Planetary Systems

(A brief introduction to planetary science)

SPA5241 Planetary Systems
The Forefront of Planetary Science

• Robotic exploration of the Solar System

• Discovery of extrasolar planets (~4,011 confirmed as of 1/19/20)
  – they are everywhere.

• Completing the inventory of the solar system

• Discovery of `extra solar’ planets (e.g., 'Planet 9' – predicted in 2016)

• Putting the solar system in context
Module Details

Lectures: Monday 9-10 (GOJ LG1), Wednesday 11-13 (GOJ UG1)

Exercise Class: Tuesday 11-12 Queen’s LG1 (starts Week 2)

Coursework Deadline: 1pm Friday

Lecturer: Dr. Craig B. Agnor

Office: G.O. Jones Room 505

Office Hours: 11-12 Monday, 2-3 Wednesday

(and by appointment)

Coursework: 10% weekly assignments

10% midterm exam (Week 8)
Module Outline

Part I: Basic physical concepts; layout of the solar system; dynamics of orbiting bodies; properties of light

Part II: Taking Inventory of the Solar System. Major, dwarf and minor planets. Distributions of bodies. Meteors, meteorites, asteroids and comets as our celestial neighbours and clues to our beginnings.

Part III: Properties of the planets and satellites. Interiors, surfaces, atmospheres and their evolution.


Part V: Extrasolar planets. Detection techniques; characteristics and distributions. Their origin and implications for the Solar System.
What this module is about - II

• What does a planetary system consist of (i.e. What’s in it)?

• What are the characteristics of these bodies?
  ➢ How do we measure them?
  ➢ How do we make sense of them?

• What physical processes control the evolution of these bodies?
  ➢ E/M Radiation, blackbody radiation
  ➢ Gravity
  ➢ Chemistry / Material Properties (e.g. Spectra, material strength, melting)
  ➢ Thermodynamics (e.g. Phase changes, equations of state), Kinetic Theory
  ➢ Fluid dynamics (atmospheric and geophysical flows)
Asteroid Ryugu Visited by Hyabusa 2

- Near Earth Asteroid
- R=432m
- 1.19AU
- Density 1.19 g/cm³
- Rotation period 7.6 hours
- Interior structure?
- Equatorial oblateness?
Planet 9?

Terrestrial Planets
How will we go about this...

• Maths involved in the module:
  ➢ Algebra and trigonometry
  ➢ Calculus
  ➢ Basic differential equations
    ▪ (e.g. Damped driven SHO).
  ➢ Approximation methods
    ▪ Mostly expansions in ‘small’ quantities.
  ➢ Some numerical simulations
    ▪ Mostly with existing online tools
Angular Measures

• The Sun and Moon have angular diameters of \(~\frac{1}{2}\degree\) while the planets are even smaller at a few ” or less.
• Stars are too small to be resolved: their apparent size is limited by turbulence in the atmosphere to be about 1”
Simple Angular Measures

We can relate an object’s physical size $D$, to its distance $r$ and angular size $\theta$:

$$\frac{D}{2\pi r} = \frac{\theta}{360}$$

At what distance would a two-pound coin subtend an angle of 1”?

Diameter=28.4 mm.
Maximum Elongation

We measure the maximum elongation of Mercury’s orbit to be about 22.7 degrees.

What does this tell us about Mercury's orbit?
The Sun

- Nearly featureless at optical wavelengths: sunspots mark regions of high magnetic field
- Other wavelengths show high level of activity
The planets

What is a planet?

• Comets, asteroids, meteroids orbit the Sun in a similar manner
  ➢ Ceres is ~1000 km in diameter (about half the size of Pluto) and round
• Some satellites are larger than Mercury and Pluto
• Many extrasolar “planets” discovered are larger than Jupiter, orbiting closer than Mercury.

• Several “trans-Neptunian” objects known, comparable to Pluto
• Eris is about the same size Pluto, and has at least one small moon (Dysnomia).
• Pluto has at least 5 satellites!
Remarkably, with a few careful observations it is possible to measure the scale of the solar system.
Size and shape of Earth

- The Earth has been known to be spherical since the time of the early Greeks. Some of the evidence in favour of this was:
Size and shape of Earth

- The Earth has been known to be spherical since the time of the early Greeks. Some of the evidence in favour of this was:
  1. at sea, land at sea level disappears before hills; hulls of ships at sea vanish before their masts
The Earth has been known to be spherical since the time of the early Greeks. Some of the evidence in favour of this was:

1. at sea, land at sea level disappears before hills; hulls of ships at sea vanish before their masts
2. the altitude of stars in the sky depends on how far north or south the observer is
Size and shape of Earth

• The Earth has been known to be spherical since the time of the early Greeks. Some of the evidence in favour of this was:
  1. at sea, land at sea level disappears before hills; hulls of ships at sea vanish before their masts
  2. the altitude of stars in the sky depends on how far north or south the observer is
  3. in lunar eclipses (Earth passing between Sun and Moon) the shadow is always circular
Size and Shape of Earth

- Eratosthenes used the assumption of a spherical Earth and his observation of the difference of altitude of the Sun at Syene (directly overhead on a known date) and at Alexandria, 5000 stadia farther north.

- Eratosthenes’ method gives a radius for Earth of ~6250km. This is very close to the modern value of 6378km.
The Moon: Eclipses

Eclipses occur when the Moon comes between the Earth and Sun.

- Provides clear evidence that Moon is closer than Sun
Eclipses are so spectacular because of the purely coincidental fact that the moon and Sun have similar angular sizes.
Lunar Eclipses

Lunar eclipses occur when Earth blocks sunlight to the Moon.

Lunar eclipses always have rounded edge: further evidence that Earth is spherical.
Distance to the Moon

Lunar eclipses can be used to determine distance to the Moon
• Angular diameter of the Sun is 0.53 degrees
• Knowing Earth’s diameter (13,000 km) you can find the extent of Earth’s shadow: 1.4 million km.
• From observing the radius of curvature of the shadow we see the angular size of Earth’s shadow at the distance of the Moon is about 1.5 degrees.
• Can use geometry to show distance to Moon is about 350,000 km
Given the angular size of the moon (0.5 deg) and its distance of 350,000 km we can find its size.
Lunar Cycle
Aristarchos observed the angle between the Moon and Sun at quarter phase; this told him the relative distances of Sun and Moon.

- Sun is about 400 times farther away than Moon
- Since Sun and Moon have the same apparent diameter when viewed from Earth, the Sun must also be 400 times larger than the Moon
Plan View of Inner Solar System
Earth from Saturn
Inclination vs. Semi-major Axis OSS
Planet 9?

Terrestrial Planets

- Mercury
- Venus
- Earth
- Mars
Sedna
800-1100 miles in diameter

Quaoar (800 miles)
Pluto (1400 miles)
Moon (2100 miles)
Earth (8000 miles)
Orbital Structure of Systems

Rings
- close to a planet (a ~ 1-3 planetary radii)
- consist of small bodies (R~1m) – Why?
- often have small moons exterior (a~3-6R) to them with sizes of R~10-100-km

Regular Satellites
- Orbit outside rings – a ~3-60 Rplanet.
- Orbits are circular and low inclination (mostly – see Triton as a counter-example) - Why?.
- Can be large in size (R > 100km – 2000-km)

Irregular Satellites
- orbit distant from planet (a > 100Rplanet roughly)
- eccentric (e~0.2-0.8), prograde, retrograde orbits (I>90 deg) – why?
- sizes range from R~200km to much smaller ~10km is detection limit)
The Outer Limits – Oort’s Comet Cloud

The Oort Cloud (comprising many billions of comets)
Solar System in the Milky Way

• Solar system is about $6 \times 10^{12}$ m in radius. Why?

• The Galaxy is more than 40 million times larger than this.

• The Sun orbits around the Galaxy once every 226 million years
Exoplanet Detection vs. Time

- ~4000 planets now known
- Green – Transiting
- Red – Radial Velocity
- Orange – Microlensing
- Blue – Direct Imaging
- Purple – Timing Variations