PLANETARY SATELLITES, ASTEROIDS, COMETS AND METEORS

Duncan Steel
University of Salford, UK

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Contents

Summary

The smaller bodies in the solar system are discussed in this article. Although their combined mass is tiny compared to that of the planets, asteroids, comets and meteoroids, they have important effects upon the terrestrial environment and this is the emphasis of the present article.

Asteroids, mainly rocky or metallic bodies in the inner solar system, orbit the Sun in various distinct populations (planet-crossers, main-belt asteroids, trans-Neptunian Edgeworth-Kuiper belt objects, Centaurs in the outer planetary region) between which there are transfers over substantial timescales. For example the main belt is the main reservoir replenishing the Earth-crossing asteroids, the latter being removed on timescales of 100 million years or less (i.e. shorter than the age of the solar system).

Comets arrive in the inner planetary region, where there is sufficient solar heating to cause the sublimation of part of their volatile constituents which makes them conspicuous, from more distant reservoirs: the Edgeworth-Kuiper belt and the Oort-Öpik cloud. Physical decay limits their lifetimes to a few thousand orbits, if they have perihelia sunward of Mars.

Each of the giant planets possesses an extensive number of natural satellites or moons. The larger satellites generally orbit relatively close to the planet in question, and are believed to be primordial (i.e. they either formed with the planet, or else arrived in their present orbits soon after the planet agglomerated). Larger numbers of small moons orbit further from the individual planets, and these are, in the main, gravitationally captured asteroids and comets. There is therefore a continuum of properties between the populations of asteroids, comets, and planetary satellites.

As comets decay under solar heating and other disruptive events, they produce meteoroid streams that gradually disperse into the background complex of interplanetary solid materials. Meteor showers are seen whenever the Earth passes through such a stream. The meteoroids involved are mostly smaller than about 1 cm in size. Larger fragments of rocky/metallic asteroids also arrive in Earth-crossing orbits and enter our atmosphere, and under stringent conditions it is feasible for such fragments to arrive at the surface intact, producing meteorites.

1. Introduction

The overall mass of the solar system is dominated by that of the Sun, with the planets comprising the next most significant portion. For example the largest planet, Jupiter, has a bulk only about one part in a thousand of the solar mass.

Smaller still than the planets, and so consisting of only a tiny fraction of the mass in the solar system, are what might be collectively termed the 'minor bodies.' These are the natural satellites (or moons) of the planets, the asteroids, the comets, and the even smaller detritus orbiting the Sun in the form of meteoroids and interplanetary dust.

The larger planetary satellites—the Earth's Moon, the four Galilean satellites of Jupiter (Io, Europa, Ganymede and Callisto), Saturn's Titan and Neptune's Triton—have all been described in *Comparative Planetology*.

This leaves, then, only the smallest of all the solid bodies in the solar system. As a fraction of the total mass of the Sun's family, they constitute rather less than 0.01%, although their total mass is not known because the majority of them are yet undiscovered: they orbit beyond the edge of the planetary system, making them dark and therefore difficult, if not impossible, to detect from the Earth. Nevertheless many are of substantial size. More important, those bodies that can strike our planet (Earth-crossing asteroids and comets) do not need to be especially large in order to wreak havoc, and an emphasis in this article is on how minor solar system bodies may affect the origin and evolution of life. We begin, though, with the moons that orbit the various planets.

2. Planetary satellites

Although their total mass is small, the minor bodies in the solar system are of central importance in various aspects of planetology. Each of the outer planets Jupiter, Saturn, Uranus and Neptune has a considerable constellation of moons. The inner, generally larger, satellites are thought to be primordial, in the main: that is, they either formed with the planet, or were captured into orbit around it soon thereafter. Further away from the planets, and often in planetocentric orbits which are unstable over intervals of millions to billions of years, are many tiny moons (see Figure 1) that seem to be captured asteroids and comets. Thus although we may often think of the solar system as a constant, unchanging system, in fact there are changes that occur over timescales generally longer than the history of human civilisation, but much shorter than the age of the system as a whole (about 4.6 billion years).

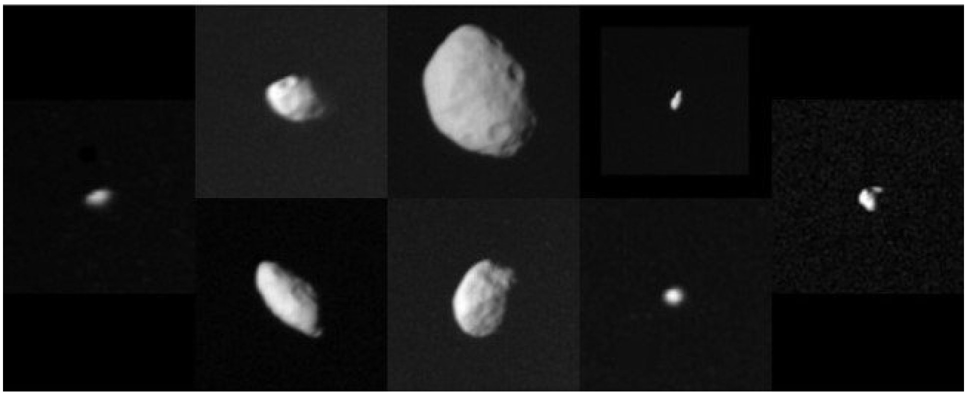

Figure1. A composite set of images of Saturn's small outer moons obtained by the Voyager 2 spacecraft in 1981, showing them at their correct relative sizes.
Source: NASA/Jet Propulsion Laboratory. Source: http://photojournal.jpl.nasa.gov/tiff/PIA01954.tif

Another example is the ring system of Saturn, which has a lifetime of the order of 100 million years, so that it has not been there since that planet agglomerated, but rather has been produced since through the break-up of one or more asteroids and/or comets passing too close to Saturn. (Note that the other giant planets—Jupiter, Uranus and Neptune—also possess extensive ring systems, although they are not as obvious as those of Saturn and have only been discovered in recent decades.) Figure 2 shows Jupiter's rings with source moons.

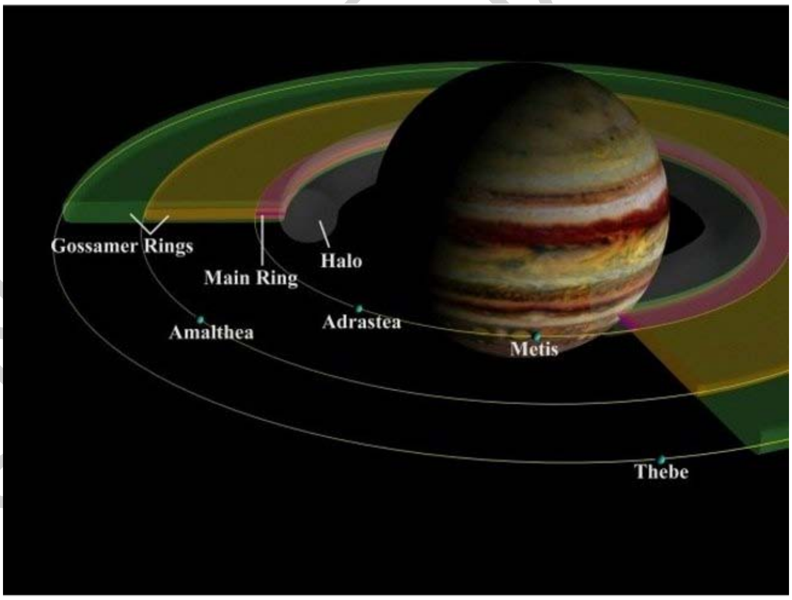

Figure 2. This schematic cut-away view of the components of Jupiter's ring system shows the geometry of the rings in relation to Jupiter and to the small inner satellites, which are the source of the dust that forms the rings.
Source: NASA/Cornell University. Source: http://photojournal.jpl.nasa.gov/tiff/PIA01627.tif

Mars is accompanied by two moons, entitled Phobos (Figure 3) and Deimos (the names mean 'fear' and 'terror'). These are actually asteroids that have been captured into orbits around this planet. Their compositions appear to be similar to carbonaceous chondrite meteorites (see sections 3 and 5 below), as is the case for about three-quarters of the asteroids in the main belt, the presumed source of these two bodies.

Table 1 lists pertinent information concerning the natural satellites of the planets. At the time of writing a total of 118 such moons are known. In the past few years the number of discovered moons has doubled, with each of the giant planets having had several small (below 20 km) moons identified by astronomers using large ground-based telescopes. It is anticipated, however, that the number could well treble over the next decade, as more distant moons ranging down to about 1 km in size are found. These small satellites are actually asteroids and comets that have been captured—often only temporarily—from heliocentric orbits. For a description of the nature of such objects, we move on to consider asteroids and comets separately in the following two sections. Note, however, that there is no clear dividing line between these bodies: many of the asteroids in the outer solar system, including those captured into planetocentric orbits, are cometary (i.e. icy) in composition and would display cometary activity (formation of a bright coma and tails) if they were to arrive in the inner solar system.

Quite apart from the major planets, it is now known that many of the minor planets (asteroids, including near-Earth asteroids) also possess satellites or moons. The first such moon to be discovered was Dactyl, a 1 km wide satellite of main-belt asteroid Ida (Figure 4, Table 2); it was serendipitously found in images returned by the Galileo spacecraft in 1993. Since then some dozens of asteroids have been shown to be accompanied by satellites in deliberate searches. In many cases the components are of similar mass, indicating that they might rather be considered to be binaries.

Figure 3. An image of Phobos obtained by the Mars Global Surveyor spacecraft in 1998. Phobos is about 21 km in size. Credit: NASA/Jet Propulsion Laboratory/Malin Space Science Systems.
Source: http://photojournal.jpl.nasa.gov/

Figure 4. Image of asteroid (243) Ida and its moon Dactyl obtained by the Galileo spacecraft in 1993. Source: NASA/Jet Propulsion Laboratory. Source: http://photojournal.jpl.nasa.gov/

Planet	Name of moon	Discovery Year	Size (km)	Distance from planet's centre (×1000 km)	Orbital Period (days)	Eccentricity	Inclination to planet's equator (degrees)
Earth	Moon	—	3,476	384	27.322	0.059	5.15 (to ecliptic)
Mars	Phobos	1877	1 × 9	9.38	0.319	0.15	1.1
	Deimos	1877	27 × 20	23.46	1.791	0.0003	1.8
Jupiter[1]	Metis	1979	60 × 35	128	0.295	0	0
	Adrastrea	1979	25 × 15	129	0.298	0	0
	Amalthea	1892	270 × 150	181	0.498	0.00	0.40
	Thebe	1979	110 × 90	222	0.675	0.02	0.8
	Io	1610	3,642	422	1.77	0.04	0.04
	Europa	1610	3,130	671	3.55	0.01	0.47
	Ganymede	1610	5,268	1,070	7.16	0.00	0.21
	Callisto	1610	4,806	1,883	16.7	0.01	0.28
	Leda	1974	15	11,170	238.7	0.15	27
	Himalia	1904	180	11,460	250.6	0.16	28
	Lysithea	1938	35	11,720	259.2	0.11	29
	Elara	1905	80	11,740	259.7	0.21	28
	Ananke	1951	30	21,280	631	0.17	147
	Carme	1938	40	22,600	692	0.21	163
	Pasiphae	1908	50	23,620	735	0.38	148
	Sinope	1914	35	23,940	758	0.28	153
Saturn[2]	Pan	1990	20	134	0.575	0	0
	Atlas	1980	40 × 30	138	0.602	0.003	0
	Prometheus	1980	150 × 70	139	0.613	0.002	0
	Pandora	1980	110 ×	142	0.629	0.004	0

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	Epimetheus	1978	140 × 105	151	0.695	0.009	0.34
	Janus	1980	200 × 150	151	0.695	0.007	0.14
	Mimas	1789	400	186	0.942	0.020	1.53
	Enceladus	1789	500	238	1.37	0.004	0.02
	Tethys	1684	1,060	295	1.89	0.000	1.09
	Telesto	1980	30 × 20	295	1.89	0	0
	Calypso	1980	30 × 15	295	1.89	0	0
	Dione	1684	1,120	377	2.74	0.000	0.02
	Helene	1980	32	377	2.74	0.01	0.2
	Rhea	1672	1,528	527	4.52	0.00	0.35
	Titan	1655	5,150	1,222	15.95	0.03	0.33
	Hyperion	1848	370 × 225	1,481	21.3	0.10	0.43
	Iapetus	1671	1,140	3,561	79.3	0.03	7.5
	Phoebe	1898	230 × 210	12,940	550.5	0.16	175.3
Uranus[3]	Cordelia	1986	25	50	0.335	0.0	0.08
	Ophelia	1986	30	54	0.376	0.01	0.10
	Bianca	1986	45	59	0.435	0.001	0.19
	Cressida	1986	65	62	0.464	0.0	0.01
	Desdemona	1986	60	63	0.474	0.0	0.11
	Juliet	1986	85	64	0.493	0.001	0.07
	Portia	1986	110	66	0.513	0.0	0.06
	Rosalind	1986	60	70	0.558	0.0	0.28
	Belinda	1986	70	75	0.624	0.0	0.0
	Puck	1985	154	86	0.762	0.0	0.03
	Miranda	1948	235	130	1.41	0.003	4.22
	Ariel	1851	580	191	2.52	0.003	0.31
	Umbriel	1851	1170	266	4.14	0.005	0.36
	Titania	1787	1580	436	8.71	0.002	0.10
	Oberon	1787	1520	583	13.5	0.001	0.10
	Caliban	1997	60	7,230	579	0.082	139.7
	Sycorax	1997	120	12,180	1,289	0.509	152.7
Neptune[4]	Naiad	1989	60	48	0.294	0.0	4.7
	Thalassa	1989	80	50	0.312	0.0	0.2
	Despina	1989	150	53	0.335	0.0	0.1
	Galatea	1989	160	62	0.429	0.0	0.1
	Larissa	1989	210x180	74	0.555	0.01	0.2
	Proteus	1989	440x400	118	1.12	0.0	0.6
	Triton	1846	2,706	355	5.88	0.000	0.0156.8
	Nereid	1949	340	5,513	360.1	0.751	7.0
Pluto	Charon	1978	1250	19.6	6.39	0.01	0.0

Notes:

(1) In addition to the 16 moons of Jupiter listed here, through to April 2003 another 36 natural satellites had been detected, mostly very small bodies near the outermost moons given above. Jupiter also possesses a ring system.

(2) As note 1, but an additional 12 small moons of Saturn are known. Saturn also possesses an extensive ring system made up of a large number of tiny satellites composed of rock and ice.

(3) As note 1, but an additional four small moons of Uranus are known, plus a ring system.

(4) As note 1, but an additional three small moons of Neptune are known, plus a ring system.

Table 1. Planetary satellites

Number	Name	Year of discovery	Size (km)	Albedo	Orbital period (years	Rotation period (hours)	Notes
1	Ceres	1801	933	0.11	4.60	9.1	First discovered/largest main-belt asteroid.
2	Pallas	1802	526	0.16	4.61	7.8	Second-largest main-belt asteroid.
3	Juno	1804	288	0.24	4.36	7.2	Eighth-largest main-belt asteroid.
4	Vesta	1807	510	0.42	3.63	5.3	Brightest/third largest main-belt asteroid.
5	Astraea	1845	117	0.23	4.13	16.8	Fifth discovered asteroid
6	Hebe	1847	186	0.27	3.78	7.3	Sixth discovered asteroid
7	Iris	1847	200	0.28	3.68	7.1	Seventh discovered asteroid
10	Hygiea	1849	408	0.07	5.55	28	Fourth-largest main-belt asteroid.
52	Europa	1858	302	0.06	5.46	5.6	Seventh-largest main-belt asteroid.
216	Kleopatra	1880	217	0.12	4.66	5.4	Radar indicates dog's bone shape.
243	Ida	1884	56	0.24	4.85	4.6	Target of *Galileo* fly-by in 1993.
253	Mathilde	1885	55	0.04	4.31	418	*NEAR-Shoemaker* fly-by in 1997.
511	Davida	1903	326	0.05	5.65	5.1	Fifth-largest main-belt asteroid.
704	Interamnia	1910	316	0.07	5.36	8.7	Sixth-largest main-belt asteroid.
951	Gaspra	1916	18	0.20	3.28	7.0	Target of *Galileo* fly-by in 1991.

Table 2. Notable main-belt asteroids

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Biographical Sketch

When this article was written, **Dr Duncan Steel,** was Reader in Space Technology at the University of Salford in England. After an education at the University of London, Steel worked at the University of Colorado in the USA and then received his Ph.D. from the University of Canterbury in New Zealand in 1984. From 1985 to 1999 he worked in Australia, mainly at the University of Adelaide and the Anglo-Australian Observatory, except for a year at the University of Lund in Sweden. His research is centered on the small bodies in the solar system: radar observations of meteors, telescopic tracking of asteroids, and dynamical studies of the evolution of such bodies. Steel is the author of 130 scientific papers, some hundreds of newspaper and magazine articles, and four popular-level books. He has also appeared in numerous documentaries on TV and radio.