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- Sometime in late 1800s: Asteroids are not planets $\Longrightarrow$ 8 planets

What is a planet?

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Summer 2006: International Astronomical Union General Assembly, Prague

$\Longrightarrow$ Resolution GA26/5 and 6:Definition of a planet

$\Longrightarrow$ 8 planets

RESOLUTION 5

Definition of a Planet in the Solar System

Contemporary observations are changing our understanding of planetary systems, and it is important that our nomenclature for objects reflect our current understanding. This applies, in particular, to the designation "planets". The word "planet" originally described "wanderers" that were known only as moving lights in the sky. Recent discoveries lead us to create a new definition, which we can make using currently available scientific information.

The IAU therefore resolves that planets and other bodies, except satellites, in our Solar System be defined into three distinct categories in the following way:

(1) A planet[1] is a celestial body that

(a) is in orbit around the Sun,

(b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and

(c) has cleared the neighbourhood around its orbit.

(2) A "dwarf planet" is a celestial body that

(a) is in orbit around the Sun,

(b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape[2],

(c) has not cleared the neighbourhood around its orbit, and

(d) is not a satellite.

(3) All other objects[3], except satellites, orbiting the Sun shall be referred to collectively as "Small Solar System Bodies".

---

1 The eight planets are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

2. An IAU process will be established to assign borderline objects into either dwarf planet and other categories.

3. These currently include most of the Solar System asteroids, most Trans-Neptunian Objects (TNOs), comets, and other small bodies.

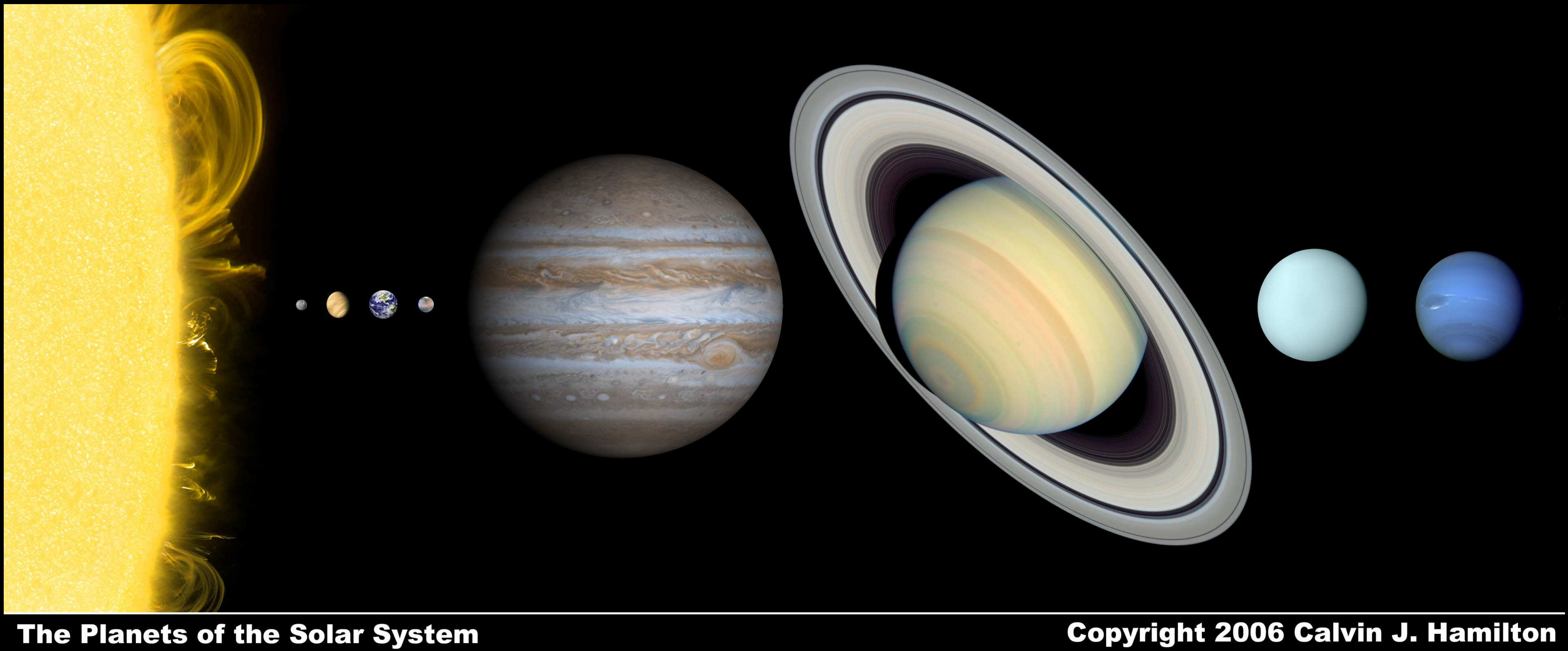
RESOLUTION 6

Pluto

The IAU further resolves:

Pluto is a "dwarf planet" by the above definition and is recognized as the prototype of a new category of Trans-Neptunian Objects[1].

1 An IAU process will be established to select a name for this category.



Relative sizes of the Sun and the planets

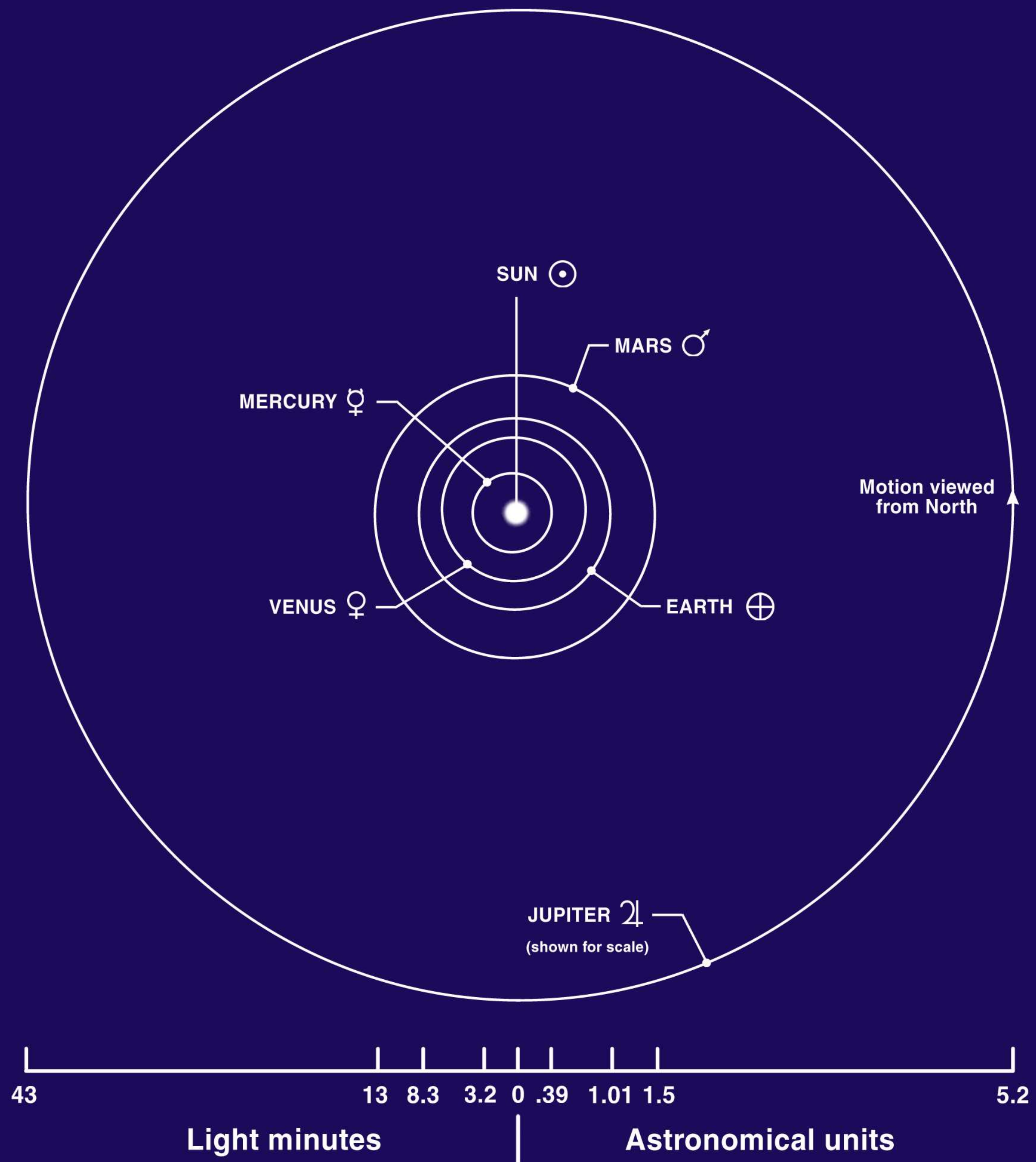
Venus Transit, 2004 June 8

Elio Daniele, Palermo

Overview, I

Division of Solar System into two major types of planets:

1. Inner "Terrestrial" Planets: Mercury, Venus, Earth/Moon, Mars:
   $\Longrightarrow$ all similar to Earth ("rocks").
   $\Longrightarrow$ *no moons* (Earth/Moon better called "twins")



The Inner Planets (SSE, NASA)

Overview, III

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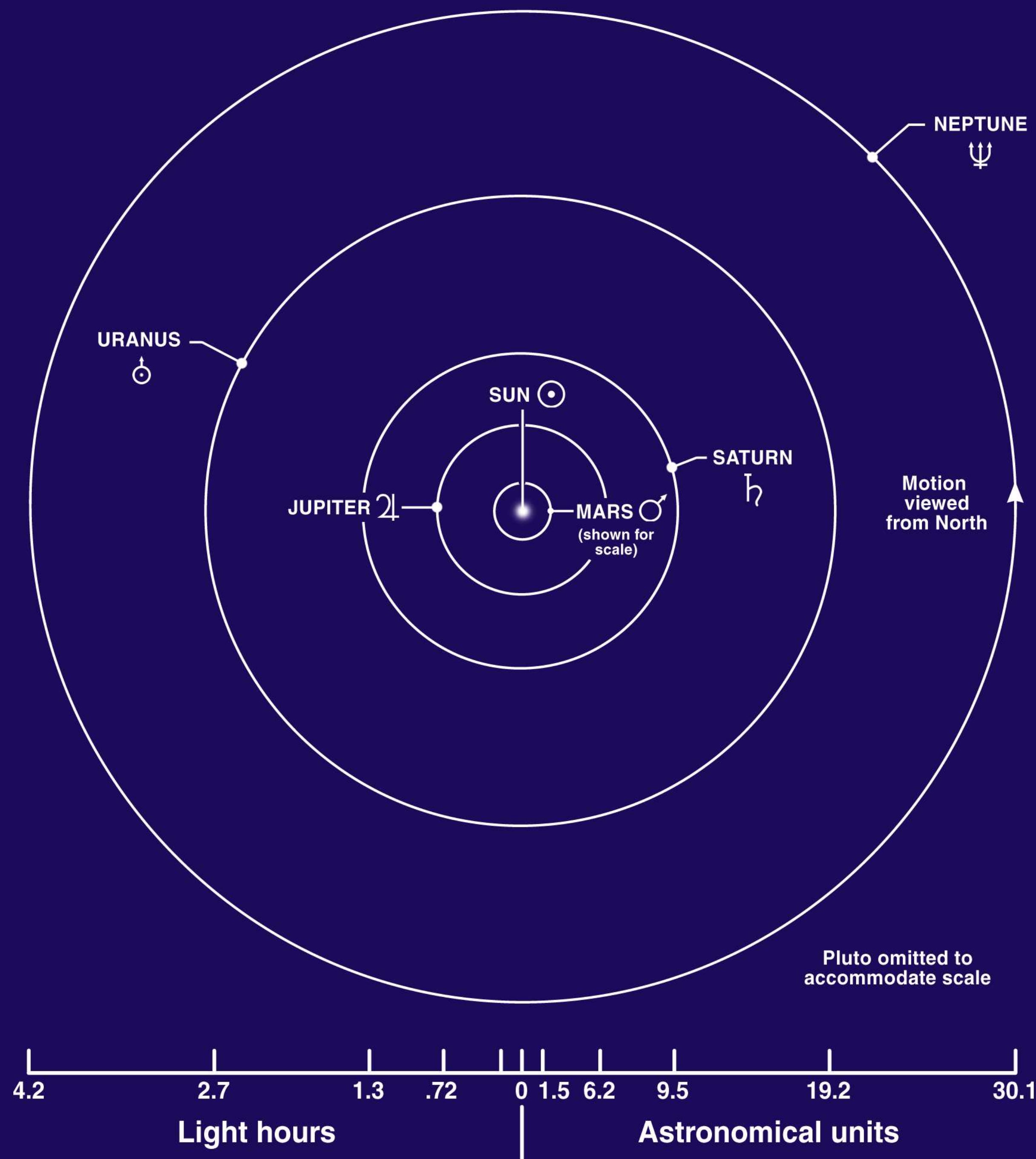
   $\Longrightarrow$ Moons of

2. Outer Planets: Jupiter, Saturn, Uranus, Neptune:
   $\Longrightarrow$ "gas giants"
   $\Longrightarrow$ all have *extensive moon systems*

Although not planets (i.e., motion not around Sun), large moons of gas giants are very similar in structure to terrestrial planets.



The Outer Planets (SSE, NASA)

Planets: Properties, I

		a [AU]	P_{orb} [yr]	i [°]	e	P_{rot}	$M/M_\oplus$	$R/R_\oplus$
Mercury	☿	0.387	0.241	7.00	0.205	58.8 d	0.055	0.383
Venus	♀	0.723	0.615	3.40	0.007	−243.0 d	0.815	0.949
Earth	⊕	1.000	1.000	0.00	0.017	23.9 h	1.000	1.00
Mars	♂	1.52	1.88	1.90	0.094	24.6 h	0.107	0.533
Jupiter	♃	5.20	11.9	1.30	0.049	9.9 h	318	11.2
Saturn	♄	9.58	29.4	2.50	0.057	10.7 h	95.2	9.45
Uranus	⛢	19.2	83.7	0.78	0.046	−17.2 h	14.5	4.01
Neptune	♆	30.1	163.7	1.78	0.011	16.1 h	17.1	3.88
(Pluto	♇	39.2	248	17.2	0.244	6.39 d	0.002	0.19)

After Kutner, Appendix D;

a: semi-major axis; P_{orb}: orbital period; i: orbital inclination (wrt Earth's orbit)
e: eccentricity of the orbit; P_{rot}: rotational period; M: mass
R: equatorial radius
1 AU $= 1.496 \times 10^{11}$ m.

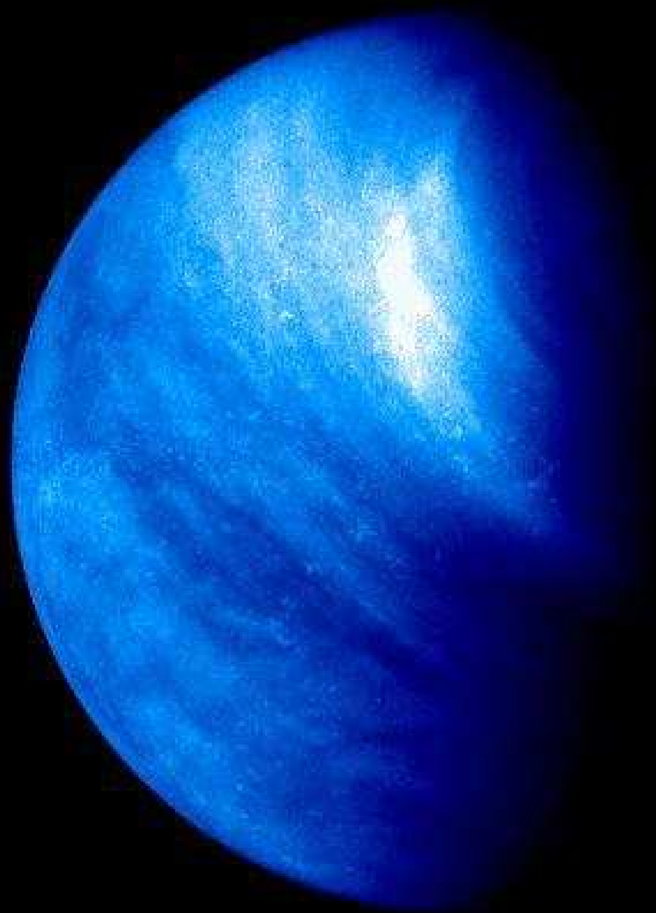

Calvin J. Hamilton

NASA/USGS

Mercury:

- not much larger than Moon
- densest of all terrestrial planets
- no evidence for atmosphere
- Rotation period: 59 d, $2/3$ of orbital period.
- surface: impact craters and tectonics
- Only information available is from Mariner 10 (three flybys, 1974/1975)
- NASA mission "Messenger"

  (launched 2004 August 3, flyby 2008 and 2009, in orbit from 2011 on)
- ESA Mission Bepi Colombo, planned for $\sim$ Aug. 2013, arrival Aug. 2019



ESA/Venus Express

Venus:

- similar size to Earth, similar structure
- insolation $\sim 2\times$ Earth
- very slow rotation (243 d, retrograde; $\Longrightarrow$ no B-field)
- very dense atmosphere: surface pressure $\sim 90\times$ Earth
- atmosphere: 96.5% CO_2, 3.5% N
  $\Longrightarrow$ strong greenhouse effect
  $\Longrightarrow$ surface temperature $\sim 460^\circ$C.
- acid rain (yes, sulphuric acid!)

Information mainly from radar surveying from Earth and from Magellan (1990–1994), plus images from Pioneer Venus Probe (1979). Several landings (Venera, 1975/1981). Currently studied by ESA's Venus Express probe (launch April 2005, arrival April 2006).

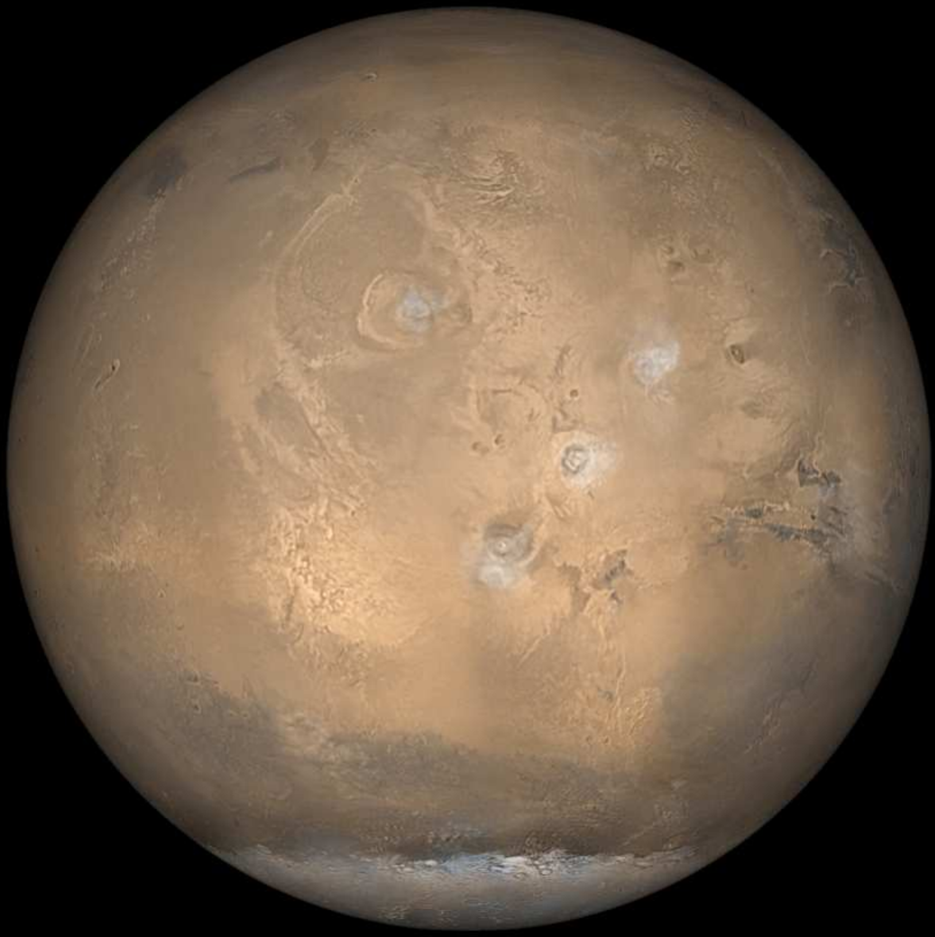
Earth/Moon, seen from Mars (NASA/Malin)

Earth:

- double planet system
- Earth surface: *dominated by plate tectonics, erosion*
- atmosphere: 80% N_2, 20%O_2
  $\Longrightarrow$ moderate greenhouse effect
  $\Longrightarrow$ surface temperature $>0^\circ$C.
- water present

Moon:

- very similar to Mercury, overall
- Mariae (plains from massive impacts) and impact craters
- Rotation synchronous to orbit around Earth

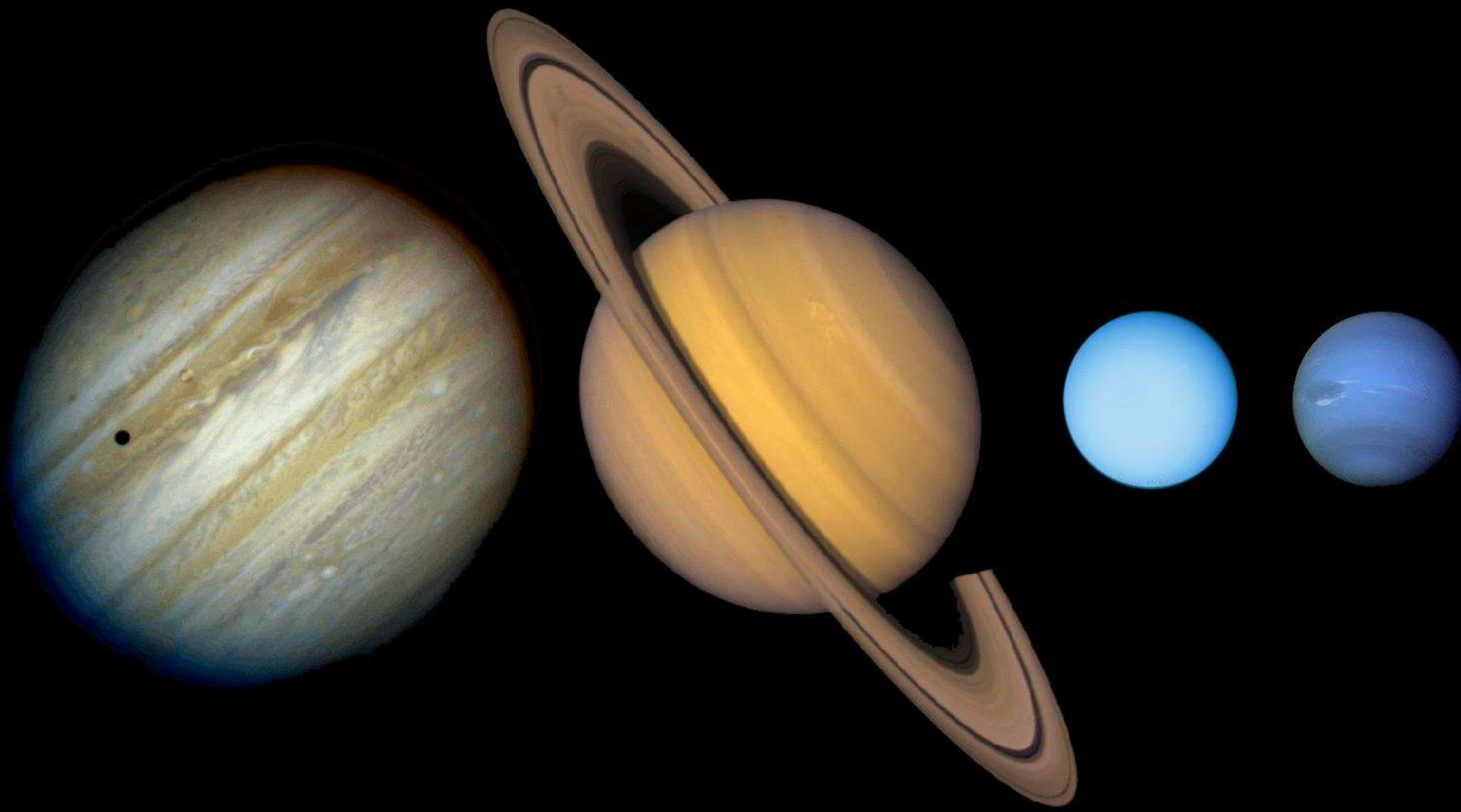


NASA, Mars Global Surveyor

Mars:

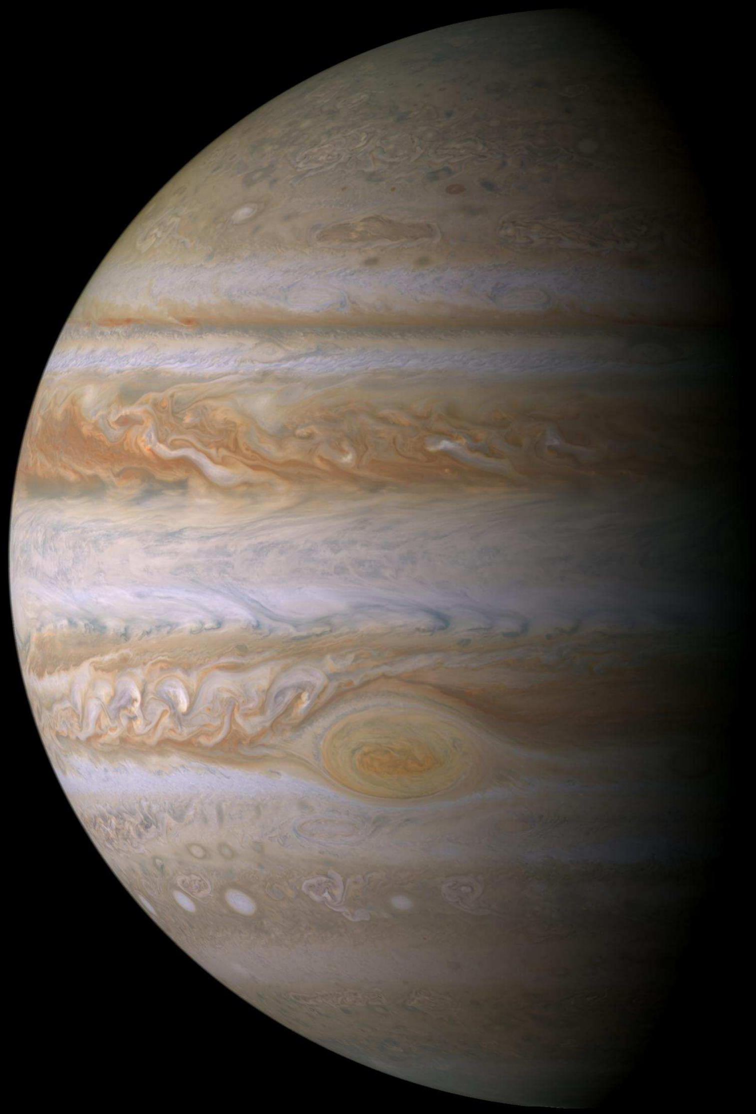
- smaller than Earth
- very low density ($\langle\rho\rangle \sim 3\,\mathrm{g\,cm^{-3}}$)
  $\Longrightarrow$ small core, probably Fe and Fe_xS_y,
- polar caps, seasons
- thin atmosphere, clouds, fog,...
- water sublimes
  $\Longrightarrow$ no liquid water today
- Volcanism (large shield volcanoes
  $\Longrightarrow$ no (?) plate tectonics)
- atmosphere: 95% CO_2
  $\Longrightarrow$ weak greenhouse effect
- two moons (captured asteroids)

Early Exploration through Mariner missions and Viking 1 and Viking 2 orbiters and landers in 1970s, recently, strong interest (NASA Mars Global Surveyor [MGS], ESA Mars Express, plus several landers). Currently best surveyed planet except for Earth.



The jovian planets, ⓒC.J. Hamilton

Jupiter:



NASA/ESA, Cassini-Huyghens

- Largest planet in solar system
- rapid rotation $\Longrightarrow$ severely flattened, banded atmosphere (Coriolis force), Great Red Spot
- strong magnetic field (strong radio emission)
- atmosphere: 75% H, 24% He (by mass), very close to solar
- differential rotation (rotation period 9h50m on equator, 9h55m on poles).
- strong magnetic field
- four major "Galilean" moons plus 59 small ones (as of Jan. 2005; all are captured asteroids)

Early Exploration 1970s through Pioneer 11 and 12, and then through the Voyager probes. Extensively studied by NASA's Galileo project (ended 2003 Sep 14).

NASA/ESA Cassini, 2004 Oct.

Saturn:

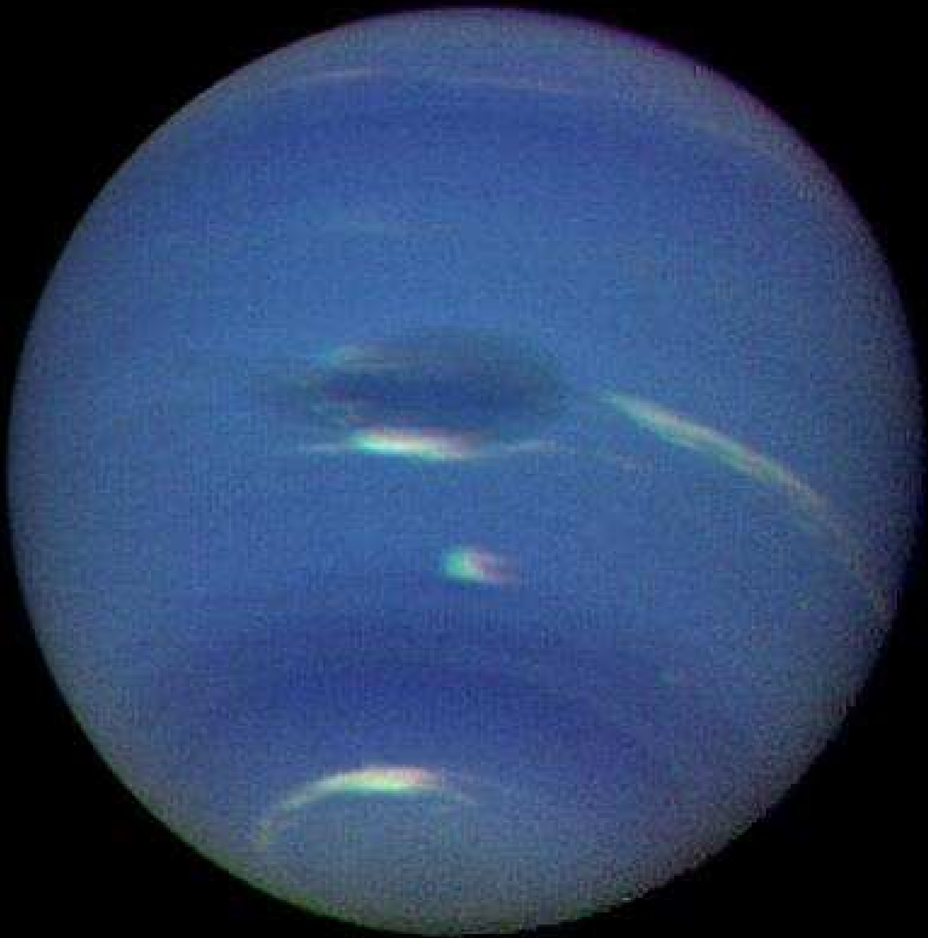
- similar to Jupiter, slightly smaller
- rapid rotation $\Longrightarrow$ flattened, banded atmosphere
- atmosphere: 75% H, 24% He (by mass), molecules etc. similar to Jupiter
- Rings!
- six major moons plus 27 small ones (as of Jan. 2005; mainly captured asteroids)
- Early Exploration in 1970s with Pioneer 11 and 12 and the Voyager probes. Studied since 2004 July 1 by NASA/ESA Cassini-Huygens project (duration: four years)

NASA Voyager 2, 1986 Jan 10

Uranus:

- atmosphere cold (59 K = -214°C)
  $\Longrightarrow$ ammonia has frozen out
- methane, hydrogen, and helium detected so far (less He than expected from Jupiter and Saturn!)
  $\Longrightarrow$ bluish color
- inclination of rotation axis: 98° ("rolling on ecliptic plane").
- small ring system
- five major moons in equatorial plane plus 22 small ones (as of Jan. 2004; captured asteroids)

Flyby of Voyager 2 in 1986 January, since then only remote sensing via Hubble Space Telescope (HST) and ground based instruments.



NASA Voyager 2

Neptune:

- atmosphere similar to Uranus, but more active; bright methane clouds above general cloud layer
- ring system (5 individual rings)
- Two major moons (Triton, 2720 km diameter(!) and Nereid 355 km), 11 captured asteroids

Flyby in 1989 August by Voyager 2, only HST since then (showed in 1995 that dark spot has vanished, detected new storm system)

Structure

Questions that we will deal with:

1. How do the planets move?

   Kepler's laws and their physical interpretation

2. What do planetary surfaces look like?

   craters, plate tectonics, volcanism

3. How do planetary atmospheres work?

   hydrostatic structure

4. What is the internal structure of the planets?

   hydrostatic structure (again)

5. Is the solar system normal?

   Are there planets elsewhere?

The Planets: Dynamics