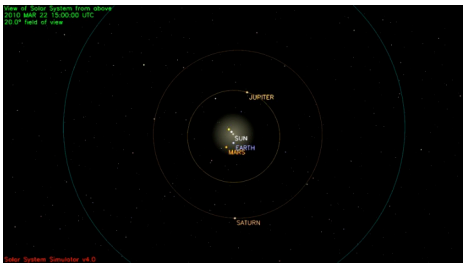
## The outer solar system: some points of physics




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

## The outer solar system is the domain of extreme cold

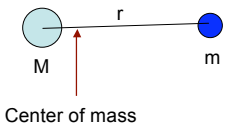
- Temperature in this room: 293K
- Ganymede: about 110K
- Titan: 94 K
- Liquid nitrogen: 77K
- Triton (moon of Neptune): 37K

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

## 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…" (p288)

## Answer: the 2 body problem

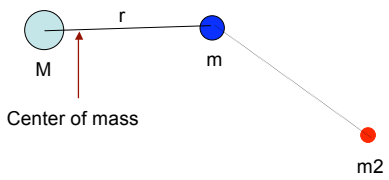



Kepler's Laws are exactly true if there are 2 objects interacting via a gravitational force

## 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?



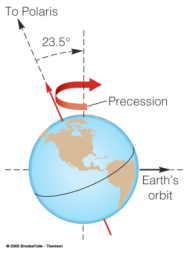

The solar system does not have just two objects in it

## 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 (m2,m3, 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

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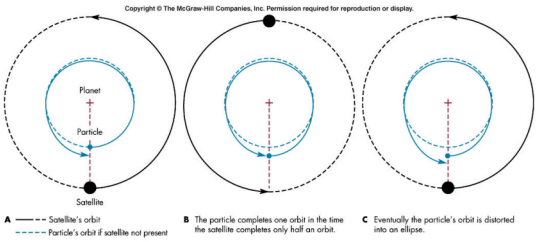
## Gaps in rings due to “resonance” between orbital period of ring particle and period of a moon of Saturn

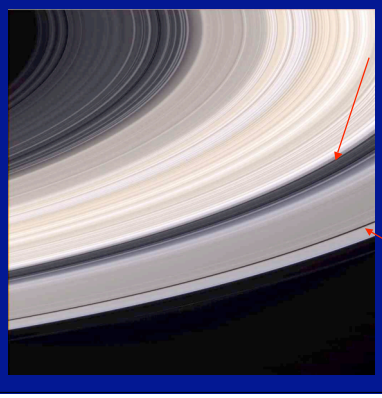



Cassini’s division due to a resonance with moon Mimas

## 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



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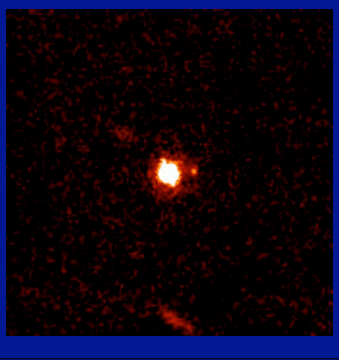
Moral of the story: with just these data, Pluto is substantially different from the other major planets we have discussed. In physical characteristics, it is more like a satellite of the outer planets

## Pluto and the Kuiper Belt

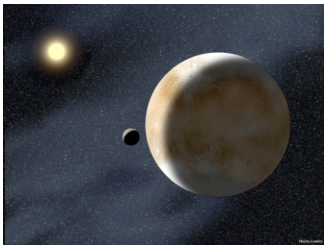
- In 1951, Gerhard Kuiper suggested a “belt” of comets in the plane of the ecliptic and outside the orbit of Pluto
- Around 1990, the first of these were discovered. Some are fairly large
- At the present 1200 have had their orbits determined, and it is estimated that there are 100,000 (almost all not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

## Discovery of Eris (2003)



## Characteristics of Eris

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



## A collection of Dwarf Planets