4.3 Small bodies of the Solar System

4.3.1 The asteroids

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4.3.1.1 Asteroid discoveries

Asteroids are rocky bodies orbiting the Sun with diameters of up to about 1000 km, most of which are found in the asteroid belt with semi-major axes from about 2 to 3.5 AU. In contrast to comets asteroids do not normally display comas or tails. As of December 2008 there were about 200000 numbered asteroids. The rate of discovery of asteroids increased dramatically in the 1990s with the availability of sophisticated CCD detectors and powerful computers. Telescope search programs can now cover large areas of sky in one night and scan large amounts of image data automatically for the presence of moving objects. The search programs are largely motivated by the hunt for near-Earth asteroids but the number of near-Earth detections is very small compared to the number of main-belt detections in the same period (around 1%).

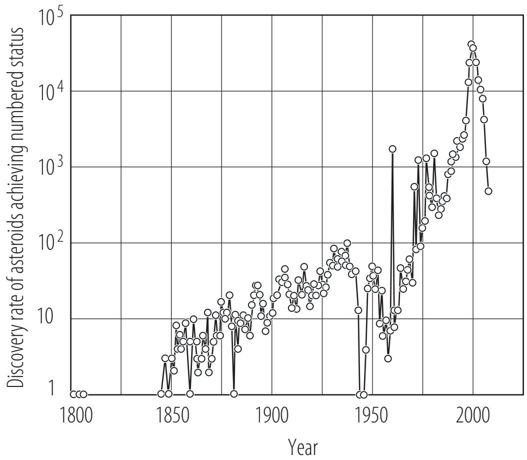

Fig. 1. Numbered Asteroids Discovered/Year (data from the Minor Planet Center, http://www.cfa.harvard.edu/iau/lists/NumberedPerYear.html). Note that the reduction in discovery rate after 2000 is due to the fact that many asteroids discovered since have not yet been assigned numbers.

4.3.1.2 Dynamical groupings

Asteroids are grouped according to the dynamical characteristics of their orbits. The list in Table 1 is not exhaustive: there are further groups and sub-groups distinguished by particular combinations of orbital elements. The common term "near-Earth asteroids" (NEAs) includes the Amors, Apollos, Atens, and IEOs. NEAs are of special interest due to their accessibility for space missions and the potential of some members of the population to collide with the Earth (Potentially Hazardous Asteroids – see Table 4). The listed approximate numbers of known objects are valid as of December 2008; these numbers increase rapidly with time as new objects are discovered. For more details and updates see the Minor Planet Center web site: http://www.cfa.harvard.edu/iau/mpc.html.

Table 1. Important dynamical groups.

Name	Semi-major axis [AU]	No. known	Notes
Trans-Neptunian objects (TNOs)[1]	> 30	1248	First TNO, 15760 (1992 QB_1), was discovered in August 1992[3].
Centaurs	5.2 - 30	87	Possibly TNOs whose orbits have been perturbed by Neptune.
Jupiter Trojans	5.05 - 5.4	2910	Associated with the Lagrangian points of Jupiter's orbit.
Main-belt	2.0 - 3.5	4.3×10^5	2.0×10^5 *numbered* asteroids.
Amors[2]	> 1	2480	1.017 < Perihelion ≤ 1.3 AU.
Apollos[2]	≥ 1	2880	Perihelion ≤ 1.017 AU.
Atens[2]	< 1	487	Aphelion ≥ 0.983 AU.
Inner Earth Objects[2]	< 1	10	Aphelion < 0.983 AU.

[1]The term TNO includes Kuiper Belt objects and associated scattered-disk objects; these and the Centaurs are icy bodies which may have much in common with comet nuclei. [2]The orbital characteristics of the different classes of NEAs are defined with respect to the Earth's perihelion (0.983 AU) and aphelion (1.017 AU) distances. [3]IAU Circular No. 5611 (1992 September 14).

4.3.1.3 Asteroid taxonomy

Asteroids are grouped into taxonomic or spectral classes according to features observed in their visible reflection spectra (Table 2). Some classification systems include geometric albedo as a classifying parameter. For example, E, M, P, and X type objects all have very similar featureless spectra. Asteroids are classified as X if the absence of observed spectral features precludes assignment to another taxonomic class. However, measurement of the object's albedo may allow refinement of an X type classification to an E, M, or P type, depending on whether the albedo is high, medium, or low, respectively. Taxonomic classification is not an exact science; published taxonomic types of asteroids may be subsequently refined or corrected in the light of better observational data or new taxonomic schemes. For a review see [02Bus2].

4.3.1.4 Near-Earth asteroids and potentially hazardous asteroids

Near-Earth asteroids
Interest in the population of NEAs has increased rapidly in recent years due to the realization that NEAs have influenced the course of evolution via dramatic impacts on the Earth and now constitute a threat to the long-term future of civilization. On the other hand, they contain resources of benefit to future space explorers, such as water and metals, and are relatively easy to reach with space missions. NEAs are becoming increasingly popular as targets for rendezvous missions and promise to provide a wealth of information about the formation and development of the planets. Physical properties of the largest NEAs are given in Table 3.

Table 2. Important asteroid taxonomic (spectral) classes.

Class	Probable mineralogy	Associated geometric albedo[1] (p_v) range	Approx. % of all classified asteroids[2]
D, P	Carbon, organic-rich silicates	0.03 - 0.06	2
C, B	Carbon, organics, hydrated silicates	0.03 - 0.1	30
M	Fe, Ni, enstatite	0.1 - 0.2	2
S	Olivine, pyroxene, metals	0.1 - 0.3	40
Q	Olivine, pyroxene, metals	0.2 - 0.5	1
V	Pyroxene, feldspar	0.2 - 0.5	3
E	Enstatite, other Fe-poor silicates	0.3 - 0.6	1
X	Unknown (signifies otherwise unclassifiable featureless spectrum)	0.03 - 0.6	15

[1]The geometric albedo p_v is the ratio of a body's (V-band) brightness at zero phase angle to the brightness of a perfectly diffusing (Lambertian) disk with the same position and apparent size as the body. [2]Estimated from the data of [02Bus1] and [89Tho].

Table 3. Physical properties of the largest near-Earth asteroids.

NEA	Diameter[1] [km]	Abs. magn. H^2 [mag]	Albedo, p_v	Spectral class	Orbital type	Data source for diam., p_v
1036 Ganymed	38.5	9.50	0.17	S	Amor	89Vee
3552 Don Quixote	18.7	13.0	0.02	D	Amor	89Vee
433 Eros	16.8	11.16	0.23	S	Amor	02Che, 04Li
4954 Eric	9.5	12.6	-	S	Amor	
1627 Ivar	9.1	12.9	0.15	S	Amor	03Del
1866 Sisyphus	8.5	13.0	0.15	S	Apollo	03Del
1980 Tezcatlipoca	5.7	13.9	0.15	S	Amor	99Har
1917 Cuyo	5.2	14.7	-	S	Amor	
5332 Davidaguilar	5.2	14.89	-	S	Amor	
3200 Phaethon	5.1	14.5	0.11	B, F	Apollo	98Har
1580 Betulia	5.0	15.1	0.07	C	Amor	05Har, 07Mag
5143 Heracles	5.0	14.0	-	O, S	Apollo	
5131 1990 BG	4.7	14.1	-	S	Apollo	
4183 Cuno	4.5	14.4	-	Q, S	Apollo	
7092 Cadmus	4.5	15.4	-	C	Apollo	
7358 Oze	4.5	14.4	-	S	Amor	
16960 1998 QS_{52}	4.3	14.3	-	S	Apollo	
887 Alinda	4.2	13.83	0.23	S	Amor	89Vee
52762 1998 MT_{24}	4.0	14.8	-	X	Apollo	

[1]Effective diameter = diameter of a sphere with the same projected area as the lightcurve-averaged projected area of the asteroid. Where no albedo is available the following taxonomic-class-dependent values have been assumed to estimate the diameter from H, the absolute magnitude: S, X, 0.2; C, 0.05. [2]Absolute magnitude is defined as the time-averaged magnitude calculated for a solar phase angle of 0° and heliocentric and geocentric distances of 1 AU. In some cases H values have been taken from the sources quoted in the final column, otherwise from the European Asteroid Research Network Database of Physical and Dynamical Properties of NEAs (http://earn.dlr.de/nea).

Potentially hazardous asteroids

The term potentially hazardous asteroid (PHA) refers to an asteroid with an absolute magnitude, H, of 22.0 or brighter, corresponding to a diameter of about 120 m or larger, and an Earth minimum orbit intersection distance (MOID) of 0.05 AU or less. A PHA is large enough to survive passage through the Earth's atmosphere and cause extensive damage on impact. As of December 2008 the number of known PHAs was 1010. Some currently predicted close approaches of PHAs to the Earth are listed in Table 4.

Table 4. Close approaches[1] of potentially hazardous asteroids within 3 lunar distances 2009 - 2178.

Asteroid no.	Name	Date	Minimum distance/lunar distance	Abs. mag. *H* [mag]	Approx. diameter[2] [m]	Data sources
99942	Apophis	2029 Apr. 13.91	0.09	19.2	270	Diam. 07Del
85640	1998 OX4	2148 Jan. 22.14	0.77	21.2	170	
137108	1999 AN10	2027 Aug. 7.29	1.02	17.9	780	
35396	1997 XF11	2136 Oct. 28.49	1.06	17.1	1060	H, diam. 04Del
	2001 GQ2	2100 Apr. 27.71	1.31	20.1	280	
	2002 AW	2103 Oct. 6.90	1.99	20.8	210	
	1999 MN	2137 June 4.26	2.11	21.4	160	
4660	Nereus	2166 Feb. 12.13	2.15	18.7	330	H, diam. 03Del
2340	Hathor	2086 Oct. 21.67	2.20	19.2	430	
	2002 AW	2132 Oct. 6.39	2.21	20.8	210	
35396	1997 XF11	2028 Oct. 26.28	2.40	16.9	1240	H, diam. 04Del
	1996 RG3	2096 Feb. 29.69	2.44	18.5	590	
27002	1998 DV9	2160 Jan. 31.27	2.53	18.2	680	
2340	Hathor	2069 Oct. 21.35	2.53	19.2	430	
	2002 AJ129	2172 Feb. 8.37	2.61	18.5	590	
	1999 MN	2110 June 4.43	2.61	21.4	160	
	2000 QK130	2145 Mar. 16.86	2.83	20.6	230	
	2007 TU24	2168 Jan. 25.85	2.94	20.3	260	

[1]Selected data from the extensive list of close approaches of PHOs maintained by the Minor Planet Center: http://www.cfa.harvard.edu/iau/lists/PHACloseApp.html. This table includes objects with multi-opposition arcs (as of December 2008) only. Consult the Minor Planet Center for updates. [2]The conversion of H to diameter assumes a typical geometric albedo of $p_v = 0.2$, except where measurements are available as indicated in the final column.

4.3.1.5 Asteroid families

Main-belt asteroid families are thought to result from catastrophic collisions and are identified dynamically on the basis of clustering of proper orbital elements (Table 5). For a review see [06Nes].

Table 5. Largest asteroid families.

Asteroid after which family is named	Proper orbital elements[1]			Approx. no. of members/total main-belt asteroids [%][2]		Dominant taxonomic class(es)[3]
	Semi-major axis [AU]	Eccentricity	Inclination [sin i]	(a)	(b)	
4 Vesta	2.361	0.099	0.111	2	5	V
8 Flora	2.201	0.144	0.093	5	6	various
10 Hygiea	3.142	0.135	0.088	1	1	C, B
15 Eunomia	2.644	0.148	0.226	3.5	3.5	S
20 Massalia	2.409	0.162	0.025	0.5	1	S, C ?
24 Themis	3.134	0.152	0.019	4.5	2	C, B
44 Nysa	2.423	0.174	0.053	3	4.5	C, S
145 Adeona	2.673	0.169	0.203	0.5	0.5	C
158 Koronis	2.869	0.045	0.038	2.5	2	S
163 Erigone	2.367	0.210	0.083	0.5	0.5	C, X
170 Maria	2.554	0.101	0.259	0.5	1.5	S
221 Eos	3.012	0.077	0.173	4	4	various
668 Dora	2.797	0.198	0.136	0.5	0.5	C
1272 Gefion	2.784	0.129	0.157	0.7	1	S

[1]Proper elements of the asteroids in the first column are from the NASA Planetary Data System catalog (EAR_A_5_DDR_PROPER_ELEMENTS_V1_0). [2]Due to blending of the families with background asteroids in orbital element space the number of members is not accurately known. This column gives an idea of the relative sizes of the families from (a) the ratio of the number of asteroids within the nominal quasi-random level distance for each family, as defined by [97Zap], to the total number (12487) in the database searched by [97Zap] (see also [95Zap]), and (b) a more recent study based on a data set of 106284 main-belt asteroids [05Nes]. [3]Taxonomic classes are from [05Mot] and [05Nes].

4.3.1.6 Asteroids with satellites and asteroid densities

Asteroids with satellites

One of the most significant recent developments in asteroid research is the discovery that many asteroids have companions. The first binary asteroid to be discovered is the 243 Ida/Dactyl system. The small moon Dactyl (diameter ~ 1 km) was found in images taken during the fly-by of Ida by the Galileo spacecraft in August 1993. Since then some 150 multiple asteroid systems have been discovered or inferred by means of various techniques, including direct imaging, adaptive optics observations, occultation, radar, and lightcurve observations (Table 6). The discovery of binary asteroids is of great significance for a number of reasons. Knowledge of the orbit of a moon about the primary asteroid enables the primary's mass to be calculated via Kepler's third law; if the size of the primary is known, its density, a fundamental parameter reflecting the composition and structure of the body, can then be calculated (see following section on asteroid bulk densities). Proposed mechanisms for the formation of multiple asteroid systems usually involve partial break up of a parent object, either via a collision, tidal disruption during a close encounter with a planet, or rotational fission. Whereas planets can acquire moons by gravitational capture, this mechanism is considered an unlikely candidate for small Solar System bodies, with the possible exception of TNOs. For a review see [06Nol].

Table 6. Numbers of asteroids with satellites.

Object type	Number of multiple systems known or suspected as of Dec. 2008	Notes
Near-Earth asteroids	35	Excludes 7 binary Mars crossers.
Main-belt asteroids	62	Incl. 45 Eugenia, 87 Sylvia, and 216 Kleopatra with 2 moons each.
Jupiter Trojans	2	
Trans-Neptunian objects	56	Incl. Pluto with 3 companions and 136108 Haumea with 2.

Data sources: W. R. Johnston (2009, http://www.johnstonsarchive.net/astro/asteroidmoons.html). P. Pravec et al. (2007, http://www.asu.cas.cz/~asteroid/binastdata.htm).

Asteroid bulk densities

Bulk densities provide important insight into the composition and inner structure of asteroids. With the exception of the largest asteroids, the carbonaceous C, F, and P types tend to have relatively low densities, possibly due to high porosity. Asteroid sizes can be determined from spacecraft, thermal-infrared measurements (see [02Har] for a review), radar observations (e.g. [02Ost]), polarimetry (e.g. [07Del]), and occultation observations (e.g. [90Dun]). There are various methods of determining asteroid masses (see [02Brit] for a review): measurement of the asteroid's gravity field by means of 1. a spacecraft, 2. observations of the perturbations of the orbits of other asteroids or Mars (applicable to large asteroids only), 3. observations of a satellite or companion asteroid by means of optical observations with adaptive optics (AO), or radar observations, 4. modeling of an eclipsing/occulting binary system from information contained in its optical lightcurve. Whereas the first two methods can yield high accuracy, the accuracy of the latter two methods is relatively low. Relatively insecure estimates have been excluded from Table 7.

Table 7. Asteroid bulk densities.

Asteroid	Orbital type[1]	Spectral type	Binary Y/N?	Diameter[2] [km]	Bulk density[3] [g cm^{-3}]	Method[4]	Source[5]
1 Ceres	MB	G	N	949 ± 12	2.12 ± 0.04	GP	
2 Pallas	MB	B	N	530 ± 10	2.71 ± 0.11	GP	
4 Vesta	MB	V	N	530 ± 10	3.44 ± 0.12	GP	
10 Hygiea	MB	C	N	407 ± 7	2.76 ± 1.2	GP	
11 Parthenope	MB	S	N	153 ± 3	2.72 ± 0.12	GP	
15 Eunomia	MB	S	N	255 ± 15	0.96 ± 0.3	GP	
16 Psyche	MB	M	N	253 ± 4	2.0 ± 0.6	GP	
20 Massalia	MB	S	N	145 ± 10	3.26 ± 0.6	GP	
22 Kalliope	MB	M	Y	166 ± 3	3.35 ± 0.33	AO	08Des
45 Eugenia	MB	F, C	Y	215 ± 15	1.1± 0.1	AO	08Mar1
87 Sylvia	MB	X, P	Y	286 ± 12	1.2 ± 0.1	AO	05Mar1
90 Antiope	MB	C	Y	87.8 ± 1	1.25 ± 0.05	AO	07Des
107 Camilla	MB	X, C	Y	250 ± 20	1.4 ± 0.3	AO	08Mar1
121 Hermione	MB	C	Y	210 ± 5	1.1 ± 0.3	AO	05Mar2
130 Elektra	MB	G	Y	215 ± 15	1.3 ± 0.3	AO	08Mar2
243 Ida	MB	S	Y	31.4 ± 1.2	2.6 ± 0.5	Spacecraft	
253 Mathilde	MB	C	N	53.0 ± 2.6	1.3 ± 0.2	Spacecraft	
283 Emma	MB	X, P	Y	160 ± 10	0.7 ± 0.2	AO	08Mar2
379 Huenna	MB	C	Y	95 ± 10	0.85 ± 0.15	AO	08Mar2
433 Eros	Amor	S	N	16.85 ± 0.10	2.67 ± 0.03	Spacecraft	02Che
617 Patroclus	Trojan	P	Y	122 ± 4	0.8 ± 0.2	AO	06Mar
704 Interamnia	MB	F	N	317 ± 6	4.4 ± 2.1	GP	
762 Pulcova	MB	F, C	Y	140 ± 3	0.9 ± 0.1	AO	08Mar1
804 Hispania	MB	P, C	N	157 ± 6	5.0	GP	
854 Frostia	MB	-	Y	12 ± 6	0.9 ± 0.2	Lightcurve	06Beh
1089 Tama	MB	S	Y	9 ± 1	2.5 ± 0.4	Lightcurve	06Beh
1313 Berna	MB	-	Y	14 ± 6	1.25 ± 0.2	Lightcurve	06Beh
3749 Balam	MB	S	Y	~ 6.6	2.6	AO	08Mar2
4492 Debussy	MB	-	Y	8 ± 3	0.9 ± 0.1	Lightcurve	06Beh
5381 Sekhmet	Aten	V	Y	1.0 ± 0.1	1.98 ± 0.65	Lightcurve	03Nei
25143 Itokawa	Apollo	S	N	0.327 ± 0.005	1.9 ± 0.13	Spacecraft	06Fuj
66391 1999 KW_4	Aten	S	Y	1.3 ± 0.04	2.0 ± 0.25	Radar	06Ost
1996 FG_3	Apollo	C	Y	1.8 ± 0.4	1.4 ± 0.3	Lightcurve	00Mot
2002 CE_{26}	Apollo	-	Y	3.46 ± 0.4	0.9	Radar	06She

[1]MB = main belt; Trojan = Jupiter Trojan asteroid. [2]In the case of binaries the diameter of the primary asteroid is given. [3]Where no uncertainties are given the density is an estimate to an accuracy of about 50%. [4]AO = adaptive optics imaging; GP = gravitational perturbations analysis. [5]Data are from the compilations of [02Bri] and [02Mer] and references therein, except where indicated in the "Source" column.

4.3.1.7 Asteroids with comet-like characteristics

The difference between asteroids and comets is not always obvious. There are a number of objects classed as near-Earth asteroids that appear to have dynamical and physical characteristics in common with comets, or at least comet nuclei. These objects may be the remnants of once active comets that are currently unable to release coma-producing volatile material and dust, possibly due to depletion after many passages through perihelion or the formation of a non-volatile crust blanketing remnant icy material. Such objects appear in telescope images as asteroids, i.e. they lack the coma and tail characteristic of comets. It appears that some 10% of near-Earth “asteroids” have a cometary origin (for a review see [02Wei]). Conversely, examples have arisen recently of objects *in the main asteroid belt* displaying comet-like activity, a phenomenon for which there is currently no generally accepted explanation [06Hsi]. It is widely accepted that objects in the outer Solar System, i.e. Centaurs, TNOs, and members of the Oort cloud population, are icy bodies with physical characteristics similar to those of comet nuclei. These bodies can evolve dynamically over long timescales into eccentric orbits that bring them into the inner Solar System, where they become activated by proximity to the Sun and appear as comets. Table 8 lists a selection of comet-like asteroids.

Table 8. Selected objects with asteroid designations having comet-like characteristics.

Object	Orbital type	Semi-major axis [AU]	Eccentricity	Inclination [°]	Spectral class	Notes
2060 Chiron	Centaur	13.71	0.381	6.934	B	First Centaur discovered. Subsequently designated as comet 95P.
3200 Phaethon	Apollo	1.271	0.890	22.18	B, F	Dynamical association with the Geminid meteor stream.
3552 Don Quixote	Amor	4.228	0.714	30.95	D	Large NEA with a comet-like orbit.
4015 Wilson-Harrington	Apollo	2.638	0.624	2.785	C, F	Originally designated as comet 107P but activity observed on only one night (Palomar Sky Survey, 1949).
7968 Elst-Pizzaro	Main belt	3.157	0.163	1.386	-	Apparent active main-belt object. Originally designated as comet 133P. Dynamical association with Themis family.
20461 Dioretsa	Damocloid[1]	23.94	0.900	160.4	-	Highly eccentric, retrograde orbit. First retrograde asteroid discovered.
118401 LINEAR	Main belt	3.195	0.193	0.238	-	Apparent active main-belt object. Subsequently designated as comet 176P.
1999 LE_{31}	Damocloid[1]	8.132	0.465	151.9	-	Second retrograde asteroid discovered.
2007 VA_{85}	Amor	4.063	0.730	132.5	-	First retrograde NEA discovered.

[1]Damocloids (an informal term) are asteroids having very eccentric, long-period orbits characteristic of comets, but displaying no coma or tail. The term derives from the prototype, 5335 Damocles.

4.3.1.8 Dwarf planets

The discovery in recent years of a number of TNOs that rival Pluto in size has led to much debate about the status of Pluto as a planet. At the 26th General Assembly of the International Astronomical Union, Prague, 2006, it was decided to re-classify Pluto and a number of other large objects as "dwarf planets". A dwarf planet is defined in IAU Resolution B5 (http://www.iau.org/Resolutions_at_GA-XXVI.340.0.html) as "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, (c) has not cleared the neighbourhood around its orbit, and (d) is not a satellite". Table 9 lists the objects currently falling into this category. It is probable that more objects will be added to this list in due course. Candidates for dwarf-planet status include the main-belt asteroids Pallas and Vesta, Pluto's companion Charon, and a number of TNOs (Table 10).

Table 9. Dwarf planets as of December 2008.

Name	Semi-major axis [AU]	Approx. diameter [km]	Previous category
134340 Pluto	39.48	2300	Planet
136108 Haumea	43.34	1150	TNO
136199 Eris	67.74	2600	TNO
136472 Makemake	45.67	1500	TNO
1 Ceres	2.766	950	Main-belt asteroid

Table 10. Candidate dwarf planets with diameters of ~ 500 km or more.

Name	Semi-major axis [AU]	Approx. diameter[1] [km]	Current category
90377 Sedna (2003 VB_{12})	520	< 1600	TNO
Charon S/1978 P1	39.48	1200	Member of Pluto system
84522 (2002 TC_{302})	55.48	1150	TNO
90482 Orcus (2004 DW)	39.40	950	TNO
50000 Quaoar (2002 LM_{60})	43.09	850	TNO
55565 (2002 AW_{197})	47.51	750	TNO
2002 MS_4	41.67	725	TNO
55637 (2002 UX_{25})	42.82	700	TNO
2003 AZ_{84}	39.69	700	TNO
90568 (2004 GV_9)	41.90	675	TNO
28978 Ixion (2001 KX_{76})	39.30	650	TNO
15874 (1996 TL_{66})	84.91	575	TNO
38628 Huya (2000 EB_{173})	39.38	550	TNO
20000 Varuna (2000 WR_{106})	43.22	500	TNO
2 Pallas	2.773	530	Main-belt asteroid
4 Vesta	2.362	530	Main-belt asteroid

[1]Source of size data on TNOs: [08Sta].

4.3.1.9 Rendezvous and fly-by missions to asteroids

Beginning with the Galileo mission fly-bys of main-belt asteroids 243 Ida and 951 Gaspra in the early 1990s, a large amount of high-quality scientific data has been gathered on a number of main-belt and near-Earth asteroids by means of space missions (Table 11). Spacecraft fly-bys and in-orbit or in-situ exploration of asteroids can provide accurate information on shape, size, mass, bulk density, cratering, the spatial distributions of surface structure, spectral properties and mineralogy, and the presence of natural satellites or moons. The unexpectedly low bulk densities measured by spacecraft, compared to meteorites and terrestrial analogues of asteroid material (2–8 g cm^{-3}), imply high porosities, which have increased speculation that some asteroids, e.g. 253 Mathilde and 25143 Itokawa, may be aggregates of components of various sizes weakly bound by gravity, or “rubble piles”. This idea is supported by the images of Itokawa returned by the Hayabusa spacecraft, revealing a highly irregular object apparently consisting of separate component blocks of various shapes and sizes. Groundbased measurements have provided further density evidence in favour of rubble piles (see Table 7). Data from space missions provide “ground truth”, allowing the analysis techniques used on groundbased astronomical data to be checked and calibrated.

Table 11. Space missions with asteroids as rendezvous or fly-by targets.

Mission	Launch	Leading country/ agency	Asteroid(s)	Fly-by date/rendezvous period	Minimum distance [km]
Galileo	18 Oct. 1989	USA	951 Gaspra 243 Ida,	29 Oct. 1991 28 Aug. 1993	1600 2400
NEAR-Shoemaker	17 Feb. 1996	USA	253 Mathilde, 433 Eros	27 Jun. 1997 14 Feb. 2000 - 12 Feb. 2001	1212 0
Deep Space 1	24 Oct. 1998	USA	9969 Braille	29 July 1999	26
Stardust	7 Feb. 1999	USA	5535 Annefrank	2 Nov. 2002	3300
Hayabusa	9 May 2003	Japan	25143 Itokawa	12 Sep. 2005 - 2006	0
Rosetta	2 Mar. 2004	ESA	2867 Steins 21 Lutetia	5 Sep. 2008 10 Jul. 2010	1700 3000
New Horizons	19 Jan. 2006	NASA	132524 APL	13 Jun. 2006	101870
Dawn	27 Sep. 2007	USA	4 Vesta 1 Ceres	14 Aug. 2011 - 22 May 2012 1 Feb. 2015 -	460 690

4.3.1.10 Asteroid naming conventions/numbering

Typically, the observatory detecting a moving object assigns a temporary code and communicates the observations, including information on position, time, and brightness, to the Minor Planet Center (MPC). The MPC attempts to link detections and match them to known objects. Once the MPC has at least two nights of observations of an apparently unknown object it is assigned a *provisional designation*. The provisional designation consists of the year of discovery followed by two letters, the first of which indicates the half-month period (Universal Time) in which the object was discovered (A = January 1-15, B = January 16-31, etc. - the letters I and Z are not used in this sequence), the second of which is a sequential counter incremented for each discovery made in the same half-month period. For example, 1999 MN was discovered in 1999 between June 16 and 30 and is the 13th object to be discovered in that period. Note that in the sequential component of the provisional designation “Z” is used but not “I”. Due to the productivity of modern search programs the number of objects discovered in a half-month period can run into hundreds. To enable provisional designations to be assigned to the 26th, 27th, etc. discoveries in the same half-month period, the sequential part of the designation may contain a numerical appendix. For example, the 25th object discovered in the period December 16-31, 2006, has the provisional designation 2006 YZ; the 26th object to be discovered in that period has the provisional designation 2006 YA_1; the 27th 2006 YB_1, etc. If more than 50 discoveries are made in a half-month period, the second letter is recycled again with the number 2 appended, etc. The appended numbers are usually written as subscript characters. Searches are made by the MPC for identifications with previously-discovered provisionally-designated objects observed at only one opposition. If an identification is made, one of the provisional designations is defined to be the *principal designation*; this would normally be the earliest provisional designation associated with a reasonable computed orbit.

Once an object has been re-detected during several subsequent oppositions it may be assigned a *permanent designation*, i.e. a number. As of December 2008 there were about 200000 numbered asteroids. The discoverer of a numbered asteroid may suggest a name and an accompanying citation, briefly describing the significance of the name (see [03Sch]). The name and citation have to be approved by the Committee for Small Body Nomenclature of the International Astronomical Union, established in 1994.

“Proposed names should be:

- 16 characters or less in length (including any spaces or punctuation),
- preferably one word,
- pronounceable (in some language),
- non-offensive,
- not too similar to an existing name of a minor planet or natural planetary satellite.

Names for persons or events known primarily for their military or political activities are acceptable only after 100 years have elapsed since the person died or the event occurred; names of pet animals are discouraged; names of a purely or principally commercial nature are not allowed. Accepted names become official when they are published, along with their accompanying citations, in the Minor Planet Circulars, issued monthly by the Minor Planet Center.” (Text quoted from the MPC web site at http://cfa-www.harvard.edu/iau/info/HowNamed.html).

4.3.1.11 References for 4.3.1

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Selected internet resources

Asteroids – Dynamic Site: http://hamilton.dm.unipi.it/astdys
European Asteroid Research Network: http://earn.dlr.de/
IAU Minor Planet Center: http://www.cfa.harvard.edu/iau/mpc.html
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Ondrejov Asteroid Photometry Project: http://www.asu.cas.cz/~asteroid/binastdata.htm