Topic 3: Earth in the Universe

Topic 3 Section 1

Overview: with over 6000 *celestial objects* (any object outside Earth's atmosphere) visible from our planet, the night sky gives rise to many questions

Origin and age of the universe

By counting years in the generations listed in the Bible, some Christians have calculated the age of the Earth to be no more than 10 000 years

Granting that God has the power to have created that way, in the scope of this course we will investigate and learn the ages most secular scientists give for the age of the Earth and the universe as well as the evidence they propose for these values

Universe – all that exists – approximate age: 13.7 billion years

Age is based on:

- expansion of the universe – Edwin Hubble and the Hubble Space Telescope data
- cosmic background radiation – measured by WMAP
- age of oldest observed stars

Big Bang theory

States that all matter and energy existed in a very small space and then exploded

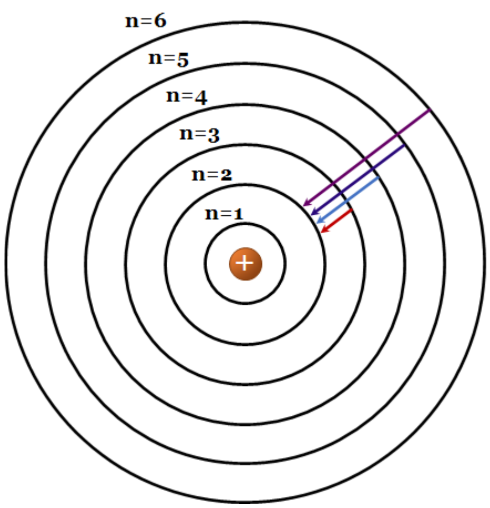
- the tiny universe exploded into energy (Let there be light.)
- the energy organized into an expanding universe of matter
- the matter organized into atoms of H and He (and very small amounts of Li)
- the atoms organized into stars (suns) due to gravity and suns made heavy atoms
- gravity holds stars into galaxies and superclusters of galaxies

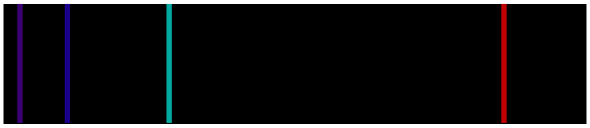
This model accounts for the expansion observed today and is evidenced by the cosmic background radiation temperature

The evidence for expansion (and the age of stars and black holes) is based on the spectra of elements, especially the element hydrogen since about 74% of the matter in the universe is hydrogen atoms

Hydrogen spectrum

When electrons drop from a higher energy level to a lower one, they give off a specific color of light





Hydrogen emission spectrum

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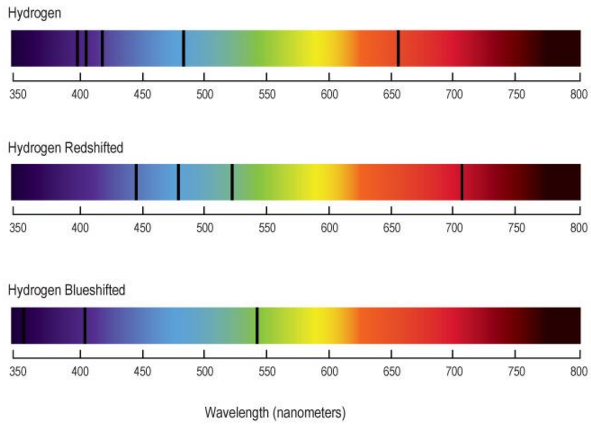
If hydrogen moves toward or away from Earth, the position of the spectral lines shifts toward the red (hydrogen is moving away) or the blue (hydrogen is moving toward Earth) end of the spectrum



Galaxy at fixed position from Earth

Galaxy moving away from Earth

Galaxy moving toward Earth

Doppler Effect – the increase (or decrease) in the frequency of sound, light, or other waves as the source and observer move toward (or away from) each other

Except for the galaxies very near to us, the observed galaxies show a red shift and are therefore moving away from us (the evidence for expansion)

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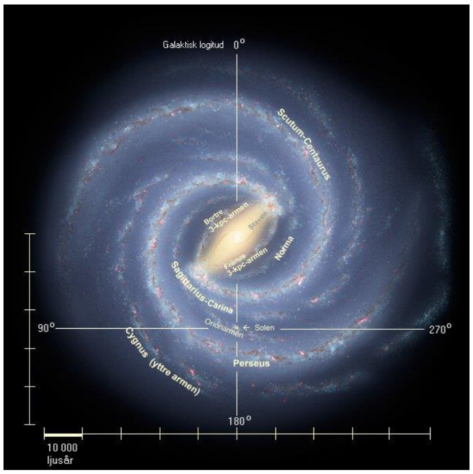
Topic 3 Section 2

Structure of the universe

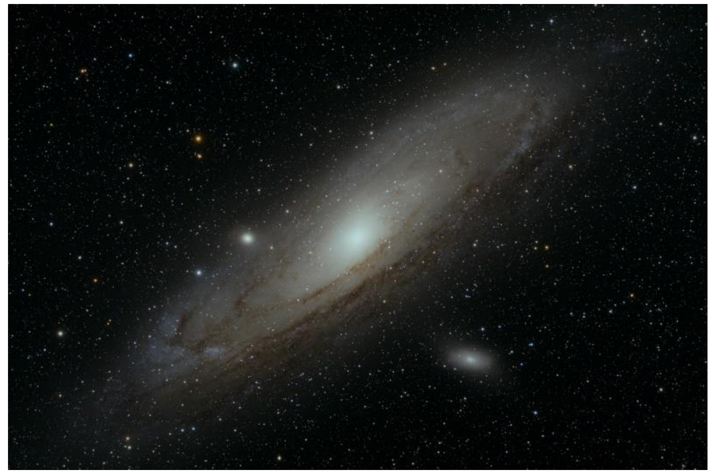
The basic structural unit of the universe appears to be the galaxy

Galaxy – hundreds of billions of stars, dust, and gas held together by gravity

The Milky Way galaxy is 100 light-years across and contains about 400 billion stars



The Milky Way Galaxy

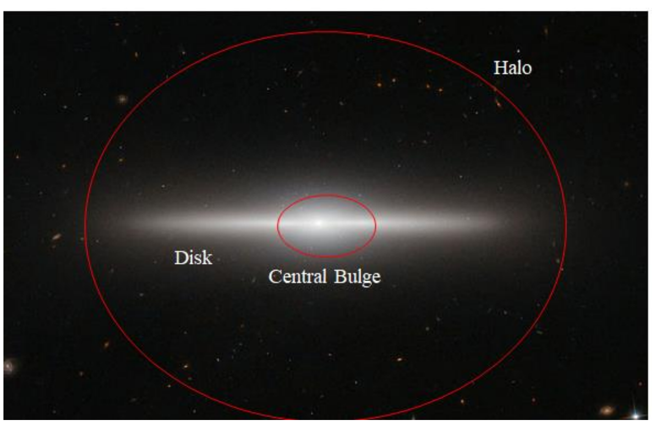


The Andromeda Galaxy

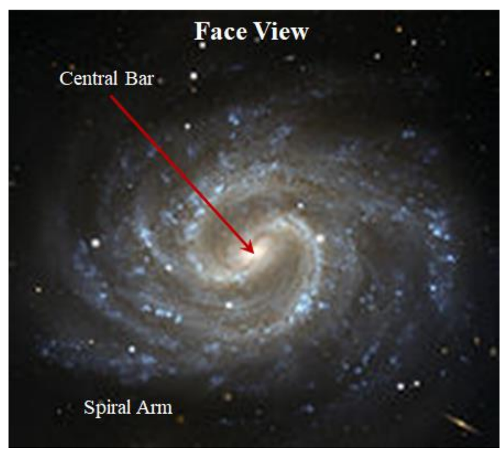
The nearby Andromeda Galaxy contains about 1 trillion stars and is about 2.5 million light years (2.5 mly) away

Typical Spiral Galaxy (like our Milky Way)

Edge View



IC 335 in Fornax



NGC 4535 in Virgo

Stars – along with dust and gas clouds, stars make up most of the visible matter in a galaxy

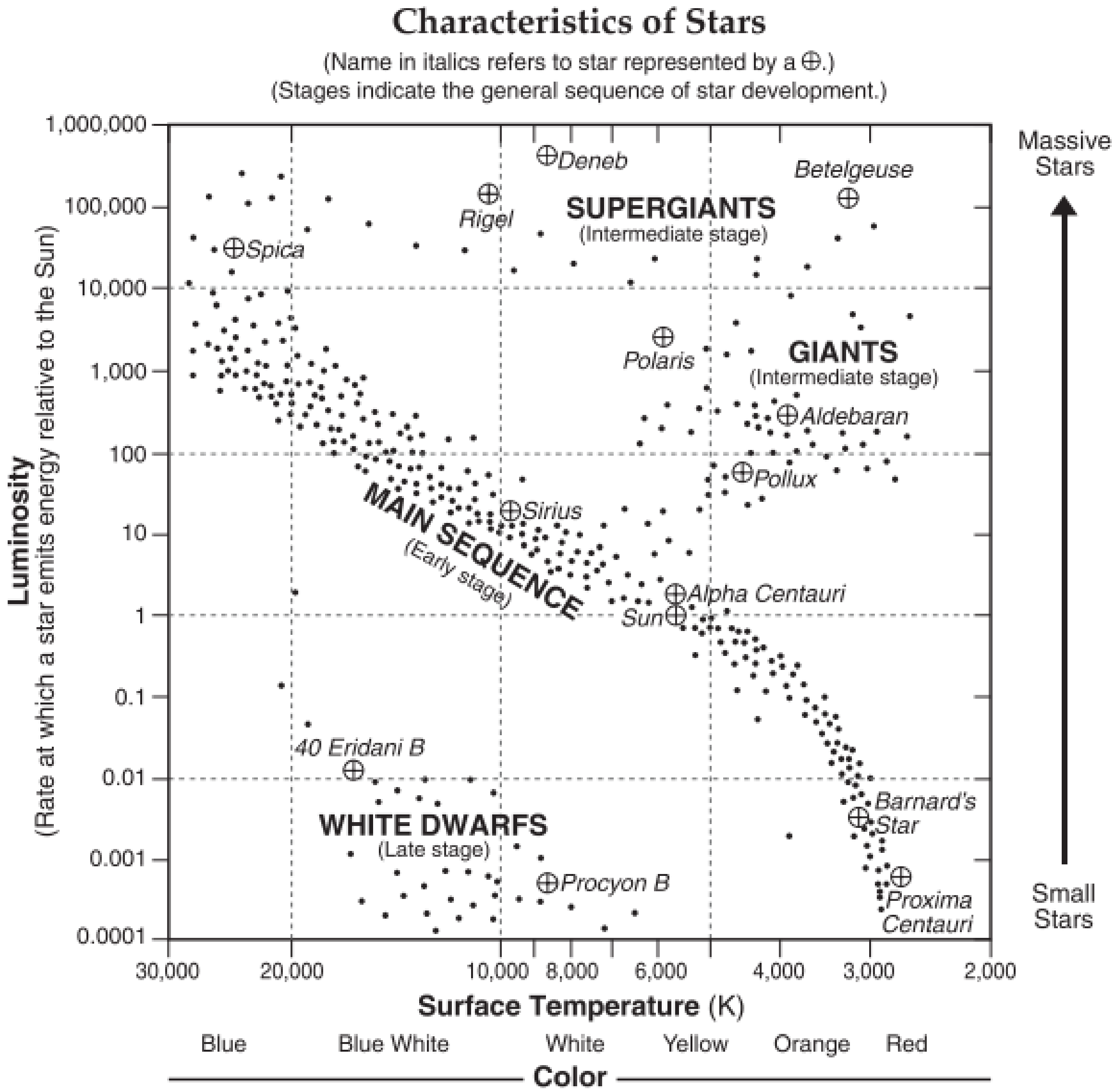
Most stars are huge balls of gas that produce enormous amounts of energy

Nuclear fusion accounts for most of the energy production of stars

About 0.07% of the mass of a H to He reaction is converted to energy by $E = mc^2$

Our sun accounts for 99.86% of the mass of our solar system

Characteristics of Stars Diagram



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The standard method used to classify or group stars is to make a plot of luminosity vs. the surface temperature of stars

- luminosity is the rate at which a star emits energy
  absolute magnitude of a star gives the brightness of a star at a standard distance
  brightness of a star relates to how bright a star appears at its actual distance
- the surface temperature of a star will determine its color

Notice that the surface temperature of a star decreases from left to right on the x-axis

- the hottest (and most massive) stars are blue and the coolest stars are red
- there are very few supermassive blue stars
- the most common stars are small and cool red dwarf stars

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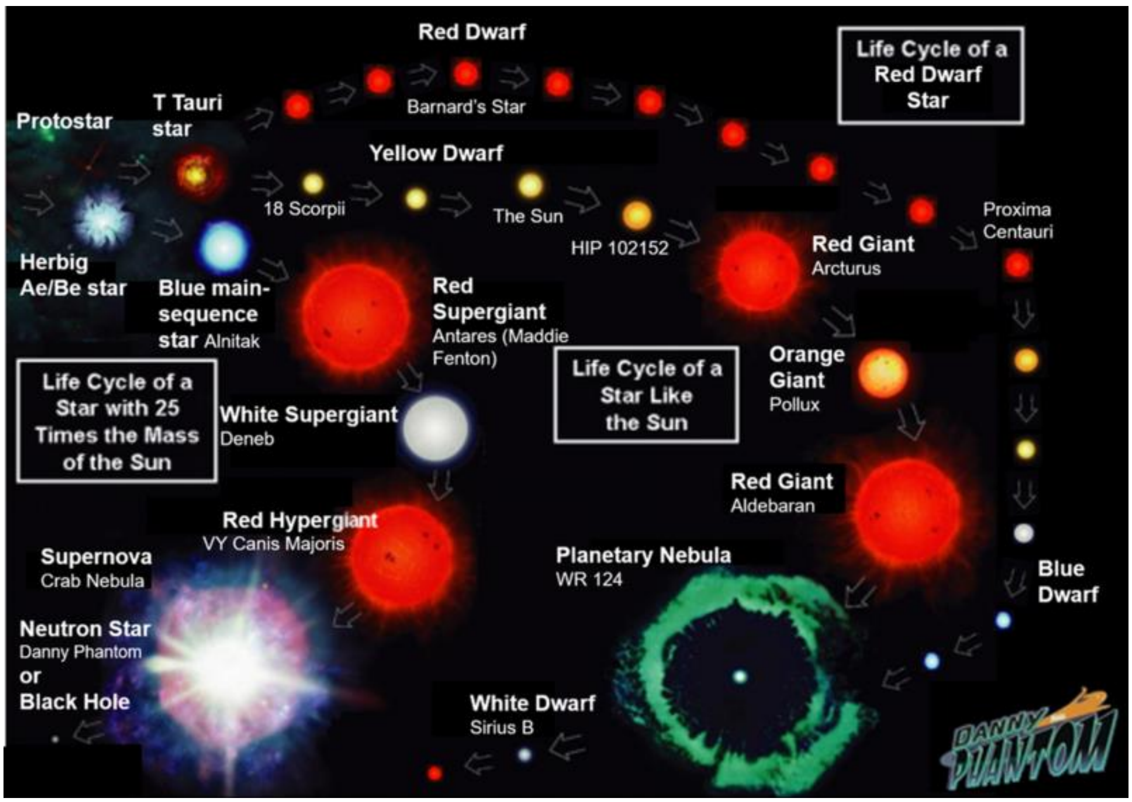
Types of stars on an H-R Diagram (star characteristic diagram)

- main sequence – stars spend most of their life spans as main sequence stars which means they are converting H to He by nuclear fusion in their core
- giant stars are red, orange, or yellow and while they are rare in number, a large proportion of stars we see in the night sky are giants because their large size makes them have high brightness
- super giant stars are dying massive stars with diameters 100 to 1000 times the sun
- white dwarfs are small dead stars (< 3 times the mass of our sun, not all are white)
- black dwarfs are the end product of white dwarf stars that are no longer hot enough to glow

Star origin and evolution



All stars form when massive gas clouds begin to collapse due to gravity

- gas clouds that form stars slightly larger than Jupiter will result in red dwarf stars
- stars less than 3 times the mass of our sun will end as planetary nebula
- very massive stars, 25 solar masses, will supernova and end as neutron stars or black holes

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Topic 3 Section 3

Solar system

Due to the recent discovery of so many exoplanets, 'the solar system' refers to our system

Our sun:

- accounts for 99.86% of the mass of the solar system
- is a medium mass star that is about 5 billion years old
- is the gravitational center of our solar system

Satellite – an object that orbits around any other object

The planets, comets, asteroids, and meteoroids are all satellites of our sun

Moons are satellites of either one of the planets or an asteroid

Earth has one natural satellite, the moon, and several thousands of man-made satellites

Planet – any object that orbits the sun and does not share an orbit with other large objects

The recent definition above limits our solar system to eight large planets

Due to their large size, gravity causes planets to form a spherical shape

Asteroid – a solid rocky/metallic body that independently orbits the sun

Most asteroids are irregular in shape, but a few are large enough to form spherical shapes

- asteroids are too small to hold an atmosphere
- asteroids are much smaller than planets (100 to 1000 km for the larger ones)
- asteroids are often called minor planets

Moon – an object that orbits a planet or asteroid as those objects orbit the sun

Including minor planets and asteroids, there are over 200 moons in our solar system

- 76 asteroids have satellites (moons)
- generally, the larger the planet the more moons it will have

Comet – often compared to a dirty snowball where the ice is water and methane

As comets near the sun, the ice begins to turn to a gas releasing gas, ions, and dust

- comets have two tails – an ion tail straight away from the sun and a curved gas/dust tail
- most comets are 1 to 100 km in diameter
- comets tend to last for months (although many move from north to south

Meteoroid – very small solid fragments that orbit the sun

Most meteoroids are the size of a grain of sand up to the size of a dime

- meteoroids that strike Earth's atmosphere and vaporize are called *meteors* most meteors we see streak across the sky are the size of a walnut
- a meteor that actually strikes Earth's surface is called a *meteorite*
- if a meteorite leaves a depression in Earth's crust, the depression is called an *impact crater*

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Evolution of the solar system

1. A shock wave in a huge gas/dust cloud started gravitational contraction (often multiple suns will form)
2. Most of the matter falls to the center forming a sun in a disk of gas and dust
   Heat from gravitational contraction stars nuclear fusion in the sun
   Clumps of dust in the disk form meteoroids, comets, and asteroids
3. Continued clumping in the disk forms larger and large lumps
   Meteoroids, comets, and asteroids form large lumps that form planets and moons
   Heat from the impacts (and radioactivity) melted planets resulting in density layering
   Continuing impacts cause solid planets to show cratering
4. A combination of heat and ions from the sun causes inner planets to lose light elements leaving rocky terrestrial planets in the inner solar system

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Topic 3 Section 4

Planet characteristics

Distance from the sun has a major effect on planet characteristics

High temperatures and pressure of hot particles from the sun drove light elements and gases away from the planets closest to the sun forming terrestrial planets

Outer planets did not receive such high temperatures and pressures, so they are gas giants

Pluto is more like an icy moon that escaped than either a terrestrial or Jovian planet which is part of the reason for it being reclassified as a minor or *dwarf planet*

Terrestrial planet properties

- close to the sun
- mostly solid with rocky surfaces (high density)
- have few or no moons or rings

Terrestrial planets include Mercury, Venus, Earth, and Mars

Jovian planet properties

- far from the sun (low density)
- mostly gaseous with large diameters, no solid surface but may have solid cores
- have many moons and rings

Motions of the planets

Planets exhibit many different motions

- they move with the solar system like a horse on a merry-go-round as they orbit the center of the Milky Way
- they rotate on an imaginary axis
- they revolve or orbit around the sun

Planet revolution

As viewed from Polaris, all the planets orbit the Sun in a clockwise direction

The orbits are elliptical (but very close to circular)

Ellipse – an oval shape with two fixed points (called *foci*)

The sum of the distances from the two foci to the ellipse is a constant

The Sun is located on one of the foci

The *major axis* is the longest straight-line distance across an ellipse and it passes through the two foci

Eccentricity [ˌeksenˈtrisədē] the amount of difference between a circle and an ellipse

$$\text{Eccentricity} = \frac{\text{distance between foci}}{\text{length of major axis}} = \frac{d}{L}$$

The eccentricity of a circle = 0

Mercury is the only planet with a large enough eccentricity that its scale orbit does not appear to be a perfect circle to the unaided human eye

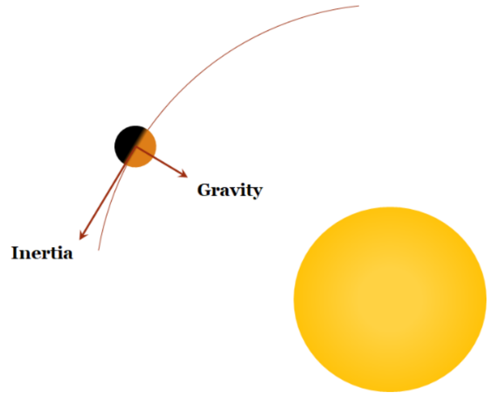
Because the orbits of the planets are elliptical, the Sun will appear slightly larger when the planet is closest to the Sun (*perihelion*) and slightly smaller when the planet is farthest from the Sun (*aphelion*)

For planet Earth, aphelion occurs at 152 000 000 km on or about 4 July and perihelion occurs at 147 000 000 km on or about 3 January

This difference of 5 000 000 km, or about 3.4%, is ***not*** the reason for the seasons

Orbital velocity, gravitation, and inertia

- Inertia – an object in at rest will remain at rest and an object in motion will remain in motion at constant velocity unless acted on by an outside force
- Gravitation – the attractive force that exists between any two objects in the universe
- The balance between inertia and gravitation is what keeps the planets in orbit because inertia tends to move the planet in a straight line while gravity causes the plane to move in an elliptical path



  - The orbits of planets and satellites is an example of a dynamic equilibrium
- Because of the eccentricity of a planet's orbit, the orbital speed of a planet varies during its year (the amount of time required for a planet to make one revolution about the Sun)
  - The closer a planet is to the sun, whether due to eccentricity or due to a smaller orbit, the faster its orbital velocity