Planetary orbits

Recall eccentricity e defined by

$$b^2 = a^2(1-e^2)$$

a, b semi-major, semi-minor axes

So $e = 0$ for a circular orbit.

Q Use the sheet of information to summarize: list planets in order of

→ eccentricity of orbit

→ inclination to ecliptic

Planetary Orbital and Satellite Data

Planet	Semimajor Axis (AU)	Orbital Eccentricity	Sidereal Orbital Period (yr)	Orbital Inclination to Ecliptic (°)	Equatorial Inclination to Orbit (°)	Number Natural Satellites
Mercury	0.3871	0.2056	0.2408	7.00	0.01	0
Venus	0.7233	0.0067	0.6152	3.39	177.36	0
Earth	1.0000	0.0167	1.0000	0.000	23.45	1
Mars	1.5236	0.0935	1.8808	1.850	25.19	2
Ceres (*dwarf planet*)	2.767	0.097	4.603	9.73		0
Jupiter	5.2044	0.0489	11.8618	1.304	3.13	63
Saturn	9.5826	0.0565	29.4567	2.485	26.73	47
Uranus	19.2012	0.0457	84.0107	0.772	97.77	27
Neptune	30.0476	0.0113	164.79	1.769	28.32	13
Pluto (*dwarf planet*)	39.4817	0.2488	247.68	17.16	122.53	3
Eris[c] (*dwarf planet*)	67.89	0.4378	559	43.99		1

[a] $M_\oplus = 5.9736 \times 10^{24}$ kg

[b] $R_\oplus = 6.378136 \times 10^{6}$ m

[c] Eris was formerly known as 2003 UB313

Terrestrial planets

	Mass (in Earth masses)	
Mercury	0.06	
Venus	0.82	
Earth	1	(Moon = 0.01)
Mars	0.11	

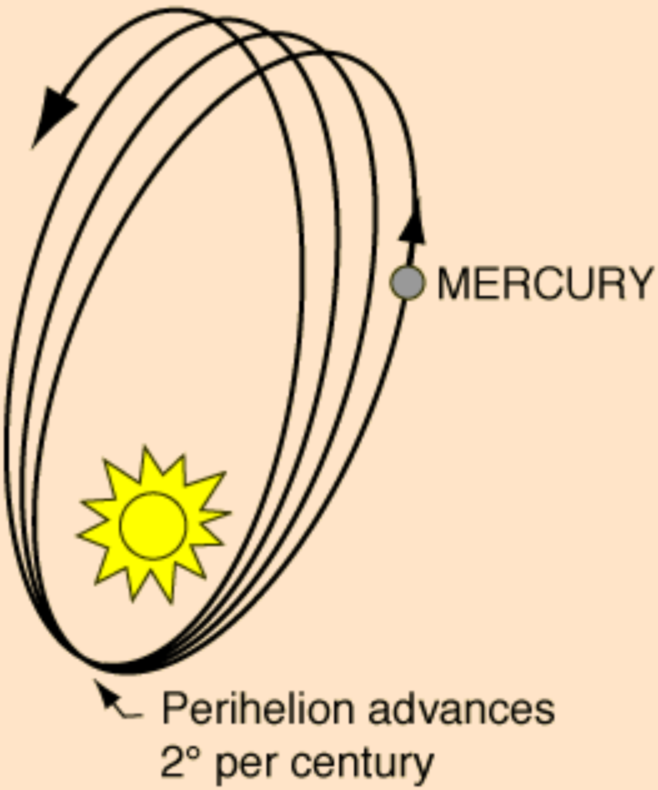
Mercury's orbit is the most elliptical, & aligned at 7° to the ecliptic.

Perihelion = 0.31 AU

aphelion = 0.47 AU

The precession of Mercury's orbit was one of the first successes of Einstein's theory of general relativity.

Advance of Mercury's Perihelion



According to Roy D. North, more precise numbers are as follows (in arcsec per Julian century):

5599	total advance with respect to to geocenter (our reference frame.)
5025	contribution of precession of Earth's equinoxes.
531	Classical or Newtonian contribution of the other planets.
43	General relativity correction (modern theory: 42.98)

Greater perihelion advances with binary pulsars.

http://hyperphysics.phy-astr.gsu.edu/hbase/relativ/grel.html#c3

Asteroids

Most asteroids orbit between Mars & Jupiter's orbits. But two are known that travel at least as far out as Saturn's orbit:

- 944 Hidalgo : eccentric orbit from just past Mars to near Saturn

  about 40 km across ; extinct comet?
  (disc. 1920)

- 2060 Chiron : orbit ranges from just inside Saturn to near Uranus.
  (disc. 1977) ~180 km across

Both orbits are inclined to ecliptic

7.3 Asteroids

Asteroids are by far the most abundant named objects in the Solar System. Over one hundred thousand asteroids have been detected, with over thirty thousand having well determined orbits, most of these occupying the **asteroid belt** between about 2 and 4 AU from the Sun (between the orbits of Mars and Jupiter, Figure 7.7). The total mass of all the bodies in the current asteroid belt is only about one-thousandth of an Earth mass, although originally, a few Earth masses of material would have been available in the solar nebula in the region. In the 19th and early 20th centuries, astronomers thought that the asteroid belt represented fragments of a single planet which had somehow disintegrated catastrophically. However the asteroids are now thought to represent fragments of *many* small planetary bodies that never managed to accrete into one single body. This is due to the strong gravitational influence of the newly formed Jupiter 'stirring up' the asteroid population, causing collisions which would repeatedly break up the bodies and so impede the formation of one single large object.

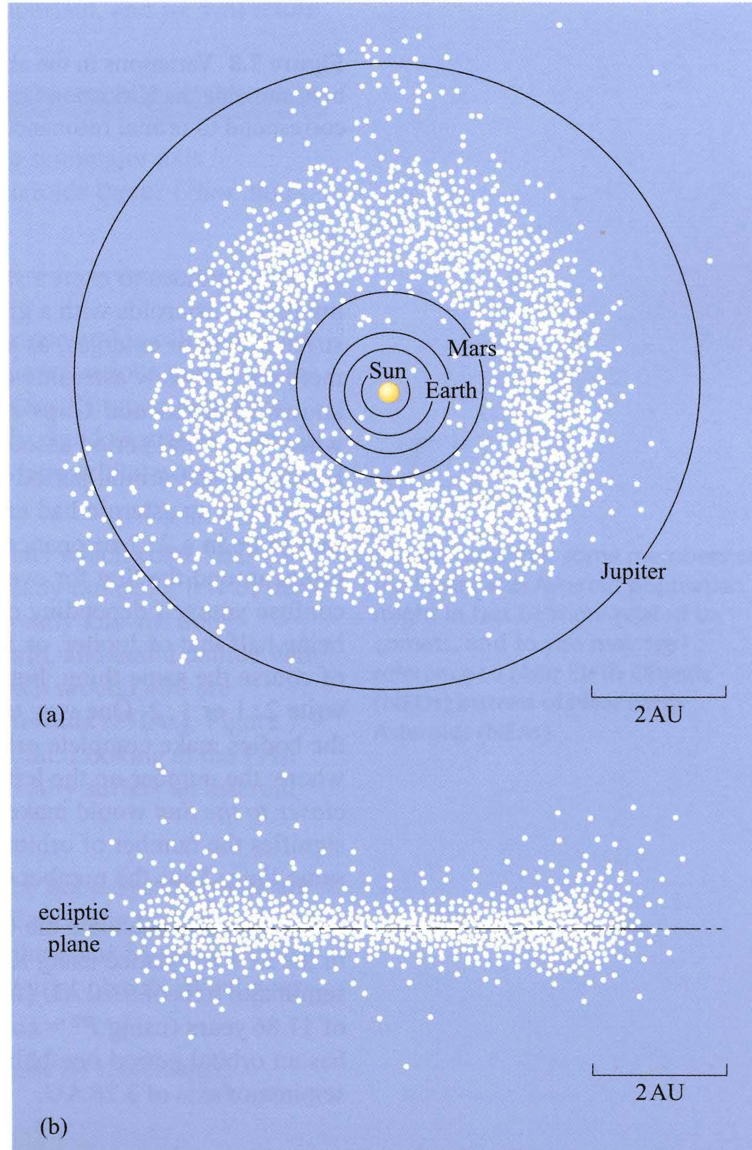
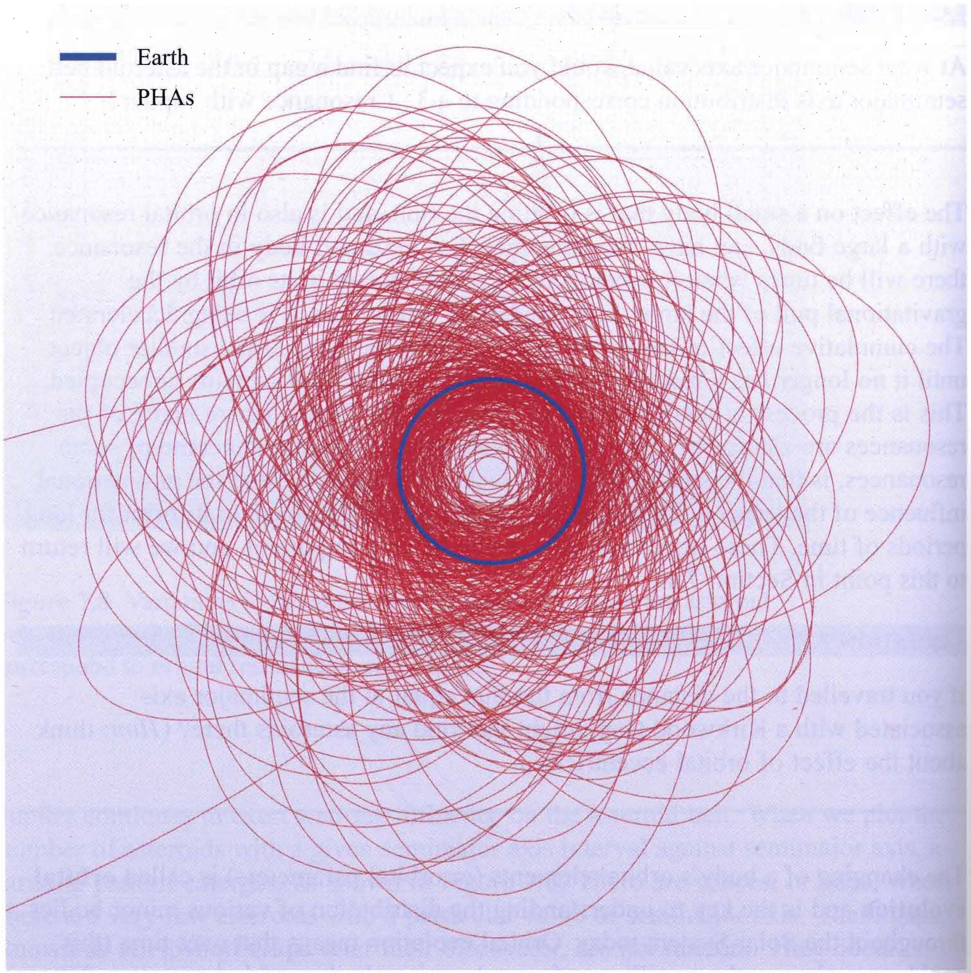


Figure 7.7 (a) A representation of the asteroid belt. It is seen that the asteroid belt is actually a diffuse cloud, or swarm of orbiting bodies. (b) A cross-section through the belt, shown on the same scale. Each individual asteroid shown moves in an orbit inclined to the ecliptic plane, so that sometimes it is above it, and sometimes below. You can imagine that collisions between asteroids will be quite common.

Figure 7.9 The orbits of known Potentially Hazardous Asteroids (PHAs). The orbit of Earth is also shown.



The very fact that we see NEAs today means that the NEA population is being continually replenished, and this happens because of the orbital evolution of objects in the inner asteroid belt. The long-term gravitational effects of Jupiter (and even Mars) give rise to a slow 'conveyor belt', which delivers bodies to the inner Solar System (although you should also appreciate that it can be a two-way process – bodies that are already in the inner Solar System can evolve outwards again). Some of the objects that make it into the inner Solar System might eventually hit one of the terrestrial planets.

Q In the minor planet center animation, there seem to be more asteroids close to the Earth in its orbit than, say, 180° away. What do you think causes this?

A It's hard to think of a physical reason for this, but easier to think of a sociological one.

Human beings are concerned about a possible direct hit on the Earth by a large object. We search harder for objects whose orbit may cross the Earth's, and work harder to derive the orbit of such objects.

This causes an artificial enhancement on the maps, which are only, of course, of known objects.

It is relatively simple to derive the orbit of an extrasolar planet (once the observations are accurate enough)

But calculating the orbit of a newly discovered asteroid is tougher. Generally they are too faint to obtain velocities, so the data are simply a number of positions in the sky with times of observation.

Q How do you think astronomers actually calculate (estimate) the orbit of a new asteroid?

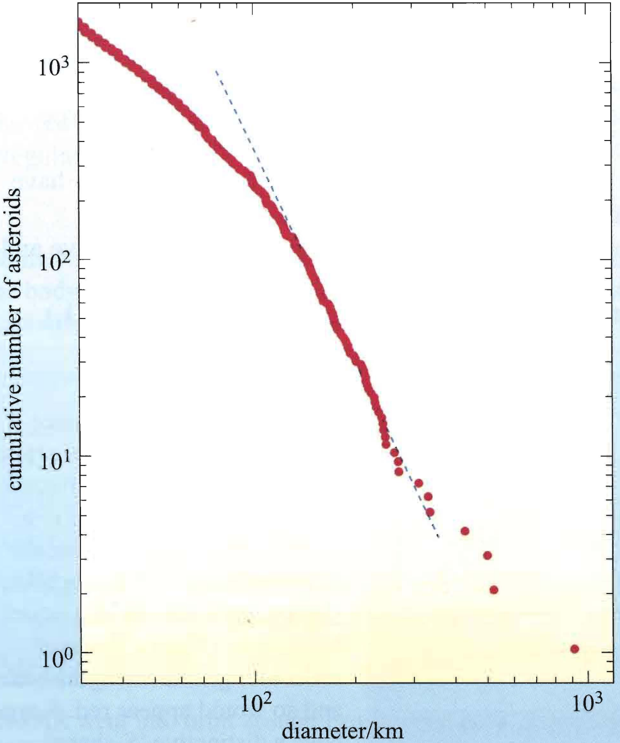


Figure 7.10 The cumulative size distribution of the known bodies in the asteroid belt, plotted logarithmically. The graph tells us the number of asteroids that have diameters greater than a given value.

Q

Why are there so many more small asteroids ?

Orbital resonances with Jupiter

The asteroids are not evenly distributed between Mars and Jupiter : there are distinct gaps called the Kirkwood gaps. These are at places where orbital periods are at simple ratios with Jupiter, such as 3:1, 2:1. Since Jupiter is always in the same place every 2nd or 3rd orbit, its extra gravitational kick de-stabilizes orbits there.

There are also places of unusual gravitational stability, and you see more ~~ast~~ asteroids there than expected. The Trojan asteroids are at the Lagrangian points L_4 & L_5 ...... these describe positions in the restricted 3-body problem that are very stable.

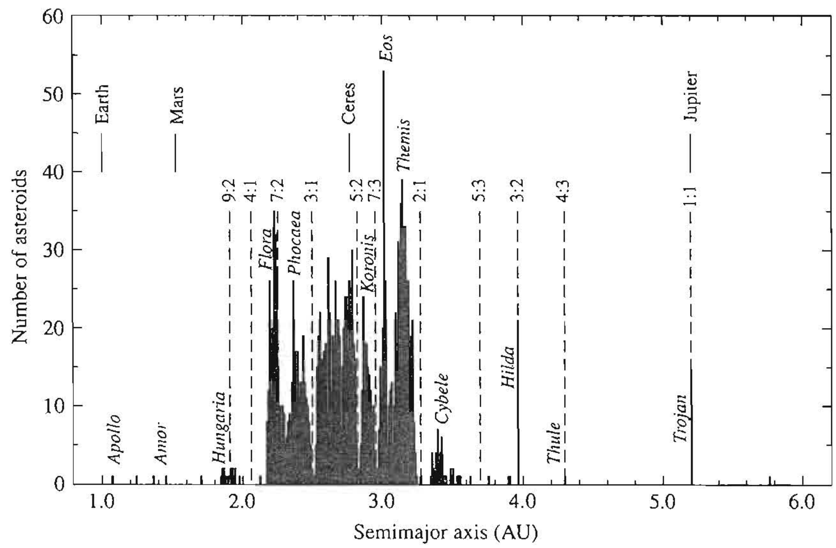


FIGURE 22.13 The distribution of 1796 asteroids in the asteroid belt. Asteroid group names and orbital resonances with Jupiter are also shown. Kirkwood gaps are evident at numerous resonance locations, and enhancements in the number of asteroids are apparent at other resonance locations. (Data from Williams, *Asteroids II*, Binzel, Gehrels, and Matthews (eds.), University of Arizona Press, Tucson, 1989.)

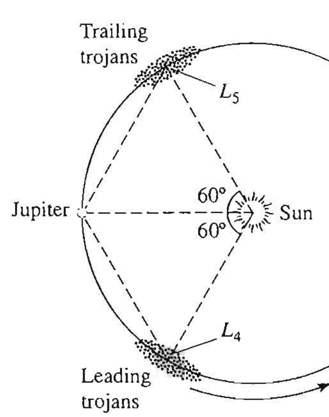


FIGURE 22.15 Trojan asteroids are located in Jupiter's orbit, either leading or trailing the planet by 60°. The occupied positions are two of the five Lagrangian points in the Sun–Jupiter system.

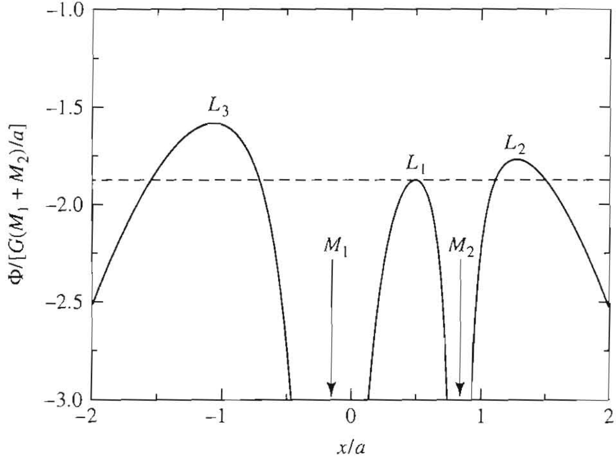


FIGURE 18.2 The effective gravitational potential Φ for two stars of mass $M_1 = 0.85\ \mathrm{M}_\odot$, $M_2 = 0.17\ \mathrm{M}_\odot$ on the x-axis. The stars are separated by a distance $a = 5 \times 10^8$ m $= 0.718\ \mathrm{R}_\odot$, with their center of mass located at the origin. The x-axis is in units of a, and Φ is expressed in units of $G(M_1 + M_2)/a = 2.71 \times 10^{11}$ J kg^{-1}. (In fact, the figure is the same for any $M_2/M_1 = 0.2$.) The dashed line is the value of Φ at the inner Lagrangian point. If the total energy per unit mass of a particle exceeds this value of Φ, it can flow through the inner Lagrangian point between the two stars.

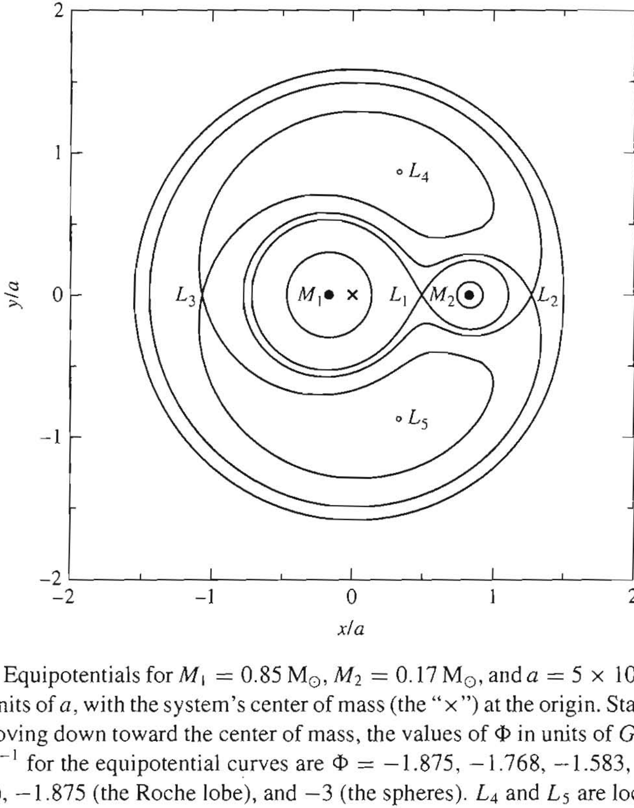


FIGURE 18.3 Equipotentials for $M_1 = 0.85\,\mathrm{M}_\odot$, $M_2 = 0.17\,\mathrm{M}_\odot$, and $a = 5 \times 10^8$ m $= 0.718\,\mathrm{R}_\odot$. The axes are in units of a, with the system's center of mass (the "×") at the origin. Starting at the top of the figure and moving down toward the center of mass, the values of Φ in units of $G(M_1 + M_2)/a = 2.71 \times 10^{11}$ J kg^{-1} for the equipotential curves are $\Phi = -1.875, -1.768, -1.583, -1.583, -1.768$ (the "dumbbell"), -1.875 (the Roche lobe), and -3 (the spheres). L_4 and L_5 are local maxima, with $\Phi = -1.431$.