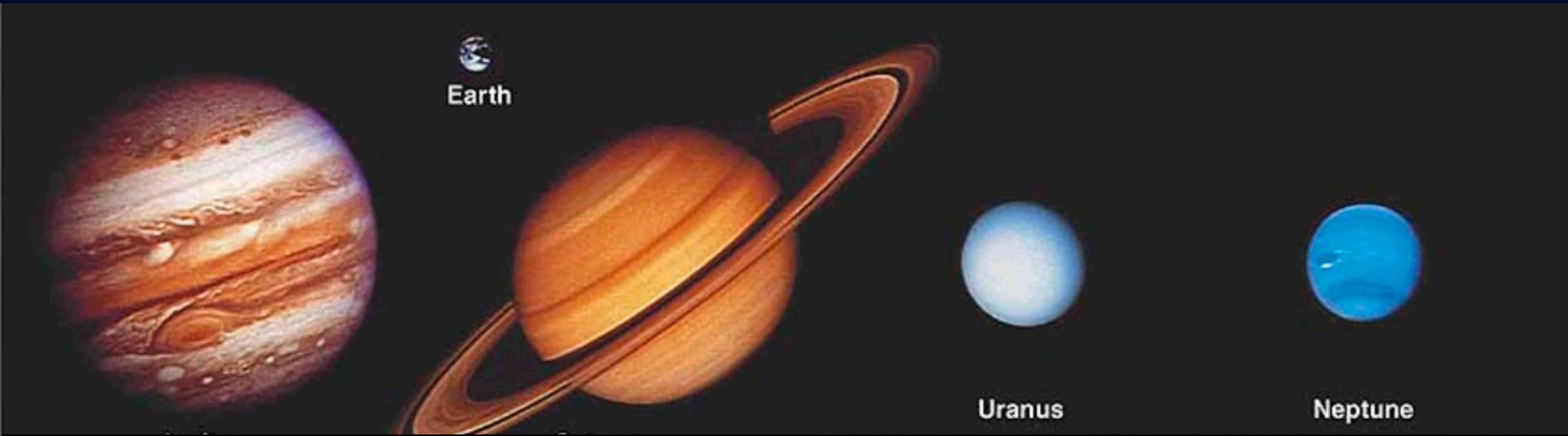
Astronomy 405
Solar System and ISM

Lecture 10
The Great World

February 6, 2013

The Jovian Planets



Jupiter	Saturn	Uranus	Neptune
5.2 AU	9.54 AU	19.2 AU	30.1 AU
318 $M_\oplus$	95 $M_\oplus$	14 $M_\oplus$	17 $M_\oplus$
11.2 $R_\oplus$	9.4 $R_\oplus$	4 $R_\oplus$	3.9 $R_\oplus$
1.33 g/cm^3	0.71 g/cm^3	1.24 g/cm^3	1.67 g/cm^3
Mostly H, He	Mostly H, He	rock, H, He	rock, H, He
14 $B_\oplus$	0.7 $B_\oplus$	0.74 $B_\oplus$	0.43 $B_\oplus$
124 K	95 K	59 K	59 K

Missions to the Giant Planets

Pioneer 10, Pioneer 11 flybys of Jupiter 1973, 1974

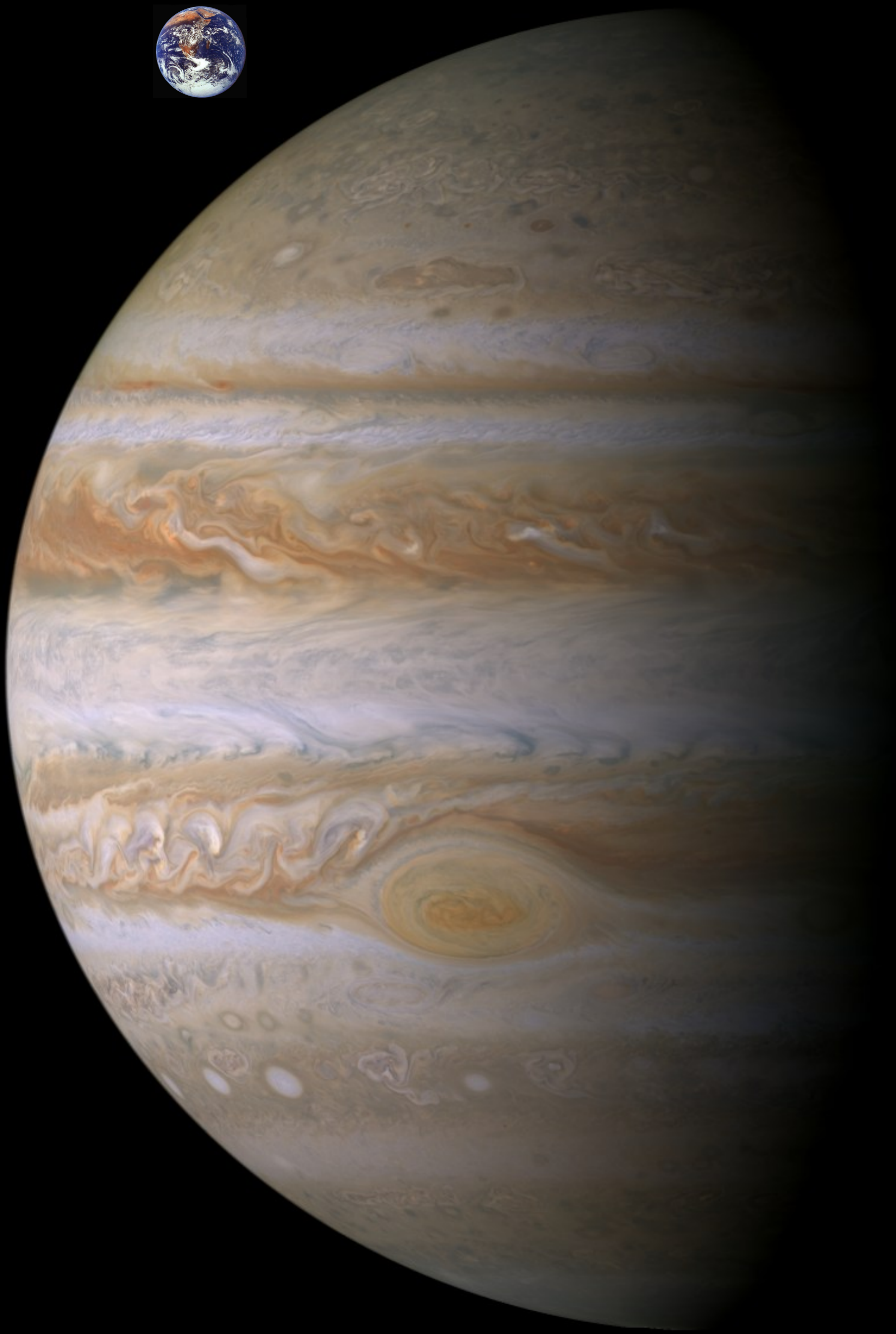
Voyager 1 and Voyager 2 launched in 1977
visited Jupiter, Saturn, Uranus, Neptune (flybys)
is now on its way out of the Solar System

Hubble Space Telescope

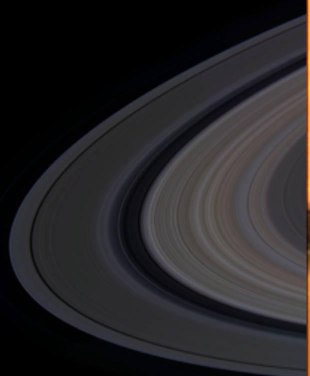
Galileo mission to Jupiter, launched in 1995
orbited around Jupiter, dropped a probe into atmosphere

Cassini-Huygens mission to Saturn, launched in 1997
Cassini orbited around Saturn, Huygens descended
into the atmosphere of Titan (2hr27min + 1hr10min)

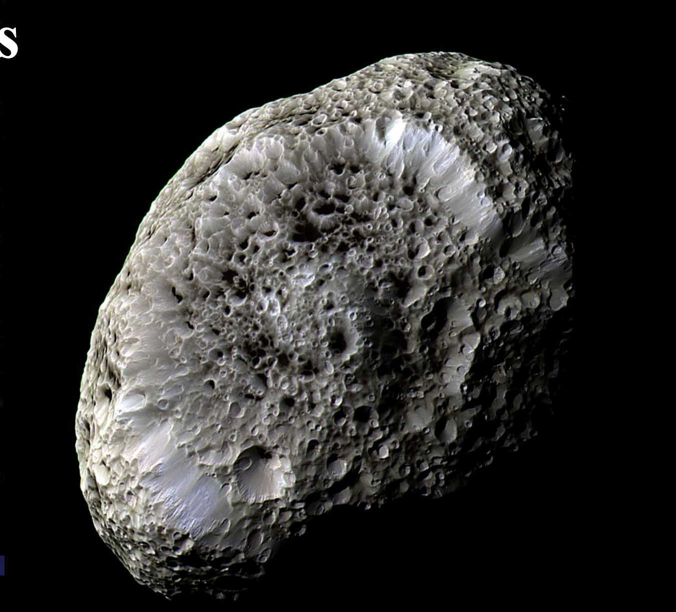
Jupiter

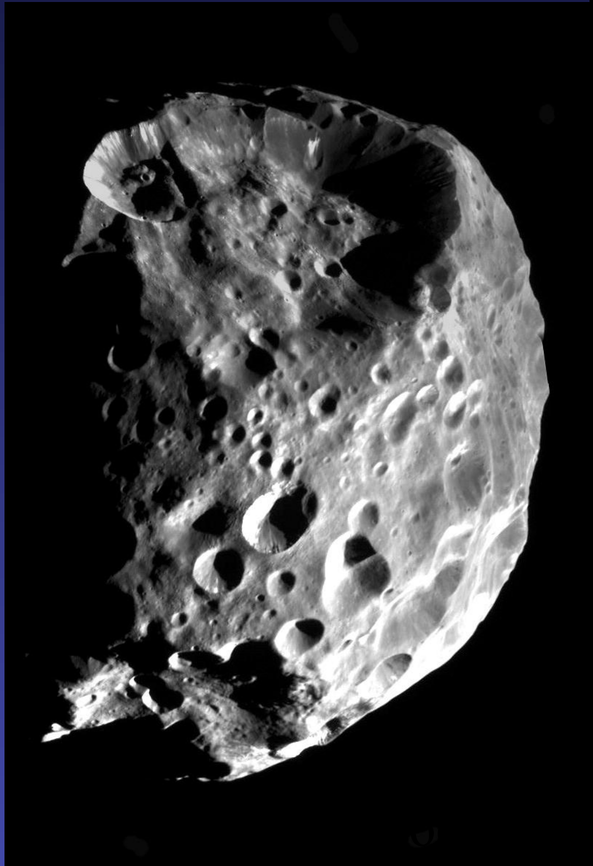


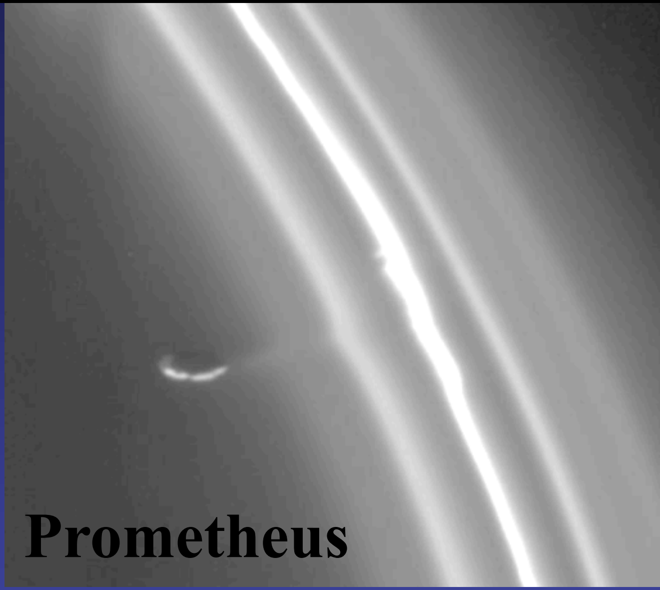
Satur



Moons…

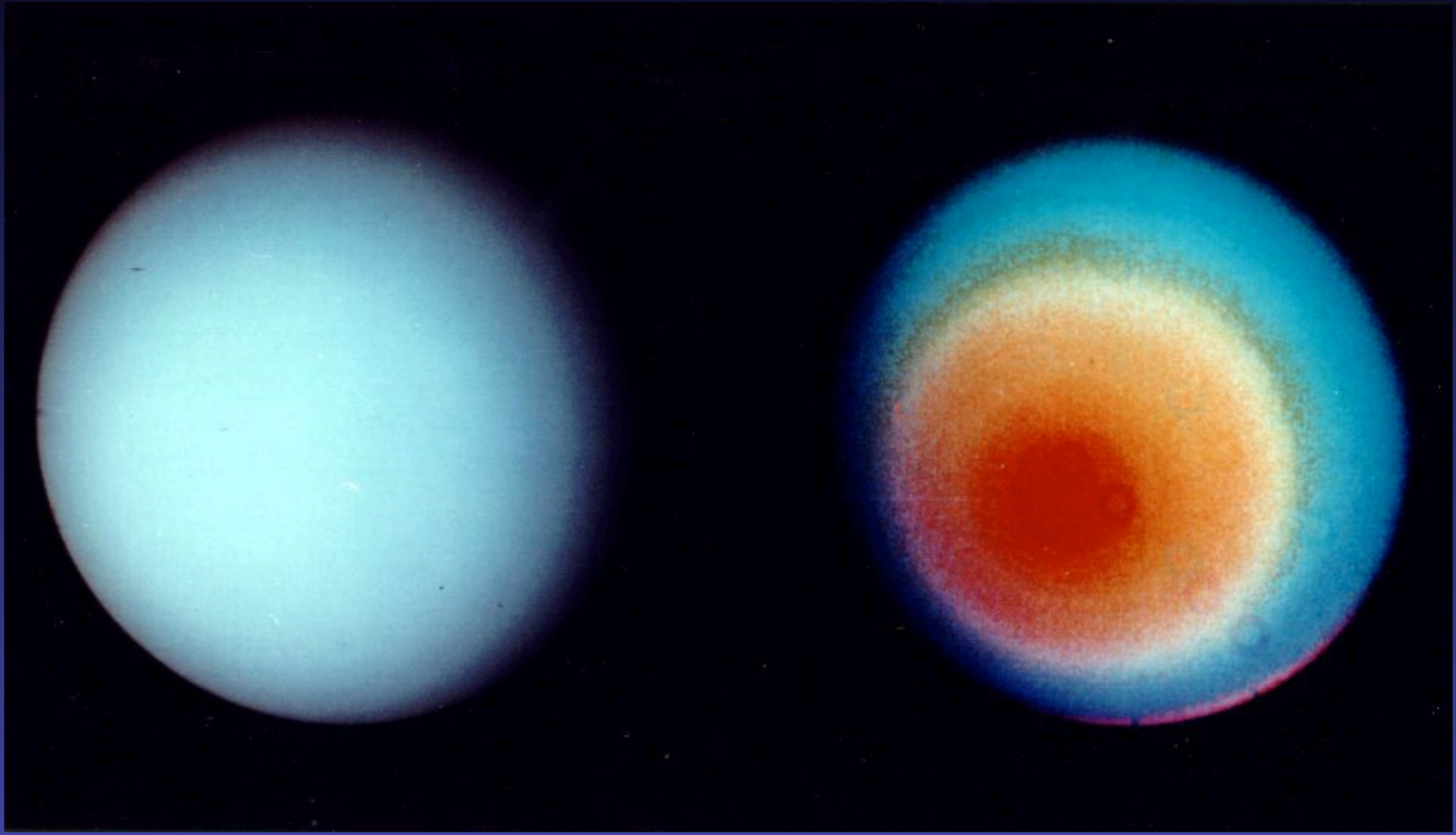




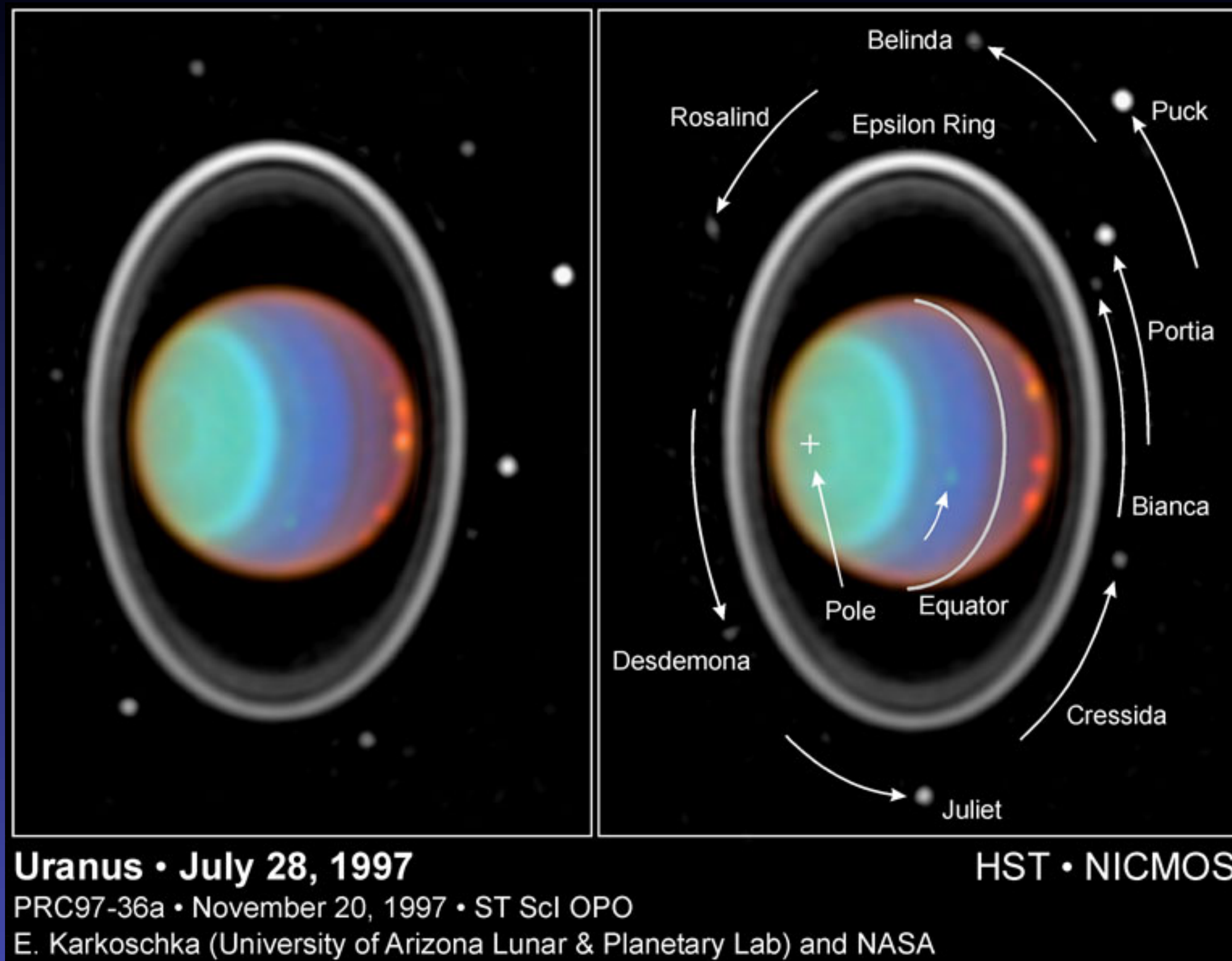


Voyager, Huygens & Cassini

Voyager Image of Uranus

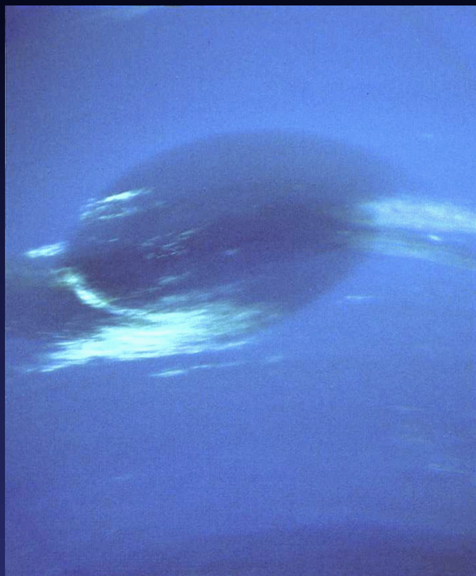


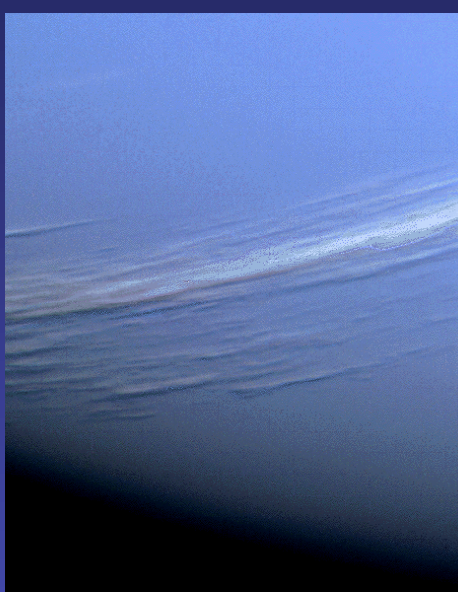
Hubble Watches Uranus

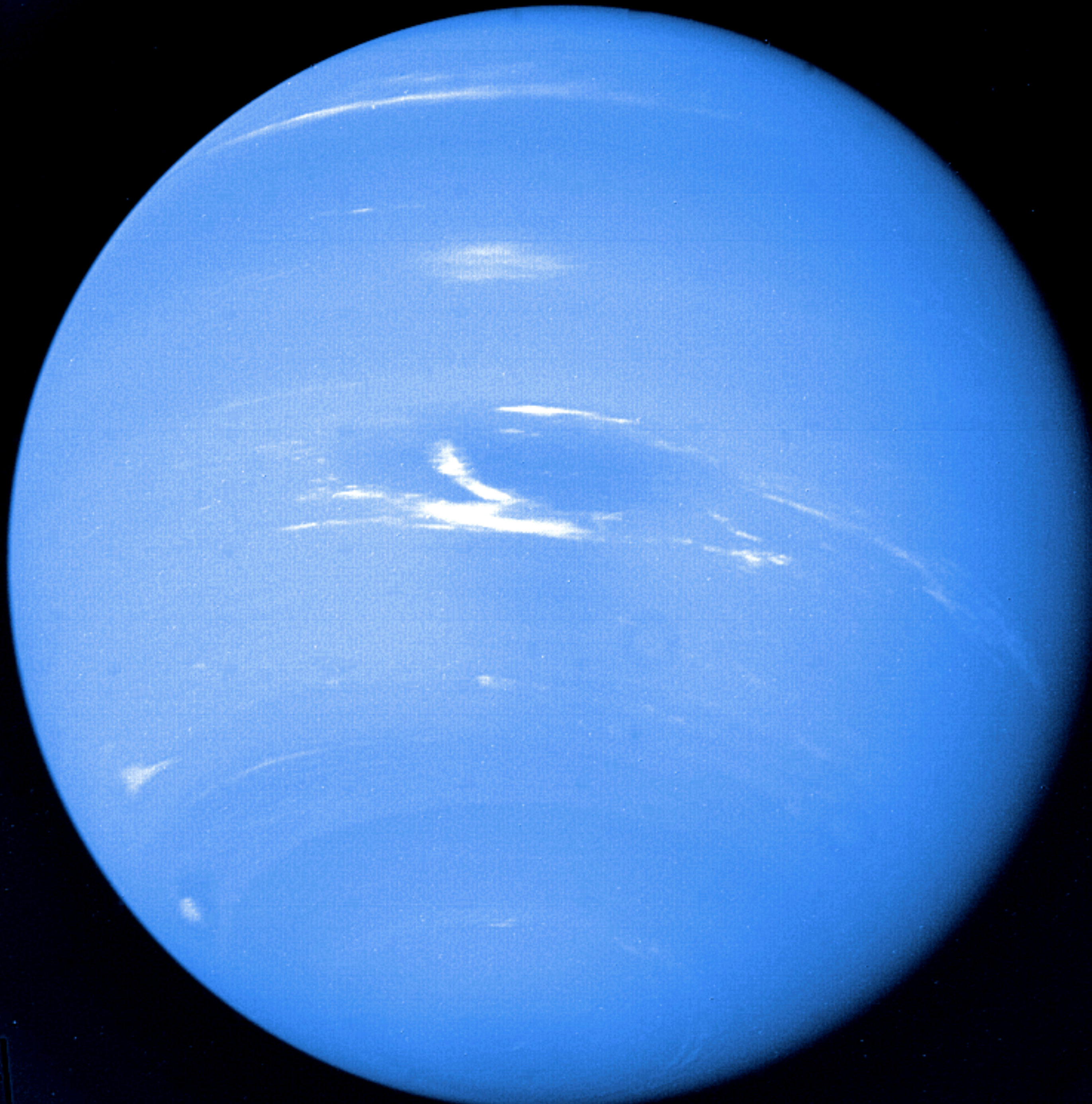


Voyager

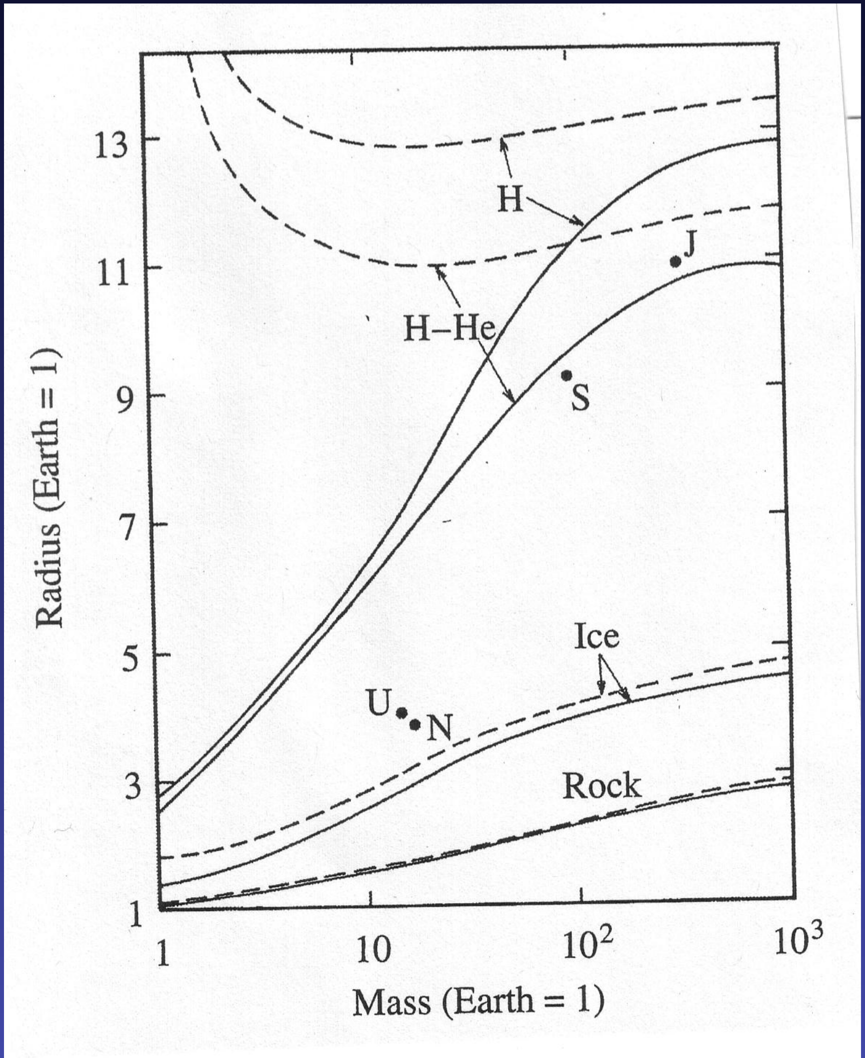
Neptune







Gas	Sun	Jupiter	Saturn	Uranus	Neptune
H_2	H: 0.835	0.864 ± 0.006	0.963 ± 0.03	0.85 ± 0.05	0.85 ± 0.05
He	He: 0.195	0.157 ± 0.004	0.034 ± 0.03	0.18 ± 0.05	0.18 ± 0.05
H_2O	O: 1.70×10^{-3}	2.6×10^{-3}	$> 1.70 \times 10^{-3}$?	$> 1.70 \times 10^{-3}$?	$> 1.70 \times 10^{-3}$?
CH_4	C: 7.94×10^{-4}	$(2.1 \pm 0.2) \times 10^{-3}$	$(4.5 \pm 2.2) \times 10^{-3}$	0.024 ± 0.01	0.035 ± 0.010
NH_3	N: 2.24×10^{-4}	$(2.60 \pm 0.3) \times 10^{-4}$	$(5 \pm 1) \times 10^{-4}$	$< 2.2 \times 10^{-4}$	$< 2.2 \times 10^{-4}$
H_2S	S: 3.70×10^{-5}	$(2.22 \pm 0.4) \times 10^{-4}$?	$(4 \pm 1) \times 10^{-4}$?	3.7×10^{-4}?	1×10^{-3}



Hydrostatic equilibrium

$dP/dr = - G\, M_r\, \rho\, /\, r^2$

Polytropic relation

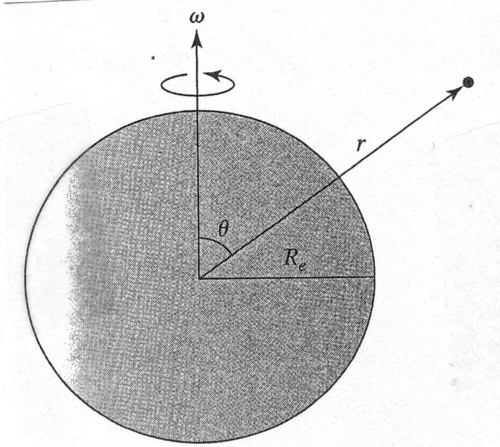
$P \propto \rho^2$

Solid curve: degenerate, zero-temperature

Dashed Curve: adiabatic temperature gradient

Gravitational potential $\Phi \equiv \frac{U}{m}$

Spherically symmetric $\Phi = -GM/r$



Non-spherical case:

$$\Phi(\theta) = -\frac{GM}{r}\left[1 - \left(\frac{R_e}{r}\right)^2 J_2\, P_2(\cos\theta) - \left(\frac{R_e}{r}\right)^4 J_4\, P_4(\cos\theta) - \cdots\right]$$

Re: equatorial radius

as $r \to \infty$, Φ approaches the form of the spherical potential.

P_2, P_4, ... are known as **Legendre polynomials**

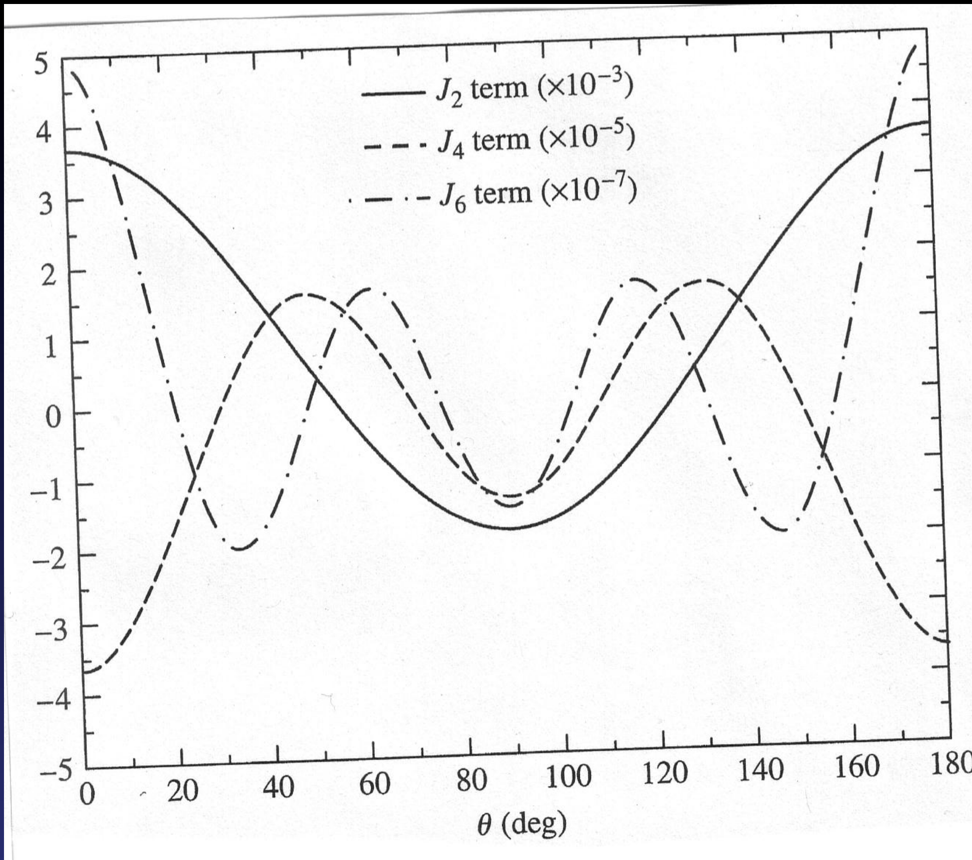
$$P_0(\cos\theta) = 1$$

$$P_2(\cos\theta) = \frac{1}{2}\left(3\cos^2\theta - 1\right)$$

$$P_4(\cos\theta) = \frac{1}{8}\left(35\cos^4\theta - 30\cos^2\theta + 3\right)$$

$$P_6(\cos\theta) = \frac{1}{16}\left(231\cos^6\theta - 315\cos^4\theta + 105\cos^2\theta - 5\right).$$

gravitational moments $(J_2,\ J_4,\ J_6, \ldots)$



b : oblateness

$$b \equiv \frac{R_e - R_p}{R_e} = 0.064874.$$

J_2 is related to b and to the moment of inertia

J_4 & J_6 sensitive to mass distribution in outer regions

Moments	Jupiter	Saturn
J_2	$(1.4697 \pm 0.0001) \times 10^{-2}$	$(1.6332 \pm 0.0010) \times 10^{-2}$
J_4	$-(5.84 \pm 0.05) \times 10^{-4}$	$-(9.19 \pm 0.40) \times 10^{-4}$
J_6	$(0.31 \pm 0.20) \times 10^{-4}$	$(1.04 \pm 0.50) \times 10^{-4}$
I/MR_e^2	0.258	0.220

Moments	Uranus	Neptune
J_2	$(0.35160 \pm 0.00032) \times 10^{-2}$	$(0.3539 \pm 0.0010) \times 10^{-2}$
J_4	$-(0.354 \pm 0.041) \times 10^{-4}$	$-(0.28 \pm 0.22) \times 10^{-4}$
I/MR_e^2	0.230	0.241

Uniform solid
$I = (2/5)\,MR^2$

Moment of Inertia for a two-zone model

Radius of the inner zone is $f\, r_e$

$$I \equiv \int_{\mathrm{vol}} a^2\, dm,$$

$$I = 4\pi \int_{z=0}^{R_p} \int_{a=0}^{a_{\max}(z)} \rho(a,z)\, a^3 da\, dz,$$

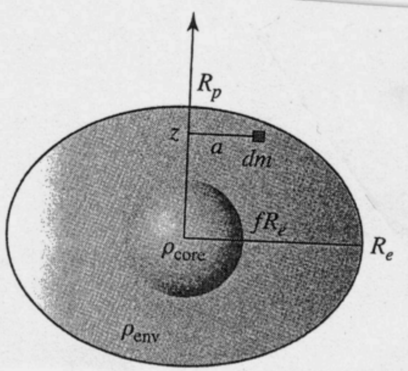
$$\left(\frac{a_{\max}}{R_e}\right)^2 + \left(\frac{z}{R_p}\right)^2 = 1.$$

$$I = \frac{8\pi}{15} R_e^4 \left[R_p \rho_{\mathrm{env}} + f^5 R_e \left(\rho_{\mathrm{core}} - \rho_{\mathrm{env}}\right)\right].$$

$$R_p = R_e(1-b),$$

$$I = \frac{8\pi}{15} R_e^5 \left[(1-b)\,\rho_{\mathrm{env}} + f^5 \left(\rho_{\mathrm{core}} - \rho_{\mathrm{env}}\right)\right].$$

$$f_{\max} = R_p/R_e = 1 - b \le 1.$$



By analyzing the gravitational field, geometry, moment of inertia, it can be concluded that Jovian planets all have dense cores, but the exact masses of the cores are not well known.

Rock/ice cores:

Jupiter ~ 10 $M_\oplus$

Saturn ~ 15 $M_\oplus$

Uranus ~ 13 $M_\oplus$

Neptune ~ 13 $M_\oplus$

Uranus and Neptune probably has 25% mass in rocks, 60-70% in ice, and only 5-15% in H, He

Internal Heat and Cooling Timescale

Jupiter absorbs (and re-emits) 5×10^{17} W of sunlight, but emits additional 3.35×10^{17} W.

$\Rightarrow$Internal heating

Gradual release of gravitational energy

Virial Theorem: in a gravitationally bound system

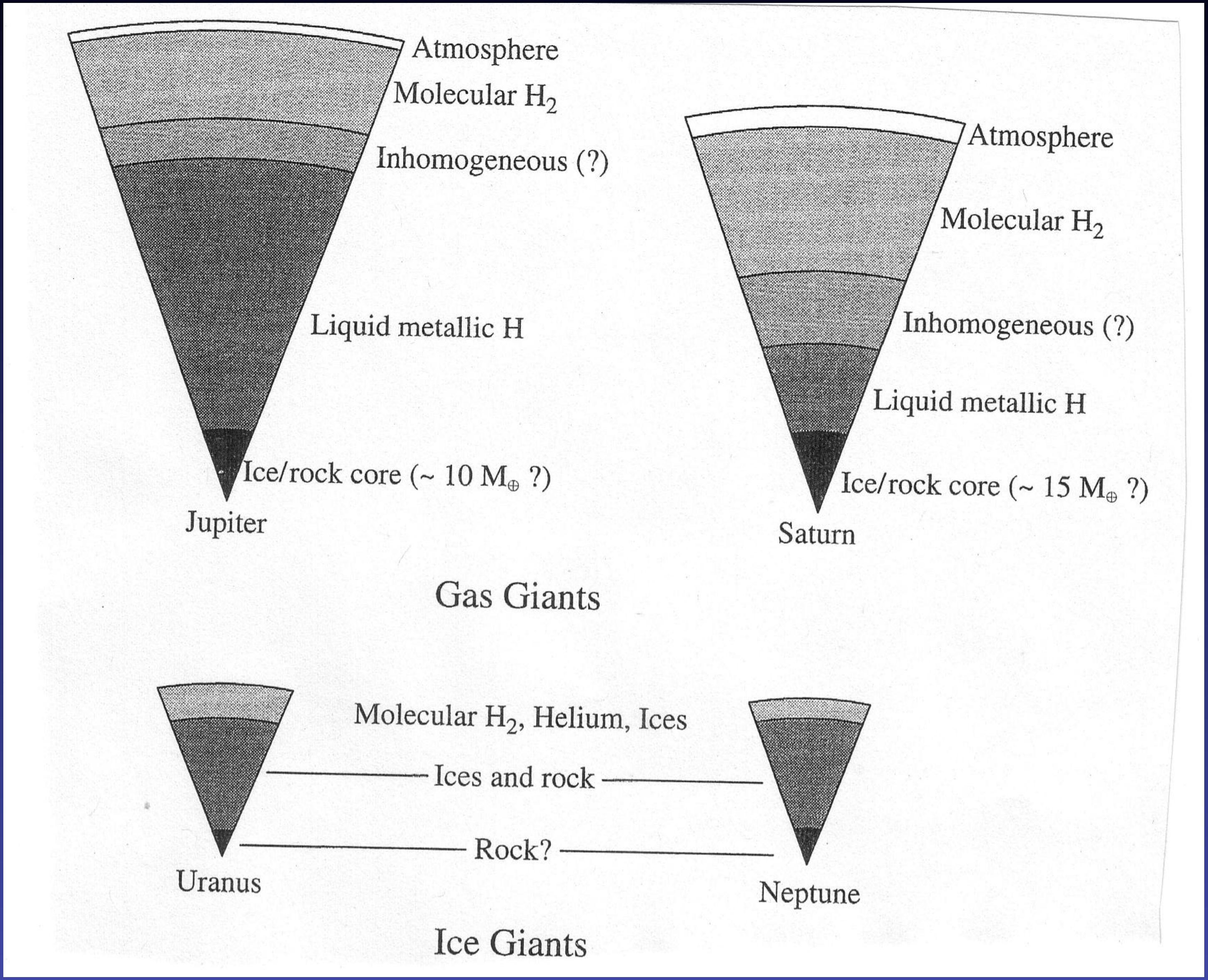
$\langle E \rangle = \langle K \rangle + \langle U \rangle = (1/2) \langle U \rangle = -(3/10)\, GM^2/R$

$$\tau_{\rm cool} = \frac{\text{total energy content}}{\text{energy loss/time}} \propto R^3/R^2 \propto R.$$

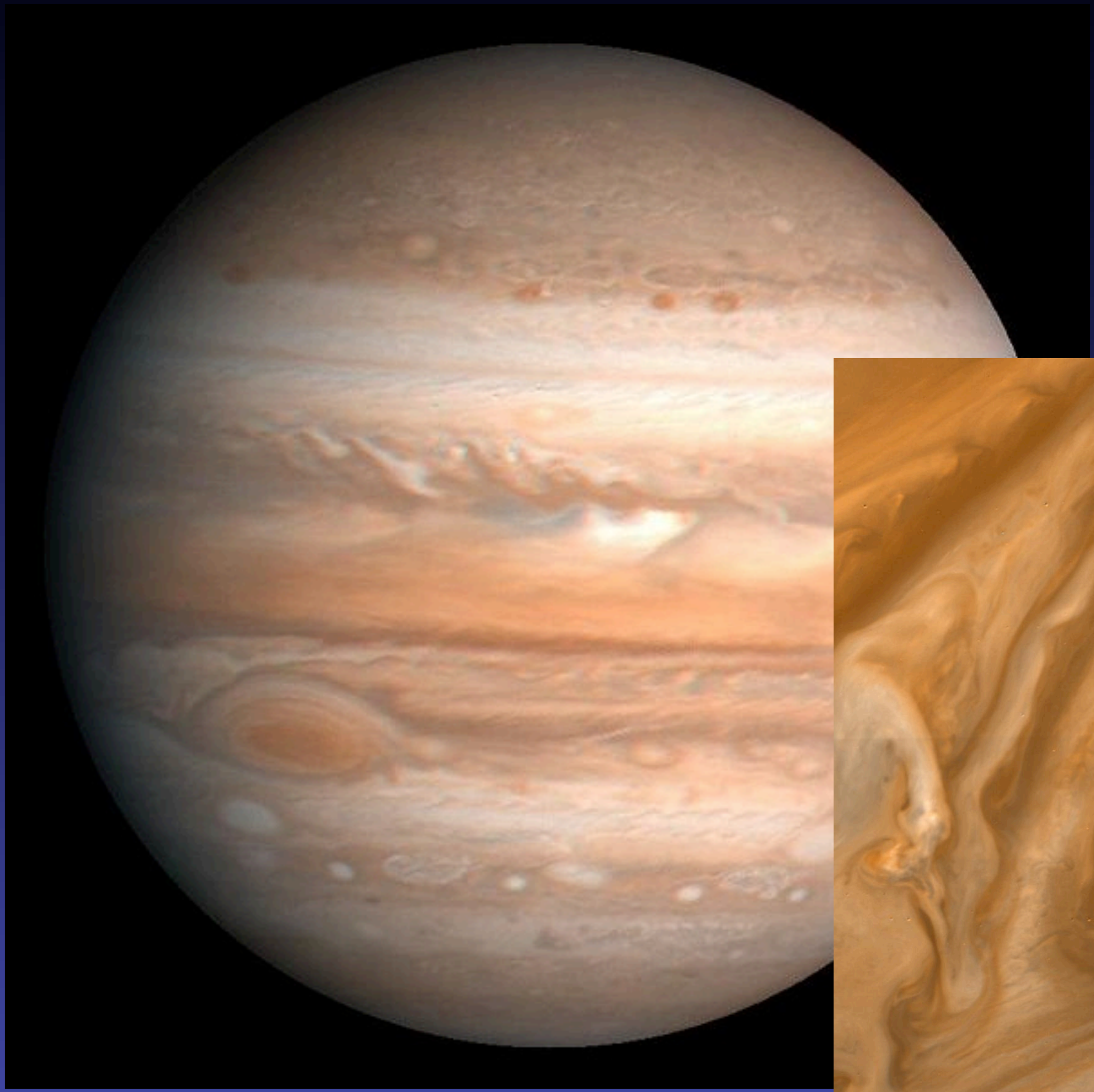
Power or Temperature	Jupiter	Saturn	Uranus	Neptune
Absorbed power (10^{16} W)	50.14 ± 2.48	11.14 ± 0.50	0.526 ± 0.037	0.204 ± 0.019
Total emitted power (10^{16} W)	83.65 ± 0.84	19.77 ± 0.32	0.560 ± 0.011	0.534 ± 0.029
Intrinsic power emitted (10^{16} W)	33.5 ± 2.6	8.63 ± 0.60	0.034 ± 0.038	0.330 ± 0.035
Effective temperature (K)	124.4 ± 0.3	95.0 ± 0.4	59.1 ± 0.3	59.3 ± 0.8

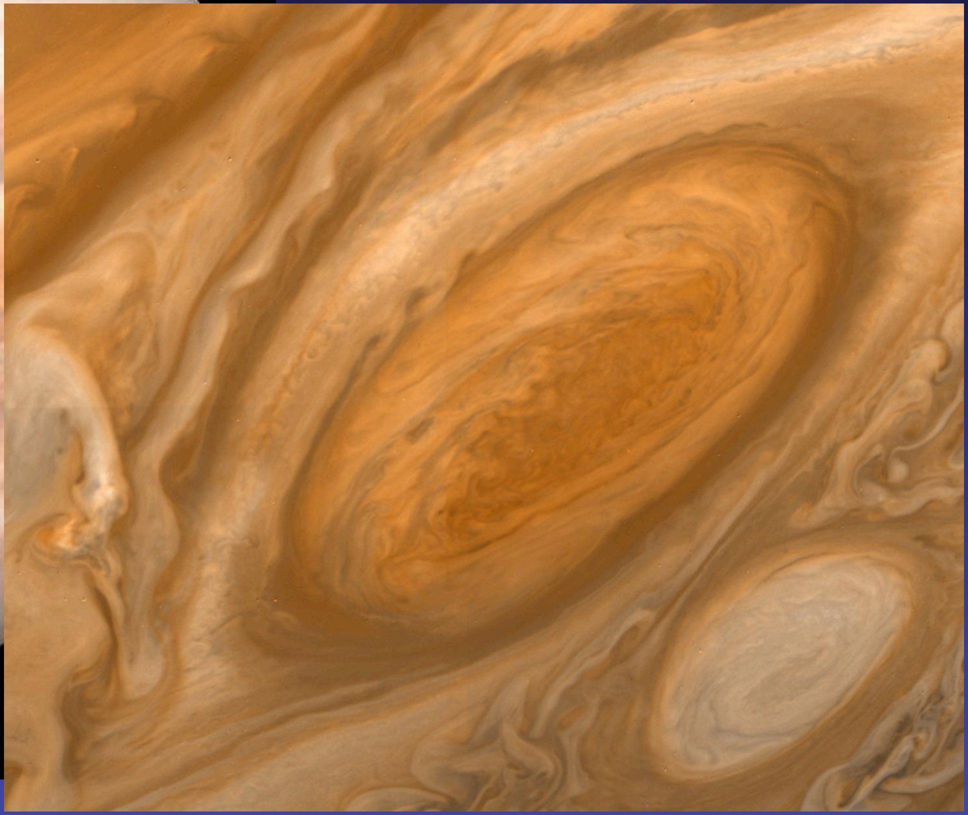
Saturn: He sinks => release energy => low abundance

Liquid mettalic hydrogen in the interior of Jupiter & Saturn
Helium-rich droplets form in the "inhomogeneous (?)" layer.



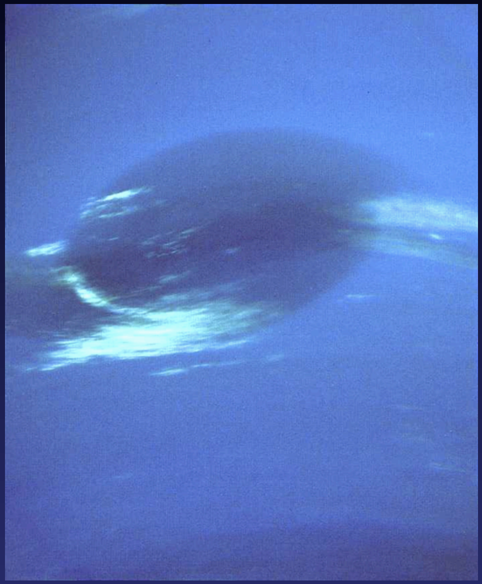
Jupiter’s Great Red Spot

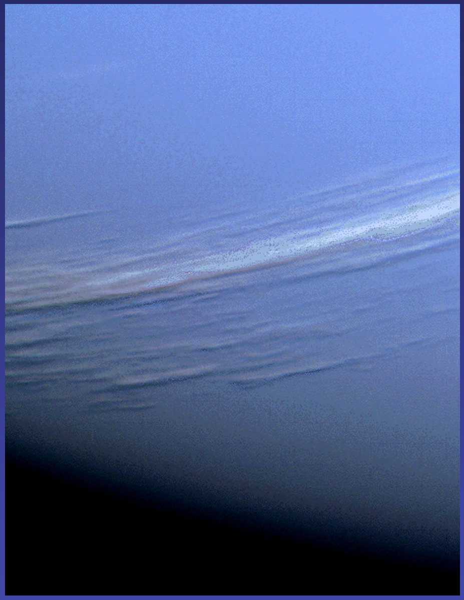


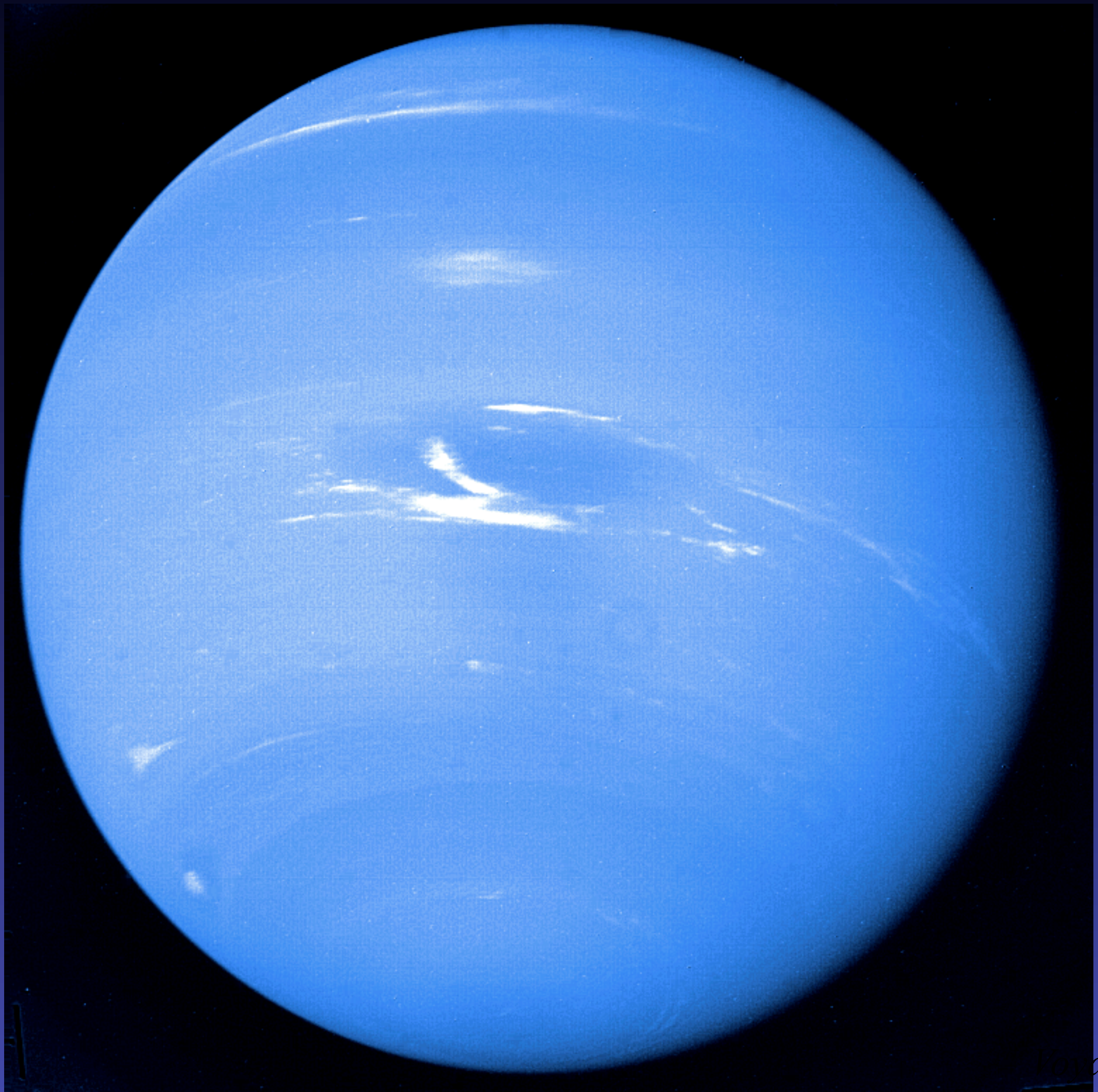


Neptune

Great Dark Spot was seen in 1989, gone in 1994, reappeared in 1995…

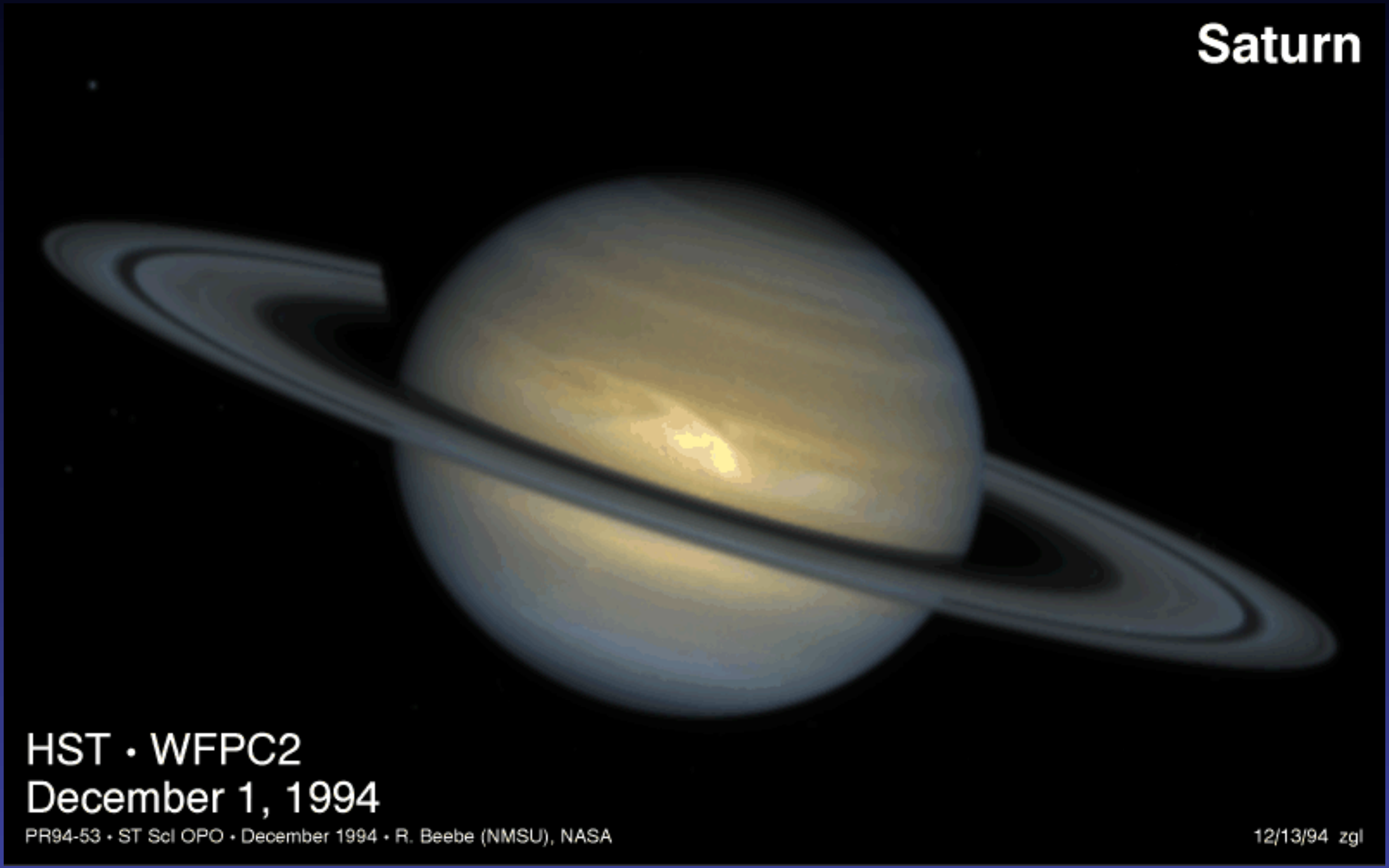






Voyager 2

Saturn's Great White Spot



Appears every 30 years. 1990, 2020, …