The Planets: Overview

What is a planet?, I

First, need to look at the definition of a planet.

Historical background:

- antiquity–1781: 6 planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn

What is a planet?, II

First, need to look at the definition of a planet.

Historical background:

- antiquity–1781: 6 planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn
- 1781: Wilhelm Herschel discovers Uranus $\Longrightarrow$ 7 planets

What is a planet?, III

First, need to look at the definition of a planet.

Historical background:

- antiquity–1781: 6 planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn
- 1781: Wilhelm Herschel discovers Uranus $\Longrightarrow$ 7 planets
- 1801: Giuseppe Piazzi: Ceres $\Longrightarrow$ 8 planets

What is a planet?, IV

First, need to look at the definition of a planet.

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- 1801: Giuseppe Piazzi: Ceres $\Longrightarrow$ 8 planets
- 1802: Heinrich Olbers: Pallas $\Longrightarrow$ 9 planets, Herschel coins term “asteroid”.

What is a planet?, V

First, need to look at the definition of a planet.

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- 1804: Karl Harding: Juno $\Longrightarrow$ 10 planets

What is a planet?, VI

First, need to look at the definition of a planet.

Historical background:

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- 1801: Giuseppe Piazzi: Ceres $\Longrightarrow$ 8 planets
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- 1804: Karl Harding: Juno $\Longrightarrow$ 10 planets
- 1807: Heinrich Olbers: Vesta $\Longrightarrow$ 11 planets

What is a planet?, VII

First, need to look at the definition of a planet.

Historical background:

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- 1804: Karl Harding: Juno $\Longrightarrow$ 10 planets
- 1807: Heinrich Olbers: Vesta $\Longrightarrow$ 11 planets
- 1845: Karl Hencke: Astrea $\Longrightarrow$ 12 planets

What is a planet?, VIII

First, need to look at the definition of a planet.

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- 1781: Wilhelm Herschel discovers Uranus $\Longrightarrow$ 7 planets
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- 1807: Heinrich Olbers: Vesta $\Longrightarrow$ 11 planets
- 1845: Karl Hencke: Astrea $\Longrightarrow$ 12 planets
- 1846: Johann Gottfried Galle discovers Neptune $\Longrightarrow$ 13 planets

What is a planet?, IX

First, need to look at the definition of a planet.

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- 1781: Wilhelm Herschel discovers Uranus $\Longrightarrow$ 7 planets
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- 1846: Johann Gottfried Galle discovers Neptune $\Longrightarrow$ 13 planets
- 1847: Karl Hencke: Hebe $\Longrightarrow$ 14 planets

What is a planet?, X

First, need to look at the definition of a planet.

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- 1846: Johann Gottfried Galle discovers Neptune $\Longrightarrow$ 13 planets
- 1847: Karl Hencke: Hebe $\Longrightarrow$ 14 planets
- 1848: Andrew Graham: Metis $\Longrightarrow$ 15 planets

What is a planet?, XI

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- 1847: Karl Hencke: Hebe $\Longrightarrow$ 14 planets
- 1848: Andrew Graham: Metis $\Longrightarrow$ 15 planets
- 1849: Annibale de Gasparis: Hygiea $\Longrightarrow$ 16 planets

What is a planet?, XII

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- 1781: Wilhelm Herschel discovers Uranus $\Longrightarrow$ 7 planets
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- 1848: Andrew Graham: Metis $\Longrightarrow$ 15 planets
- 1849: Annibale de Gasparis: Hygiea $\Longrightarrow$ 16 planets
- 1849: Annibale de Gasparis: Parthenope $\Longrightarrow$ 17 planets

What is a planet?, XIII

First, need to look at the definition of a planet.

Historical background:

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- 1781: Wilhelm Herschel discovers Uranus $\Longrightarrow$ 7 planets
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- 1848: Andrew Graham: Metis $\Longrightarrow$ 15 planets
- 1849: Annibale de Gasparis: Hygiea $\Longrightarrow$ 16 planets
- 1849: Annibale de Gasparis: Parthenope $\Longrightarrow$ 17 planets
- Sometime in late 1800s: Asteroids are not planets $\Longrightarrow$ 8 planets

What is a planet?, XIV

- 1930: Clyde Tombaugh: Pluto ($d = 2400\,\text{km}$) $\Longrightarrow$ 9 planets

What is a planet?, XV

- 1930: Clyde Tombaugh: Pluto ($d = 2400\,\text{km}$) $\Longrightarrow$ 9 planets
- 2002: Chad Trujillo & Michael Brown 50000 Quaoar ($d \sim 1300\,\text{km}$)

What is a planet?, XVI

- 1930: Clyde Tombaugh: Pluto ($d = 2400$ km) $\Longrightarrow$ 9 planets
- 2002: Chad Trujillo & Michael Brown 50000 Quaoar ($d \sim 1300$ km)
- 2003: Brown et al.: 90377 Sedna (1200 km $\lesssim d \lesssim$ 1800 km)

What is a planet?, XVII

- 1930: Clyde Tombaugh: Pluto ($d = 2400$ km) $\Longrightarrow$ 9 planets
- 2002: Chad Trujillo & Michael Brown 50000 Quaoar ($d \sim 1300$ km)
- 2003: Brown et al.: 90377 Sedna (1200 km $\lesssim d \lesssim$ 1800 km)
- 2005: Brown et al.: 2003 UB313 (aka "Xena") ($d \sim 2400$ km)
  $\Longrightarrow$ 136199 Eris
  $\Longrightarrow$ 10 planets ?!?

What is a planet?, XVIII

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- BUT: High frequency of discovering transneptunian objects

What is a planet?, XIX

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  $\Longrightarrow$ 136199 Eris
  $\Longrightarrow$ 10 planets ?!?
- BUT: High frequency of discovering transneptunian objects

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.

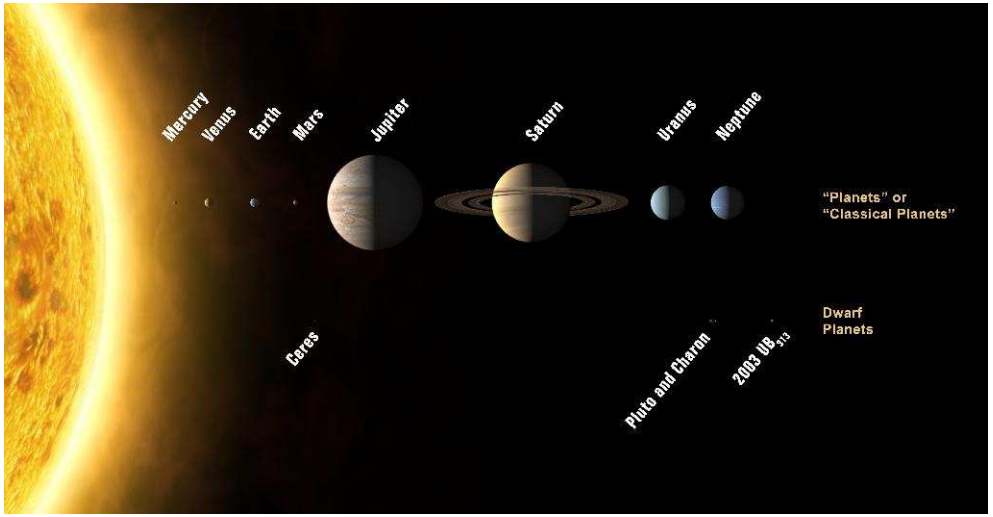
The IAU therefore resolves that planets and other bodies, except satellites, in our Solar System be defined into three distinct categories in the following way:

(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.



8 Planets and 3 dwarf planets IAU0603

RESOLUTION 6

Pluto

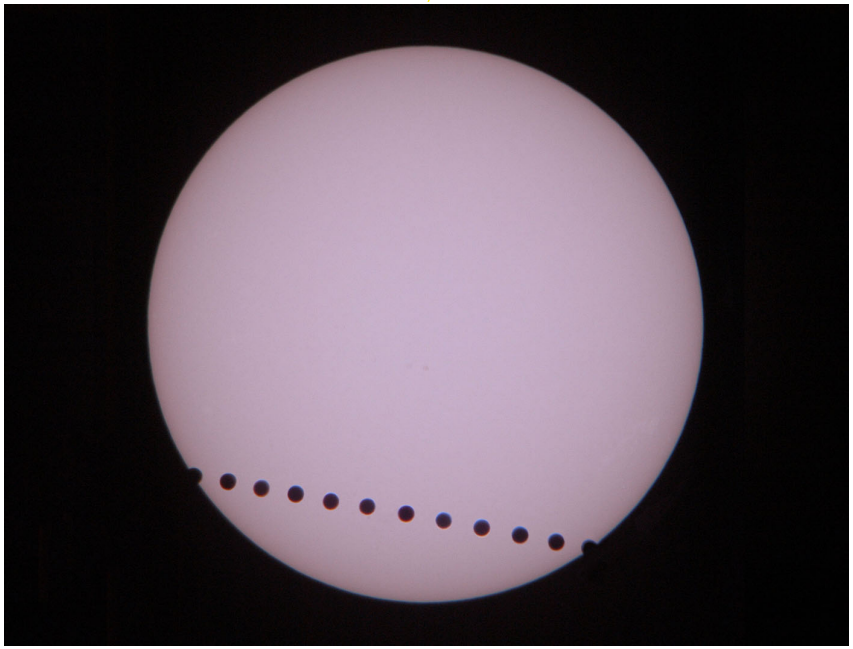
The IAU further resolves:

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

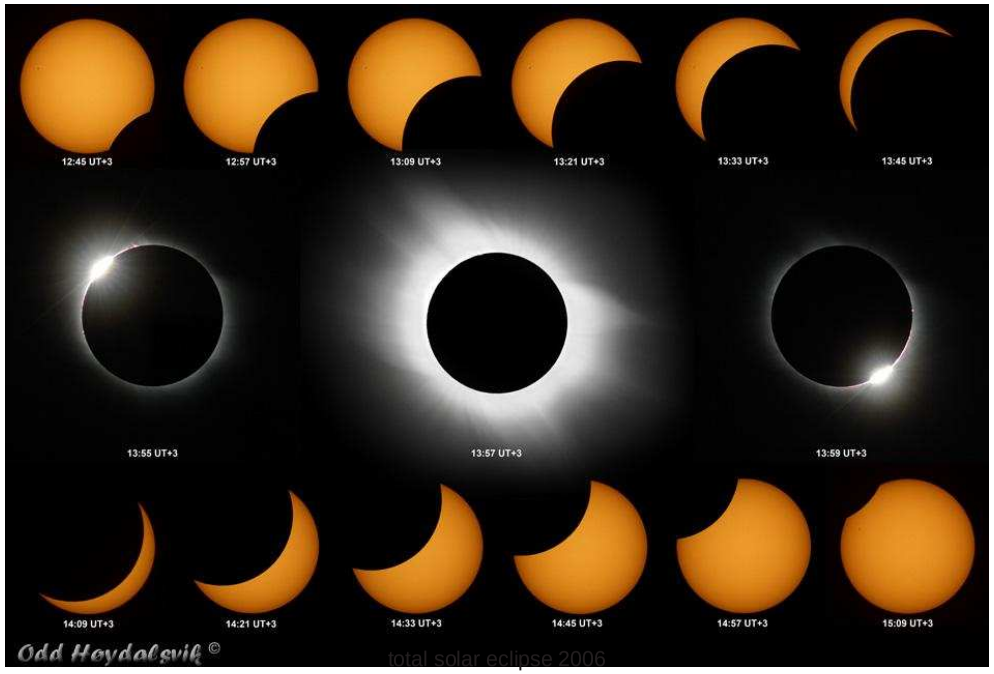
1 An IAU process will be established to select a name for this category.

3–3

Venus Transit, 2004 June 8



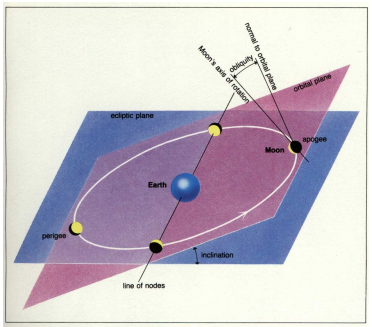
Elio Daniele, Palermo



total solar eclipse 2006

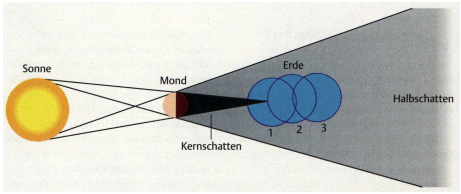
Moon and Sun have very similar apparent diameters: Eclipses

Eclipses

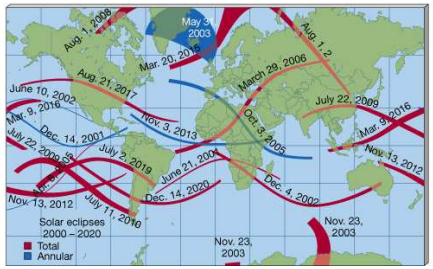


- Ecliptic: orbital plane of the Earth around the Sun.
- orbital plane of the moon inclined wrt. ecliptic by $i = 5^\circ$
- line of nodes: intersection of the two orbital planes
- eclipses occur only when Moon is close to one of the nodes
  $\Longrightarrow$ two eclipse seasons per year

Eclipses



moon's orbit is elliptical:
$\Longrightarrow$ distance varies:
1,2: total solar eclipse
3: annular solar eclipse

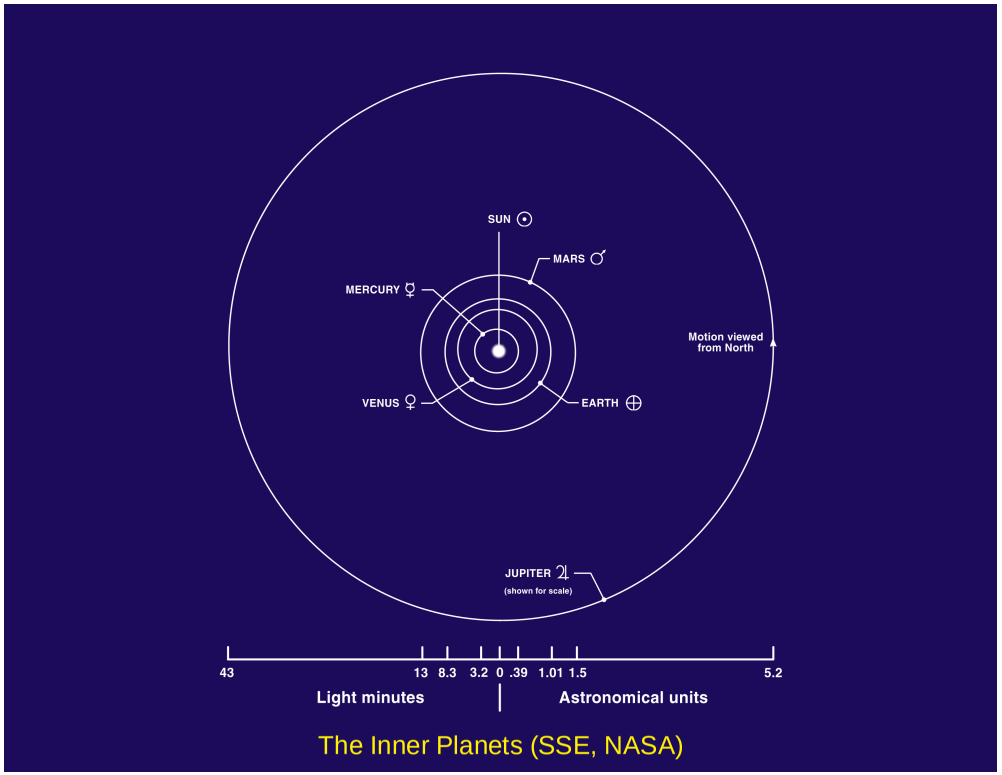


shadow hits only small parts of the earth

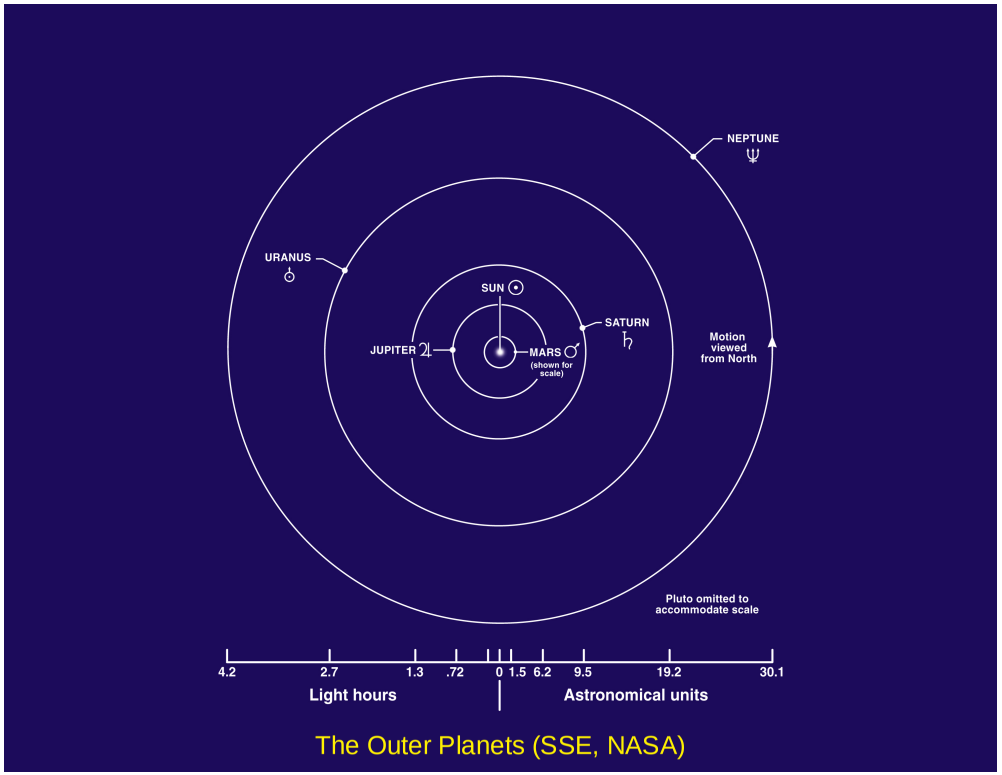
Overview, I

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)



The Outer Planets (SSE, NASA)

Overview, III

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

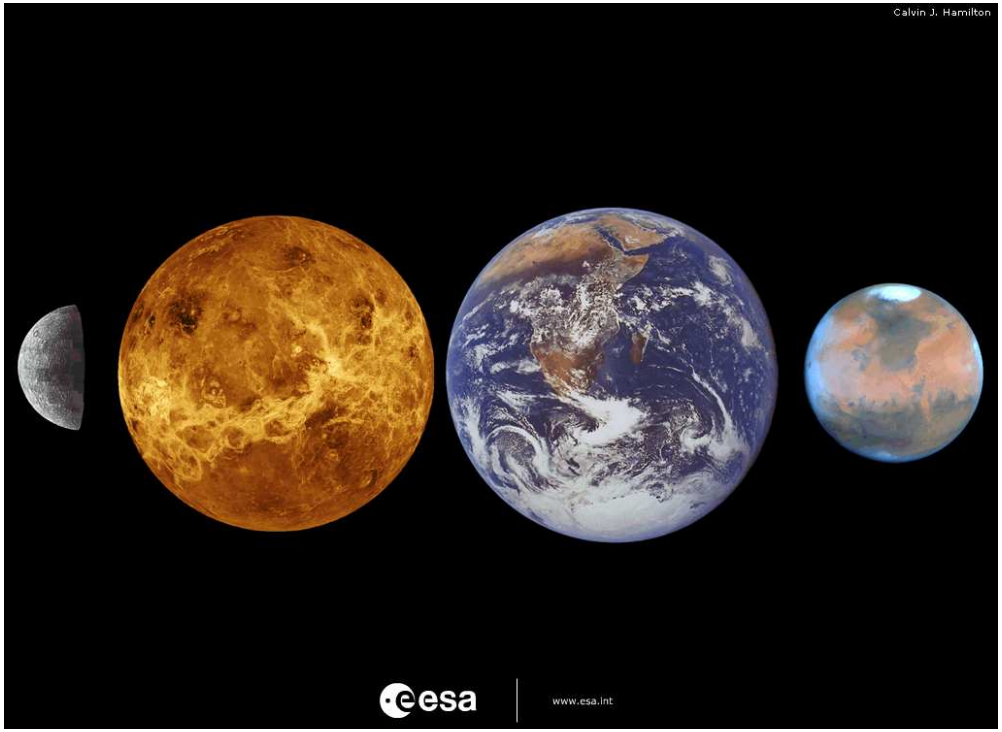
Although not planets (i.e., motion not around Sun), large moons of gas giants are very similar in structure to terrestrial planets.

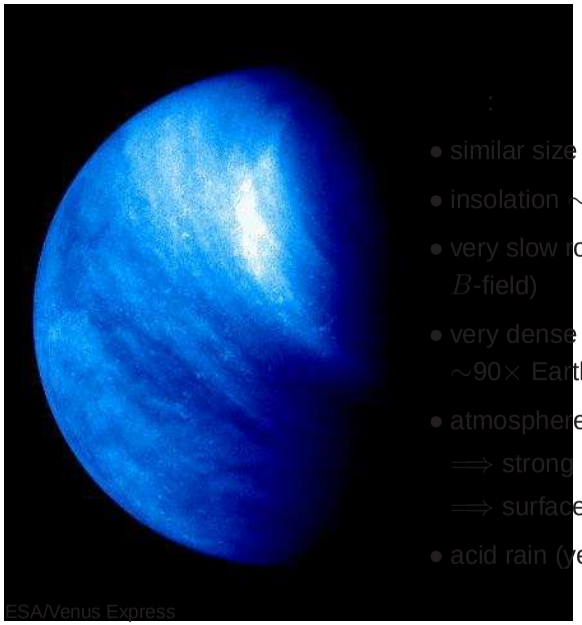
Planets: Properties, I

		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.

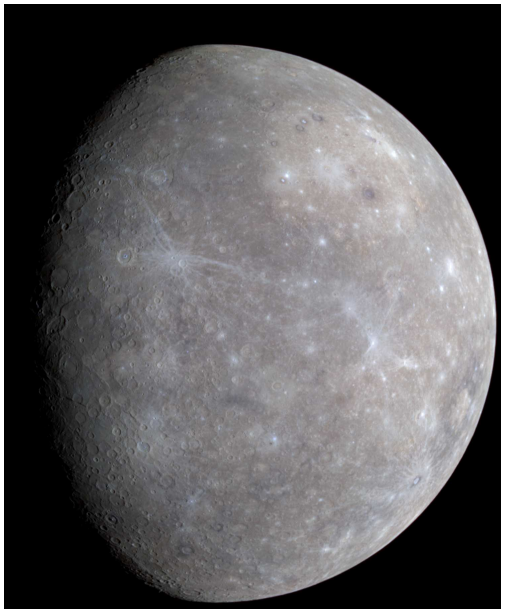




Venus:

- 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, mission until mid-2009).



NASA/MESSENGER, 2008 Jan

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
- Early information available from Mariner 10 (three flybys, 1974/1975)
- NASA mission "Messenger"
  (launched 2004 August 3, flybys 2008 and 2009, in orbit from 2011 on)
- ESA Mission Bepi Colombo, planned for $\sim$ Aug. 2013, arrival Aug. 2019

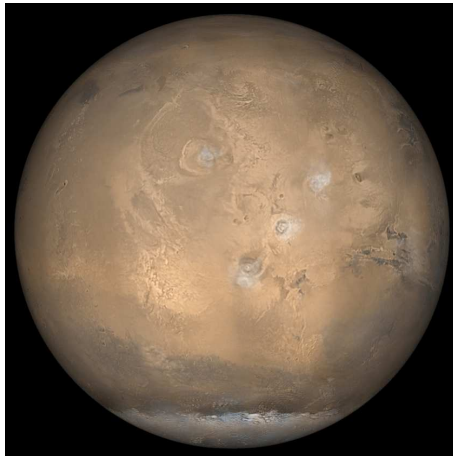
Earth/Moon, seen from Mars (NASA/Malin)

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

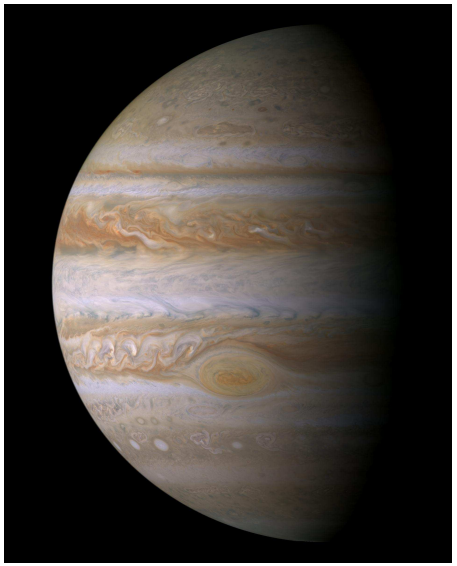


NASA, Mars Global Surveyor

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.

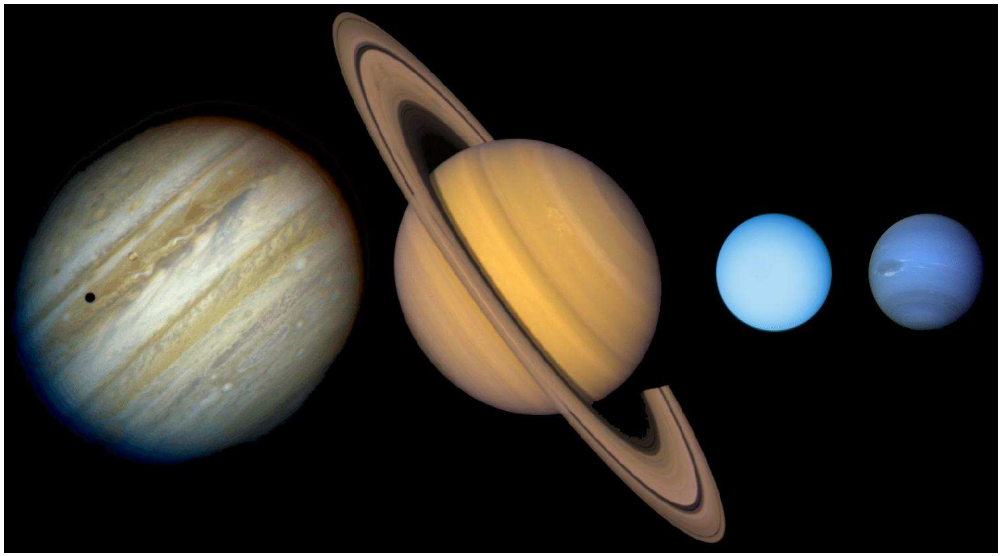


NASA/ESA, Cassini-Huyghens

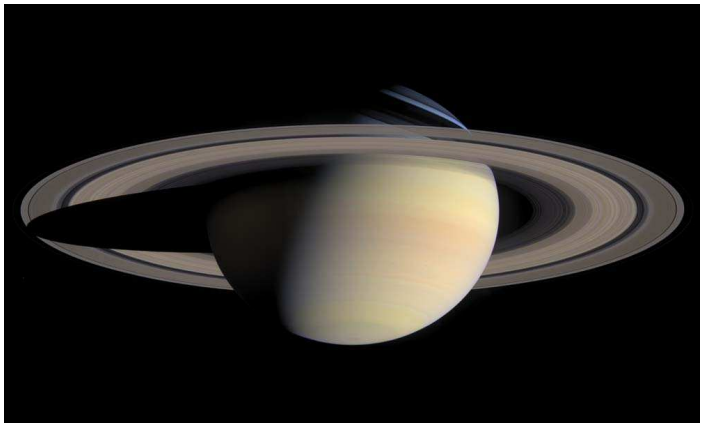
Jupiter:

- 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 9 h 50 m at equator, 9 h 55 m at poles)
- strong magnetic field
- four major “Galilean” moons plus 59 small ones (as of 2008 Oct; captured asteroids)

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



The jovian planets, ©C.J. Hamilton



NASA/ESA Cassini, 2004 Oct.

Saturn:

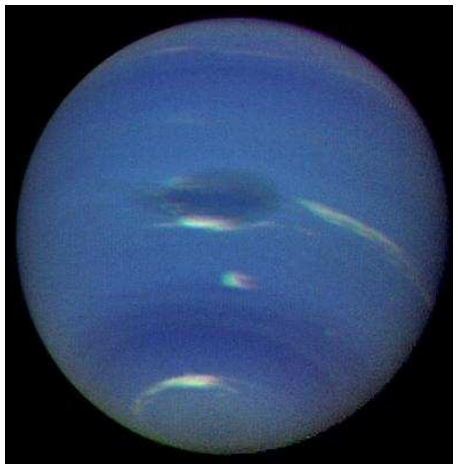
- similar to Jupiter, slightly smaller
- rapid rotation $\Longrightarrow$ flattened, banded atmosphere
- atmosphere: 75% H, 24% He (by mass), molecules etc. similar to Jupiter
- Rings!
- six major moons plus 54 small ones (as of Oct 2008; mainly captured asteroids)
- Early Exploration in 1970s with Pioneer 11 and 12 and the Voyager probes.
  Studied since 2004 July 1 by NASA/ESA Cassini-Huygens project (duration until 2010)

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 Oct 2008; captured asteroids)

Flyby of Voyager 2 in 1986 January, since then only remote sensing from 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. What do planetary surfaces look like?
   craters, plate tectonics, volcanism
2. What is the internal structure of the planets?
   hydrostatic structure
3. How do planetary atmospheres work?
   hydrostatic structure (again)
4. How do the planets move?
   Kepler's laws and their physical interpretation
5. Is the solar system normal?
   Are there planets elsewhere? (Later in the class)