4.2.2 Basic data of planetary bodies

H. Hussmann, F. Sohl, J. Oberst

The planets and their moons are – apart from the Sun – the main constituents of the Solar System. In this section the basic physical characteristics and the dynamical states (rotational state and orbits) of planets, dwarf planets, satellites, and rings are summarized.

4.2.2.1 General definitions

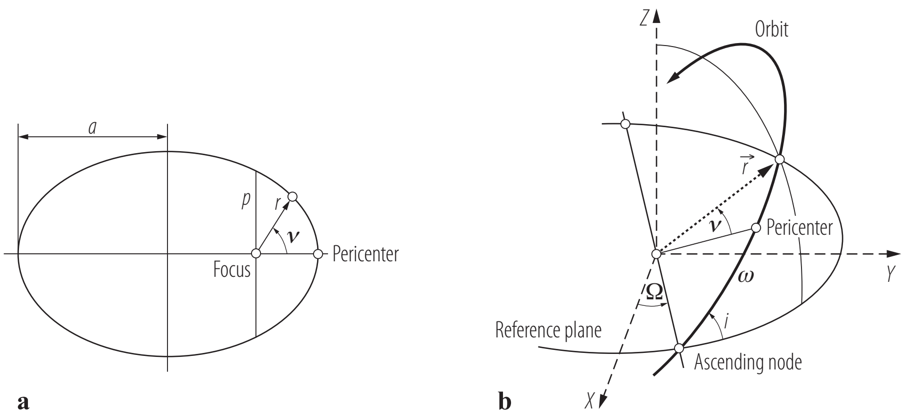
In the following we list the definitions related to orbital elements, time standards, reference frames and units, which are used in the subsequent tables.

4.2.2.1.1 Orbital elements

In Fig.1 the orbital elements are defined with respect to a reference frame, e.g. the *International Celestial Reference Frame* (ICRF) [98Fei, 02Sei]. The ICRF is IAU-adopted and approximately coincides with the Mean Dynamical Frame J2000 with the origin in the Solar System's barycenter [07Sei]. All elements given in this subsection are for bound elliptical orbits. For further information including other types of trajectories, see e.g., [99Mur]. The set of orbital elements used in Fig.1 is the following:

1. The *semi-major axis* a is the distance from the center of the ellipse to the pericenter (or apocenter) of the orbit.
2. $e = \sqrt{1 - p/a}$ is the *eccentricity* ($0 < e < 1$). a and e or equivalently a and the *semilatus rectum* p define the shape and size of an elliptical orbit.
3. The *inclination* i ($0 \le i \le \pi$) is the angle between the orbital plane and the reference plane (e.g., ecliptic, or equatorial plane of the primary). The orbit of a body revolving about a primary is called *prograde* for $i < \pi/2$ and *retrograde* for $\pi/2 < i \le \pi$.
4. For $i \neq 0$ the orbit intersects the reference plane at two points, the nodes. At the ascending node the orbiting body moves from below to above the reference plane, i.e. from negative to positive Z-values in Fig 1b. Ω ($0 \le \Omega \le 2\pi$), the *longitude of the ascending node*, is the angle measured from a reference direction (e.g., vernal equinox in the ecliptical system) to the ascending node. Ω is lying in the reference plane. Per definitionem $\Omega = 0$, if $i = 0$.
5. The *argument of pericenter* ω ($0 \le \omega \le 2\pi$) is the angle between the ascending node and the pericenter. ω lies in the orbital plane. The three elements i, Ω and ω define the orientation of the elliptical orbit. Together with e and a the shape, size and orientation of the orbit is completely determined. A sixth element is required to define the position of the body along the orbit.
6. The *true anomaly* ν ($0 \le \nu \le 2\pi$) is the angle from pericenter to the actual position of the orbiting body at a given time t. ν has a very obvious geometrical meaning. However, according to Kepler's 2nd law it does not increase linearly with time along the orbit. Therefore other elements, e.g., *mean anomaly, mean longitude, time of pericenter passage etc.* (see below) are frequently used.

The set of six elements (a, e, i, Ω, ω, ν) at a given time t completely characterizes the state of the orbiting body at that time (*epoch*). In the special case of the two-body problem, the orbital elements are constant over time (with the exception of the true anomaly ν, of course, which varies



a **b**

Fig. 1. Geometrical illustration of the orbital elements of an elliptical orbit as described in the text. (a) a is the *semi-major axis*. p is the *semilatus rectum*, the connecting line between the focus and the orbit perpendicular to the semi-major axis. *Pericenter* and *apocenter* are the points of minimum and maximum distance, respectively, from the primary. The latter is located in one focus of the ellipse. The connecting line between these points is called *line of apsides*. (b) the orientation of an orbit (bold line) with respect to a reference system is given by the *inclination* i, the *longitude of ascending node* Ω, and the *argument of pericenter* ω. The *true anomaly* ν is the angle between the position vector of the body in orbit and the pericenter.

between 0 and 2π during each revolution). If perturbations are taken into account, the orbital elements are functions of time and have to be referred to a certain point in time (*osculating elements*).

Various equivalent sets of orbital elements are used in the literature (e.g., [99Mur, 06Sei]). In this section we additionally use the *longitude of pericenter*[1] $\varpi = \Omega + \omega$, the *mean motion* $n = 2\pi/T$, where T is the orbital period, the *mean anomaly* $M = n(t - \tau)$, where t is time and τ is the *time of pericenter passage*, and the *mean longitude* $\lambda = M + \varpi$. From Kepler's 3rd law the orbital period T is given by $T^2 = 4\pi^2 a^3/(G(m_1 + m_2))$, where G is the gravitational constant and m_1 and m_2 are the masses of the central and orbiting body, respectively. An alternative to a set of orbital elements often used in numerical calculations is the *state vector* consisting of three cartesian coordinates and the three corresponding velocities at a given time. In three-dimensional space the state vector is equivalent to the description of a particle's (or point-mass') dynamical state by six orbital elements. For transformations between the various reference systems, between the sets of elements commonly in use, and between elements and state vectors, see e.g., [99Mur].

Orbits of planets are generally referred to the *ecliptic* which is the mean plane of the Earth's orbit around the Sun. Satellite orbits are often referred to the equatorial plane of the primary planet or to the *Laplace plane* which is defined as the plane in which the satellite's nodal precession due to perturbations from other satellites, planets, the Sun or higher moments of the primary planet's gravitational field is contained (on average). An equivalent definition is the plane normal to the satellite's orbital precession pole.

4.2.2.1.2 Time standards

Several time conventions are used to describe orbits and positions of planets and satellites. Here we briefly mention the ones, which are used in the following tables (for an exact definition of time standards, which cannot be given here, see, e.g. [06Sei]):

[1]Note that Ω and ω do not lie within the same plane when $i \neq 0$. However, the definition $\varpi = \Omega + \omega$ is used in either case.

- The *International Atomic Time* scale (TAI) is a statistical timescale based on a large number of atomic clocks, located around the world. Its unit is the (SI) second defined as the duration of 9,192,631,770 cycles of radiation corresponding to the transition between two hyperfine levels of the ground state of cesium 133.

- The *Coordinated Universal Time* (UTC) is the standard time on the prime meridian at Greenwich. UTC is an atomic timescale that is kept in close agreement with the *Universal Time* (UT), a measure of time that conforms to the mean diurnal motion of the Sun and serves as the basis of civil timekeeping. Because of small irregularities of the Earth's rotation, UTC is updated with *leapseconds* two times a year, on January 1 and July 1, if necessary. UTC is related to TAI by UTC = TAI − leapseconds.

- The *Terrestrial Time* (TT) (former *Terrestrial Dynamical Time* (TDT)) is the theoretical time scale of apparent geocentric ephemerides of Solar System bodies. It applies to clocks at sea-level, and it is tied to TAI through TT = TAI + $32\overset{s}{.}184$. The units of TT are SI seconds, and the offset of $32\overset{s}{.}184$ with respect to TAI is fixed.

- The *Barycentric Dynamical Time* (TDB), is the independent argument of ephemerides and dynamical theories that are referred to the Solar System barycenter. TDB differs from TT only by periodic variations. For conversion from TT to TDB, see e.g., [06Sei].

- The *Julian Date*, JD is the number of *Julian days* since 12:00 Universal Time on 1 January 4713 B.C. A *Julian day* is one day in astronomical units, defined as 86,400 sec. One *Julian year* has 365.25 Julian days and one *Julian century* consists of 36,525 Julian days. Julian dates can be expressed in dynamical time (TT) or universal time (UT). If precision is of concern, the timescale should be specified after the Julian date, e.g., Julian date 2451545.0 TT. Sometimes *Julian Ephemeris Day* (JED) is used instead of JD.

- The *Modified Julian Date* MJD is defined as MJD = JD − 2400000.5. An MJD day thus begins at midnight, civil date. It is frequently used instead of the Julian date.

- J2000 is the current epoch used in astronomical tables. It is equivalent to (a) the Julian date 2451545.0 TT, or January 1, 2000, 12:00:00.0 TT; (b) to January 1, 2000, 11:59:27.816 TAI or (c) to January 1, 2000, 11:58:55.816 UTC.

4.2.2.1.3 Astronomical units

The IAU system of astronomical units of time, mass, and length is frequently used in tables of Solar System objects (e.g., [06Sei]).

- The astronomical unit of time is the interval of one day defined as 86400 s. An interval of 36525 days is one Julian century.

- The astronomical unit of mass is the mass of the Sun ($M_\odot = 1.9891 \times 10^{30}$ kg in SI-units).

- The astronomical unit of length is that length for which the Gaussian gravitational constant k takes the value $k = 0.01720209895$ when the units of measurement are the astronomical units of length, mass and time. The dimensions of k^2 are those of the constant of gravitation, i.e. length$^3 \times$ mass$^{-1} \times$ time^{-2}. The value of the Gaussian constant is fixed and is used to define the unit of length. The latter can be understood as the orbital radius of a ficticious planet with zero mass (i.e. $M_\mathrm{Sun} \gg M_\mathrm{Planet}$ implying $M_\mathrm{Sun} + M_\mathrm{Planet} = M_\mathrm{Sun}$) on a circular orbit around the Sun whose orbital period T is given by $T = 2\pi/k$, measured in days. That planet revolves about the Sun at a distance in SI units of AU = $1.49597871464 \times 10^{11}$ m (astronomical unit AU in meters). Because of the fixed definition of the Gaussian constant the Earth's semi-major axis is not exactly unity (see Table 2) in astronomical units.

4.2.2.2 Planets

The planets of the Solar System can be divided in two major groups: a) the *terrestrial planets*, Mercury, Venus, Earth and Mars in the inner region of the Solar System (semi-major axes 0.39–1.52 AU) and b) the *gaseous planets* Jupiter, Saturn, Uranus and Neptune in the outer region (semi-major axes 5.20–30.07 AU). Because of their differing compositions the subgroups *gas giants* for Jupiter and Saturn and *icy giants* for Uranus and Neptune are sometimes used in the literature. The main physical data of the planets and their orbital characteristics are summarized in Table 1 and Table 2. More detail on the physical properties and the dynamical states of the planets is given in the following sections.

Basic thermal characteristics of the planets are summarized in Table 3. The *planetary solar constant* S is the rate of energy per unit area that is received due to the solar luminosity at all wavelengths at the mean distance of the respective planet right at the top of the planet's atmosphere. It is thus a measure for the rate of energy that a planet (or e.g., the solar panels of a spacecraft in orbit around that planet) could in principal receive from the Sun. However, due to reflectance at the planet's surface and atmosphere, the absorbed energy is less than that. A measure for the reflected sunlight is the planet's *albedo*. The *geometric albedo* A, $0 \leq A \leq 1$ is the ratio of the brightness of a planet for phase angle zero (illuminating source, reflecting body and

Table 1. Basic physical data of the *planets* of the Solar System (more detailed data is given in the following subsections). R is the mean radius, M the mass, ρ the bulk density, P_{rot} the sidereal rotation period, P_{orb} the sidereal orbit period, and g, the equatorial gravitational acceleration at the surface. Negative rotational periods correspond to retrograde rotation. The radii of Jupiter, Saturn, Uranus and Neptune correspond to the one-bar surface and are not necessarily the appropriate values to be used in dynamical studies, e.g. radius and J_2 values should be always used in a consistent way. References: [92Sei, 07Sei, 95Yod].

	R [km]	M [10^{24} kg]	ρ [kg m^{-3}]	P_{rot} [days]	P_{orb} [years]	g [m s^{-2}]
Mercury	2439.7 ± 1.0	0.3302	5427	56.6462	0.2408467	3.70
Venus	6051.8 ± 1.0	4.8685	5204	−243.01	0.61519726	8.87
Earth	6371.00 ± 0.01	5.9736	5515	0.99726968	1.0000174	9.78
Mars	3389.50 ± 0.2	0.64185	3933	1.02595675	1.8808476	3.69
Jupiter	69911 ± 6	1898.6	1326	0.41354	11.862615	23.12
Saturn	58232 ± 6	568.46	687	0.4375	29.447498	8.96
Uranus	25362 ± 7	86.832	1318	−0.65	84.016846	8.69
Neptune	24622 ± 19	102.43	1638	0.768	164.79132	11.00

Table 2. Mean orbital elements of the *planets* of the Solar System at the epoch of J2000 (Julian date JD 2451545.0) with respect to the mean ecliptic and equinox of J2000. a semi-major axis, e eccentricity, i inclination, ϖ longitude of perihelion, Ω longitude of ascending node, λ mean longitude. Data for the Earth are actually for the Earth-Moon barycenter. Data taken from [99Mur], see also [92Sta].

	a [AU]	e	i [deg]	ϖ [deg]	Ω [deg]	λ [deg]
Mercury	0.38709893	0.20563069	7.00487	77.45645	48.33167	252.25084
Venus	0.72333199	0.00677323	3.39471	131.53298	76.68069	181.97973
Earth	1.00000011	0.01671022	0.00005	102.94719	348.73936	100.46435
Mars	1.52366231	0.09341233	1.85061	336.04084	49.57854	355.45332
Jupiter	5.20336301	0.04839266	1.30530	14.75385	100.55615	34.40438
Saturn	9.53707032	0.05415060	2.48446	92.43194	113.71504	49.94432
Uranus	19.19126393	0.04716771	0.76986	170.96424	74.22988	313.23218
Neptune	30.06896348	0.00858587	1.76917	44.97135	131.72169	304.88003

Table 3. Thermal characteristics of the *planets* of the Solar System. S is the planetary solar constant, T the mean temperature (surface or at 1 bar level for the giant planets), A the geometric albedo, and P the atmospheric pressure. Reference: [95Yod].

	S [Wm^{-2}]	T [K]	A	P [bar]
Mercury	9936.9	100-700	0.106	$< 10^{-12}$
Venus	2613.9	735	0.65	90
Earth	1367.6	270	0.367	1.0
Mars	589.0	210	0.150	0.0056
Jupiter	50.5	165 ± 5	0.52	
Saturn	15.04	134 ± 4	0.47	
Uranus	3.71	76 ± 2	0.51	
Neptune	1.47	72 ± 2	0.41	

observer aligned) to the brightness of a plane, perfectly diffusing disk of the same size and distance of the planet. The lower the albedo of a planet the more radiation from the Sun is absorbed. Mean equilibrium surface temperatures T are given, taking the Sun's radiation and the planet's albedo and atmosphere into account. Two values —for day- and night-side— are given for Mercury which is lacking a dense atmosphere. For the terrestrial planets the atmospheric surface pressures P are also listed.

4.2.2.3 Dwarf planets

In 2006 the IAU passed the definition of *planets* and *dwarf planets* of the Solar System. Five objects of the Solar System have been classified as dwarf planets so far (as of Dec. 2008): the largest main-belt asteroid *Ceres*, and the Trans-Neptunian objects *Pluto*, *Eris*, *Makemake*, and *Haumea*. Tables 4 and 5 summarize the physical and orbital properties of these objects. *Ceres*' shape can be best approximated by an oblate spheroid with significantly differing principal axes. *Haumea* has a very elongated shape and an extremely small rotation period. Many large trans-neptunian objects (TNO's) including several *dwarf planet candidates* have been detected in the outer Solar System in recent observational campaigns. The number of TNO's in general and the number of dwarf planets is expected to further increase in the coming years.

4.2.2.4 Satellites

With the exceptions of Mercury and Venus, all planets of the Solar System, as well as many asteroids and trans-neptunian objects, have one or more satellites. The radii of the satellites range from a few km up to a few 1000 km. Jupiter's satellites *Ganymede* and *Callisto*, as well as the Saturnian satellite *Titan* exceed planet Mercury in size. Table 6 gives the number of known moons of planets and dwarf planets. The giant planets are surrounded by systems of satellites, generally consisting of small inner satellites, orbiting close to the planet on almost circular orbits in the equatorial plane, mid-sized and/or large satellites, likewise on almost circular near-equatorial orbits, and a typically large number of small outer satellites on highly inclined, eccentric orbits. The satellites of the latter group, the *irregular* satellites are probably captured objects, as indicated by their high orbital inclinations and eccentricities. Many of the irregular satellites revolve about their primaries in a retrograde sense. Due to similar capture processes and collisional histories, several groups of irregular satellites (e.g., the prograde *Himalia* group, and the retrograde *Ananke*, *Carme* and *Pasiphae* groups in the Jupiter system) can be distinguished by similarities in their

Table 4. Physical data of the *dwarf planets* of the Solar System. The first two columns give the name, minor planet catalogue number, and former designation, respectively. R is the mean radius, M the mass, ρ the bulk density, $P_{\rm rot}$ the sidereal rotation period, and $P_{\rm orb}$ the sidereal orbit period. *Ceres* is an oblate spheroid with significant differences in the two axes. The two radii along the principal axes (equatorial and polar) are given here. The negative rotation period of *Pluto* indicates its retrograde rotation. * The shape of *Haumea* is extremely elongated with approximate axes as given here. References: [07Sei, 05Tho, 95Yod, 08Bro, 06Rab]

	Number	R [km]	M [10^{20} kg]	ρ [kg m^{-3}]	$P_{\rm rot}$ [d]	$P_{\rm orb}$ [yr]
Ceres	1	487.3 ± 1.8 454.7 ± 1.6	9.395 ± 0.125	2077 ± 31	0.378125	4.607
Pluto	134340	1145	130.5 ± 0.6	2030 ± 60	−6.3867	247.92065
Eris (2003 UB_{313})	136199	1200 ± 50	166 ± 2	2300 ± 30		558.75
Makemake (2005 FY_9)	136472	750 ± 150				306.17
Haumea (2003 EL_{61})	136108	$\approx 100 \times 750$ $\times 1000$*	42.1 ± 0.1	≈ 2600	0.1631	283.28

Table 5. Mean orbital elements of the *dwarf planets* of the Solar System at the epoch of JD 2454600.5 TDB, i.e. May 14, 2008, 00:00h. The orbital elements for Pluto are for JD 2454000.5 TDB corresponding to Sep 22, 2008, 00:00h. Data of Makemake and Haumea is at epoch 2454800.5 (2008-Nov-30.0) TDB. a is the semi-major axis, e the eccentricity, i the inclination, ω the argument of perihelion, Ω the longitude of ascending node, M the mean anomaly at epoch. Inclination, argument of perihelion, and longitude of ascending node are referred to the J2000 ecliptic plane. Reference: [08JPL] and references therein.

	a [AU]	e	i [deg]	ω [deg]	Ω [deg]	M [deg]
Ceres	2.7667817	0.07954162	10.58640	72.96457	80.40699	301.6548490
Pluto	39.4450697	0.25024871	17.08900	112.59714	110.37696	25.2471897
Eris (2003 UB_{313})	67.840	0.43747	44.0790	151.57	35.9276	198.490
Makemake (2005 FY_9)	45.426	0.161	28.999	295.154	79.572	151.598
Haumea (2003 EL_{61})	43.133	0.195	28.22	239.184	122.103	202.675

Table 6. Total *number of known satellites* of planets and dwarf planets in the Solar System (as of Dec. 2008). The total number is further divided in classes of objects ordered by size. Whereas no further discoveries of large and mid-sized satellites can be expected for the planets, the number of small satellites of the giant planets as well as the number of dwarf planet satellites will almost certainly further increase due to future observational campaigns and missions.

Primary	Total	Large $R > 1000$ km	Mid-size $1000 > R > 100$ km	Small, inner $R < 100$ km	Small, outer
Earth	1	1	0	0	0
Mars	2	0	0	2	0
Jupiter	63	4	0	4	55
Saturn	60	1	8	14	37
Uranus	27	0	5	13	9
Neptune	13	1	2	5	5
Pluto	3	0	1	2	0
Eris	1	0	0	1	0
Haumea	2	0	0	2	0

orbital elements (e.g., inclination). The *regular* orbits of the inner and large satellites suggest that they were formed simultaneously with their respective central planets. There is an observational bias in the number of small satellites of the giant planets due to the planets' distances from Earth. Many of the small satellites have been discovered in recent observational campaigns or by recent space missions, e.g., *Galileo* and *Cassini*. Additionally, all giant planets possess ring systems made up of small particles. Analogeous to the IAU definition of planets, an object can be considered as a satellite if it is an isolated body orbiting a planet or —if located within a ring system— if it is massive enough to open a gap in the rings.

Most of the small satellites (from 100-km class objects down to 1-km class objects) are irregularly shaped. The large satellites and most of the mid-sized moons have spherical or slightly ellipsoidal shapes due to self-gravity and in response to rotation and tidal forces exerted by the primary planet. As a consequence of tidal despinning all large and mid-sized satellites, as well as most of the small inner satellites rotate synchronously, i.e. like Earth's Moon they are locked in a 1:1 spin-orbit coupling. An important exception is the irregularly-shaped Saturnian satellite *Hyperion*, which rotates chaotically. The spin axes of the large and mid-sized satellites are all roughly perpendicular to the orbital plane, which in most cases nearly coincides with the equatorial plane of the planet. Details on the rotational states are given in the next section.

Based on their bulk composition derived from mean densities, surface spectroscopy and cosmochemical arguments of the satellites' origins, the moons can be devided into two groups, the *rocky satellites* including the Earth's *Moon* and the Jovian satellites *Io* and *Europa* with densities of about 3000 kg m^{-3} or more, and the *icy satellites*, such as *Ganymede* and most of the other satellites in the outer Solar System with densities between roughly 1000 and 2000 kg m^{-3}. The moons of the latter group contain silicate rock in addition to a large fraction of water ice (roughly about 50% by mass). Some satellites, e.g., Neptune's satellite *Triton* contain relatively high amounts of rock compared to water ice.

In Table 7 and Table 8 the basic physical and orbital characteristics of the 'classical' satellites are listed. These tables contain all the large and mid-sized satellites with radii > 100 km. Additionally, we have included the satellites of Mars, *Phobos* and *Deimos*.

In Tables 9–18 data for the small satellites of the giant planets are listed along with their IAU names. In cases where no names have yet been assigned, the preliminary designation is given. The 'S' stands for 'satellite' followed by the year of the new satellite's discovery. The following letter is the initial of the respective primary planet, followed by the subsequent number of newly discovered satellites in the specified year. E.g., 'S/2001 U3' is the third newly discovered satellite of Uranus of 2001.

Table 19 provides the data of the satellites of the dwarf planets, *Nix* and *Hydra* – the newly discovered satellites of Pluto – and *Dysnomia*, a satellite of Eris. It is remarkable that the ratio of the orbital periods of Pluto's satellites *Charon*, *Nix* and *Hydra* is close to 1:4:6. However, it has not yet been confirmed that the satellites are indeed locked in stable resonances. Besides Pluto and Eris several trans-neptunian objects and main-belt asteroids have satellites.

4.2.2.5 Rings

The four giant planets all have ring systems with Saturn's the most prominent and visible from the Earth with telescopes. A large number of known satellites are embedded in the ring systems. Some of them shepherd rings to sharpen their edges (e.g., [99Mur]) such as *Prometheus* and *Pandora* shepherding Saturn's F-ring. Others, like Saturn's moon *Pan* open gaps in the ring systems. It is generally held that the rings and the embedded satellites are continuously created and destroyed by impacts and accretion. In two cases – Jupiter's rings and Saturn's E-ring – the rings are supplied with material by eruptions on the geologically active moons *Io* and *Enceladus*, respectively. In some cases the ring material is not distributed homogeneously along the ring. The optically thicker parts of Neptune's *Adams*-ring were first recognized as *arcs*. The physics of the rings and the ring-moon interactions, responsible for many features in the ring systems have been recently reviewed by [06Esp]. Tables 20–23 summarize the main known properties of the rings. The data are adopted from the NSSDC planetary data fact sheet [08NSS]. It has been reported that *Rhea*, a satellite of Saturn, has a tenuous ring [08Jon]. However, a ring around *Rhea* has not yet been detected in the imaging data obtained with the *Cassini* spacecraft (as of Nov. 2008).

Table 7. Basic physical data of the *major satellites* of the planets and Pluto. The table contains all satellites with mean radii exceeding 100 km and the two Martian satellites. R is the mean radius, M the mass, ρ the mean density, and P_{orb} the sidereal rotation period. The satellites are ordered by their corresponding central planets (Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto) divided by horizontal lines and by their distance from the primary. The last column indicates the satellites' spin states. 's' stands for 'synchronous', i.e. the orbital period P_{orb} being equal to the rotational period; and 'c' stands for 'chaotic'. References: [08JPL, 07Sei]. Data on the small inner satellites and outer irregular satellites are given in Tables 9–19.

Object	R [km]	GM [km^{3}s^{-2}]	M [10^{20} kg]	ρ [kg m^{-3}]	P_{orb} [days]	Spin
Moon	1737.4 ± 1	4902.801 ± 0.001	734.8	3344 ± 5	27.322	s
Phobos	11.1 ± 0.15	0.0007158 ± 0.0000005	1.1×10^{-4}	1872 ± 76	0.319	s
Deimos	6.2 ± 0.18	0.000098 ± 0.000007	1.5×10^{-5}	1471 ± 166	1.262	s
Io	1821.46	5959.916 ± 0.012	893.2	3528 ± 6	1.769	s
Europa	1562.09	3202.739 ± 0.009	480.0	3013 ± 5	3.551	s
Ganymede	2632.345	9887.834 ± 0.017	1481.9	1942 ± 5	7.155	s
Callisto	2409.3	7179.289 ± 0.013	1075.9	1834 ± 4	16.69	s
Mimas	198.2 ± 0.5	2.530 ± 0.012	0.38	1152 ± 27	0.942	s
Enceladus	252.1 ± 0.2	7.210 ± 0.011	1.1	1606 ± 12	1.370	s
Tethys	533.0 ± 1.4	41.210 ± 0.007	6.2	956 ± 8	1.888	s
Dione	561.7 ± 0.9	73.113 ± 0.003	11.0	1469 ± 12	2.737	s
Rhea	764.3 ± 1.8	154.07 ± 0.16	23.1	1233 ± 10	4.518	s
Titan	2575 ± 2	8978.19 ± 0.06	1345.5	1880 ± 4	15.95	s
Hyperion	133 ± 8	0.37 ± 0.02	5.6×10^{-2}	569 ± 108	21.28	c
Iapetus	735.6 ± 3.0	120.50 ± 0.03	18.1	1088 ± 18	79.33	s
Phoebe	106.7 ± 1	0.5531 ± 0.0006	8.3×10^{-2}	1633 ± 49	550.31	s
Miranda	235.8 ± 0.7	4.4 ± 0.5	0.66	1201 ± 137	1.413	s
Ariel	578.9 ± 0.6	90.3 ± 8.0	13.5	1665 ± 147	2.520	s
Umbriel	584.7 ± 2.8	78.2 ± 9.0	11.7	1400 ± 163	4.144	s
Titania	788.9 ± 1.8	235.3 ± 6.0	35.3	1715 ± 44	8.706	s
Oberon	761.4 ± 2.6	201.1 ± 5.0	30.1	1630 ± 43	13.46	s
Proteus	208 ± 8	3.36	0.5	1300	1.122	s
Triton	1352.6 ± 2.4	1427.9 ± 3.5	214.0	2061 ± 7	5.877	s
Nereid	170 ± 25	2.06	0.3	1500	360.14	s
Charon	605 ± 8	$108. \pm 6.$	16.2	1853 ± 158	6.387	s

Table 8. Mean orbital elements of the *major satellites* of the planets and Pluto at epoch (1) 2000 Jan. 1.50 TT, (2) 1950 Jan. 1.00 TT, (3) 1997 Jan. 16.00 TT, (4) 2004 Jan. 1.00 TT, (5) 1980 Jan. 1.0 TT, (6) 1989 Aug. 25.00 TT, (7) 1989 Aug. 18.50 TT. The table contains all satellites with mean radii exceeding 100 km and the two Martian satellites. a is the semi-major axis, e the eccentricity, ω the argument of pericenter, M the mean anomaly, i the inclination, and Ω the longitude of ascending node. The elements of the Moon are referred to the ecliptic; the one's of the Uranian satellites to the planet's equator. Charon's barycentric elements are referred to its mean orbit: ICRF right ascension = 133.05142°, ICRF declination = –6.17674°. All other elements are referred to the local Laplace planes which are in most cases (close to the planet) only slightly different from the equatorial plane of the planet. In cases where the elements are referred to the local Laplace planes the declination, Dec., and right ascension, R.A., of the plane's pole is given with respect to the ICRF. The last column, tilt, gives the angle between the planet equator and the Laplace plane. Reference: [08JPL] and references therein. Data on the small inner satellites and outer irregular satellites are given in Tables 9–19.

Object	a [km]	e	ω [deg]	M [deg]	i [deg]	Ω [deg]	Dec. [deg]	R.A. [deg]	Tilt [deg]
Moon (1)	384,400	0.0554	318.15	135.27	5.16	125.08			
Phobos (2)	9,380	0.0151	150.247	92.474	1.075	164.931	317.724	52.924	0.046
Deimos (2)	23,460	0.0002	290.496	296.230	1.793	339.600	316.700	53.564	0.897
Io (3)	421,800	0.0041	84.129	342.021	0.036	43.977	268.057	64.495	0.000
Europa (3)	671,100	0.0094	88.970	171.016	0.466	219.106	268.084	64.506	0.016
Ganymede (3)	1,070,400	0.0013	192.417	317.540	0.177	63.552	268.168	64.543	0.068
Callisto (3)	1,882,700	0.0074	52.643	181.408	0.192	298.848	268.639	64.749	0.356
Mimas (4)	185,540	0.0196	14.352	255.312	1.572	153.152	40.590	83.539	0.001
Enceladus (4)	238,040	0.0047	211.923	197.047	0.009	93.204	40.587	83.539	0.001
Tethys (4)	294,670	0.0001	262.845	189.003	1.091	330.882	40.581	83.539	0.002
Dione (4)	377,420	0.0022	168.820	65.990	0.028	168.909	40.554	83.542	0.005
Rhea (4)	527,070	0.0010	256.609	311.551	0.331	311.531	40.387	83.556	0.029
Titan (4)	1,221,870	0.0288	185.671	15.154	0.280	24.502	36.470	83.936	0.600
Hyperion (4)	1,500,880	0.0274	324.183	295.906	0.630	264.022	37.258	83.819	0.461
Iapetus (4)	3,560,840	0.0283	275.921	356.029	7.489	75.831	288.818	78.667	14.968
Phoebe (4)	12,947,780	0.1635	345.582	287.593	175.986	241.570	277.897	67.124	26.891
Miranda (5)	129,900	0.0013	68.312	311.330	4.338	326.438			
Ariel (5)	190,900	0.0012	115.349	39.481	0.041	22.394			
Umbriel (5)	266,000	0.0039	84.709	12.469	0.128	33.485			
Titania (5)	436,300	0.0011	284.400	24.614	0.079	99.771			
Oberon (5)	583,500	0.0014	104.400	283.088	0.068	279.771			
Proteus (7)	117,647	0.0005	301.706	117.050	0.026	162.690	299.583	42.417	0.479
Triton (6)	354,800	0.0000	344.046	264.775	156.834	172.431	299.452	43.395	0.513
Nereid (6)	5,513,400	0.7512	280.830	359.341	7.232	334.762	282.462	75.854	33.783
Charon (1)	17,536	0.0022	71.255	147.848	0.001	85.187			

Table 9. Mean orbital elements and sizes of *Jupiter's small inner satellites* at the epoch of 1997 Jan. 16.00 TT referred to the local Laplace planes. a is the semi-major axis, e the eccentricity, ω the argument of pericenter, M the mean anomaly, i the inclination, and Ω the longitude of ascending node. P is the sidereal orbital period and R is the mean radius. Right ascension and declination of the Laplace plane pole with respect to the ICRF are given by 268.057° and 64.495°, respectively. The angle between Jupiter's equator and the Laplace plane is 0° for all four satellites. References: [08JPL, 07Sei].

satellite	a [km]	e	ω [deg]	M [deg]	i [deg]	Ω [deg]	P [days]	R [km]
Metis	128,000	0.0012	297.177	276.047	0.019	146.912	0.295	21.5 ± 2.0
Adrastea	129,000	0.0018	328.047	135.673	0.054	228.378	0.298	8.2 ± 2.0
Amalthea	181,400	0.0032	155.873	185.194	0.380	108.946	0.498	83.45 ± 2.4
Thebe	221,900	0.0176	234.269	135.956	1.080	235.694	0.675	49.3 ± 2.0

Table 10. Mean orbital elements and sizes of *Jupiter's small satellites* with assigned IAU names at epoch (1) 2000 Jan. 1.00 TT, (2) 2002 May. 6.00 TT, (3) 2002 May. 6.00 TT, (4) 2003 Jun. 10.00 TT. a is the semi-major axis, e the eccentricity, and i the inclination. The latter is referred to the local Laplace planes. P is the sidereal orbital period and R is the satellite's mean radius. The declination, Dec., and right ascension, R.A., of the Laplace plane's pole are given with respect to the ICRF. The last column, tilt, gives the angle between the planet equator and the Laplace plane. Reference: [08JPL] and references therein.

satellite	a [km]	e	i [deg]	P [days]	R [km]	R.A. [deg]	Dec. [deg]	Tilt [deg]
Themisto (2)	7,284,000.	0.2428	43.254	130.02	4.0	272.709	66.701	2.924
Leda (1)	11,165,000.	0.1636	27.457	240.92	10	271.668	66.848	2.788
Himalia (1)	11,461,000.	0.1623	27.496	250.56	85	275.667	67.429	4.269
Lysithea (1)	11,717,000.	0.1124	28.302	259.20	18	271.356	67.115	2.953
Elara (1)	11,741,000.	0.2174	26.627	259.64	43	273.200	68.246	4.282
Carpo (4)	17,058,000.	0.4316	51.628	456.30	1.5	273.325	67.004	3.311
Euporie (3)	19,304,000.	0.1432	145.767	550.74	1.0	273.181	66.708	3.061
Orthosie (3)	20,720,000.	0.2808	145.921	622.56	1.0	273.134	66.956	3.225
Euanthe (3)	20,797,000.	0.2321	148.910	620.49	1.5	273.207	66.739	3.089
Harpalyke (2)	20,858,000.	0.2269	148.644	623.32	2.2	273.235	66.919	3.225
Praxidike (2)	20,908,000.	0.2311	148.975	625.39	3.4	273.018	66.760	3.051
Thyone (3)	20,939,000.	0.2286	148.509	627.21	2.0	273.541	66.846	3.258
Mneme (4)	21,035,000.	0.2301	148.693	620.04	1.0	273.243	66.598	3.004
Iocaste (2)	21,060,000.	0.2158	149.425	631.60	2.6	273.218	66.883	3.194
Helike (4)	21,069,000.	0.1506	154.853	626.32	2.0	273.287	66.793	3.149
Hermippe (3)	21,131,000.	0.2096	150.725	633.90	2.0	273.271	66.864	3.195
Thelxinoe (4)	21,164,000.	0.2194	151.370	628.09	1.0	273.335	66.729	3.119
Ananke (1)	21,276,000.	0.2435	148.889	629.77	14	279.087	66.152	4.891
Eurydome (3)	22,865,000.	0.2759	150.274	717.33	1.5	273.195	66.716	3.070
Arche (4)	23,355,000.	0.2496	165.017	731.95	1.5	273.233	66.797	3.137
Pasithee (3)	23,004,000.	0.2675	165.138	719.44	1.0	273.156	66.761	3.091
Chaldene (2)	23,100,000.	0.2521	165.190	723.72	1.9	273.258	66.763	3.120
Isonoe (2)	23,155,000.	0.2471	165.272	726.23	1.9	273.237	66.798	3.139
Erinome (2)	23,196,000.	0.2664	164.936	728.46	1.6	273.208	66.761	3.105
Kale (3)	23,217,000.	0.2599	164.996	729.47	1.0	273.325	66.774	3.147
Aitne (3)	23,229,000.	0.2643	165.091	730.18	1.5	273.158	66.812	3.127
Taygete (2)	23,280,000.	0.2525	165.268	732.41	2.5	273.156	66.761	3.090
Kallichore (4)	23,288,000.	0.2503	165.127	728.73	1.0	273.295	66.789	3.149
Eukelade (4)	23,328,000.	0.2634	165.240	730.47	2.0	273.244	66.754	3.110
Carme (1)	23,404,000.	0.2533	164.907	734.17	23	272.620	66.689	2.897
Kalyke (2)	23,483,000.	0.2471	165.179	742.06	2.6	273.223	66.766	3.112
Sponde (3)	23,487,000.	0.3121	150.998	748.34	1.0	273.138	66.737	3.069
Megaclite (2)	23,493,000.	0.4198	152.766	752.86	2.7	273.239	66.767	3.118
Hegemone (4)	23,577,000.	0.3396	154.186	739.88	1.5	273.251	66.734	3.099
Pasiphae (1)	23,624,000.	0.4090	151.431	743.63	30	273.440	67.645	3.835
Cyllene (4)	23,809,000.	0.4115	150.389	752.00	1.0	273.399	66.714	3.127
Sinope (1)	23,939,000.	0.2495	158.109	758.90	19	273.266	66.880	3.211
Aoede (4)	23,980,000.	0.4311	158.260	761.50	2.0	273.306	66.775	3.142
Autonoe (3)	24,046,000.	0.3168	152.416	760.95	2.0	273.181	66.815	3.136
Callirrhoe (2)	24,103,000.	0.2829	147.167	758.77	4.3	272.836	66.537	2.844
Kore (4)	24,543,000.	0.3245	144.969	779.17	1.0	273.997	66.902	3.428

Table 11. Mean orbital elements and sizes of *Jupiter's small satellites* without assigned IAU names at epoch 2002 May. 6.00 TT. a is the semi-major axis, e the eccentricity, and i the inclination. i is referred to the local Laplace planes. P is the sidereal orbital period and R is the mean radius. The declination, Dec., and right ascension, R.A., of the Laplace plane's pole are given with respect to the ICRF. Tilt is the angle between the planet equator and the Laplace plane. References: [08JPL] and *[08She].

satellite	a [km]	e	i [deg]	P [days]	R [km]	R.A. [deg]	Dec. [deg]	Tilt [deg]
S/2000 J11*	12,555,000	0.248	28.30	287.0	2.0			
S/2003 J2	28,455,000.	0.4074	157.321	981.55	1.0	273.212	66.862	3.177
S/2003 J3	20,224,000.	0.1969	147.541	583.88	1.0	273.534	66.855	3.262
S/2003 J4	23,933,000.	0.3620	149.574	755.26	1.0	273.154	66.748	3.081
S/2003 J5	23,498,000.	0.2476	165.239	738.74	2.0	273.283	66.805	3.157
S/2003 J9	23,388,000.	0.2627	165.076	733.30	0.5	273.177	66.779	3.109
S/2003 J10	23,044,000.	0.4294	165.069	716.25	1.0	273.227	66.798	3.136
S/2003 J12	17,833,000.	0.4920	151.104	489.72	0.5	273.299	66.911	3.237
S/2003 J15	22,630,000.	0.1944	146.551	689.77	1.0	273.080	66.311	2.768
S/2003 J16	20,956,000.	0.2266	148.512	616.33	1.0	273.242	66.591	2.998
S/2003 J17	22,983,000.	0.2381	164.921	714.51	1.0	273.190	66.782	3.114
S/2003 J18	20,426,000.	0.0601	145.908	596.58	1.0	272.778	66.632	2.893
S/2003 J19	23,535,000.	0.2559	165.154	740.43	1.0	273.267	66.795	3.146
S/2003 J23	23,566,000.	0.2738	146.397	732.45	1.0	272.604	66.531	2.773

Table 12. Planetocentric Saturn-equatorial orbital elements and sizes of *Saturn's small innermost moons* at epoch (1) JED 2451545.0, (2) JED 2453491.9, and (3) JED 2453005.5 These moons are located within Saturn's A and F-ring. a is the semi-major axis, e the eccentricity, i the inclination, Ω the longitude of ascending node, ϖ the longitude of pericenter, λ the mean longitude. P is the orbital period and R is the mean radius [06Spi, 08JPL], *[05IAU].

satellite	a [km]	e	i [deg]	Ω [deg]	ϖ [deg]	λ [deg]	P [days]	R [km]
Pan (1)	133,584	0.000035	0.001	20	176	146.59	0.57505	12.8
Daphnis (2)	136,504	0	0	0	0	222.952	0.59408	3.5*
Atlas (3)	137,670	0.0012	0.003	0.500	332.021	129.760	0.60169	10
Prometheus (3)	139,380	0.0022	0.008	259.504	63.893	306.117	0.61299	46.8 ± 5.6
Pandora (3)	141,720	0.0042	0.050	327.215	50.676	253.373	0.62850	40.6 ± 4.5
Janus (3)	151,460	0.0068	0.163	46.899	288.678	171.432	0.69466	90.4 ± 3.0
Epimetheus (3)	151,410	0.0098	0.351	85.244	37.847	346.196	0.69433	58.3 ± 3.1

Table 13. Mean orbital elements and sizes of *Saturn's small satellites* at epoch 2004 Jan. 1.00 TT referred to Saturn's equator. These moons are located between the orbits of Mimas and Dione. M is the mean anomaly, and ω the argument of pericenter. All other quantities are the same as in the previous table. References: [08JPL, 07Sei], *[08She]. ***Anthe's* elements at epoch 2007 May 30 04:02:02.511 UTC; longitudes are measured from ascending node of Saturn's equator at epoch on the Earth mean equator at J2000; i is measured relative to Saturn's equatorial plane at epoch [08Coo].

satellite	a [km]	e	ω [deg]	M [deg]	i [deg]	Ω [deg]	P [days]	R [km]
Methone*	194,440	0.0001	292.695	163.735	0.007	321.745	1.010	1.5
Anthe**	197,669	0.001	0.16	5 ± 1	53.42	141.715	1.0365	0.9
Pallene	212,280	0.0040	216.475	125.909	0.181	114.430	1.154	4
Telesto	294,710	0.0002	341.795	200.143	1.180	300.256	1.888	11 ± 4
Calypso	294,710	0.0005	234.788	101.961	1.499	25.327	1.888	9.5 ± 4
Polydeuces*	377,200	0.0192	200.028	191.220	0.177	304.799	2.737	2
Helene	377,420	0.0071	292.056	134.070	0.213	40.039	2.737	16 ± 4

Table 14. Mean orbital elements and sizes of *Saturn's irregular satellites* at epoch 2000 Feb. 26.00 TT. a is the semi-major axis, e the eccentricity, and i the inclination. The latter is referred to the ecliptic. P is the sidereal orbital period and R is the satellite's mean radius. Reference: [08JPL] and references therein, and *[08She].

satellite	a [km]	e	i [deg]	P [days]	R [km]
Kiviuq	11,110,000	0.3289	45.708	449.22	8
Ijiraq	11,124,000	0.3164	46.448	451.42	6
Paaliaq	15,200,000	0.3630	45.084	686.95	11.0
Skathi	15,540,000	0.2698	152.630	728.20	4
Albiorix	16,182,000	0.4770	34.208	783.45	16
S/2007 S2	16,725,000	0.1793	174.043	808.08	3*
Bebhionn	17,119,000	0.4691	35.012	834.84	3.0
Erriapo	17,343,000	0.4724	34.692	871.19	5
Siarnaq	17,531,000	0.2960	46.002	895.53	20
Skoll	17,665,000	0.4641	161.188	878.29	3*
Tarvos	17,983,000	0.5305	33.827	926.23	7.5
Tarqeq	18,009,000	0.1603	46.089	887.48	3.5*
Greip	18,206,000	0.3259	179.837	921.19	3*
S/2004 S 13	18,404,000	0.2586	168.789	933.48	3.0
Hyrokkin	18,437,000	0.3336	151.450	931.86	4*
Mundilfari	18,628,000	0.2099	167.473	952.77	3.5
S/2006 S1	18,790,000	0.1172	156.309	963.37	3*
Jarnsaxa	18,811,000	0.2164	163.317	964.74	3*
S/2007 S3	18,975,000	0.1851	174.528	977.80	2.5*
Narvi	19,007,000	0.4308	145.824	1003.86	3.5
Bergelmir	19,336,000	0.1428	158.574	1005.74	3.0
S/2004 S 17	19,447,000	0.1793	168.237	1014.70	2.0
Suttungr	19,459,000	0.1140	175.815	1016.67	3.5
Hati	19,846,000	0.3713	165.830	1038.61	3.0
S/2004 S 12	19,878,000	0.3260	165.282	1046.19	2.5
Bestla	20,192,000	0.5176	145.162	1088.72	3.5
Thrymr	20,314,000	0.4664	175.802	1094.11	3.5
Farbauti	20,377,000	0.2396	156.393	1085.55	2.5
Aegir	20,751,000	0.2520	166.700	1117.52	3.0
S/2004 S 7	20,999,000	0.5299	166.185	1140.24	3.0
Kari	22,089,000	0.4770	156.271	1230.97	3.5*
S/2006 S3	22,096,000	0.3979	158.288	1227.21	3*
Fenrir	22,454,000	0.1363	164.955	1260.35	2.0
Surtur	22,704,000	0.4507	177.545	1297.36	3*
Ymir	23,040,000	0.3349	173.125	1315.14	9
Loge	23,058,000	0.1856	167.872	1311.36	3*
Fornjot	25,146,000	0.2066	170.434	1494.20	3.0

Table 15. Mean equatorial orbital elements and sizes of *Uranus' small inner satellites* at epoch (1) 1986 Jan. 19.50 TT or (2) 2004 Aug. 25.50 TT. a is the semi-major axis, e the eccentricity, ω the argument of pericenter, M the mean anomaly, i the inclination, and Ω the longitude of ascending node. P is the sidereal orbital period and R is the mean radius. References: [08JPL, 07Sei] and *[08She].

satellite	a [km]	e	ω [deg]	M [deg]	i [deg]	Ω [deg]	P [days]	R [km]
Cordelia (1)	49,800	0.0003	136.827	254.805	0.085	38.374	0.335	20.1 ± 3
Ophelia (1)	53,800	0.0099	17.761	116.259	0.104	164.048	0.376	21.4 ± 4
Bianca (1)	59,200	0.0009	8.293	138.486	0.193	93.220	0.435	$25.7 \pm 2.$
Cressida (1)	61,800	0.0004	44.236	233.795	0.006	99.403	0.464	39.8 ± 2
Desdemona (1)	62,700	0.0001	183.285	184.627	0.113	306.089	0.474	32.0 ± 4
Juliet (1)	64,400	0.0007	223.819	244.696	0.065	200.155	0.493	46.8 ± 4
Portia (1)	66,100	0.0001	222.433	218.312	0.059	260.067	0.513	67.6 ± 4
Rosalind (1)	69,900	0.0001	140.477	136.181	0.279	12.847	0.558	$36. \pm 6$
Cupid (2)	74,392	0.0013	247.608	163.830	0.099	182.793	0.613	5*
Belinda (1)	75,300	0.0001	42.406	357.224	0.031	279.337	0.624	40.3 ± 8
Perdita (2)	76,417	0.0116	253.925	192.405	0.470	309.376	0.638	10*
Puck (1)	86,000	0.0001	177.094	245.796	0.319	268.734	0.762	$81. \pm 2.$
Mab (1)	97,736	0.0025	249.565	273.769	0.134	350.737	0.923	5*

Table 16. Mean semi-major axis a, mean eccentricity e, mean inclination i (referred to the local Laplace planes), orbital period P and radii R of *Uranus' irregular satellites* at epoch 2004 Jul. 14.00 TT. The declination, Dec., and right ascension, R.A., of the Laplace plane's pole are given with respect to the ICRF. Tilt is the angle between the planet equator and the Laplace plane. Reference: [08JPL] and references therein.

satellite	a [km]	e	i [deg]	P [days]	R [km]	R.A. [deg]	Dec. [deg]	Tilt [deg]
S/2001 U 3	4,276,000	0.1459	145.220	266.56	6	276.911	64.927	98.522
Caliban	7,231,000	0.1587	140.881	579.73	49	277.436	64.637	98.722
Stephano	8,004,000	0.2292	144.113	677.36	10	272.003	66.170	97.916
Trinculo	8,504,000	0.2200	167.050	749.24	5	271.873	66.318	97.786
Sycorax	12,179,000	0.5224	159.404	1288.30	95	272.154	66.466	97.615
S/2003 U 3	14,345,000	0.6608	56.630	1687.01	6	272.570	65.736	98.278
Prospero	16,256,000	0.4448	151.966	1978.29	15	271.470	66.399	97.747
Setebos	17,418,000	0.5914	158.202	2225.21	15	272.151	66.317	97.759
S/2001 U 2	20,901,000	0.3682	169.840	2887.21	6	271.934	66.322	97.776

Table 17. Mean semi-major axis a, mean eccentricity e, mean inclination i, sidereal orbital period P and radii R of *Neptune's small inner satellites* at epoch 1989 Aug 18 0.50 TT, referred to the local Laplace planes. The declination, Dec., and right ascension, R.A., of the Laplace plane's pole are given with respect to the ICRF. Tilt is the angle between the planet equator and the Laplace plane. Reference: [08JPL] and references therein.

satellite	a [km]	e	i [deg]	P [days]	R [km]	R.A. [deg]	Dec. [deg]	Tilt [deg]
Naiad	48,227	0.0004	4.746	0.294	$33. \pm 3.$	299.431	42.940	0.448
Thalassa	50,075	0.0002	0.209	0.311	$41. \pm 3.$	299.431	42.939	0.449
Despina	52,526	0.0002	0.064	0.335	$75. \pm 3.$	299.431	42.937	0.451
Galatea	61,953	0.0000	0.062	0.429	$88. \pm 4.$	299.430	42.925	0.462
Larissa	73,548	0.0014	0.205	0.555	$97. \pm 3.$	299.429	42.897	0.490

Table 18. Mean semi-major axis a, mean eccentricity e, mean inclination i (referred to the ecliptic), and sidereal orbital period P of *Neptune's small outer satellites* at epoch 2003 Jun. 10.00 TT. Orbital elements are referred to the ecliptic plane. The mean radii of these objects range between 20 and 30 km. Reference: [08JPL] and references therein.

satellite	a [km]	e	i [deg]	P [days]
Halimede	16,611,000	0.2646	112.712	1879.08
Sao	22,228,000	0.1365	53.483	2912.72
Laomedeia	23,567,000	0.3969	37.874	3171.33
Psamathe	48,096,000	0.3809	126.312	9074.30
Neso	49,285,000	0.5714	136.439	9740.73

Table 19. Mean semi-major axis a, mean eccentricity e, and sidereal orbital period P of *dwarf planet satellites*. With inclinations of about 0.2 deg referred to Charon's mean orbital plane, all three satellites of Pluto lie almost in the same plane. Assuming the density of Charon for Nix and Hydra, the radii of the latter are estimated to be 88 and 72 km, respectively. Assuming the albedo of Eris for Dysnomia, the radius of the latter is estimated to be 75 km. References: [08JPL, 05Bro, 08Bro, 08Gre, 08Tho, 06Bar, 09Rag]. More data on Charon can be found in Table 7 and Table 8.

satellite	primary	a [km]	e	P [days]
Charon	Pluto	17,536	0.0022	6.387
Nix	Pluto	48,708	0.0030	24.8562 ± 00013
Hydra	Pluto	64,749	0.0052	38.2065 ± 0.0014
Dysnomia	Eris (2003 UB_{313})	$37,350 \pm 140$	≈ 0	15.774 ± 0.002
Namaka	Haumea (2003 EL_{61})	$\approx 25,660$	0.25	18.3
Hi'iaka	Haumea (2003 EL_{61})	$\approx 49,880$	≈ 0.05	49.4

Table 20. The rings of *Jupiter*. R is the radius, D the optical depth, A the albedo, and S the surface density [08NSS].

	R [km]	D	A	S [kg m^{-2}]
Jupiter equator	71,492			
Halo	100,000 - 122,000	3×10^{-6}		
Main	122,000 - 129,000	5×10^{-6}	0.015	5×10^{-5}
Gossamer (inner)	129,000 - 182,000	1×10^{-7}		
Gossamer (outer)	182,000 - 224,900			

Table 21. The rings of *Saturn*. R is the radius, D the optical depth, A the albedo, T the thickness, S the surface density, and e the eccentricity [08NSS].

	R [km]	D	A	T [m]	S [kg m^{-2}]	e
Saturn equator	60,268					
D inner edge	66,900					
D outer edge	74,510					
C inner edge	74,658	0.05 - 0.10	0.12 - 0.30	5	14 - 50	
Titan ringlet	77,871				170	0.00026
Maxwell gap/ringlet	87,491				170	0.00034
C outer edge	92,000	0.12	0.2	5	20 - 70	
B inner edge	92,000	0.4 - 2.5	0.4 - 0.6	5 - 10	200 - 1000	
B outer edge	117,580	1.8				
Cassini divison		0.05 - 0.15	0.2 - 0.4	20	180 - 200	
A inner edge	122,170	0.4 - 1.0	0.4 - 0.6	10 - 30	300 - 400	
Encke gap	133,589					
A outer edge	136,775	0.6	0.4 - 0.6	10 - 30	200 - 300	
F ring center	140,180	0.1	0.6			0.0026
G inner edge	170,000	1×10^{-6}		10^5		
G outer edge	175,000					
E inner edge	181,000	1.5×10^{-5}		10^7		
E outer edge	483,000			10^7		

Table 22. The rings of *Uranus*. R is the radius, D the optical depth, A the albedo, W the width, and e the eccentricity [08NSS].

	R [km]	D	A	W [km]	e
Uranus equator	25,559				
6	41,837	0.3	0.015	1.5	0.0010
5	42,234	0.5	0.015	2	0.0019
4	42,571	0.3	0.015	2	0.0011
Alpha	44,718	0.4	0.015	4 - 10	0.0008
Beta	45,661	0.3	0.015	5 - 11	0.0004
Eta	47,176	0.4	0.015	1.6	
Gamma	47,627	0.3	0.015	1 - 4	0.0011
Delta	48,300	0.5	0.015	3 - 7	0.00004
Lambda	50,024	0.1	0.015	2	0.
Epsilon	51,149	0.5 - 2.3	0.018	20 - 96	0.0079

Table 23. The rings of *Neptune*. R is the radius, D the optical depth, A the albedo, and W the width [08NSS].

	R [km]	D	A	W [km]
Neptune equator	24,764			
Galle (1989N3R)	41,900	0.00008	0.015	2000
LeVerrier (1989N2R)	53.200	0.002	0.015	110
Lassell (1989N4R)	53.200	0.00015	0.015	4000
Unnamed	61,950			
Adams (1989N1R)	62,933	0.0045	0.015	50
Arcs in Adams Ring				
Courage	62,933	0.12		15
Liberté	62,933	0.12		15
Egalité 1	62,933	0.12	0.040	15
Egalité 2	62,933	0.12	0.040	15
Fraternité	62,933	0.12		15

Acknowledgments: We thank Stefanie Hempel for invaluable help in preparing the tables and Tilman Spohn for constructive comments on the manuscript.

4.2.2.6 References for 4.2.2

92Sei Seidelmann, P.K.: editor, Explanatory Supplement to the Astronomical Almanac, University Science Books, Mill Valley, CA, USA, 1992.

92Sta Standish, E.M, et al.: In: Seidelmann, P.K., editor, Explanatory Supplement to the Astronomical Almanac, University Science Books, Mill Valley, CA, USA, 1992.

95Yod Yoder, C.F.: In: Ahrens, T., editor, Global Earth Physics. A handbook of physical constants, pages 1-31, American Geophysical Union, Washington, 1995.

98Fei Feissel, M., Mignard, F.: Astr. Astrophys. **331** (1998) L33-L36.

99Mur Murray, C.D., Dermott, S.F.: Solar System Dynamics, Cambridge University Press, Cambridge 1999.

02Sei Seidelmann, P.K., Kovalevsky J.: Astr. Astrophys. **392** (2002) 341-351.

05Bro Brown, M.E., Trujillo, C.A., Rabinowitz, D.L.: Astrophys. J. **635** (2005) L97-L100.

05IAU IAU Circular No. 8524 (2005).

05Tho Thomas, P.C. et al.: Nature **437** (2005) 224-226.

06Bar Barkume, K.M., Brown, M.E., and Schaller, E.L.: Astrophys. J. **640** (2006) L87-L89.

06Esp Esposito, L.: Planetary Rings (2006) Cambridge Univ. Press 216pp.

06Rab Rabinowitz, D.L. et al.: Astrophys. J. **639** (2006) 1238-1251.

06Sei Seidelmann, P.K. (Ed.): 2006, Explanatory Supplement to the Astronomical Almanac, University Science Books, Mill Valley, CA, USA.

06Spi Spitale, J.N. et al.: Astron. J. **132** (2006) 692-710.

07Sei Seidelmann, P.K. et al.: Celest. Mech. Dyn. Astr. **98** (2007) 155-180.

08Bro Brown, M.E.: In: Barucci, M.A., Boehnhardt, H., Cruikshank, D.P. and Morbidelli, A., editors, The Solar System beyond Neptune, pages 335-344, The University of Arizona Press, Tucson 2008.

08Coo Cooper, N.J. et al.: Icarus **195** (2008) 765-777.

08Gre Greenberg, R., Barnes, R.: Icarus **194** (2008) 847-849.

08Jon Jones, G.H. et al.: Science **319** (2008) 1380-1384.

08JPL JPL Solar System Dynamics website: `http://ssd.jpl.nasa.gov`, as of Dec. 2008.

08NSS NASA's National Space Science Data Center website:
`http://nssdc.gsfc.nasa.gov/planetary/`, as of Nov. 2008.

08She Sheppard, S.S.: The Giant Planet Satellite and Moon Page.
`http://www.dtm.ciw.edu/sheppard/satellites/`, as of July 2008.

08Tho Tholen, D.J. et al.: Astron. J. **135** (2008) 777-784.

09Rag Ragozzine, D., Brown, M.E.: Astron. J. (accepted), arXiv:0903.4213v1 [astro-ph.EP].