Gravity: Motivation

• An initial theory describing the nature of the gravitational force by Newton is a product of the resolution of the Geocentric-Heliocentric debate (Brahe’s data and Kepler’s analysis)

• Gravity is a major force in the formation and dynamics of solar systems and galaxies. It plays a large role in structuring the matter and energy of the Universe

• Supportive reading Chaisson and McMillan Chapter 1
Solar System Overview

• Our solar system consists of the sun and collection of bodies and debris that orbit it. This debris and its collective configuration holds clues as to how the solar system formed and evolved.

• An alternate definition has the solar system as the region where the solar magnetic field is dominant.
Entire Solar System: Orbits to Scale
Most asteroids are found

a) beyond the orbit of Neptune.
b) between Earth and the Sun.
c) between Mars and Jupiter.
d) in the orbit of Jupiter, but 60 degrees ahead or behind it.
e) orbiting the jovian planets in captured, retrograde orbits.
Inner Solar System: Looking Down on the Ecliptic
 Inner Solar System: Looking at the Ecliptic Edge On
Outer Solar System: Looking Down on the Ecliptic
Outer Solar System: Looking at the Ecliptic Edge On
Solar System Overview

• Substantially more to the solar system than the well known planets.

• The known solar system is relatively flat. Most objects have orbital planes that are closely aligned to the ecliptic.

• All objects are generally revolving around the Sun in the same direction.
Solar System Overview

• Distances from planets to the Sun where found from Kepler’s Law once a reference distance was known (Earth-Sun distance from transit of Venus, Venus-Earth from radar ranging).

• Masses of solar system objects may be found by applying Newton’s Universal Law of Gravitation to its satellites (natural or artificial, G had to have been measured).

• Knowing distances to solar system objects and their angular size, the diameters of the objects may be determined.
Question 2

Which of the following are terrestrial planets?

a) only Earth
b) Earth, Moon, and Venus
c) Mercury, Venus, Earth, and Mars
d) Mercury, Venus, Earth, Moon, Mars, and Pluto
e) Mercury, Venus, Earth, Moon, Mars, and Ceres

• Rocky
• Medium-sized circular objects
• Nearly circular orbits in the ecliptic plane relatively close to the Sun
• High density 5000 kg/m$^3$ (water 1000 kg/m$^3$, iron 8000 kg/m$^3$)
Solar System Overview: Jovian Planets.

• Gaseous

• Large objects

• Nearly circular orbits in the ecliptic plane relatively far from the Sun

• Low Density \( \sim 1000 \text{ kg/m}^3 \) (water 1000 kg/m\(^3\), iron 8000 kg/m\(^3\))
Solar System Overview: Dwarf Planets

• Dwarf Planets: Large enough that its own gravity has pulled it in to a spherical shape but not large enough to have cleared debris from its orbit.

• Dwarf Planets: Pluto and Eris (2005) in the Kuiper belt and Ceres the largest asteroid in the asteroid belt
Solar System Overview

• Asteroids: Small rocky bodies (largest are \(~100's\) of km) mainly located between the orbits of Mars and Jupiter.

• Comets: Small icy objects (water ice, ammonia ice, methane ice) orbiting the Sun in the Kuiper belt ("regular" orbits outside of Neptunes orbit) and the Oort cloud (less systematic orbits further away)
Solar System Overview

• Annually, the Sun appeared to move against the background of stars along the Zodiac in a plane called the ecliptic.

• Due to the tilt of the Earth’s rotational axis with respect to the ecliptic, the celestial equator (perpendicular to the rotational axis) and the ecliptic do not coincide. Thus latitude at which the Sun is overhead changes throughout the year.
Solar System Overview

• However, we know it is the Earth that moves around the Sun and thus it is the Earth that travels in the plane of the ecliptic.

• Most of the planets in the solar system orbit the Sun in (or near) the ecliptic (equatorial plane of the Sun. That is their orbits are only slightly inclined to the ecliptic plane.
Entire Solar System: Orbits to Scale
Size of Solar System Bodies to Scale

- Sun
- Mercury
- Venus
- Earth
- Mars
- Jupiter
- Saturn
- Uranus
- Neptune
- Pluto

1.4 million kilometers
Scale Model of Solar System and Beyond

- Scale: \( R_{sun} = 6.96 \times 10^5 \text{ km} = 10 \text{ cm} = R_{soccer\ ball} \)
- Using this scale, we can calculate (see below) the size of the planets and distances between the planets in the scale model.

\[
\frac{R_{ModJup}}{R_{ActJup}} = \frac{R_{ModSun}}{R_{ActSun}}
\]

\[
R_{ModJup} = \frac{R_{ModSun}}{R_{ActSun}} R_{ActJup} = \frac{10\text{ cm}}{6.96 \times 10^5 \text{ km}} \times 6.99 \times 10^4 \text{ km} = 1\text{ cm}
\]

Results of calculations based on the scale above are presented in the following table. See also Mathematical Insight 1.2 in Bennett
# Scale Model of Solar System and Beyond

<table>
<thead>
<tr>
<th></th>
<th>Actual Radius Km</th>
<th>Scale Radius (cm)</th>
<th>Actual Distance to Sun (km)</th>
<th>Scale Distance to Sun (m)</th>
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<td>Sun</td>
<td>6.96E+05</td>
<td>10</td>
<td>5.79E+07</td>
<td>8.32E+00</td>
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<td>3.49E-02</td>
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<td>8.71E-02</td>
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<tr>
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<tr>
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<td>1.44E+13</td>
<td>3.00E+17</td>
<td>4.31E+10</td>
</tr>
</tbody>
</table>
Perspective

• In a scale model where the Sun is the size of a soccer ball, Jupiter is the size of grape located one football field away.

• In a scale model where the Sun is the size of a soccer ball, Earth is twenty steps away and the size of the tip of a pen.

• In a scale model where the Sun is the size of a soccer ball, Pluto is smaller than the tip of a pen and about one half a mile away.
Perspective

- In a scale model where the Sun is the size of a soccer ball located in Oneonta, Alpha Centauri is located somewhere on the west coast of the United States.
- In a scale model where the Sun is the size of a soccer ball, the center of the Milky Way is located on Venus.
Solar System Overview

• Note that the planet’s orbits are confined to the plane of the ecliptic (small inclination)

• Note that the orbits of the planets are roughly circular (eccentricity of zero)

• Note that the orbits of Pluto and some comets are highly inclined and highly eccentric
Recall that comets have highly elliptical orbits. Thus there is a large difference between their closest approach to the Sun (perihelion) and their furthest distance from the Sun (aphelion). (E.g. Comet Encke)
Comet Neat at Perihelion

Comet Neat has entered the field of view of one of the SOHO satellites coronographs. The occulted sun is represented by a white circle at the center of the image and the comet is the striking object in the upper right hand corner.

http://soho.nascom.nasa.gov/
Entire Solar System: Orbits to Scale
Solar System Overview

• Note that all of the planets revolve around the Sun in the same direction

• Note that most planets rotate in the same direction as their revolution (Venus rotates in the opposite direction)

• Note that most of the planet’s axes of rotation are roughly perpendicular to the ecliptic (Uranus axis of rotation is almost parallel to the ecliptic)

• Note that most of the satellites of the planets have orbital characteristics similar to those of the planets
Solar System Formation Clues

• The orbital planes of the planets are nearly the same and lie almost in the equatorial plane of the Sun.

• The planets revolve around the Sun in the same direction in nearly circular orbits.

• Most planets rotate in the same direction that they revolve and their axis of rotation is approximately perpendicular to the equatorial plane of the Sun.

• The characteristic above dominate but there are anomilies (e.g. Venus and Uranus) that need to be addressed.
Solar System Formation Clues (cont.)

- The satellite systems of the outer planets have similar characteristics to those described above.
- There are two major categories of planets: rocky terrestrial planets near the Sun and large hydrogen rich planets (Jovian) further out.
- There are a huge number of asteroids and comets that seem to reside primarily in regions known as the asteroid belt, Kuiper belt and Oort cloud.
Nebula Hypothesis
Collapse of Solar Nebula

Solar Nebula starts to contract under the mutual gravitational force of its constituents. As the radius of the cloud decreases it must rotate faster to conserve angular momentum.
As the cloud spins about a vertical axis, the increased centripetal acceleration (due to increased speed of rotation) takes up (balances) the gravitational force so that the horizontal contraction slows. The vertical contraction continues and the cloud flattens.
Protoplanets form from the condensation, collision and subsequent gravitational attraction of Nebula material.
Protoplanets form from the condensation, collision and subsequent gravitational attraction of Nebula material.
Properties of Solar System Objects

With an overall goal of perhaps understanding the origins of the solar system, we begin to discuss some of the properties of objects within our solar system (focusing on the most interesting or dramatic examples)

• Motion (Revolution and Rotation)
• Crust: Composition and Dynamics
• Core: Composition and Dynamics
• Atmosphere: Composition and Dynamics
• Magnetic Field