



**Fig. 1.** (see color-picture part, page 617) The eight planets Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune are shown with their correct relative sizes (the distances are not to scale). The compilation also includes the dwarf planet Pluto and its moon Charon. The dark spot on Jupiter is the shadow of Io, one of the four Galilean Moons. ©C.J. Hamilton

## 4.2 The planets and their satellites

### 4.2.1 Introduction

TILMAN SPOHN

Humanity has always been fascinated with the wandering stars in the sky, the planets. Ancient astrologists have observed and used the paths of the planets in the sky to time the seasons and to predict the future. Observations of the planets helped Johannes Kepler to formulate his laws of planetary motion and revolutionize the perception of the world. Explaining the anomalous perihelion precession of the orbit of Mercury was among the first successes of Albert Einstein's theory of general relativity that again revolutionized our understanding of the world. The future detection of habitable planets around other stars may motivate another revolution of our thinking.

With the advent of the space age, the planets have been transferred from bright spots in the sky to worlds of their own right that can be explored *in-situ* and using remote sensing tools. The terrestrial planets are of particular interest to the geoscientist because comparison with our own planet allows a better understanding of our home, the Earth. Venus offers an example of a runaway greenhouse that has resulted in what we would call a hellish place. With temperatures of around 450 °C and a corrosive atmosphere that is also optically non-transparent, Venus poses enormous difficulties to spacecraft exploration. Mars is a much friendlier planet to explore but a planet where greenhouse effects and atmospheric loss processes have resulted in a cold and dusty desert. But aside from considerations of the usefulness of space exploration in terms of understanding Earth, the interested mind can visit astounding and puzzling places. There is the dynamic atmosphere of Jupiter with a giant thunderstorm that has been raging for centuries. There is Saturn with its majestic rings and there are Uranus and Neptune with complicated magnetic fields. These giant planets have moons that are astounding. There is the volcanic satellite of Jupiter, Io that surpasses the Earth and any other terrestrial planet in volcanic activity and surface heat flow. This activity is powered by tides that twist the planet such that its interior partially melts. A much smaller moon of Saturn, Enceladus, also has geysers that could be powered by tidal

heating. Its volcanic activity releases water vapor not lava. There is another moon of Saturn, Titan, that hides its surface underneath a layer of photochemical smog in a thick nitrogen atmosphere and there are moons of similar sizes that lack any comparable atmosphere. Miranda, a satellite of Uranus, appears as if it had been ripped apart and later reassembled. And Triton, a satellite of Neptune, has geysers of nitrogen powered by solar radiation. Magnetic field data suggest that icy moons orbiting the giant planets may have oceans underneath thick ice covers. These oceans can, at least in principle, harbor or have harbored life. Moreover, there are asteroids with moons and comets that may still harbor the clues to how the Solar System and life on Earth formed.

In the following chapters, we will present basic data about the Solar System and briefly summarize the results of space exploration, laboratory measurements and theoretical work. Although we aim at providing a broad overview we will certainly miss valuable aspects and our approach will be biased by our view of the Solar System as geoscientists. We will start with a brief overview and a definition of a planet. Section 4.2.2 will introduce basic data. Section 4.2.3 will present the terrestrial planets. The following section 4.2.4 is devoted to the giant planets while section 4.2.6 collects data of successful missions to date.

#### 4.2.1.1 Structure and dimension of the Solar System

The Solar System contains a myriad of bodies ranging in size from the Sun to miniscule dust particles. The Encyclopedias of Planetary Sciences [97Shi] and the Solar System [99Wei] and the Planetary Companion [98Lod] are useful sources of information about the Solar System. A collection of recent reviews in planetary science can be found in [07Spo]. Valuable collections of planetary data can also be found on <http://ssd.jpl.nasa.gov> and on <http://nssdc.gsfc.nasa.gov>. A collection of images of planetary surfaces can be found in the NASA photo journal on <http://photojournal.nasa.gov>.

The Sun, a middle-aged main sequence star, contains 98.8% of the mass of the Solar System but only 0.5% of its angular momentum. The next smaller body, Jupiter, still 300 times more massive than Earth (see Table 1, section 4.2.2.2), contains more than 60% of the mass of the rest. Jupiter is the biggest of the *giant planets*, a group of gaseous planets that constitute a major subgroup of the Solar System. The giant planets are – in addition to Jupiter – Saturn, Uranus, and Neptune. The latter two are sometimes called the sub-giants or the ice giants because they are notably smaller than Saturn and Jupiter and because they mostly consist of water, methane and ammonia, components often collectively called the planetary ices. Earth, the biggest member of the other major subgroup of family members, the *terrestrial planets*, is the only planet on which we know to date that life had a chance to develop. The members of this group are: Mercury, the innermost planet, Venus, Earth's twin with respect to size and mass, Earth and Mars. The latter planet has the best chance of having developed some primitive forms of life, which makes it the prime target of present day space missions. The terrestrial planets together have about 0.005% of the mass of the Solar System. In addition to the planets the Solar System has five dwarf planets (Ceres, Pluto, Eris, Makemake, and Haumea; see definition in 4.2.1.2) and 169 moons (as of Feb. 2008) and a large number of small bodies including comet nuclei.

The terrestrial planets occupy the inner Solar System between 0.3871 AU, the orbit of Mercury and 1.524 AU, the orbit of Mars (an astronomical unit is equivalent to the length of the semi-major axis of the Earth's orbit,  $1.4959 \times 10^8$  km). Beyond the inner Solar System is the asteroid belt stretching from 2.3 AU to 3.3 AU. The asteroid belt contains approximately 400,000 asteroids, the biggest being Ceres, Pallas and Vesta. Its members are speculated to be the parent bodies of most meteorites (stones from space found on Earth's surface). The outer Solar System stretches beyond the asteroid belt and contains the giant Planets Jupiter and Saturn and the sub-giants Uranus and Neptune. Beyond the orbit of Neptune there is the Kuiper belt and finally the hypothetical Oort cloud. The Kuiper Belt stretches between 30 AU (roughly the orbit of Neptune) to at least 50 AU and contains Pluto, Sedna and Eris. Kuiper Belt objects are mostly unexplored. The Oort cloud is believed to be the source of the long-period comets. The outer reaches of the Kuiper belt and the inner reaches of the Oort cloud are sometimes termed the scattered disk.

The extent of the Solar System is difficult to define. The orbit of the outermost planet Neptune has a semi-major axis of 30.07 AU. The Kuiper belt is held to stretch between 30 and 50 AU. The semi-major orbital axis of the dwarf planet Eris is 39.48 AE. It is believed to be a member of the scattered disk. The hypothetical Oort cloud is thought to stretch between 50 AU and 50,000 AU (roughly equivalent to one light year, 1 Ly. The light year is a commonly used unit to measure large distances from the Earth). The minor body Sedna has a semi-major axis of 1004 AU (perihelion at 76 and aphelion at 928 AU) and is thought to be a member of the inner Oort cloud. In the Oort cloud, the gravitational pull of the Sun is weak but it is believed to dominate over that of neighboring stars up to a distance of 2 Ly. Another measure of the extent of the Solar System is the size of its magnetosphere, the heliosphere. The heliopause that marks the outer boundary of the heliosphere is believed to be at roughly 100 AU.

#### 4.2.1.2 Definition of a planet in the Solar System

The International Astronomical Union (IAU) introduced the class of dwarf planets in 2006. These are intermediate in size between the terrestrial planets and small bodies such as cometary nuclei and most asteroids. The IAU has so far identified the following five celestial bodies as dwarf planets – Pluto, the former asteroid Ceres, the Trans-Neptunian Object (TNO) Eris, a.k.a. 2003UB313, Makemake, and Haumea. Other candidate bodies such as asteroid Vesta and the TNO Sedna are under consideration. A planet of our Solar System according to the IAU resolution 5 [06IAU] 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. A dwarf planet according to the resolution satisfies a) and b) but has NOT cleared its neighbourhood and d) is not a satellite. See also [06Bas] for a discussion of the term “planet”.

#### 4.2.1.3 References for 4.2.1

- 97Shi Shirley, J.H., Fairbridge, R.W. (Eds): Encyclopedia of Planetary Sciences. Chapman and Hall, London 1997.
- 98Lod Lodders, K., Fegley, B.: The Planetary Scientist's Companion. Oxford University Press, N.Y. 1998.
- 99Wei Weissmann, P.R., McFadden, L.-A.A., Johnson, T.V.: The Encyclopedia of the Solar System. Academic, San Diego, Calif. 1999.
- 06Bas Basri, G., Brown, M.E.: Annual Review of Earth and Planetary Sciences **34** (2006) 193.
- 07Spo Spohn, T. (2007) Treatise on Geophysics Vol. 10, Elsevier, Amsterdam.

#### Internet Resources

IAU [http://www.iau.org/fileadmin/content/pdfs/Resolution\\_GA26-5-6.pdf](http://www.iau.org/fileadmin/content/pdfs/Resolution_GA26-5-6.pdf)