## ASTRONOMICAL OBJECTS (Page 4).

**Star:**

Ball of gas that generates energy by nuclear fusion in its core. Also includes white dwarfs, protostars, neutron stars.

**Planet:**

Object (solid or gaseous) that orbits a star. Radius > 1000 km.

**Moon (Satellite):**

"Rocky or icy" object that orbits a planet.

**Asteroid:**

Small rocky object that orbits a star.

**Comet:**

Small icy object that orbits a star.

**Solar System:**

Star (or more) plus the planets, etc that orbit the star.

**Star Cluster:**

Group of stars (100 to $10^6$). Born from the same cloud of gas at the same time.

Some are held together by gravity.
Some are dispersing.

**Galaxy:**

An island of stars ($10^6$ to > $10^{12}$), and perhaps, interstellar gas.

Types: Elliptical, Spiral, Irregular

**Galaxy Cluster:**

A collection of galaxies (10's to > 1000) held together by gravity.
Small clusters (< 100) are groups.

**Universe:**

All matter and energy:
Visible universe: that which, in principle, can be detected.

**Objects that emit visible light.**

Sun, stars, gaseous nebulae, galaxies

**Objects that do not generate their own visible light.**

Planets, satellites, asteroids, comets, dark nebulae, dark matter
First 4 may be seen by reflected light.

**Scientific Notation**

$100 = 1 \times 10^2$ $\quad$ $1{,}000{,}000 = 1 \times 10^6$

$0.01 = 1 \times 10^{-2}$ $\quad$ $0.000001 = 1 \times 10^{-6}$

**Units**

Science (and most countries) use SI units.
(Systeme International d'Unites). Often known as metric system.

| | S.I. | cgs | Imperial |
|---|---|---|---|
| Length | m | cm | ft |
| Mass | kg | gm | lb |
| Time | s | s | s |
| Temperature | K | K | F |

**Temperature**

Measure of average kinetic energy in random motions.
(Lowest energy state; no thermal motion)

T(Kelvins) = T(Celsius) + 273.15

Example:

| | | |
|---|---|---|
| Water freezes at | 273K | 0°C |
| Water Boils | 373K | 100°C |

**Units of Convenience:**

Radius of Sun = $6.96 \times 10^8$ m
$= 1\ R_\odot$

Most Stars: Radius ~ 0.1 to 30 $R_\odot$ (Giants 1000 $R_\odot$)

Mass of Sun = $2.0 \times 10^{30}$ kg
$= 1\ M_\odot$

Most Stars: Mass ~ 0.1 $M_\odot$ to 100 $M_\odot$

Luminosity of Sun = $3.8 \times 10^{26}$ Watt
$= 1\ L_\odot$

Most Stars: L ~ 0.001$L_\odot$ to $10^6\ L_\odot$

## SIZE-SCALES

**Astronomical Unit:**

Use to measure Planetary distances.

Average distance Sun to Earth = 1 AU

= $1.5 \times 10^{11}$ m

Distance from Sun to:

| | | | |
|---|---|---|---|
| Mercury | = 0.39 AU, | Venus | = 0.72 AU |
| Earth | = 1.0 AU, | Jupiter | = 5.2 AU |
| Pluto | = 40 AU | | |

**Light year:**

A measure of distance, NOT time.

The distance traveled by light in 1 year.

Light travels at a CONSTANT speed of $3.0 \times 10^5$ km/s (186,000 miles per hour).

**1 light year**

= Speed of light x 1 year

= $3.0 \times 10^8$ [m/s ] x 1 [yr] (365.25 [d/yr] x 24 [hr/d] x 60 [min/hr] x 60 [s/min])

= $9.46 \times 10^{15}$ m

**Some conversions:**

1 light second = 186,000 miles = $1.86 \times 10^5$ miles

= 300,000 km = $3 \times 10^5$ km

1 light minute = $1.12 \times 10^7$ miles= $1.80 \times 10^7$ km

1 light year = $5.88 \times 10^{12}$ miles = $9.46 \times 10^{12}$ km

Note that 1 mile = 1.61 km

**Distance Scales:**

Distance between:

Pittsburgh and California = 0.02 light seconds

Earth and Moon = 1.3 light seconds

Earth and Sun = 8.3 light minutes

Earth and Mars (closest approach) = 3.1 light minutes

Earth and Jupiter (closest approach) = 35 light minutes

Earth and Neptune or Pluto (closest approach) = 4 light hours

Sun and nearest star (Proxima Centauri) = 4.2 light years

Sun and nearest galaxy (LMC) = 160,000 light years

Sun and most distant known quasar = $1 \times 10^{10}$ light years

Note: Size of Milky Way Galaxy = $10^5$ light years

NB: We see the Universe as it was in the Past:

Space is mostly empty.

Scale Comparison.

Earth: Basketball 0.3 m diameter (1ft)

Sun: Sphere 33 m in diameter located at 3.5 km

Pluto: Tennis ball 140 km away.

Proxima Centauri: At $10^6$ km ( beyond Earth's Moon).

Astronomical diagrams are NOT drawn to scale.

**TIME**

Age of Universe: 12 to 16 billion years ( ~$14 \times 10^9$ years).

Scale comparison:

Age of Universe:

1 year

| | |
|---|---|
| Formation of Earth ($4.5 \times 10^9$ yrs old) | August |
| Rise of Invertebrate life: | 13th December |
| Rise of Dinosaurs | 25th December |
| Earliest Human ancestors | 9:00 pm, December 31 |
| Modern humans evolve | 11:58 pm, Decmber 31 |
| Kepler and Galileo | 11:58:59 pm |

## Some Key Ideas

**Composition of universe:**

| | Initial | Today |
|---|---|---|
| Hydrogen | 75% | 70% |
| Helium | 25% | 28% |
| Metals | 0% | 2% |

Metals made by nuclear fusion in stars:

e.g. $4H \rightarrow He$ + energy, $3He \rightarrow C$ + energy

NB: Metal --- In astronomy, elements other than H and He.

**Universe is expanding:**

Distant (i.e., non local group) galaxies are moving away from us.

The more distant a galaxy, the faster the galaxy is moving away from us:

Speed of galaxy proportional to its distance from us.

**Universe contains Dark matter:**

Dark: not visible via electromagnetic radiation (light, heat, etc)

Not H, He, etc

Unknown (?) but has a gravitational influence.

**Universe is Evolving.**

e.g., more blue galaxies

**Universe was MUCH hotter and denser in the past**

Origin of universe called the Big-Bang

## The Scientific Method

**Science:**

- Evident in all aspects of life (TV, cars, telephone, health).
- Concerned with understanding the laws that govern the universe on all scales. From these laws we make predictions.
- Quantitative predictions provide a means to test the laws.
  - Modern scientists do not try to answer the ultimate question, i.e., why the Universe formed.

**Scientific Method:**

- Observation
- Experiment
- Theory

  - Gather Data
  - Form Theory
  - Test Theory

**NB: No theory is irrefutable**

A theory is acceptable only as long as it explains existing observations.

Faith requires belief. Not dependent on laws of nature. Can be contradicted by observation.

Crackpot theories make no testable predictions!

Experiments play a key role in most science disciplines.

Experiments require:

- Careful design.
- Control experiments (eg Placebo in medicine).
- Understanding of measurement errors.

Poor experimental design gives bad results.

- Cold Fusion
- Telephone survey

## The Role of Descriptions and Models in Science

### Descriptive astronomy topics include:

- The configuration of the Sun, Earth, and Moon during a lunar eclipse.
- The characteristics of Earth's seasons
- The colors of various types of stars
- Observed changes in the diameter, brightness, and color of a star at different times during its life
- The stellar populations of a spiral galaxy (like the Milky Way)
- The properties of objects in the observable Universe etc....

Descriptions are useful, but they don't tell us how something came to be or what the future will be.

Need to understand the physical process occurring, and need to MODEL those processes. An accurate model allows one to probe the past and extrapolate into the future (i.e., to make predictions).

Models have various levels of complexity.

Models can tell you:

1. When a future lunar eclipse will occur.
2. Why orientation effects cause the Earth's seasons.
3. Why a star's color depends on its surface temperature (and ultimately its age and mass).
4. Why a star's diameter, brightness, and color change as it ages.
5. Why a galaxy has a spiral structure.
6. Why the fate of our Universe depends on its mass.

Predictions have various degrees of success:

1. In physics, models for gravitational, electromagnetic, and nuclear forces give very accurate predictions for simple problems.
2. However, complex physical processes require complex equations which are hard to solve!
3. Biological and behavioral sciences are too complex for accurate predictions.
4. Some physical systems don't allow accurate predictions (chaos)

### MODEL PREDICTIONS VERSUS MODEL CONCEPTS

Model predictions:

- Testable through experimentation and observation.

Model concepts:

- Difficult to test.
- Sometimes are not specifically testable.

Although a model or theory can be disproved, a model or theory can not be proved to be uniquely correct.

## Gravity Theory

### Gravity is the dominant force in the Solar System.

1. Gravity holds the Sun together (while the pressure caused by the high temperatures tries to push the Sun apart).
2. Gravity causes the planets, asteroids, and comets to orbit around the Sun.
3. The gravity of the Earth-Moon system causes the tides.

Newton's concept for the theory of gravity uses invisible lines of force which causes masses to pull on one another. Newton's theory makes extremely accurate predictions under normal conditions.

Einstein's concept for gravity, called General Relativity, is based on geometry. Mass (or Energy) causes space to be curved.

- Objects feel the effects of this curvature, like something pulling on all the parts of our body, causing it to follow the most natural curved path in space.
- When gravity is extremely strong, Einstein's theory is more accurate than Newton's theory.
- A change in the distribution of matter creates a disturbance in the geometry of space-time. This disturbance, called gravitational radiation, moves through space at 300,000 km/s.

## Electromagnetic Theory

In electromagnetic theory (Maxwell) an accelerating electric charge will produce a disturbance, called electromagnetic radiation (EMR), which moves through space at 300,000 km/s. We see some EMR (or photons) with our eyes (visible light) and feel heat energy (infrared) from photons when our body absorbs them. Radio and TV waves are also types of EMR.

## Experiments in Astronomy and Astrophysics.

Unlike most other sciences because experiments are (generally) limited to making observations.

An astronomer can't do something to an astronomical object and see what happens.

Fortunately we see stars and galaxies at different stages of their evolution.

## Spaceship Earth

**No absolute reference frame.**

Must define the frame in which we make our observations and conclusions.

**An observer of the sky will find qualitative differences between the motions of:**

Sun, Moon, any one of the planets, stars

Observed motions of celestial bodies are primarily governed by 4 types of movement in the Solar System.

1. Daily or Diurnal Motion
   - The Earth rotates about its axis approximately once each day.
     - This causes celestial bodies (i.e., sun, stars, planets) to appear to rise and set approximately once each day when observed from moderate latitudes. Gives rise to concept of Celestial sphere. Two points, the South and North celestial poles, do not "move".
   - Celestial sphere: Imaginary sphere on which celestial objects appear to reside when viewed from the Earth.
2. Annual Motion
   - The Earth revolves around the Sun approximately once each year (365 days).
     - Each day the Sun moves about 1 degree east with respect to the background stars (since a circle has 360 degrees).
     - Different stars seen at different times of the year
     - Means of distinguishing the seasons.
3. Motion of the Moon
   - The Moon revolves around the Earth approximately once each month. Each day the Moon moves about 12 degrees east with respect to the background stars.
4. Planets revolve around the Sun.
   - Due to their orbital motion about the Sun, and the Earth's motion, their apparent motion is more complex.
   - However, their positions with respect to the background stars don't change more than a few degrees from night-to-night, and usually the change is much less.

**Ecliptic**

- Apparent path of the sun on the celestial sphere.
- Defined by the plane of the Earth's orbital motion about the Sun.
- Sequence of 12 constellations through which Sun passes is called the zodiac.
- The Moon and planets lie near the ecliptic.

**Celestial Equator**

Intersection of the plane passing through the Earth's equator and the Celestial sphere.

The plane of the Earth's revolution about the Sun, the plane of the Earth's rotation, and the plane of the Moon's revolution about the Earth are all tilted with respect to one another. This causes seasons on Earth, and the solar and lunar eclipse cycles.

The celestial equator is tilted by 23.5 deg with respect to the ecliptic plane. This causes the seasons.

The orbital plane of the moon is tilted by approximately 5 deg with respect to the ecliptic.

**Sun crosses the celestial equator twice each year.**

- Vernal (Spring) Equinox (approx. Mar 21)
- Autumnal Equinox (approx. Sep 22)

**Summer Solstice**

- Sun reaches most northerly point above the celestial equator.
- At a latitude of 23.5 deg N the sun is at the zenith at noon (local time). This defines the Tropic of Cancer.

**Winter Solstice**

- Sun reaches most southerly point below celestial equator.

**Seasons**

Caused by:
- Tilt of the Earth's axis, &
- orbital motion of the Earth about the Sun.

The Earth's rotation axis is inclined at 23.5$^{o}$ away from the perpendicular to the plane of the Earth's orbit.

Northern Summer:
- Northern hemisphere is pointed towards the Sun.

Northern Winter:
- Northern hemisphere is pointed away from the Sun.

Summer months warmer because:
- Sun spends longer above the horizon.
- Rays strike the ground more perpendicularly.

Question: What season is it in Australia now?

## Phases and Eclipses:

**Moon completes one orbit around the Earth (as defined by the stars) in approximately 27.3 days. This is** one sidereal month**.**

**Each day the Moon moves about** 13 degrees **east with respect to the background stars.**

**The Phases:**

**Defined by the position of the Moon relative to the Earth and Sun. It takes approximately 29.5 days to complete a full cycle of phases --- one synodic (or lunar) month.**

**The synodic period is longer than the sidereal month because of the earth's orbital motion about the sun.**

**new moon, waxing crescent, first quarter, waxing gibbous , full moon, waning gibbous, last quarter, waning crescent,** new moon.

**NB**

Waxing **-- Apparent illuminated area increasing with time.**

Waning **- Apparent illuminated are decreasing.**

**Each moon phase defines a particular Sun-Earth-Moon geometry.**

**Crescent**

**Angular distance (*between a line joining the Sun and the Earth, and a line joining the Earth and the Moon*) is less than 90$^{o}$. Less than half of the illuminated hemisphere is seen from Earth.**

**First quarter**

**Angular distance is 90$^{o}$. Half of the illuminated moon is seen.**

**Gibbous**

**Angular distance is greater than 90$^{o}$. More than half of the illuminated hemisphere is seen from Earth.**

Note:

**Observe a "thin" waxing crescent. As "thin", Moon must be close to Sun. Because it is a waxing crescent, the moon must lie slightly east of the Sun. On successive days the moon will move east with respect to the sun.**

**A first quarter moon will rise at approximately noon.**

**A full moon will rise around sunset.**

**Eclipses:**

**Occur when one body passes in front of another.**

**Solar Eclipse**

**Occurs when the Moon passes between the Earth and the Sun. The Sun is occulted, and the Moon's shadow falls on the Earth. This happens when the Moon's phase is NEW.**

**TOTAL eclipse:**

**Occurs when the Moon hides the Sun's disc completely, allowing the Corona to be seen (Moon is closest to Earth).**

**ANNULAR eclipse:**

**Occurs when the alignment is perfect but the Moons angular diameter is too small to fully block the Sun (i.e. the Moon is at it's greatest distance from Earth).**

**The eclipse path (region from which eclipse can be seen) is quite narrow --- always less than 270km. Totality lasts less than 7.5 minutes.**

**Lunar Eclipse**

**Occurs when the Earth passes between the Moon and the Sun. The Earth's shadow falls on the Moon. This happens when the moons phase is FULL.**

**During a lunar eclipse the Moon can appear reddish. This is caused by the refraction of sunlight by the Earth's atmosphere. Totality can last for up to 1hr 42 minutes.**