## Planetary Orbits

Recall eccentricity e defined by:

$$
b^{2}=a^{2}\left(1-e^{2}\right)
$$

The semi-major axis is represented by a and the semi-minor axis is $b$.

Therefore, $\mathrm{e}=0$ for a circular orbit.

## Question:

## Use the sheet of information below to summarize

 the list of planets in order of:- eccentricity of orbit
- inclination to ecliptic

| Planet | Planetary Orbital and Satellite Data |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Semimajor <br> Axis (AU) | Orbital Eccentricity | Sidereal <br> Orbital <br> Period (yr) | Orbital <br> Inclination to Ecliptic $\left({ }^{\circ}\right)$ | Equatorial Inclination to Orbit ( ${ }^{\circ}$ ) | 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 ${ }^{\text {c }}$ (dwarf planet) | 67.89 | 0.4378 | 559 | 43.99 |  | 1 |
| $\begin{aligned} & { }^{{ }^{a} M_{\oplus}}=5.9736 \times 10^{24} \mathrm{~kg} \\ & { }^{{ }^{0}} R_{\oplus}=6.378136 \times 10^{6} \mathrm{~m} \end{aligned}$ <br> ${ }^{c}$ Eris was formerly know | as 2003 UB3I |  |  |  |  |  |

## 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, and aligned at $7^{\circ}$ 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):
total advance with

5599 | respect to to geocenter |
| :--- |
| (our reference frame.) |
| contribution of |

5025 precession of Earth's
equinoxes.

## Asteroids:

Most asteroids orbit between Mars and Jupiter's orbit, but two are known that travel at least as far as Saturn's orbit:

## 944 Hidalgo:

- Has an eccentric orbit from just past Mars to near Saturn
- About 40 km across
- Discovered in 1920
- Orbital inclination of 43 degrees
- Close encounter with Jupiter in past?



## - 2060 Chiron:

- Orbit ranges from just inside Saturn to near Uranus
- About 180 km diameter
- Discovered in 1977

Chiron and Hidalgo are both examples of objects called Centaurs: bodies which orbit between the asteroid belt and the Kuiper belt


A cross-section through the asteroid belt. 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.


The orbits of known

Potentially Hazardous

Asteroids (PHAs). The orbit of
Earth is also shown.

## Question:

In the minor planet center animation, there seems to be more asteroids
close to the earth in its orbit, than $180^{\circ}$ away.

What do you think causes this?

## Answer:

It's hard to think of a physical reason for this, but it's 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 maps, which are of known objects.

## Calculating orbits for asteroids

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. In general, they are too faint to obtain velocities, so the data are simply a number of positions in the sky with times of observation.

## Question:

How do you think astronomers actually calculate the orbit of a new asteroid?


From Pater and Lissauer "Planetary
Sciences"

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.
"Debiased" means that the numbers have been corrected for observational biases
(Note Tunguska-type upper limit)

## Question:

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 places where orbiter periods are of simple ratios with Jupiter, such as 8:1,2:1. since Jupiter is always in the same place every $2^{\text {nd }}$ or $3^{\text {rd }}$ orbit, it's extra gravitational kick destabilizes orbits there.
- There are also places of unusual gravitational stability, where more asteroids exist than expected. The Trojan asteroids are at the Lagrangian points $L_{4}$ and $L_{5}$. These describe positions in the restricted three-body problem that are very stable.


The radial distribution of asteroids in the asteroid belt, from Pater and Lissauer's text. 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.


Trojan asteroids are located in Jupiter's orbit, either leading or trailing the planet by $60^{\circ}$. The occupied positions are two of the five Lagrangian points in the sun-Jupiter system.


Equipotentials for two stars: $M_{1}=0.85_{\odot}, M_{2}=0.17_{\odot}$


The effective gravitational potential for two stars:
$M_{1}=0.85_{\odot}, M_{2}=0.17_{\odot}$ on the X-axis.
Three Lagrange points are marked

