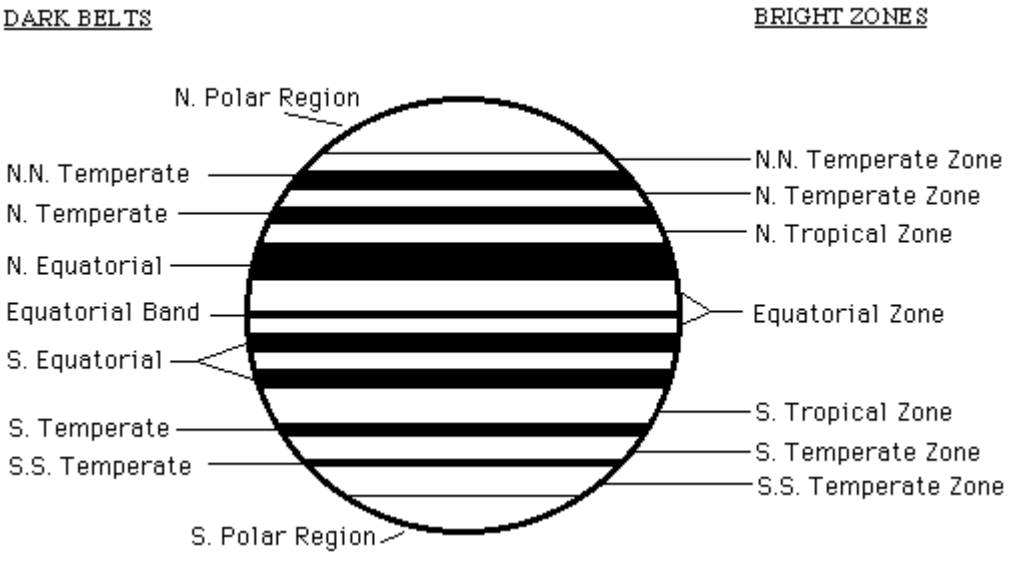
Atmospheres of the Giant Planets



Atmospheres of the Giant Planets

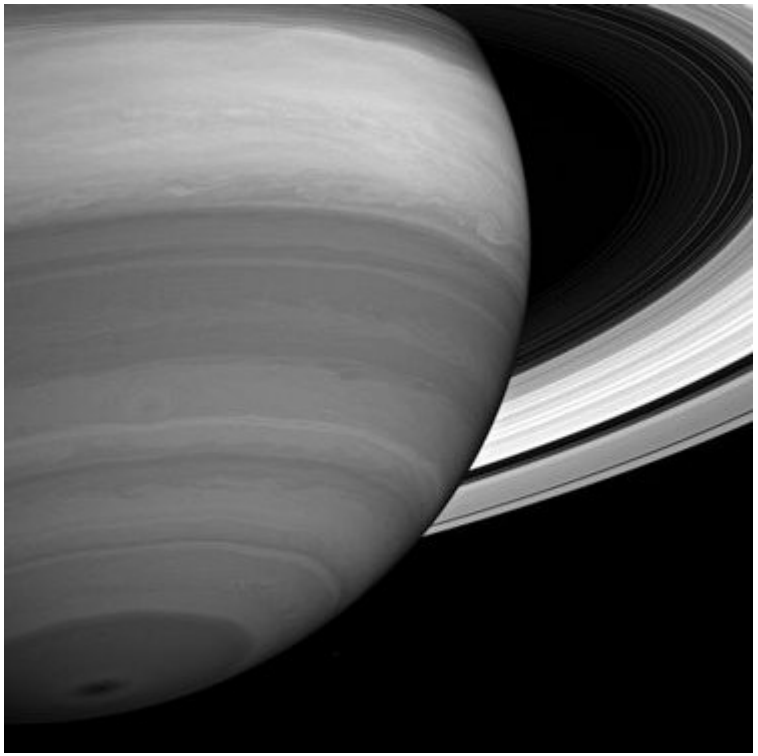


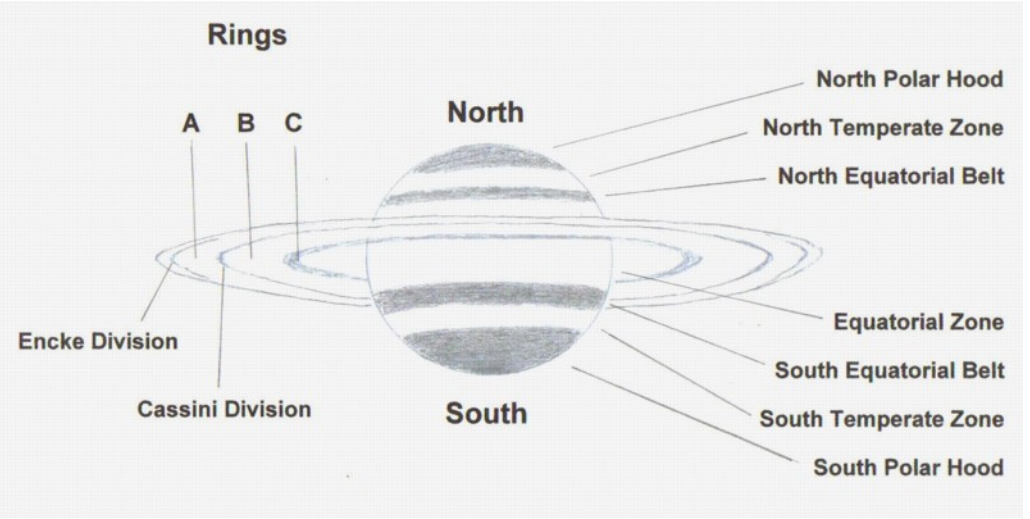
Atmospheres of the Giant Planets



Bands and Storms

Atmospheres of the Giant Planets



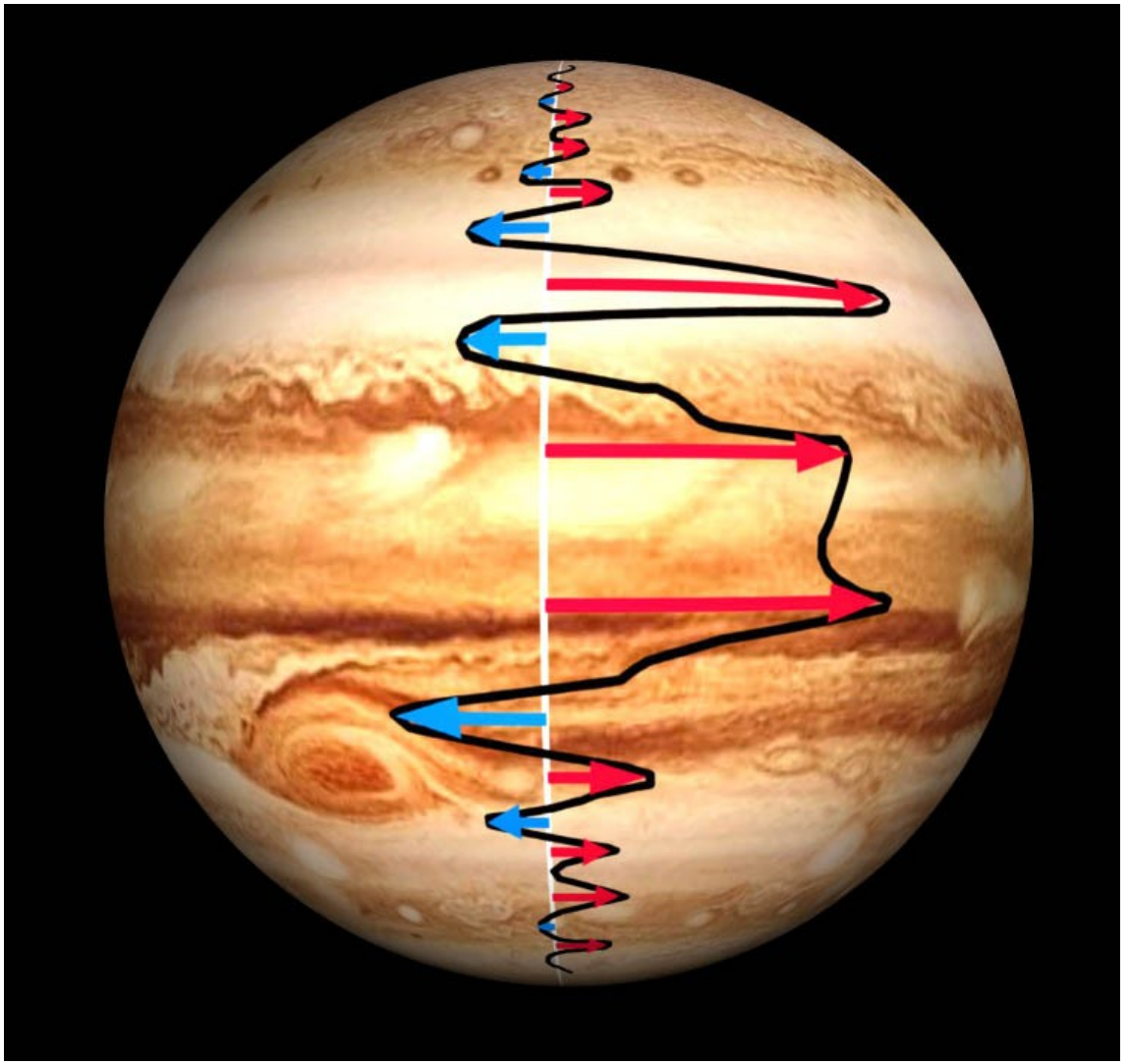


Bands and Storms

Atmospheres of the Giant Planets

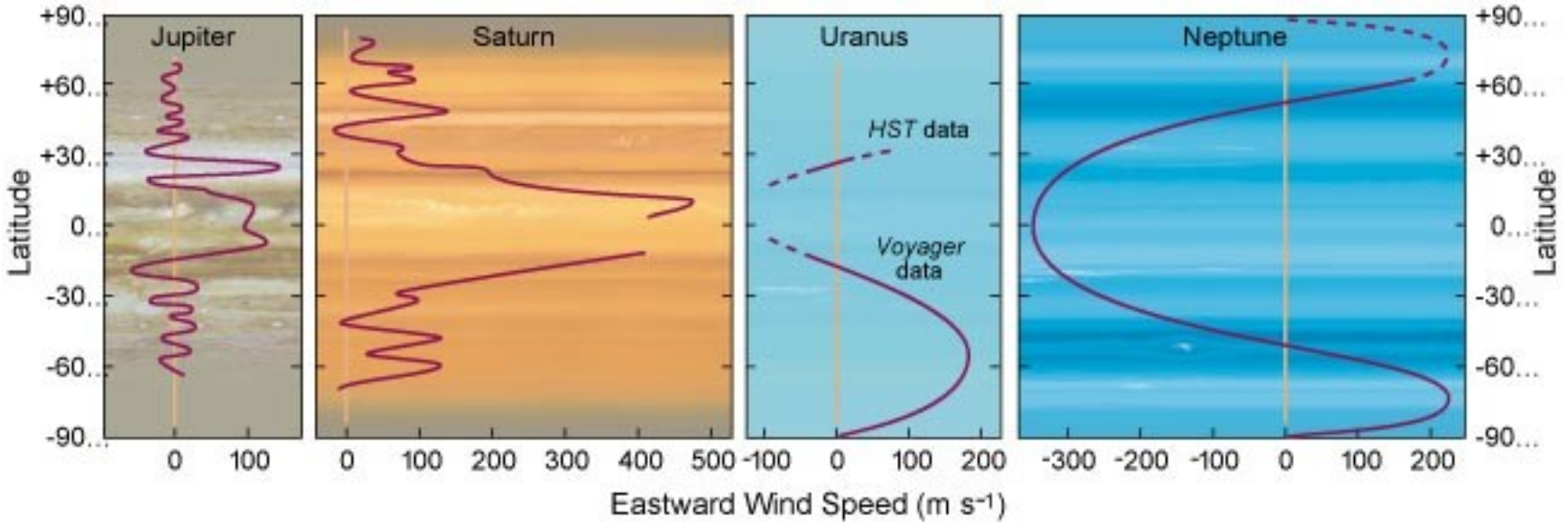
Bands and Zones

Large scale winds
of alternate direction

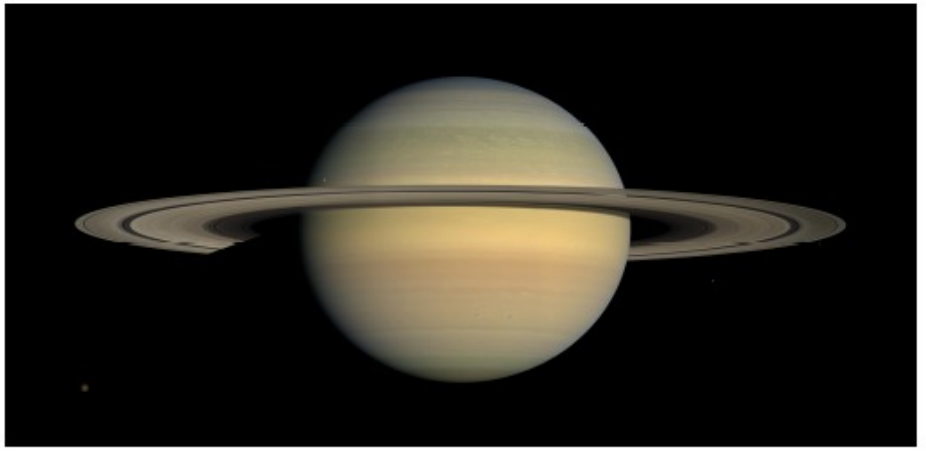


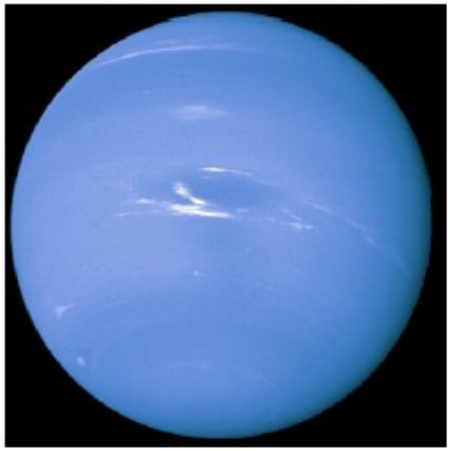
Atmospheres of the Giant Planets

Wind Speeds



Clouds of the Giant Planets

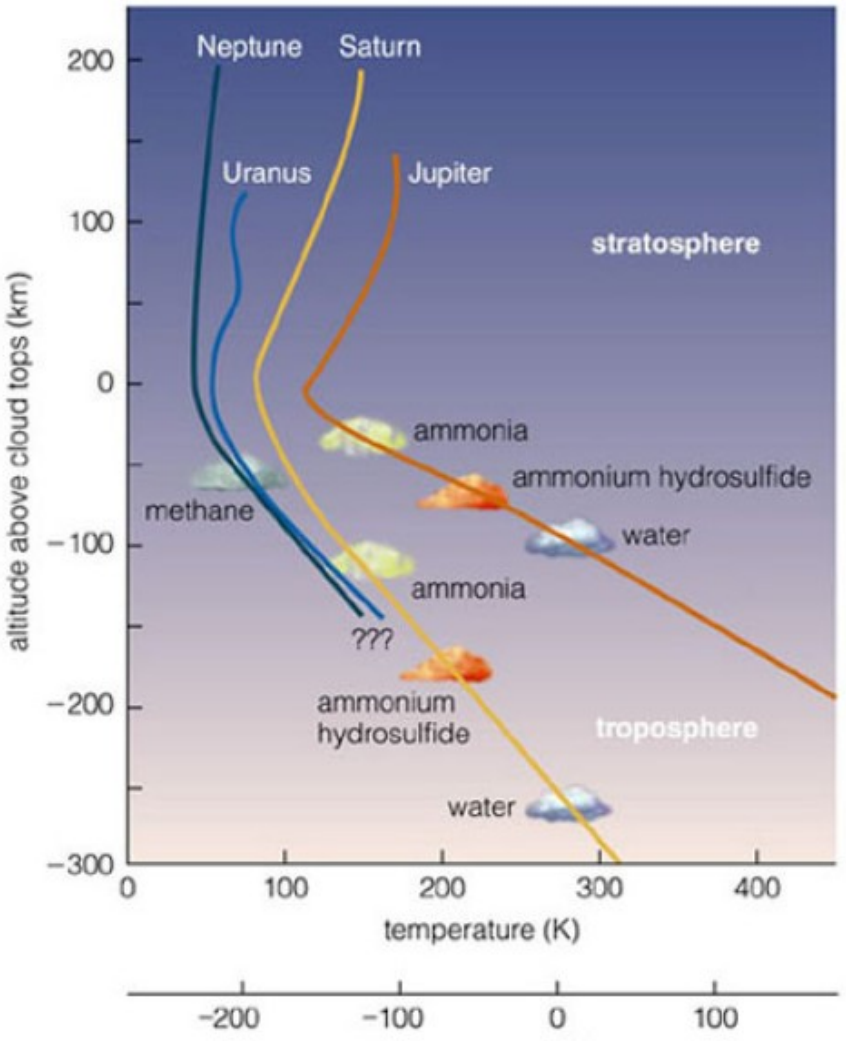




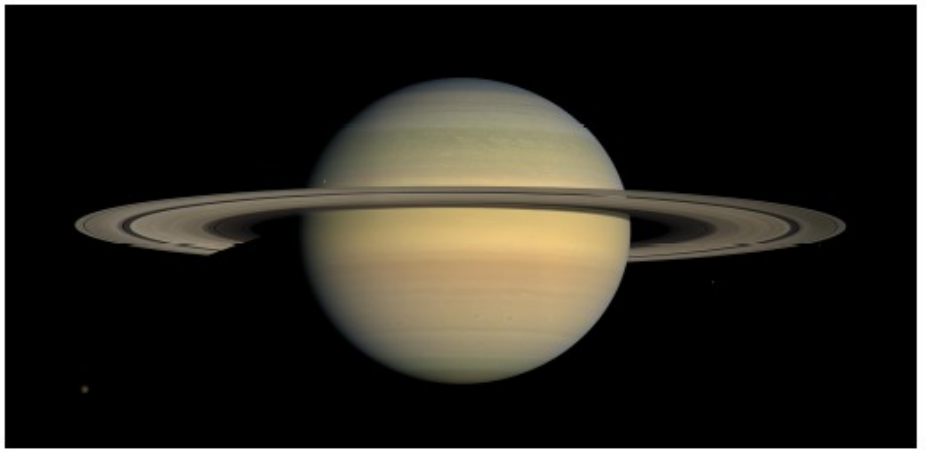
Molecules condense at different temperatures

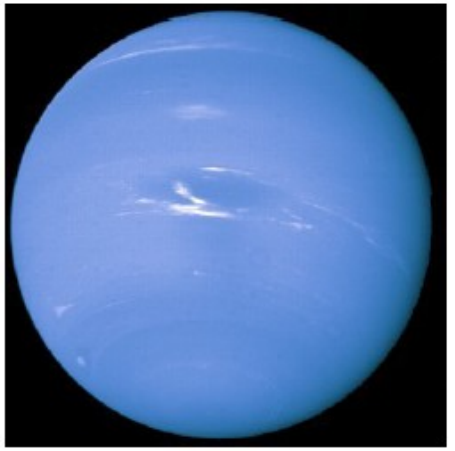
H_2O	~300K
NH_3	~140K
CH_4	~80K

Atmospheric Temperatures



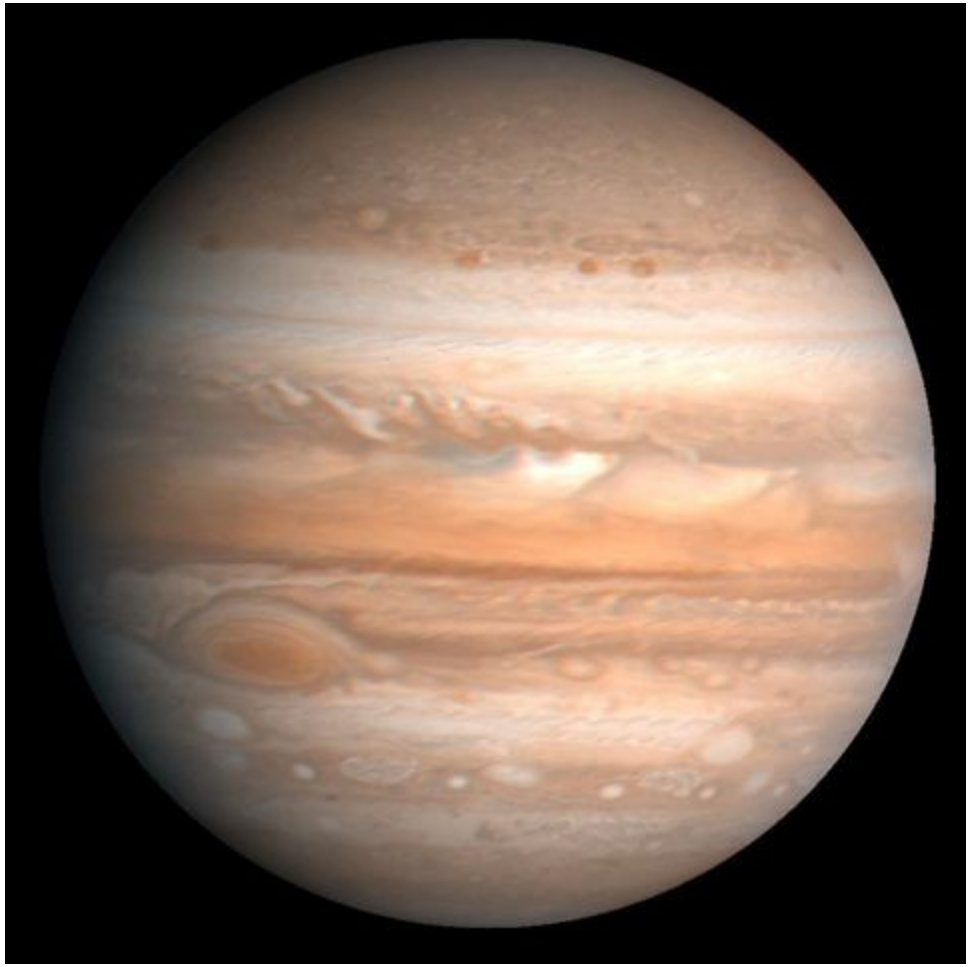
Ammonia and Methane Clouds





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

Clouds of Jupiter

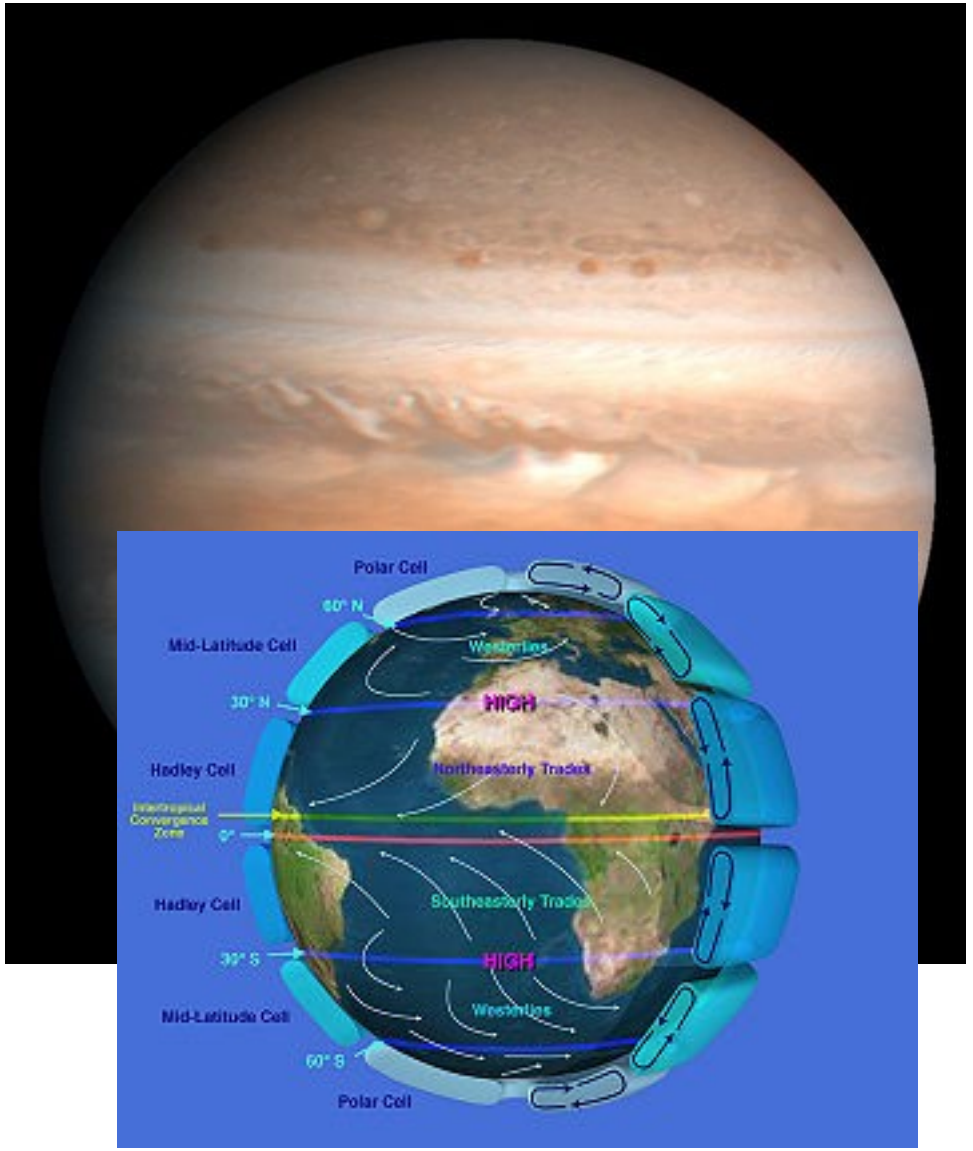


Bright ***Zones***
Dark ***Belts***

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***

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

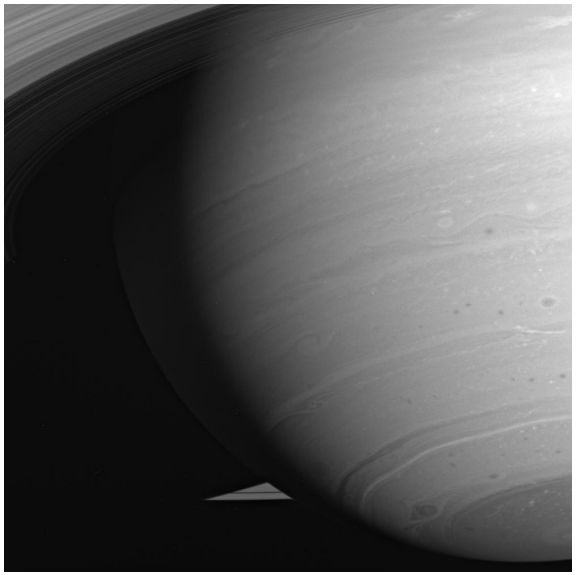
Bright zones:
High ammonia clouds
shielding brown stuff below

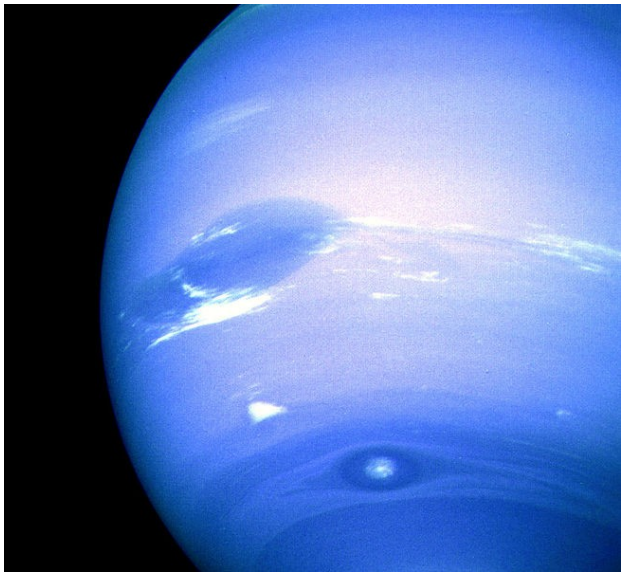
In Jupiter

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

Cold air sinks, **heats**,
dry in ammonia - > ***Belts***.

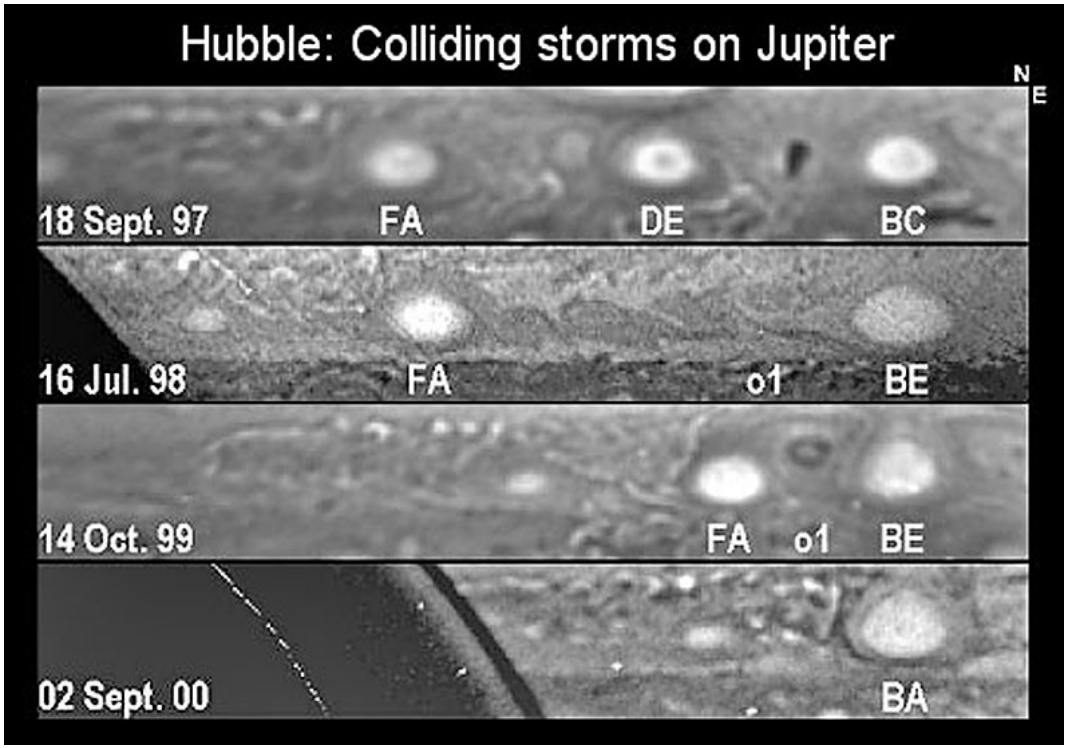
Atmospheres of the Giant Planets



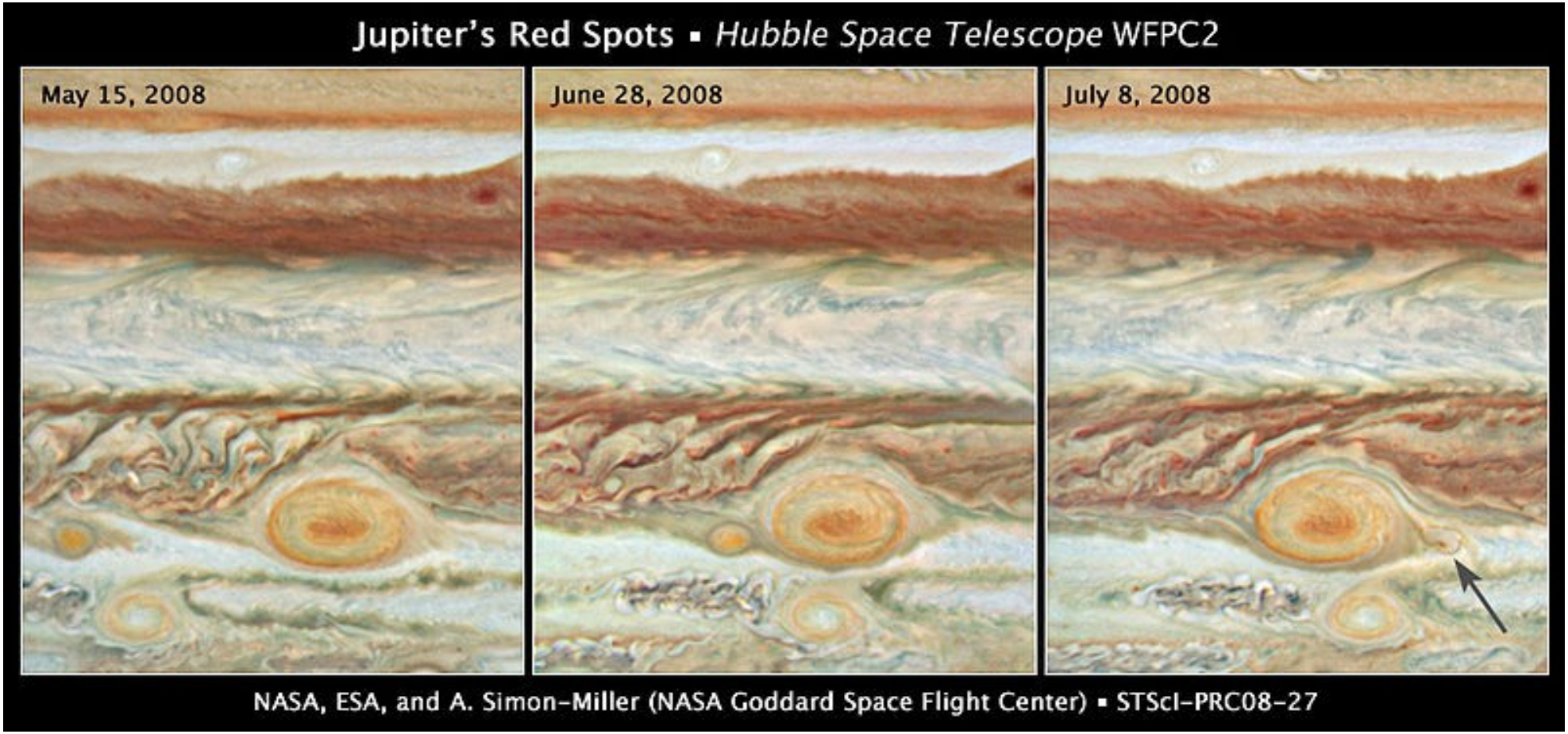


Storms !!

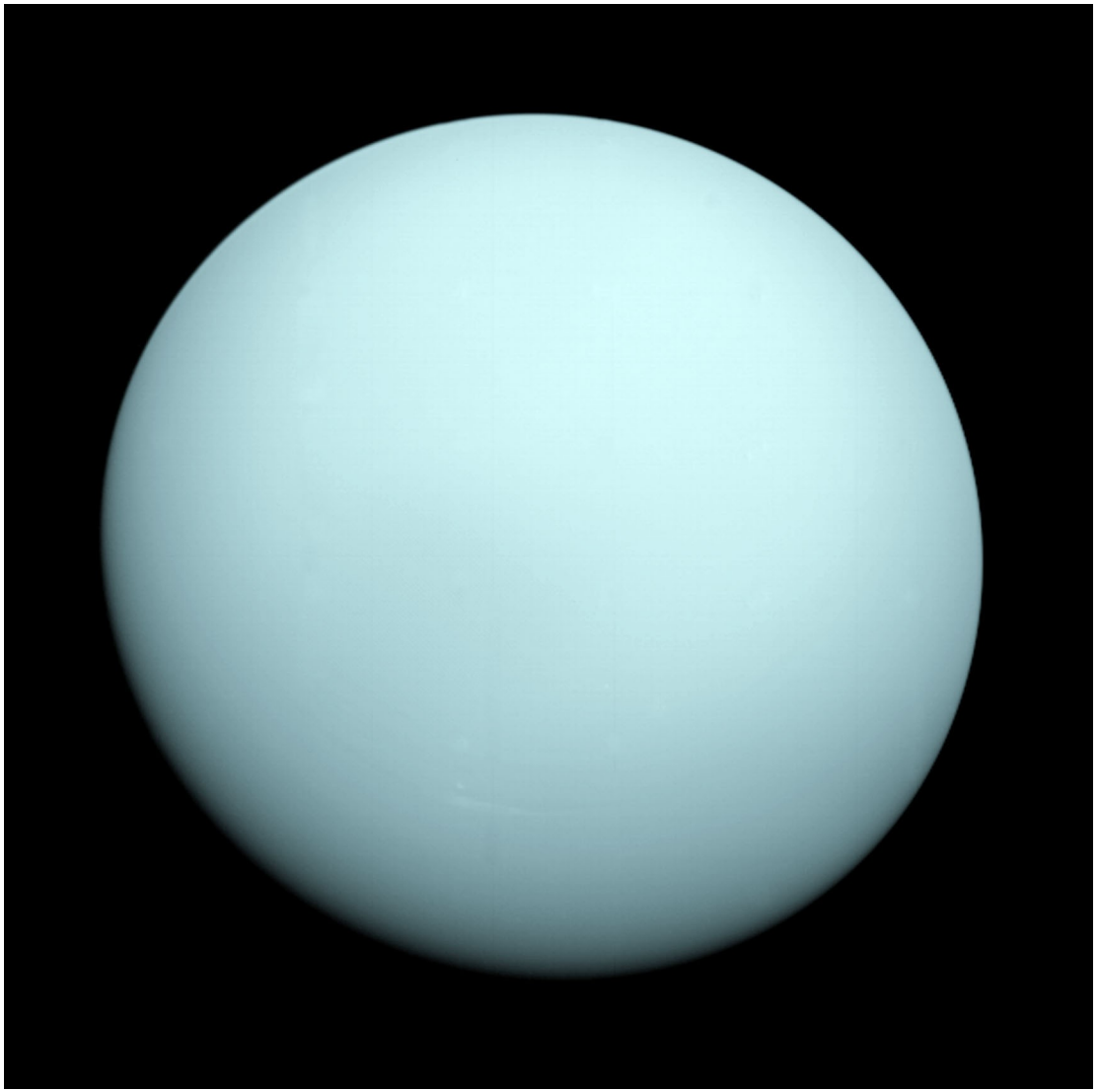
Merging Storms



Jupiter's Red Spots

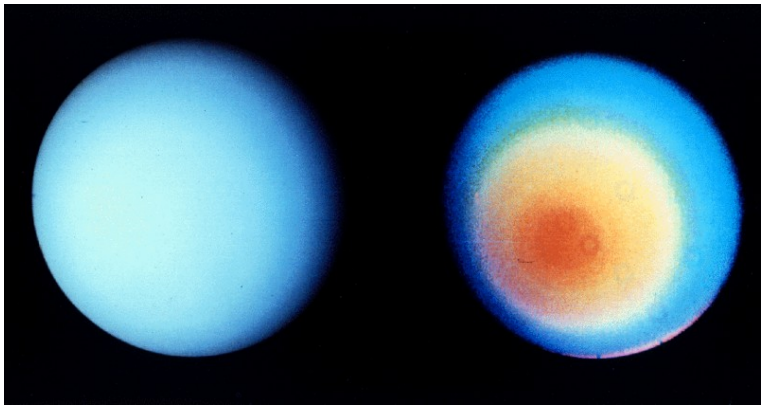


Uranus

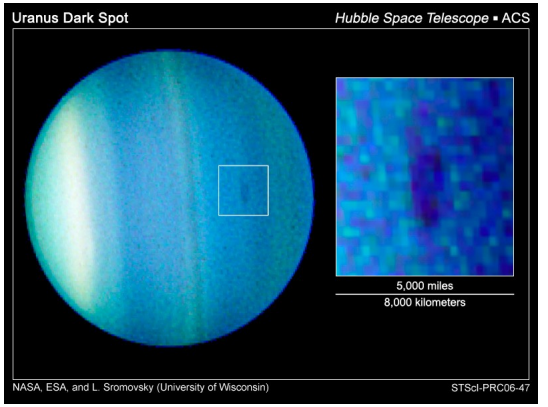


Featureless...

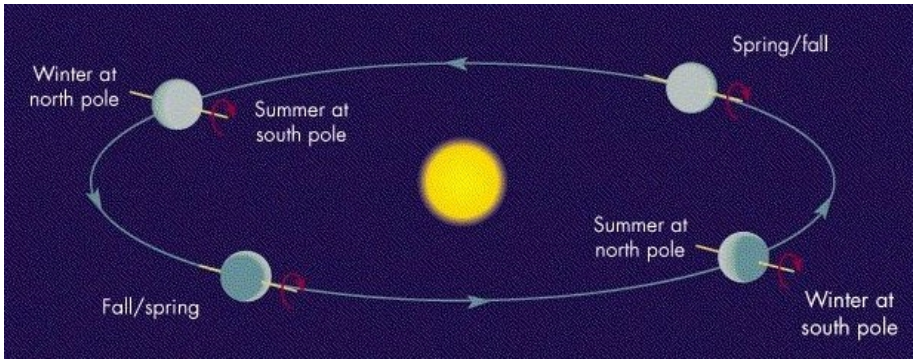
Not quite featureless...



Uranus in false color: ***Bands !***

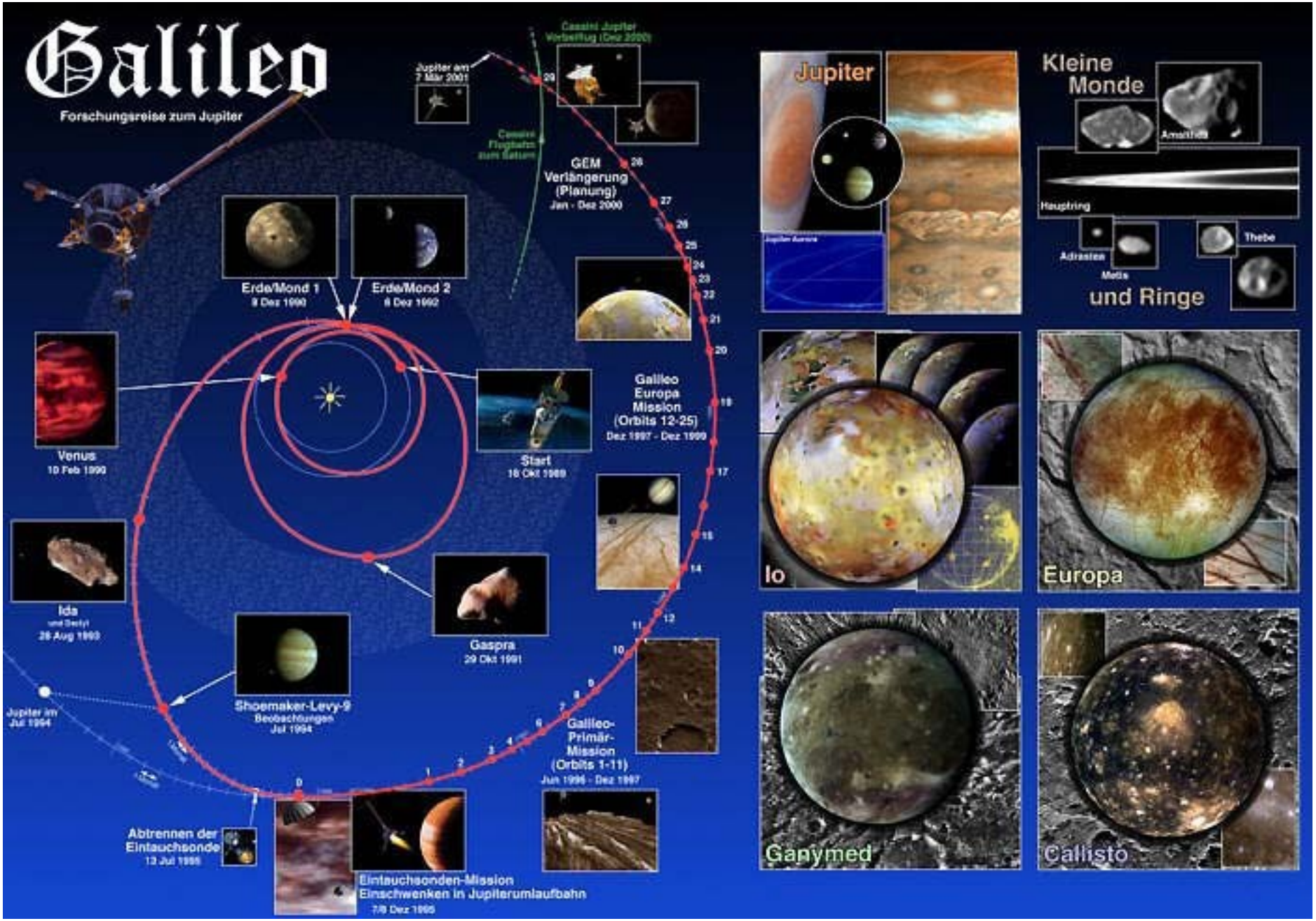


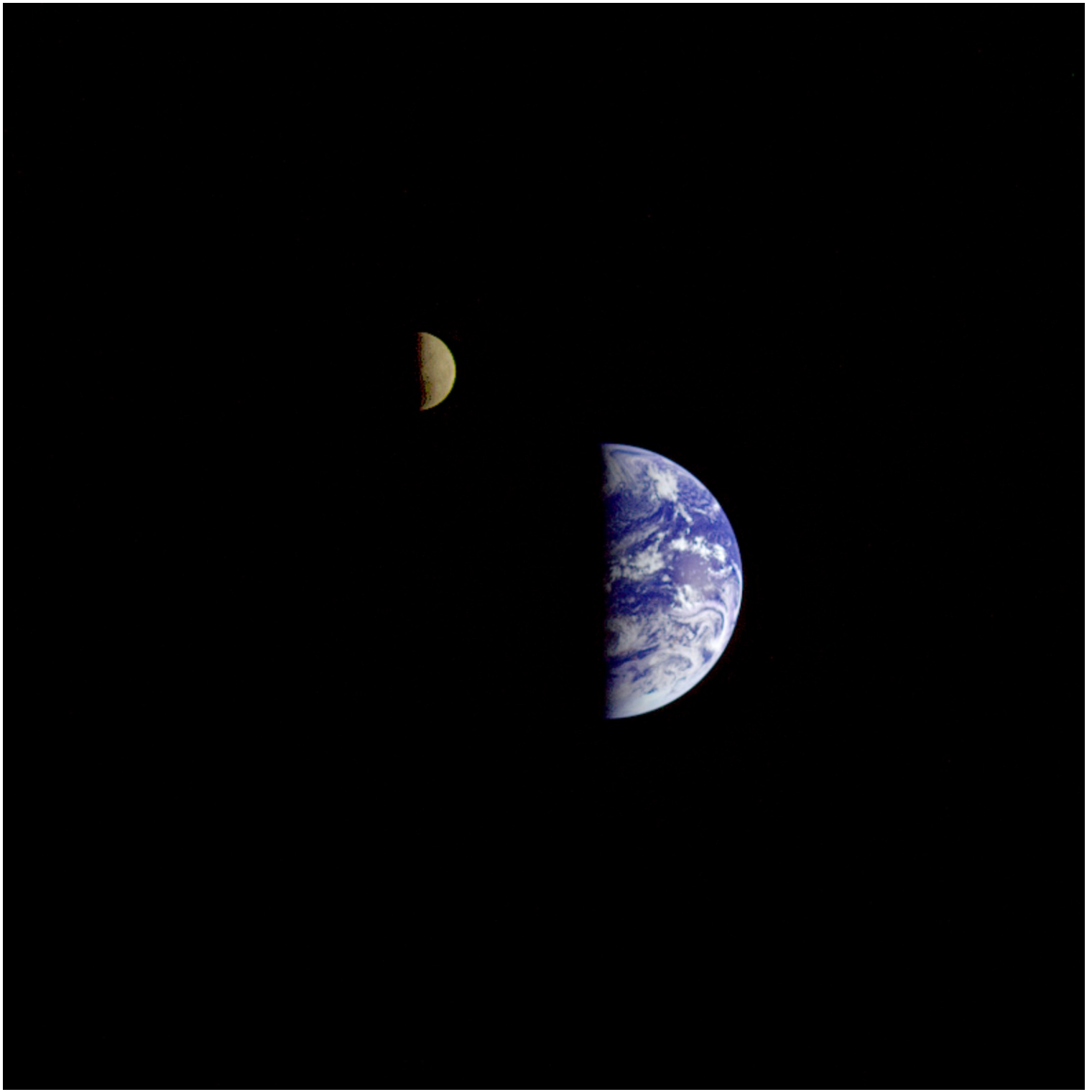
Recently seen by Hubble: ***Storms !***



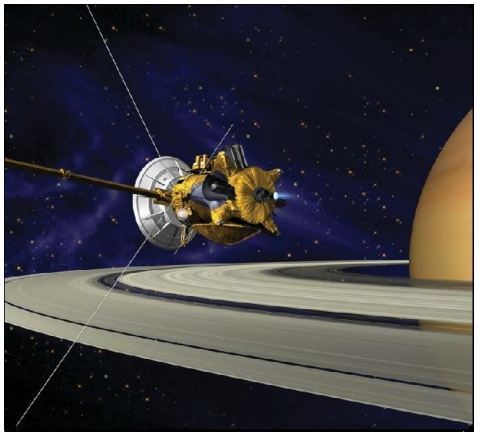
Due to the extreme axial tilt,
weather in Uranus may be **highly seasonal**,
being more Neptune-like in the equinoxes.

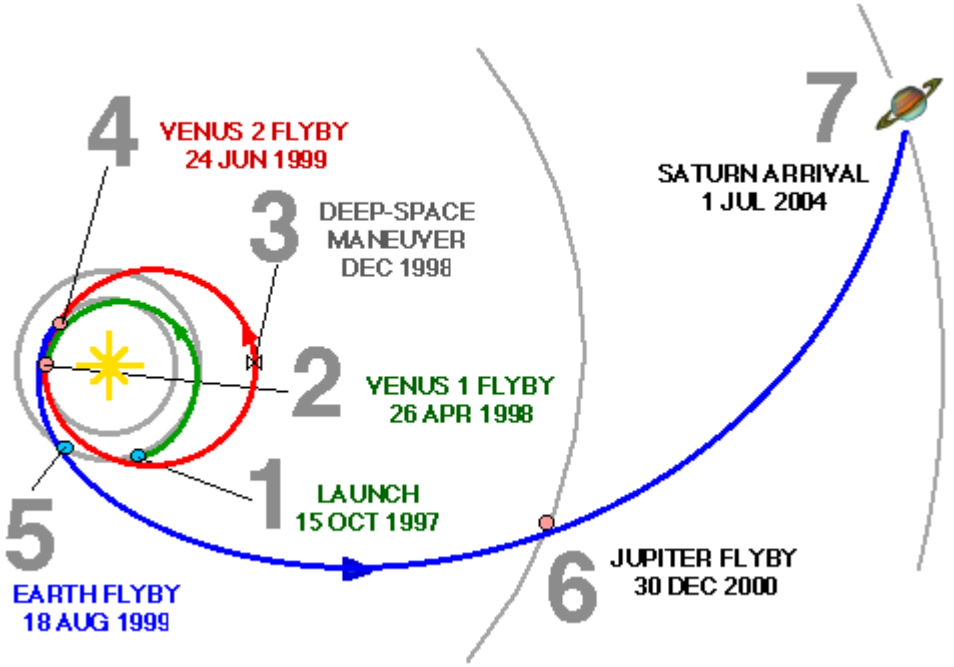
Mission to Jupiter: Galileo

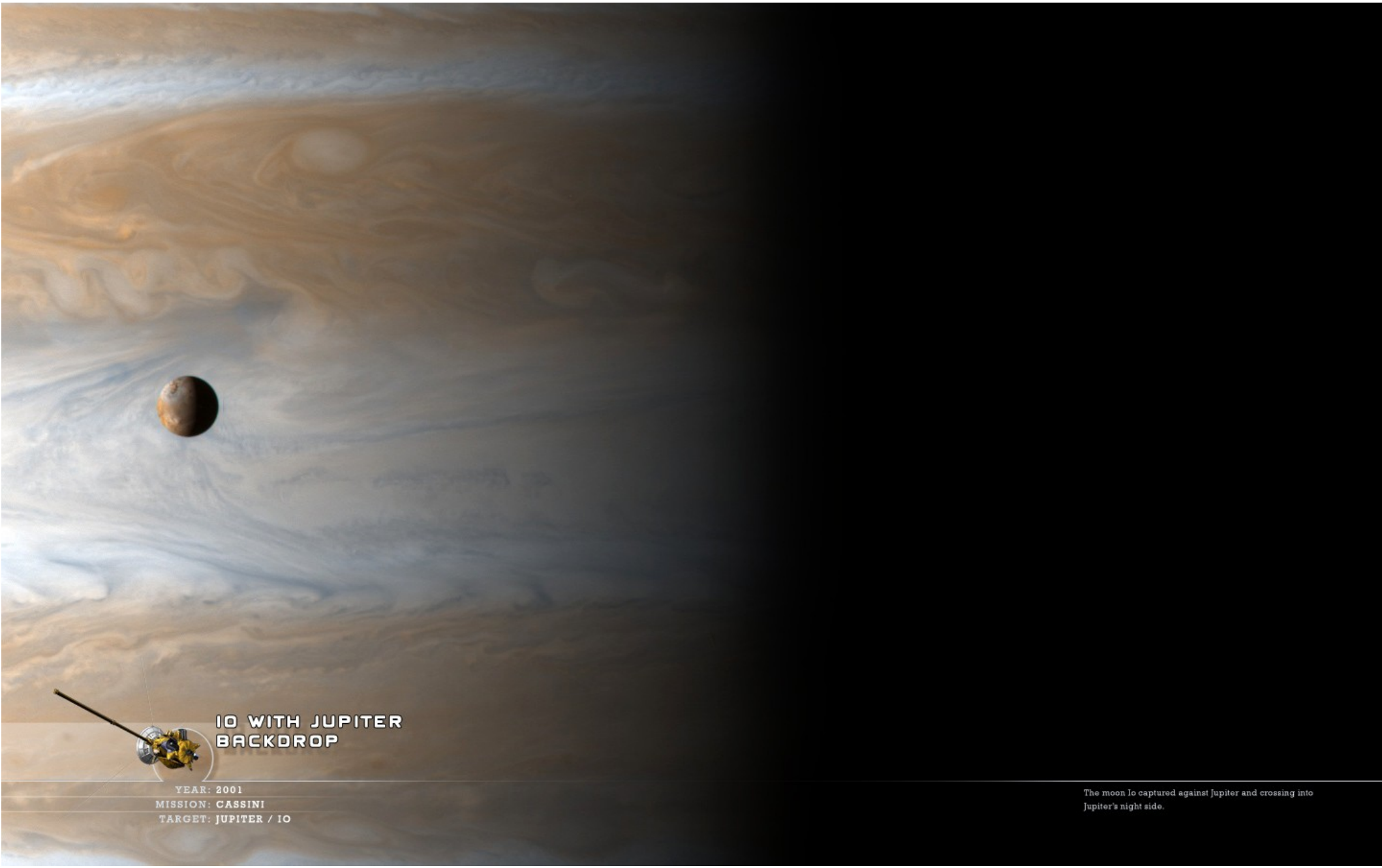




Mission to Saturn: Cassini



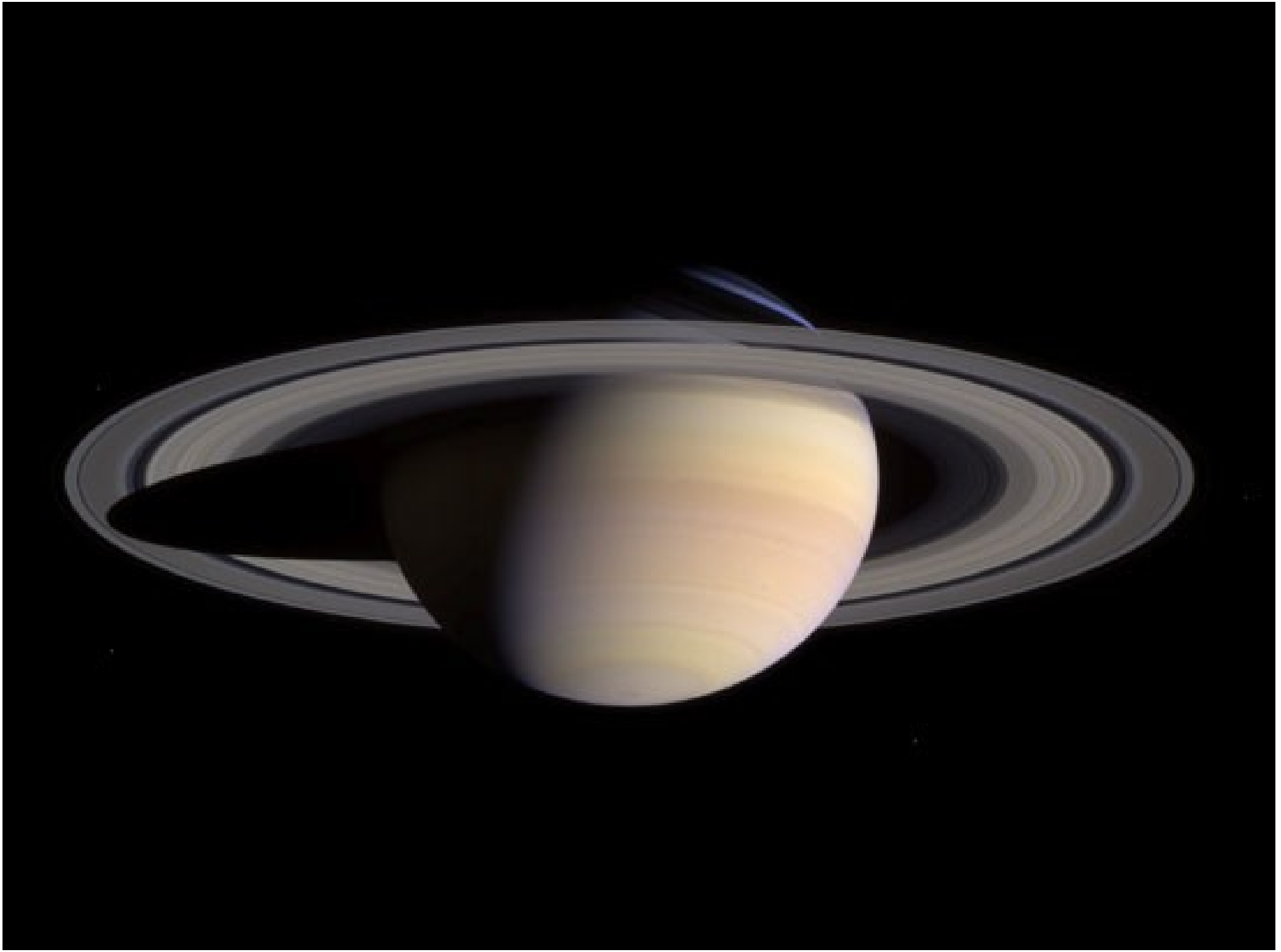




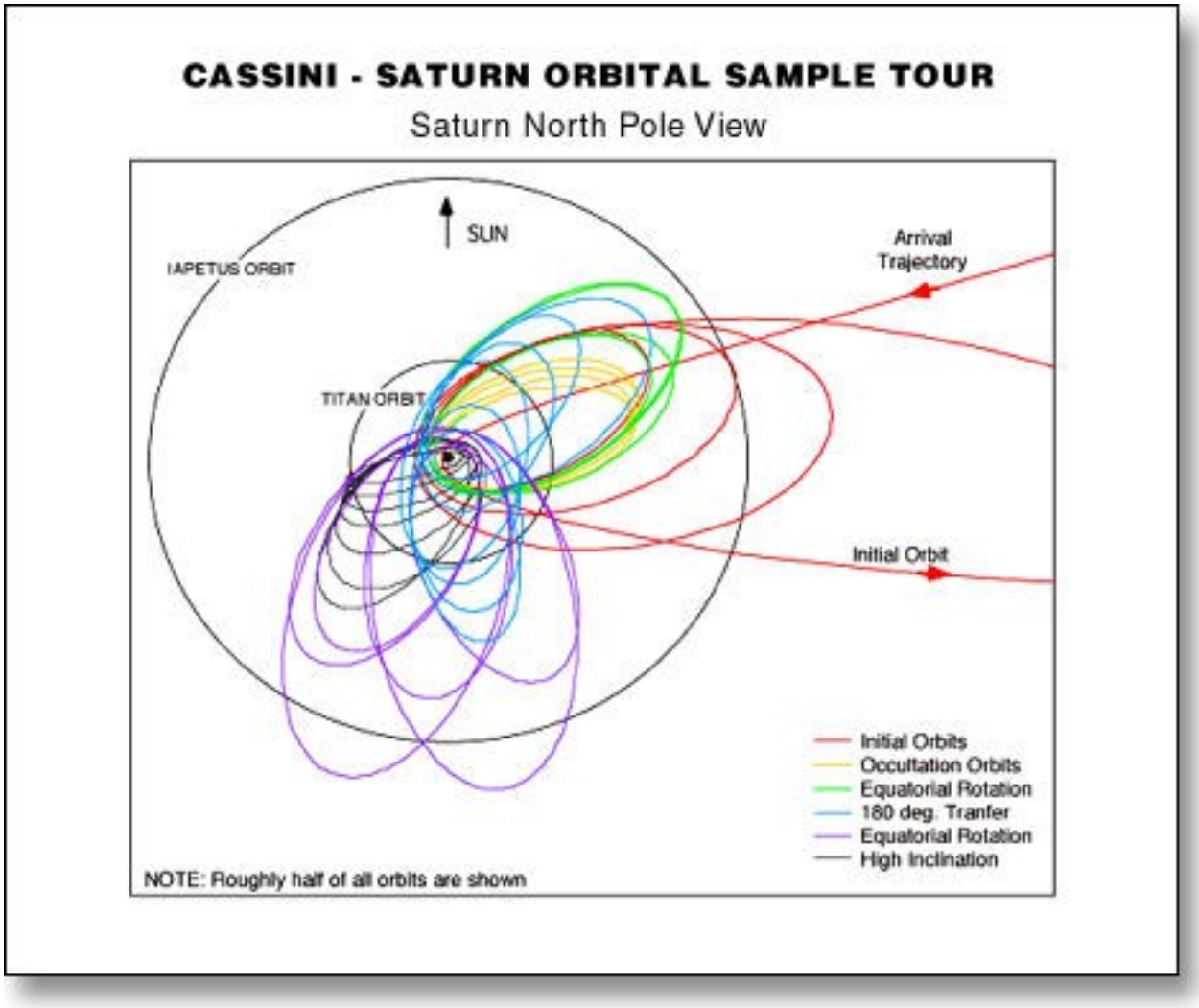
IO WITH JUPITER BACKDROP

YEAR: 2001
MISSION: CASSINI
TARGET: JUPITER / IO

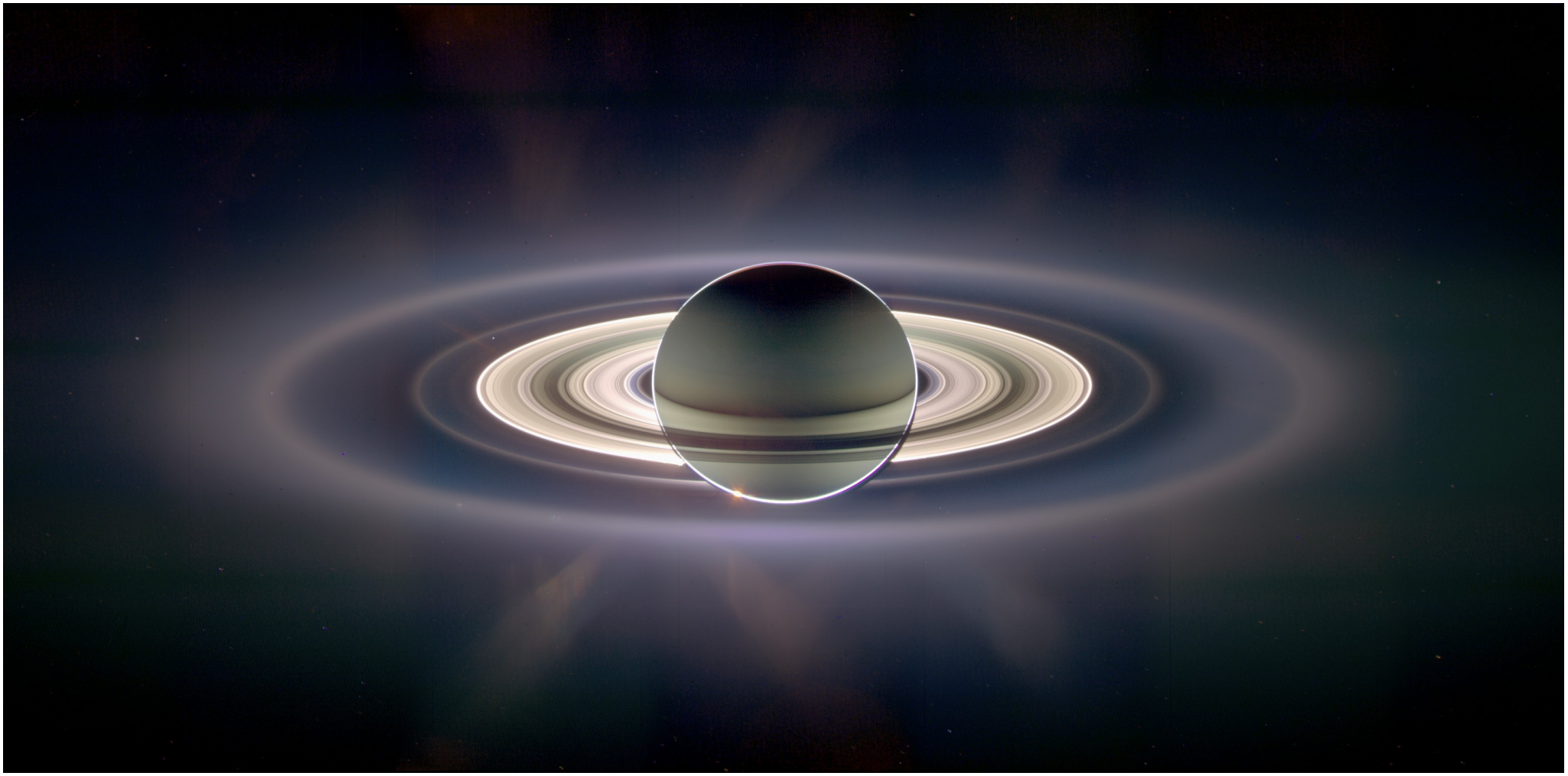
The moon Io captured against Jupiter and crossing into Jupiter's night side.



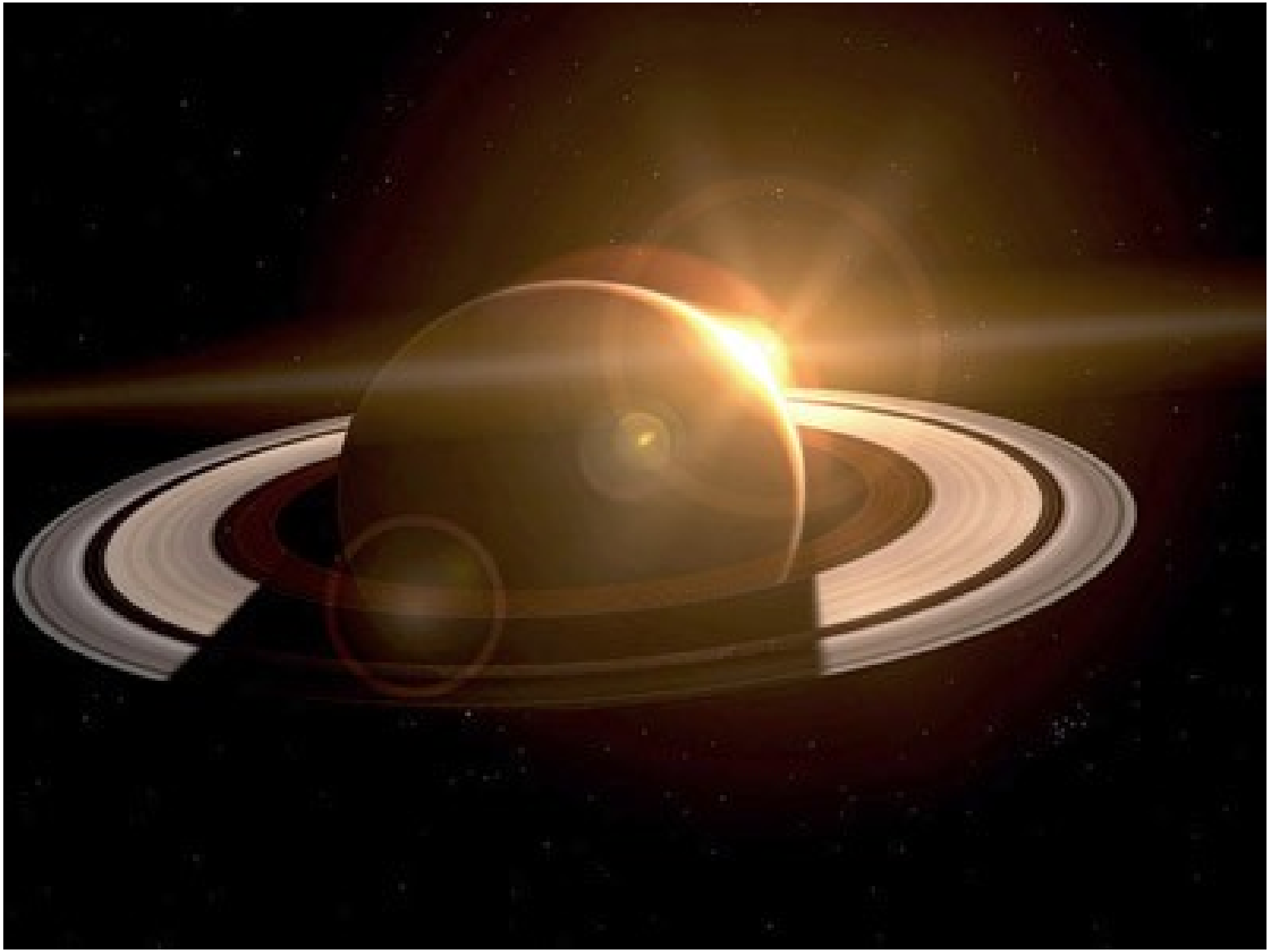
Cassini orbiting Saturn



Ringshine

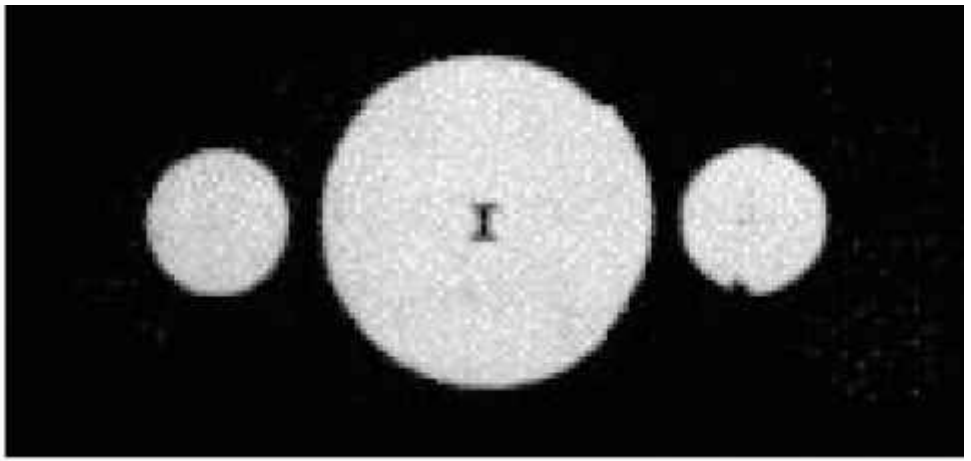


Planetary Rings



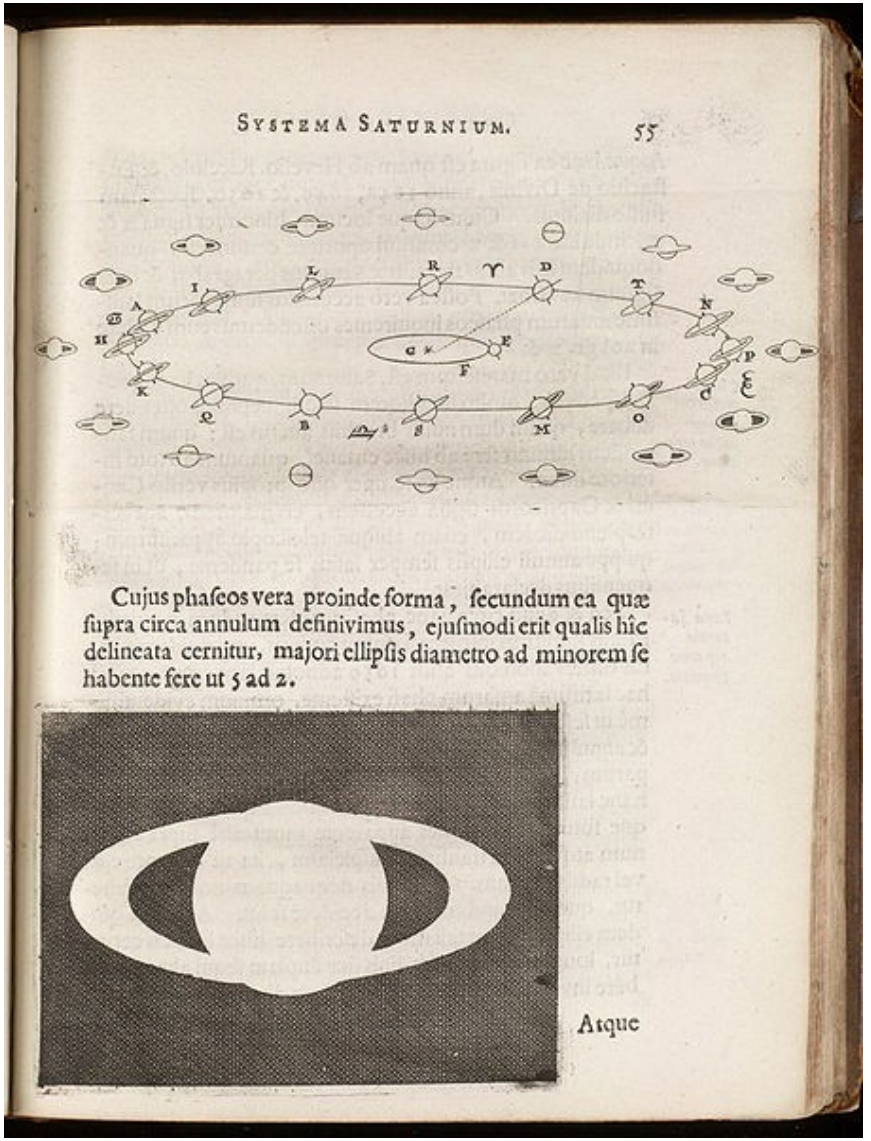
Planetary Rings

Galileo's drawing, 1610.



"I do not know what to say in a case
so surprising, so unlooked for, so novel."

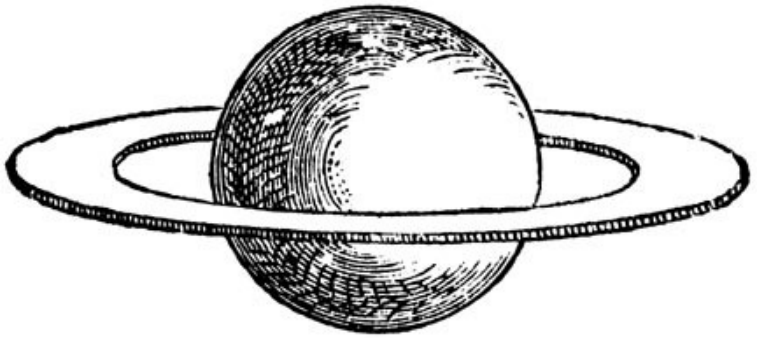
Planetary Rings


SYSTEMA SATURNIUM. 55

Cujus phaſeos vera proinde forma, ſecundum ea quæ ſupra circa annulum definivimus, ejuſmodi erit qualis hîc delineata cernitur, majori ellipſis diametro ad minorem ſe habente fere ut 5 ad 2.

Atque

Huygens's drawings, 1659.



"Saturn is surrounded by a thin flat disk, nowhere touching the planet"

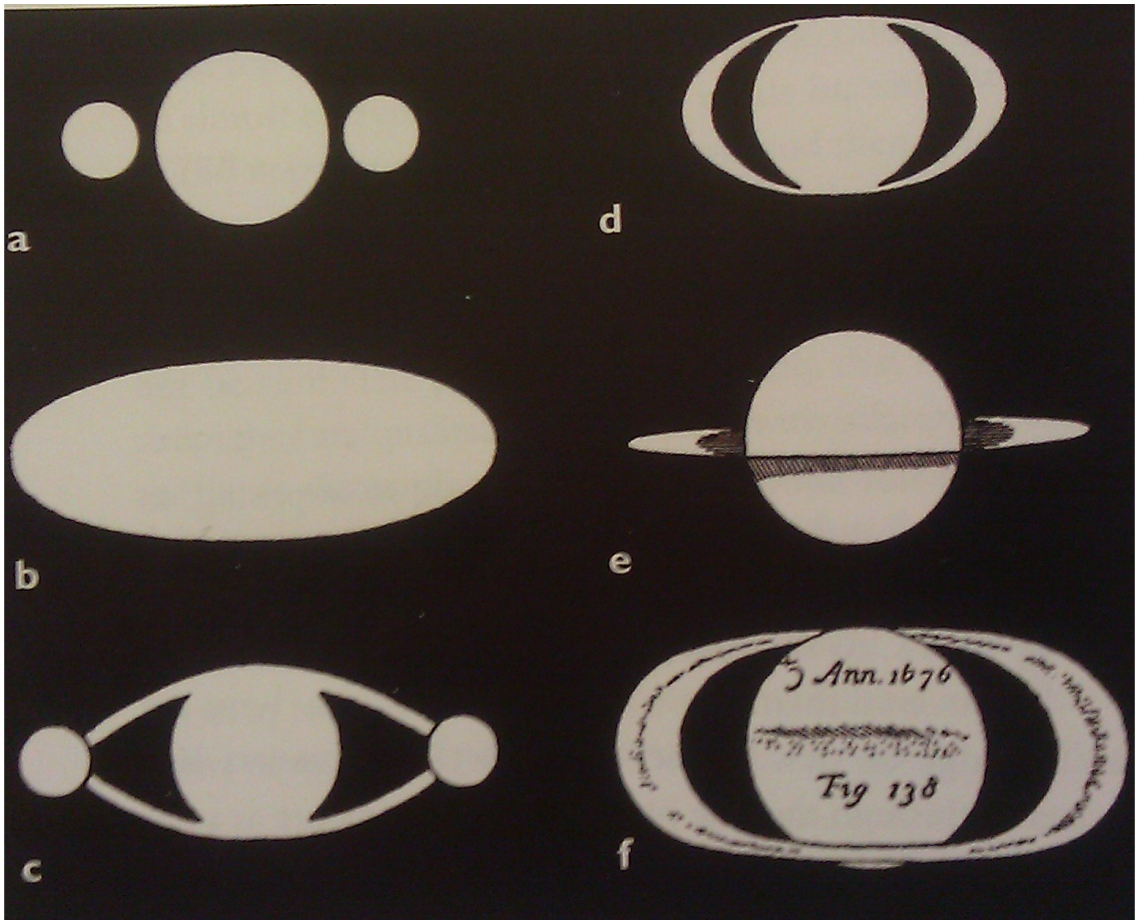
Planetary Rings

Other drawings from the 17th century

Galileo, 1610

Gassendi, 1634

Fontana, 1646



Riccioli, 1648

Huygens, 1655

Cassini, 1676

Planetary Rings

What are these rings???

Solid? Liquid? Particulate?

Planetary Rings

Maxwell's proof

James Clerk Maxwell
(1831-1879)

Planetary Rings

Maxwell's proof

There are some questions in Astronomy, to which we are attracted rather on account of their peculiarity, […] than from any direct advantage which their solution would afford to mankind.

[…] I am not aware that any practical use has been made of Saturn's Rings […]

But when we contemplate the Rings from a purely scientific point of view, they become the most remarkable bodies in the heavens. [..] When we have actually seen that great arch swung over the equator of the planet without any visible connection, we cannot bring out minds to rest. […] We must explain its motion on the principles of mechanics.

[…]

60 pages of calculations

[…]

[…] We conclude, therefore, that the rings must consist of disconnected particles; these may be either solid or liquid, but they must be independent. […] The final result, therefore, of the mechanical theory is, that the only system of rings which can exist is one composed of an indefinite number of unconnected particles, revolving around the planet with different velocities according to their respective distances.

By A. Hall.

T 1859, May 29^{d}·0077 Washington M.S.T.
Log q 9·303310
ω 281° 58′ 10″·7 or π = 75° 9′ 46″·1
Ω 357 7 56·8
i 95 50 56·8 i = 84 9 3·2
Motion Retrograde.

The comet will probably be visible after its perihelion passage.

On the Stability of the Motion of Saturn's Rings; an Essay which obtained the Adams' Prize for the Year 1856, *in the University of Cambridge.* By J. Clerk Maxwell, M.A. late Fellow of Trinity College, Cambridge: Professor of Natural Philosophy in the Marischal College and University of Aberdeen. Cambridge: Macmillan and Co., 1859.

The following abstract of an important paper has been kindly drawn up by the Astronomer Royal for the use of the readers of the *Monthly Notices*:—

The remarkable essay of which we have given the title was published in the beginning of the present year. The subject of it is so interesting, the difficulty of treating it in its utmost generality so considerable, and the results at which the author arrives so curious, that we think a brief abstract of it will be acceptable to the readers of the *Monthly Notices*. We shall commence with a very imperfect reference to preceding investigations on the same subject.

The first to which we shall allude is Laplace's, in the *Mécanique Céleste*, livre III. chapitre vi. Laplace considers a ring of *Saturn* as a solid, the form of which is investigated as if it were fluid (a mode of treatment whose result, in respect of the form of equilibrium, is evidently good for a solid), and finds, that if the breadth and thickness of the ring are very small in comparison with its distance from *Saturn*, its section may be an ellipse; and it appears that the formula for the proportion of the axes of the ellipse admits of its being considerably flattened. But Laplace rather inclines to the supposition that there are several rings, each existing by its own proper theory. Then remarking on the appearances noticed by some observers which seem to indicate irregularities in the rings, he adds, "J'ajoute que ces inégalités sont nécessaires pour maintenir l'anneau en équilibre autour de *Saturne*," and gives an in-

C

Planetary Rings

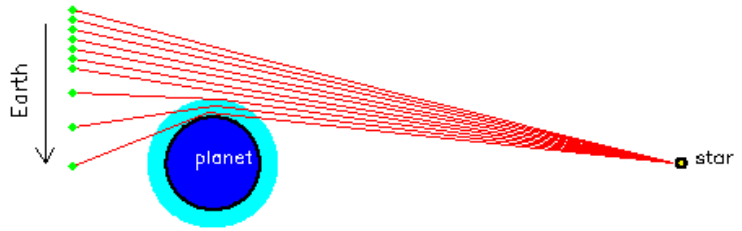
Why only Saturn has rings?

Carl Sagan

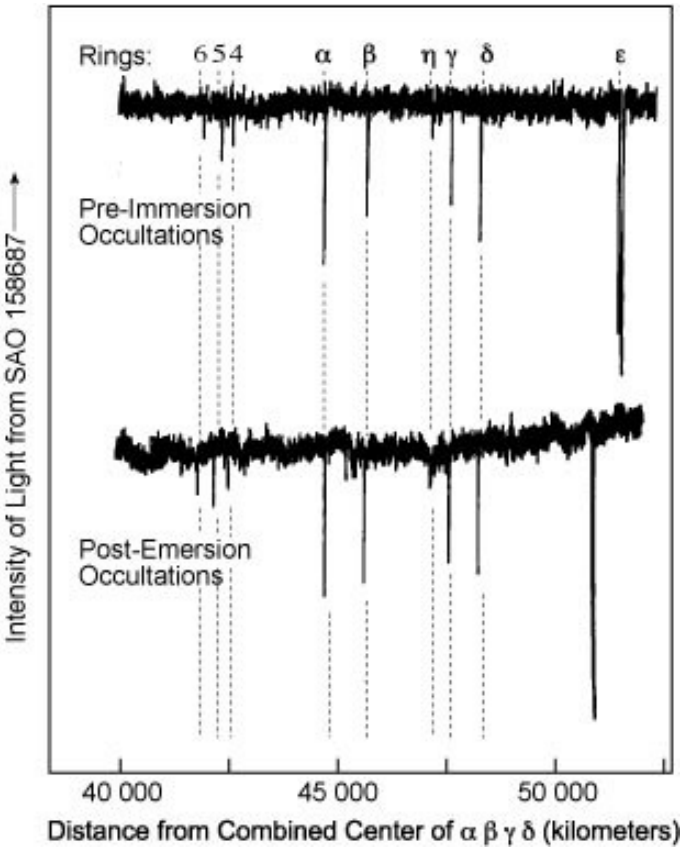
Rings of Uranus

Occultations

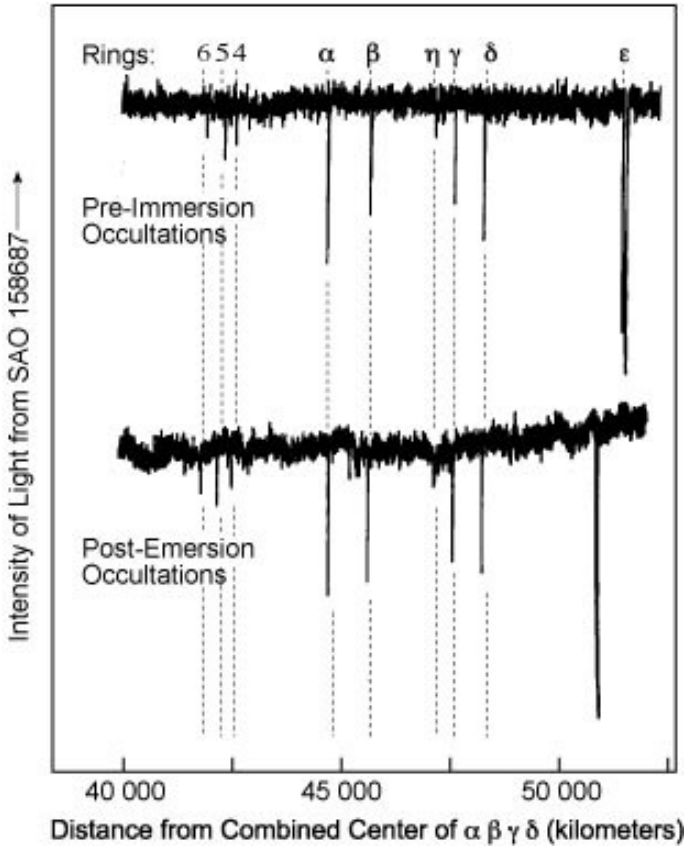
stellar occultation



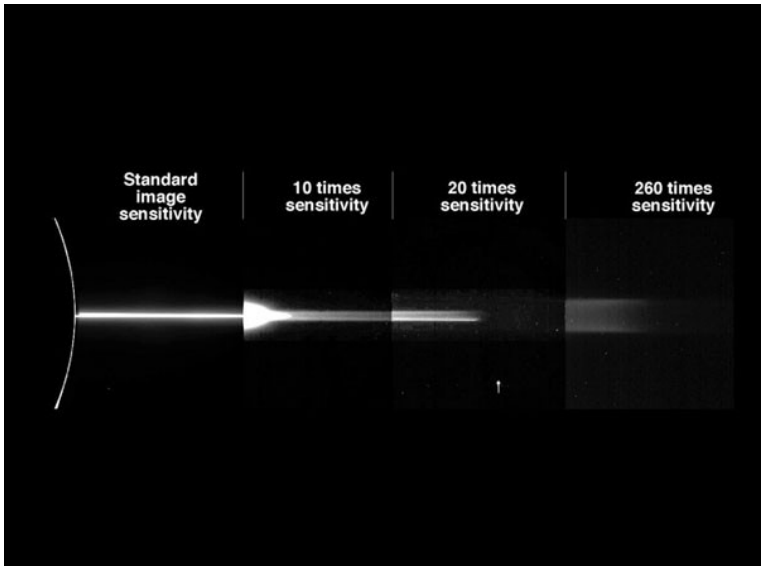
Uranus occults a star

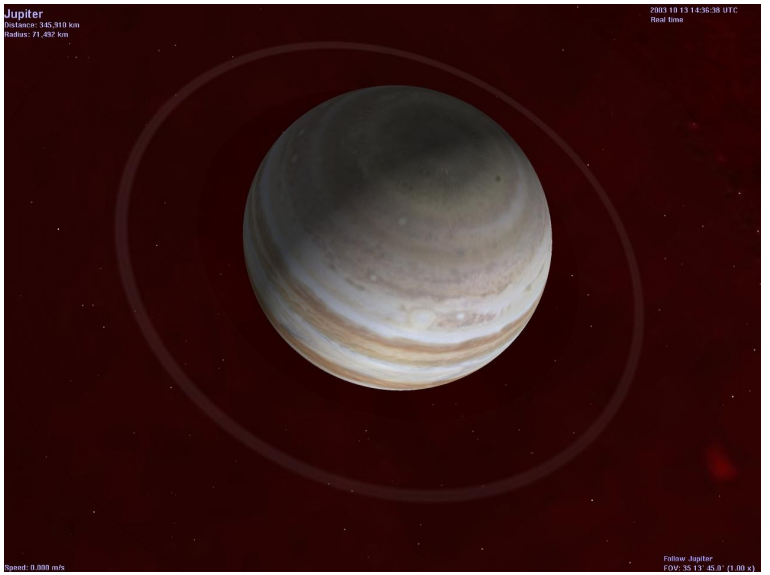


Rings of Uranus



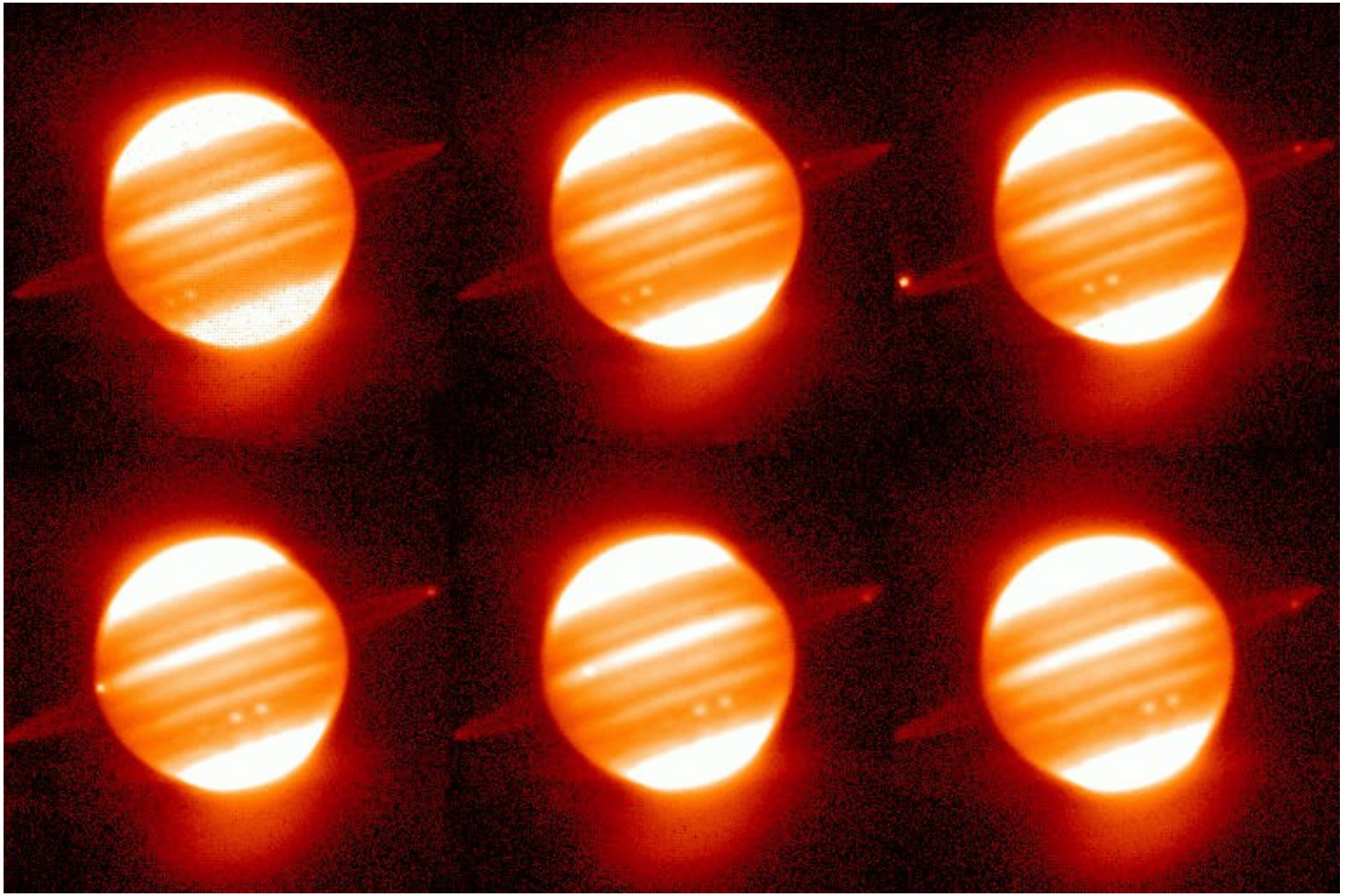
Rings of Jupiter





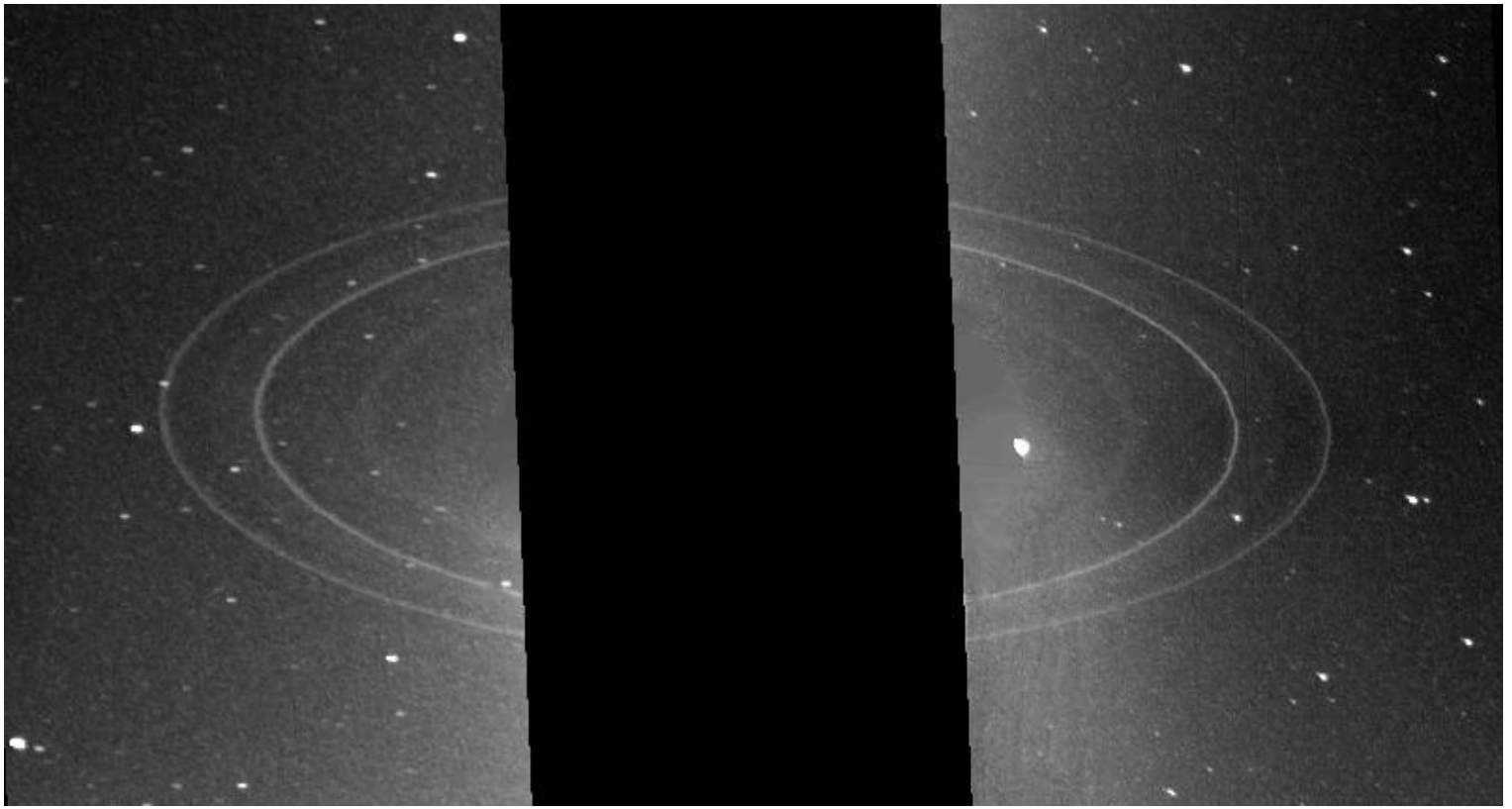
A very faint ring system
discovered by Voyager 1.

Rings of Jupiter



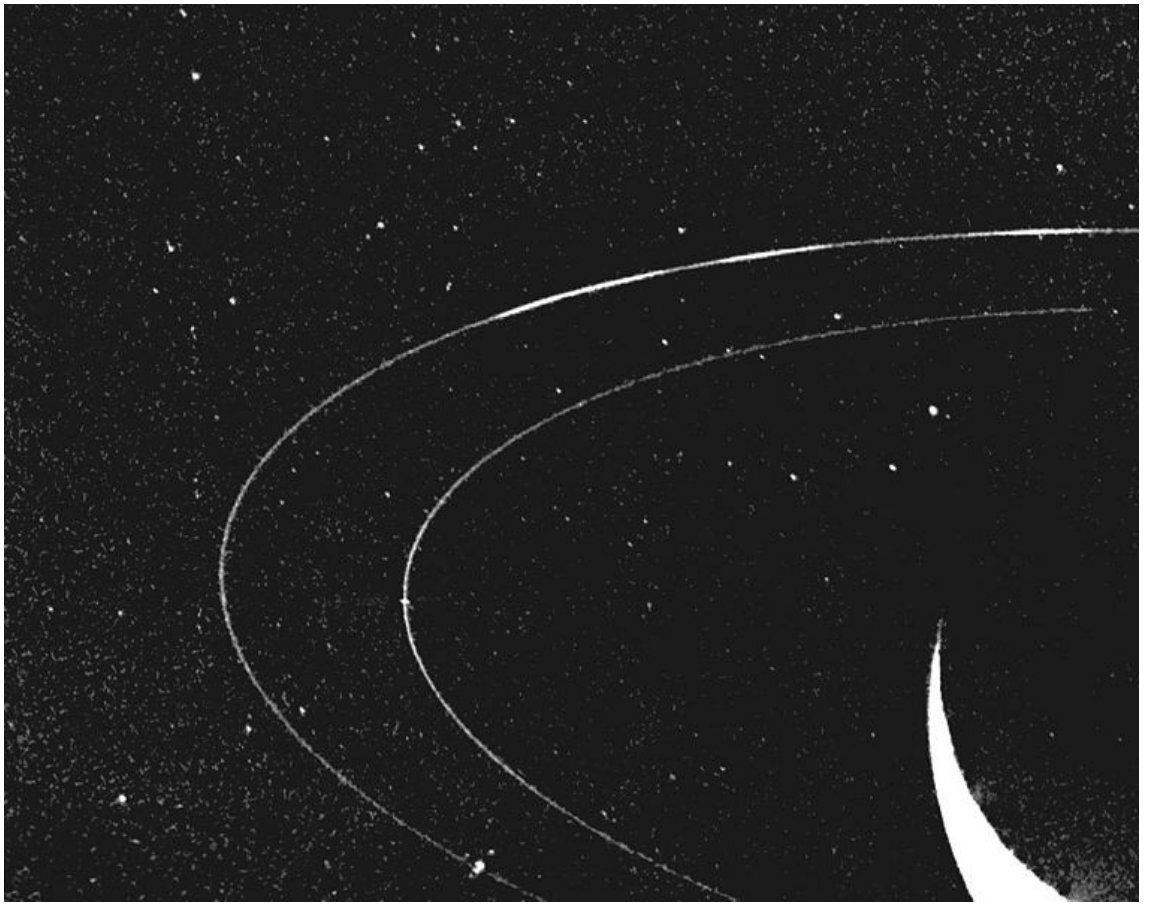
Viewed with Keck,
with a methane filter.

Rings of Neptune



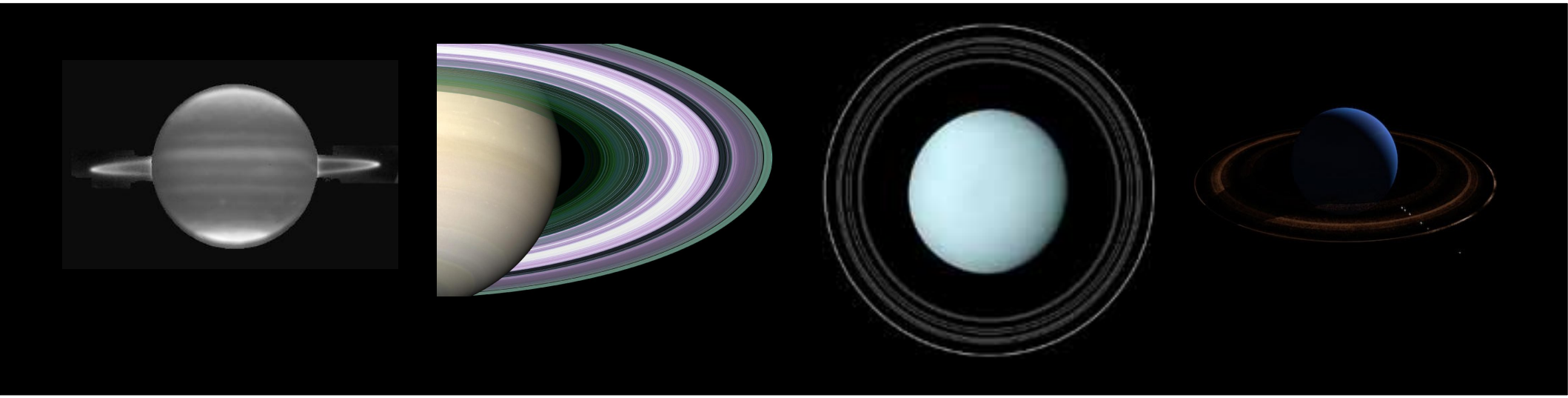
A very faint ring system,
similar to Jupiter's rings
discovered by Voyager 2.

Rings of Neptune

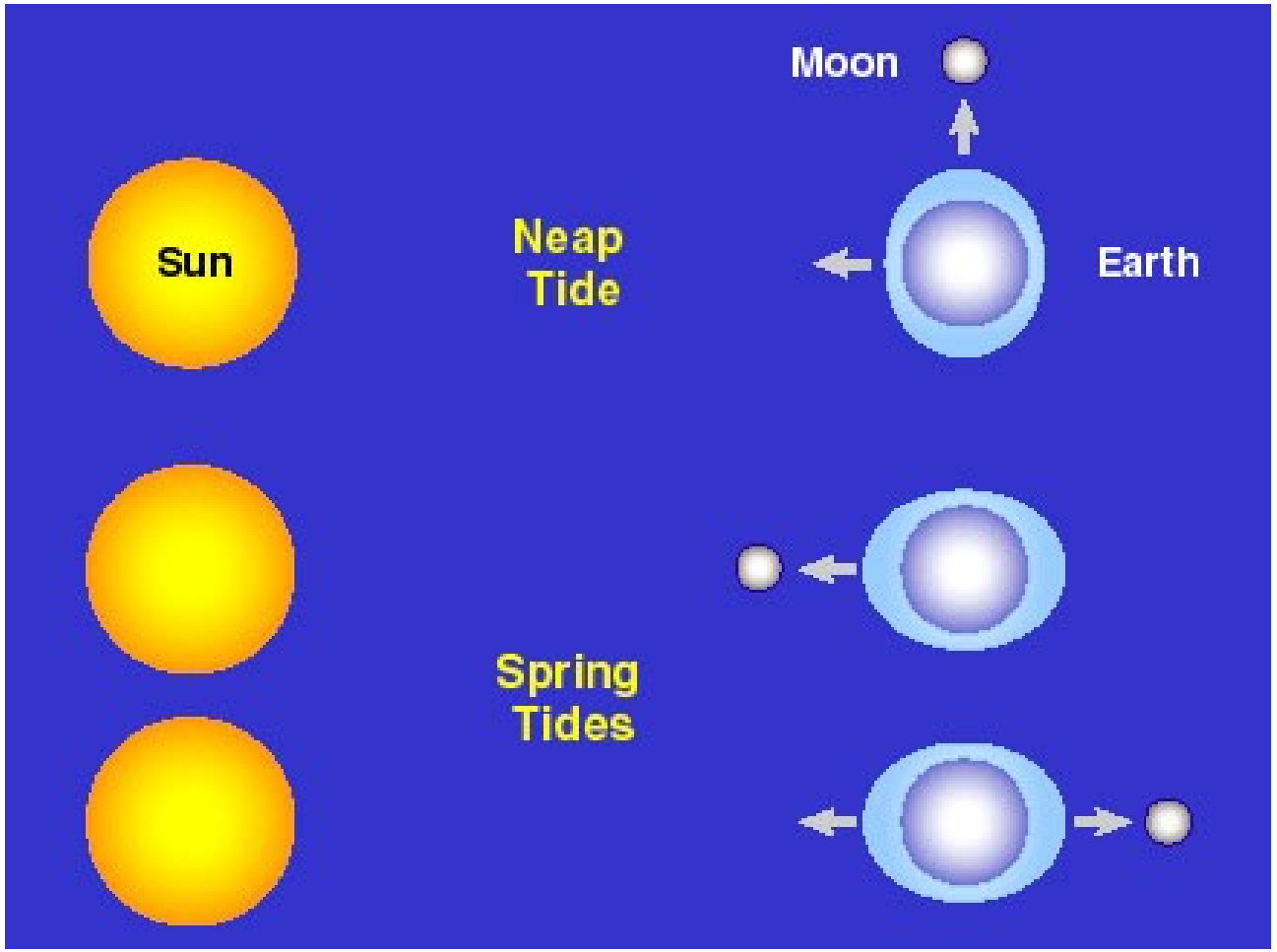


Arcs!!!

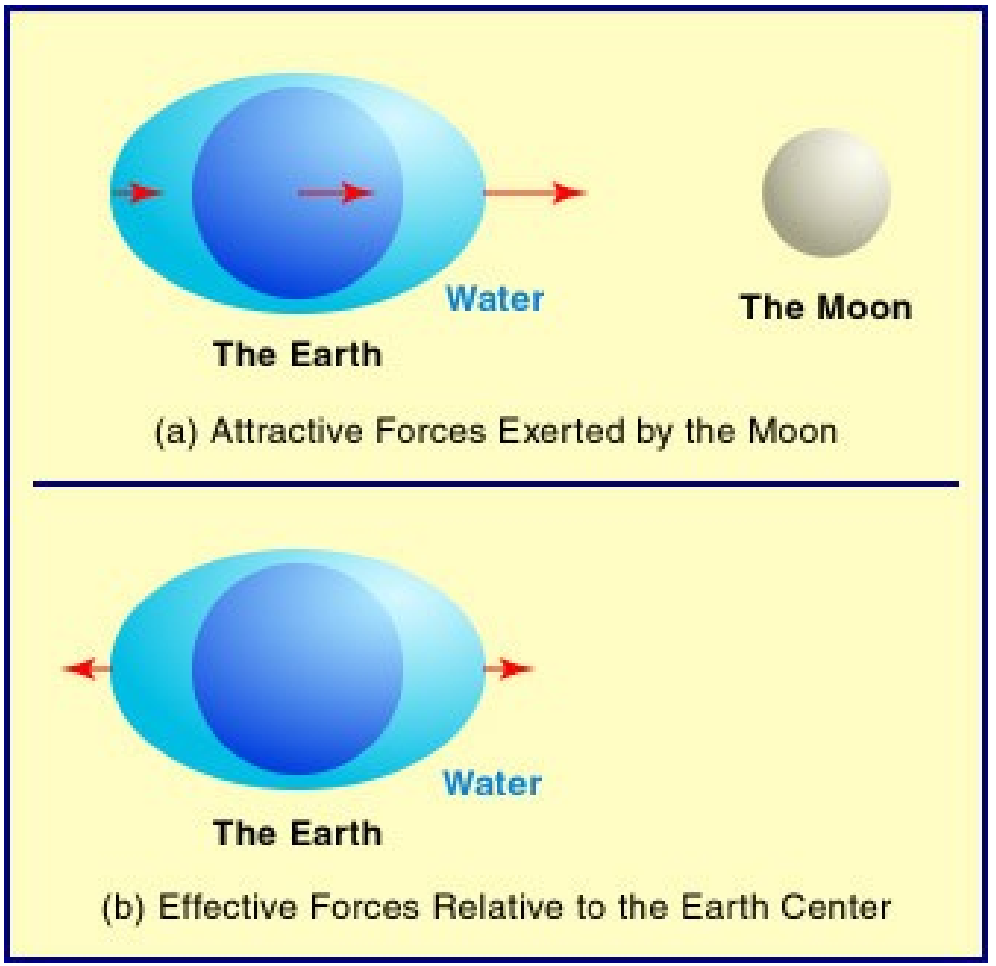
Ring Systems

Jupiter	Saturn	Uranus	Neptune
			
Fine, diffuse dust, very dark.	Icy boulders, very bright.	Rocky boulders, dark.	Pebbles (?) Dark and reddish (?)

Tides



Tides

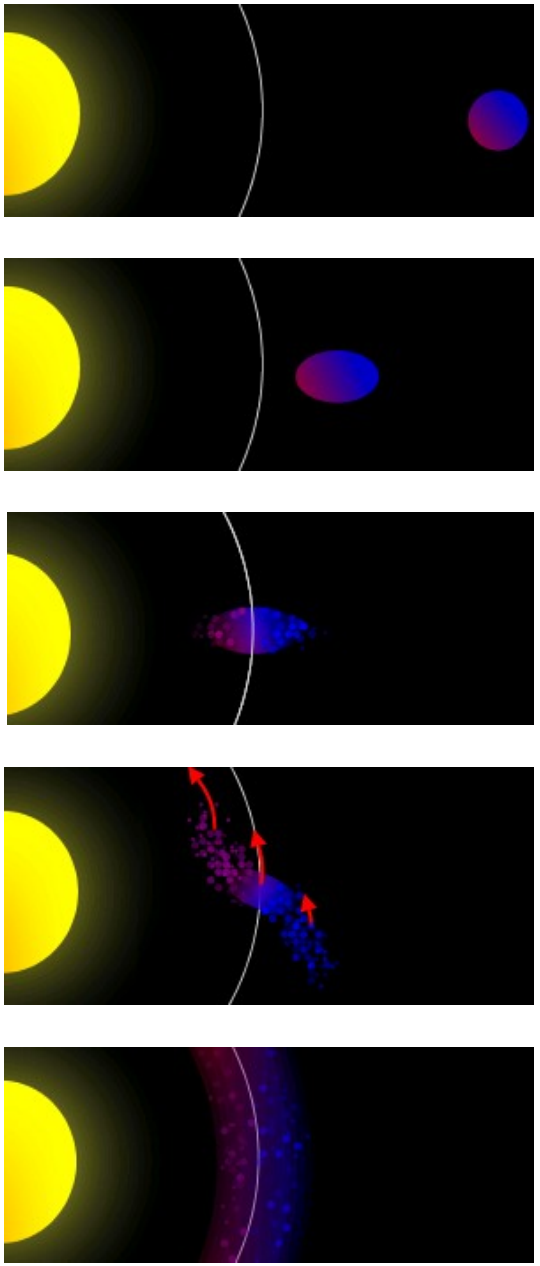


The side closer to the Moon experiences a greater pull than the side further out.

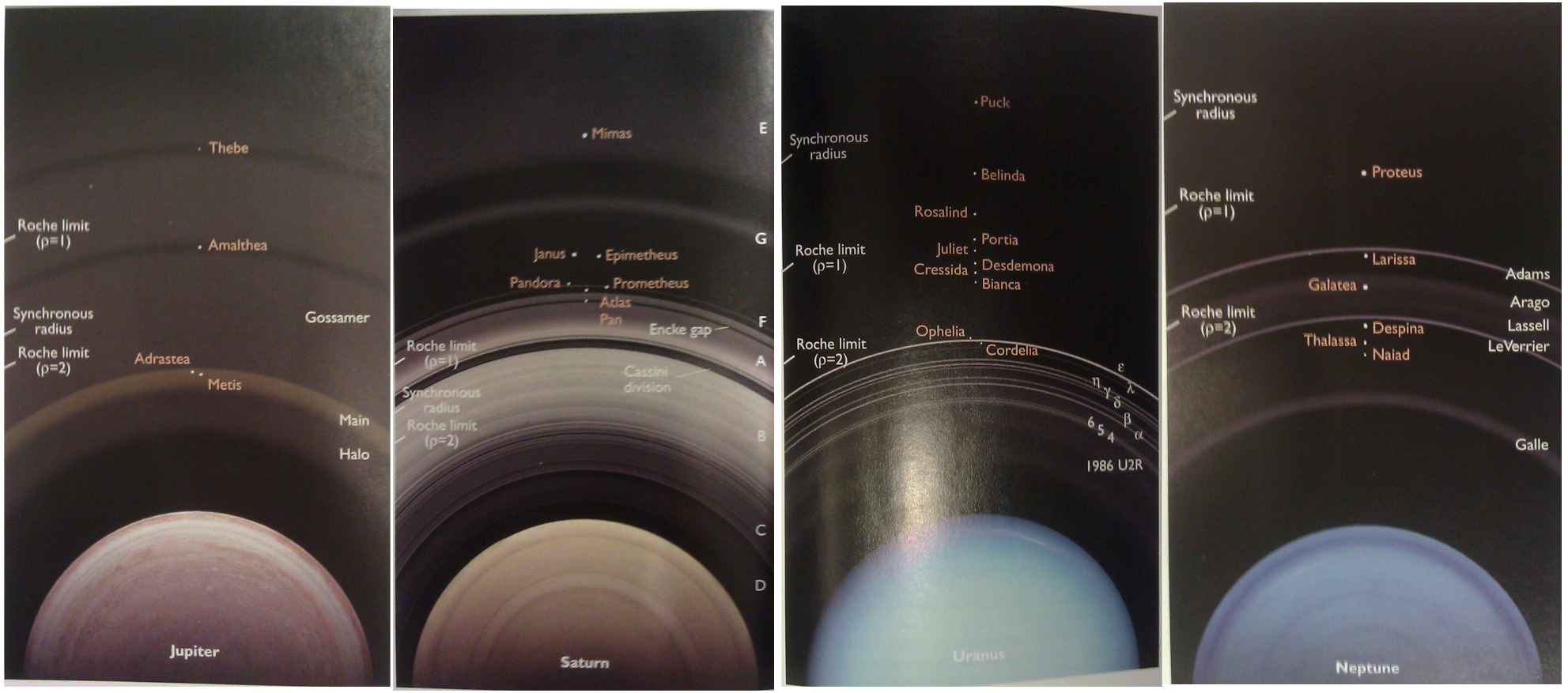
The effective result is a *differential* force we call **Tidal Force**.

Roche Limit

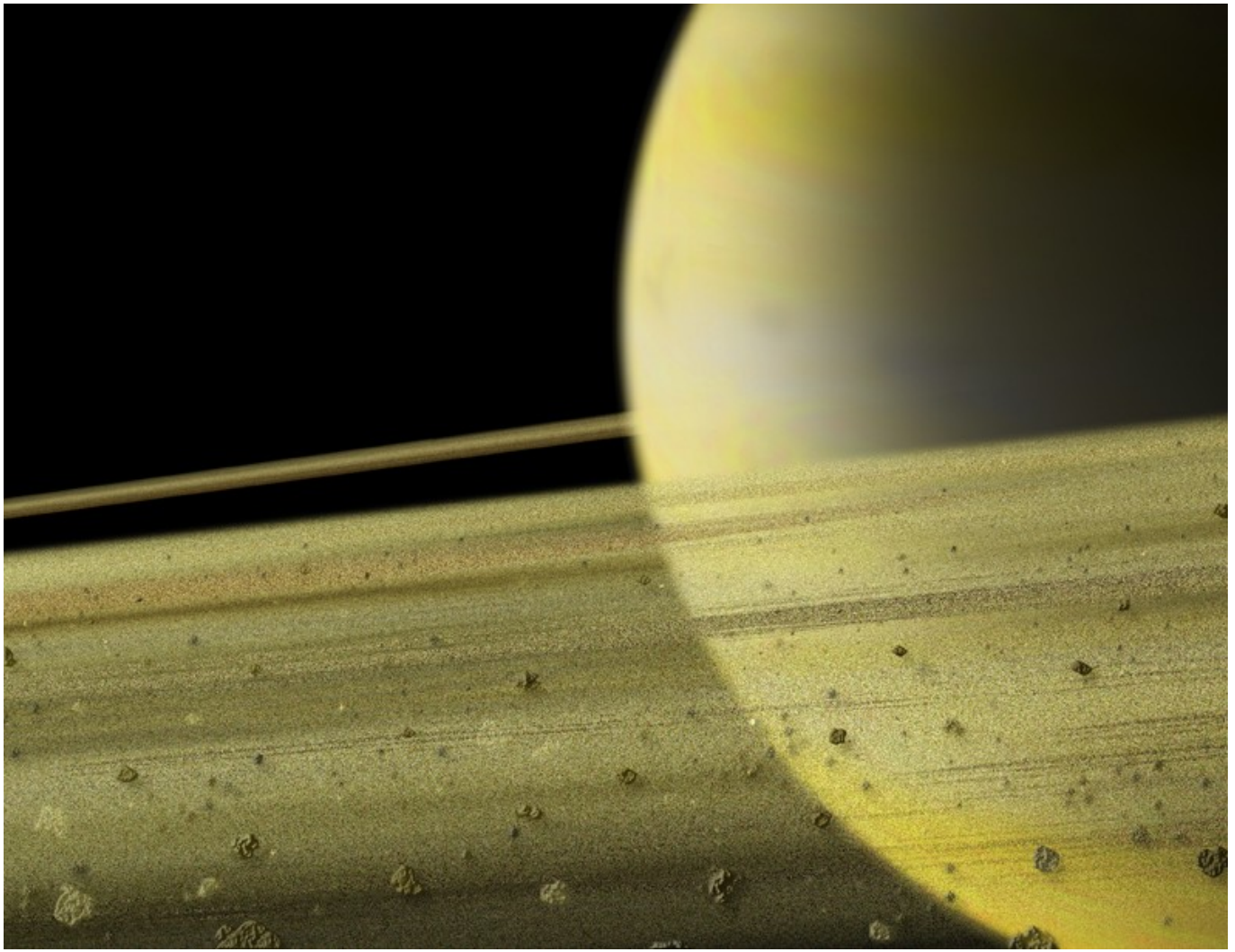
Limit where the
tidal force is **stronger** than the **internal forces**
holding the body together



All ring systems are inside their planet's Roche limit



Ring formation: Competing theories



1). Moon that got too close

2). Leftover material that could not coalesce into moons