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1 Lecture 2

1.1 Biology

Definition. *Biology*
Biology is the study of the formation and evolution of life.

- Planetary science and astronomy yield context for life.
- Biological research is limited to Earth-based life, yielding poor context for possibilities of universal life.
- Understanding the conditions that led to life on Earth helps us identify potential locations for extraterrestrial life.

1.2 The Human Adventure

- The development of Astronomy is deeply intertwined with the development of civilisation and changes in society.
- Revolutions in astronomy have gone hand in hand with giant leaps in technology and science.
- Astronomy is the science that asks the deep question about the origins of humanity.

1.3 Modern View of the Universe

- What is our physical place in the universe?
- What is known about planets, stars, galaxies, space and time?
- How do we know what we know?

1.4 Universal Objects

Definition. *Star*
A *star* is a large, glowing ball of mostly hydrogen gas that generated heat and light by nuclear fusion. Larger stars generally have shorter lifespans.

Note. Hydrogen is the lightest and most abundant element in the universe.

Definition. *Planet*
A *planet* is a moderately large object which orbits a star; it shines by reflected light. They may be rocky, icy, or gaseous in composition.

Pluto and the family of objects beyond Neptune are now called "dwarf planets".

Definition. *Moon*
A *moon* is an object which orbits a planet—may also be referred to as a *satellite*.

Definition. *Asteroid*
An *asteroid* is a relatively small and rocky object which orbits a star. They usually do not have the mass (and thus the gravity) to be spherical in shape.

Definition. *Comet*
Comets are icy dust balls that get vaporised when they get too close to a star, leaving a bright trail in the sky. They usually originate outside the solar system.

Definition. *Solar (Star) System*
A star and all the material that orbits it, including planets, asteroids and comets, and all the moons that orbit those planets.

Definition. *Nebula*
A *nebula* is a cloud of gas that is gravitationally attracted to itself, and will eventually become a star (system). Like most things, it is mostly composed of hydrogen, but also contains small solid particulates of carbon and silicon.

Definition. *Galaxy*
An enormous "island of stars" far out in space, all held together by gravity and orbiting a common centre.

Definition. *Universe*
The sum total of all matter and energy; that is, everything within and between all galaxies.

Definition. *Astronomical Unit*
The (average) distance from the Earth to the Sun is 150 million km or 93 million miles, and is called an *astronomical unit.*

Definition. *Atom*
Atoms are the microscopic "building blocks" of all chemical elements—92 of which occur in nature.

1.5 Where Do We Come From?

- The first (and simplest) atoms (hydrogen and helium) were created during the *Big Bang.*
- More complex atoms (like carbon and oxygen) were created much later, inside stars.
- As stars age and die, they expel matter into space, which in turn forms new stars and planets.

1.6 Light is the Measure of All Things

- The speed of light is the absolute speed limit of the universe.
- As far as we know, there are no methods of travelling faster than light.

1.7 A Universe in Motion

- We are constantly moving in space—on "spaceship Earth". The earth rotates around its axis once per day, which results in a speed of around 1000 mph at the equator.

2 Lecture 3

The Earth is non-stationary—it is moving through space at extreme speeds. The universe is also expanding, and things are all getting further and further away from us. The reason that we aren't getting further and further away from the Earth is because gravity is usually enough to hold things together (when things are close enough).

Note. We are not in a particularly special place in the universe, nor are we at a special time.

2.1 Planetary Science

Definition. *Planetary Science*
Planetary science is the study of the creation and evolution of planetary bodies, moons, asteroids, comets, etc.

Studying solar system bodies investigates why life formed on some worlds, and not others.

- All the planets orbit the Sun in elliptic paths, all in the same plane.
- The tilt of the planet is the main reason for the seasons.

2.1.1 Annual Motion Definitions

Definition. *Ecliptic*
The *ecliptic* is the apparent path of the Sun through the sky.

Definition. *Equinox*
The *equinox* is where the ecliptic intersects the celestial equator.

Definition. *Solstice*
The *solstice* is where the ecliptic is farthest from the celestial equator.

Definition. *Zodiac*
The *zodiac* is the constellations which lie along the ecliptic.

2.2 The Parsec

Definition. *Parsec*
We define one *parsec* to be 3.26 light-years.

We can calculate the distance to a star by using the parallax effect, namely

$$\text{Distance in parsecs} = \frac{1}{\text{Parallax in seconds}}.$$

2.3 The Science of Astronomy

Copernicus proposed the heliocentric model in 1543, but his model was no more accurate than geocentric models, because he used perfect circles for the orbits. Tycho Brahe tried, but failed, to detect stellar parallax, so he thought Earth was at the centre of the solar system and other planets went around the Sun. He would go on to hire Johannes Kepler, who used Tycho's observations to discover the *truth* of planetary motion. Johannes Kepler first tried to use circular orbits, but a discrepancy led him to propose elliptical orbits.

2.4 Kepler's Laws

1. The orbit of each planet around the Sun is an ellipse.
2. As a planet moves around its orbit, it sweeps out *equal areas in equal times*.

   > **Note.** Planets move *faster* the closer they are to the Sun.

3. More distant planets orbit the Sun at slower *average* speeds, obeying the relationship

   $$p^2 = a^3,$$

   where p is the orbital period (in years) and a is the average distance from the Sun (in AU).

2.5 Galileo Discoveries

- Galileo showed that objects will stay in motion unless a force acts on them to slow them down.
- Galileo proved that there are imperfections on the celestial bodies: sunspots on the Sun, craters on the moon, etc.
- Galileo proved that stars are much further than Tycho thought, so the undetectable parallax was justified.
- There are objects that do not orbit the Earth (the moons of Jupiter).
- By observing the phases of Venus, he showed that Venus does not orbit the Earth.

2.6 Hallmarks of Science

1. Modern science seeks explanations for observed phenomena that rely solely on *natural* causes.
2. Science progresses through the creation and testing of models of nature that explain the observations as simply as possible.
3. A scientific model must make *testable predictions* about natural phenomena that would force us to revise/abandon the model if it does not agree with observations.

> **Definition.** *Scientific Theory*
> A *scientific theory* must:
>
> - Explain a wide variety of observations with a few simple principles.
> - Must be supported by a large, compelling body of evidence.
> - Must not have failed any crucial test of its validity.

3 Lecture 4

3.1 Describing Motion

Definition. *Kinematics*
We define *speed* to be the rate at which an object moves, given by

$$\text{speed} = \frac{\text{distance}}{\text{time}}.$$

Velocity is similar to speed, but also has a direction. *Acceleration* is *any* change in velocity (magnitude or direction). Both velocity and acceleration have magnitude and direction, so they are *vectors*.

3.2 Acceleration Due to Gravity

All falling objects near the Earth's surface accelerate at the *same* rate, independent of the mass of each object. On Earth, this has the value 9.8 m/s^2.

3.3 Momentum and Force

Linear momentum is given by the mass of an object times the velocity of that object, or

$$p = m \cdot v.$$

Newton found that a net force changes momentum. The difference between mass and weight is that mass is the amount of matter in an object, whereas weight is the force that acts upon an object.

3.4 Newton's Laws of Motion

Newton realised that the same physical laws that operate on Earth also operate in outer space.

1. An object moves at a constant velocity unless a net force acts to change its speed or direction.
2. Force is mass times acceleration, or $F = ma$. In other words, force is the rate of change of momentum: $F = \frac{\mathrm{d}p}{\mathrm{d}t}$.
3. Every force has an equal and opposite reaction force.

Note. Reaction forces act upon different objects.

3.5 The Gravitational Force

1. Every mass attracts every other mass.
2. Attraction is *directly* proportional to the product of their masses.
3. Attraction is *inversely* proportional to the square of the distance between their centres.

This is given by the equation

$$F_g = G\frac{M_1 M_2}{d^2},$$

where G is a constant.

3.6 "Conservation" Laws

There are three important conservation laws:

- Conservation of linear momentum (mv)
- Conservation of angular momentum (mvr)
- Conservation of energy

The conservation of angular momentum is the reason why planets move slowly the further away they are from the Sun, and faster when they are closer. It is also the reason why clouds of gas (large r) eventually contract into spinning disks (smaller r).

3.6.1 Energy

- Energy makes matter move.
- Energy is conserved, but it can transfer from one object to another and change in form.
- All energy can be traced back to the Big Bang.

3.6.2 Types of Energy

- Kinetic Energy (motion) is given by the equation: $K.E. = \frac{1}{2}mv^2$.
- Radiative (light).
- Potential (or stored).

Energy is measured in Joules, and power is measured in Joules per second, or Watts.

3.6.3 Thermal Energy

Thermal energy is a sub-type of kinetic energy—the collective *kinetic energy* of many particles. It is related to temperature, but *not* the same. Temperature is the *average* kinetic energy of the many particles in a substance, not the sum.

> **Note.** Absolute zero is the temperature when particles stop moving.

3.6.4 Gravitational Potential Energy

On Earth, it depends on the mass of an object (m), the strength of gravity (g), and the distance an object could potentially fall (h). Thus the gravitational potential energy is given by $U_g = mgh$.

3.7 Mass-Energy

Mass itself is a form of energy, given by $E = mc^2$, where c is the speed of light.

- A small amount of mass can release a lot of energy.
- Concentrated energy can spontaneously turn into particles, for example particle accelerators.