The outer solar system: some points of physics

A few points of physics I didn’t deal with earlier

The outer solar system is the domain of extreme cold

- Temperature in this room: 293K
- Ganymede: about 110K
- Titan: 94 K
- Liquid nitrogen: 77K
- Triton (moon of Neptune): 37K

At these temperatures, ordinary materials have extraordinary properties. Diatomic nitrogen is a liquid, water is a mineral.

Next topic: gravitational “perturbations”

- What does that mean?
- We saw early in the semester that planetary orbits are ellipses (parameters are semimajor axis, eccentricity, inclination)
- Would seem to be fixed for a given planet
- Then, what is the meaning of statements in the book like:
  - “Ganymede’s orbital distance is increasing…” (p327)
  - “planetary rings are formed when a body…ventured within the Roche Distance…” (p298)

Answer: the 2 body problem

Kepler’s Laws are exactly true if there are 2 objects interacting via a gravitational force

Center of mass

M m

r
In the case of the 2 body problem, there is an "exact solution" to the equations of motion

- Both objects $M$ and $m$ move on elliptical orbits around the center of mass
- Depending on how the system was formed, the semimajor axis, eccentricity, and inclination will be different
- However, for 2 bodies, the semimajor axis, eccentricity, etc, stay the same forever

So how can orbits of solar system objects change with time?

The solar system does not have just two objects in it

Why Kepler's Laws are pretty good (a "good approximation")

- For all solar system objects, almost all of the time, the strongest gravitational force is between $m$ (the object) and $M$ (the Sun). Gravitational forces with other objects ($m_2, m_3, etc$) are weaker, and can be considered as perturbations
- As a result, orbits are very close to ellipses, but elements of the ellipses can change with time

Examples of perturbations

- Precession of the line of nodes of the Moon's orbit
- Precession of the rotation axis of the Earth
- Slow changing of the eccentricity of orbits of planets including the Earth
Particularly strong perturbations are those called “resonant”

Definition of resonance in physics: a system with a natural period of oscillation is forced, or acted on, by an external agent which is also periodic, and there is a relation between the two periods.

Gaps in the rings of Saturn

- There are annular bands in which there are no ring particles
- Most prominent examples are Cassini’s Division and Encke’s Division.
- This is due to orbital resonance with one of the moons of Saturn (see p286)

Cassini’s Division and Encke’s Gap

Cassini’s Division

Encke’s Gap
Potential complaint about course to this point:
"I've learned a lot about a bunch of objects I had never heard of, and haven't learned anything about objects I had heard about"

Examples: Pluto, comets, dinosaur-killing asteroids

Orbital characteristics of Pluto
- A=39.53 au
- P=248.5 years (how do we know that?)
- Eccentricity=0.248
- Inclination to plane of ecliptic= 17.15 degrees

Any reaction to these numbers?

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Moral of the story: with just these data, Pluto is substantially different from the other major planets we have discussed. In physical characteristics, it is more like a satellite of the outer planets
Pluto and the Kuiper Belt

- In 1951, Gerard Kuiper suggested a “belt” of comets in the plane of the ecliptic and outside the orbit of Pluto.
- Around 1990, the first of these were discovered. Some are fairly large.
- At the present 1200 have had their orbits determined, and it is estimated that there are 100,000 (almost all not yet discovered) with diameters > 100km.

Characteristics of Eris

- $A=67.7$ au
- $P=560$ years
- $E=0.443$
- $I=44$ degrees
- $D=2400$ km
- $M=0.0025$ Earth masses
- Surface temperature=30K