Astrobiology

Components of the Universe

- The normal (baryonic) matter in the universe is mostly made up of hydrogen (75%) and helium (25%)

Galaxies – The Milky Way

- Galaxies are made up of gas, dust and stars (our galaxy is The Milky Way)
- The Milky Way is a spiral galaxy consisting of a flat disc and central bulge
- Within the disc, spiral arms contain mainly younger stars
- The Milky Way is approximately 50,000 light years in radius
- The region between spiral arms is not empty, it contains interstellar medium (ISM)
- ISM is composed of gas and dust and makes up 10% of the mass of the galaxy
- Galaxies contain giant clouds called Giant Molecular Clouds (GMCs)
- GMCs are the places where the most young stars form

Attractions of Masses

- G is the Universal Gravitational Constant ($6.67 \times 10^{-11}\ m^3kg^{-1}s^{-2}$)
- M1 and M2 are the (point) masses involved
- r is the distance between M1 and M2

- In a cloud of gas, the net force acts inwards towards the centre of the cloud (where more mass is concentrated) and the cloud collapses on itself, contracting
- The particles in the gas also have thermal/kinetic energy (KE_{av})

$$KE_{av} = \frac{1}{2}mv^2 = \frac{3}{2}kT$$

- m is the mass of the gas molecules (mainly H_2)
- v is the velocity at which the gas particles move
- k is the Boltzmann constant ($1.38 \times 10^{-23}\ JK^{-1}$)
- T is the temperature of the gas

- In a hot gas, the particles move more rapidly and have a higher kinetic energy
- In a cool gas, the particles move more slowly and have a lower kinetic energy
- The force exerted by gases with high kinetic energy, acts outwards
- Clouds of molecular gas in a galaxy will therefore experience gravity acting inwards and thermal pressure acting outwards
- For gravity to dominate and cause a molecular cloud to contract and form stars, we need high gravitational force (large mass of gas) or low thermal pressure (cool gas) or both
- Star formation can also be caused by cooling or compressing a gas cloud
- This may occur as a results of supernova explosions, density waves in galaxies, stellar motions, and stellar winds from hot, young stars in OB associations

$F_G > KE_{av}$

- Gas cloud collapses and heats up
- Increase density (must be triggered) or low temperature (can happen on its own) can cause this
- Molecules are good at radiating energy, thereby cooling the gas

$F_G < KE_{av}$

- Gas cloud expands and cools

$F_G = KE_{av}$

- Gas cloud is in hydrostatic equilibrium and the system is stable

Collapse and Accretion

- When gravity dominates, the gas cloud contracts (each particle is pulled towards the centre by all the other particles in the cloud)
- The more particles that accumulate in the centre, the stronger the gravitational pull is on the other particles and the faster they move

- As the gas begins to heat up, it is called a proto-star
- The collapsing gas cloud gathers infalling material from the surrounding cloud, called accretion (accumulation of matter)
- If the original cloud was rotating, a disc forms
- The central proto-star often emits material perpendicular to the disc in a bipolar outflow
- Accretion ends when the entire cloud has been accreted onto the protostar or when the star begins to radiate energy
- Energy is radiated from the core when the star undergoes fusion (turns on)
- This exerts a force opposing gravity, leading to hydrodynamic equilibrium (star is unlikely to accrete material in this state)

Stars

- Stars can be different shapes, colours and brightness's (depending on how far away they are and how bright they actually are)
- A star's 'true' brightness (not affected by distance) is called its luminosity (L) or absolute brightness
- Luminosity measures the total energy emitted by the star each second
- The sun's luminosity is 3.839×10^{26} Watts
- Star clouds often fragment into smaller clumps (which can also form stars)
- Most stars form in clusters (these stars most likely form from the same cloud at the same time)
- Within clusters there are single stars, stars in pairs (binaries/binary systems) stars in groups of three (triples/triple systems) or more (multiples/multiple systems)
- There are 2 types of clusters; open clusters and globular clusters
- **Open clusters** contain 10 – 1000's of stars which are loosely bound to each other (they can be any age)
- **Globular clusters** contain 10 – 1000's or millions of stars and are found mostly in the halo of the Galaxy (mostly older stars)
- Planets form in a similar way to stars
- The difference between planets and stars is their mass, stars are massive enough for fusion to occur in their core whereas planets are significantly less massive and do not undergo fusion

Stellar Distances

- The moon is closest to earth (380,000 km away)
- The nearest star is 100 million times further away
- The speed of light is approximately 3×10^8 m/s
- A year is 3.1×10^7 s
- A light year is 9.3×10^{15} m
- Stellar distances are measured using light years
- The distance to the nearest star is approximately 4 light years
- The parsec (parallax second or pc) is the distance at which the Sun-Earth separation, 1 AU, subtends an angle of 1 arcsecond (1/3600 of a degree)

- Kiloparsecs (kpc = 1000 pc)
- Megaparsecs (Mpc = 10^6 pc)

- To measure the parallax, we measure the apparent change in position of a nearby object relative to more distant stars as the Earth moves around the Sun. This measurement should be done as further apart as possible (eg. 6 months apart) to get the maximum apparent displacement to be able to measure the parallax

$$d = \frac{1}{p}$$

- d is the distance in parsecs
- p is the parallax angle in arcseconds

- Once a star is more than a few parsecs away the angles become too small to measure accurately
- The closest star to the Sun is Proxima Centauri (4.22 ± 0.01 light years)

Stellar Colour/Brightness

$$E = h\nu$$

- E is energy in joules
- h is Planck's constant (6.626×10^{-34} m^2 kg/s)
- ν is the frequency in Hertz (Hz)

$$c = \upsilon\lambda$$

- c is the speed of light (3×10^8 m/s)
- υ is velocity in m/s
- λ is wavelength in m

- Energy is related to wavelength such that:

$$E = h\frac{c}{\lambda}$$

- Energy is inversely proportional to wavelength (as wavelength increases, energy will decrease)
- Therefore, blue light, with its shorter wavelength, indicates hotter temperatures than red light
- Wein's law states that the λ_{peak} (wavelength of the peak) changes with temperature

$$\lambda_{peak} = \frac{3 \times 10^6 [\text{nm K}]}{T[\text{K}]}$$

- Hotter stars emit more light
- Stefan Boltzmann's law states that the area under the curve corresponds to apparent brightness/the energy emitted by the star per unit area (flux)

$$F = \sigma T^4$$

- F is flux in W m^{-2}
- T is temperature in K
- σ (sigma) is Stefan-Boltzmann constant 5.67×10^{-8} in W $m^{-2}K^{-4}$

$$L = (4\pi R^2) \times (\sigma T^4)$$

- L is luminosity/absolute brightness in watts (W)
- R is the stellar radius in m

- After we measure the apparent brightness of a star, we measure its distance to determine its luminosity (as its distance from earth affects its true brightness)
- The inverse distance law states that the intensity of radiation (brightness) falls with distance squared

$$F = \frac{L}{d^2}$$

- Brightness is often measured using magnitudes (lower the magnitude, the brighter the star)
- The ratio of photons of each colour provides a quantitative measure of colour, called the colour index
- The colour index doesn't necessarily tell us the true colour of the star directly as dust and gas between the star and the observer can change the apparent colour of the light, in a process called reddening.
- A common colour index is B-V

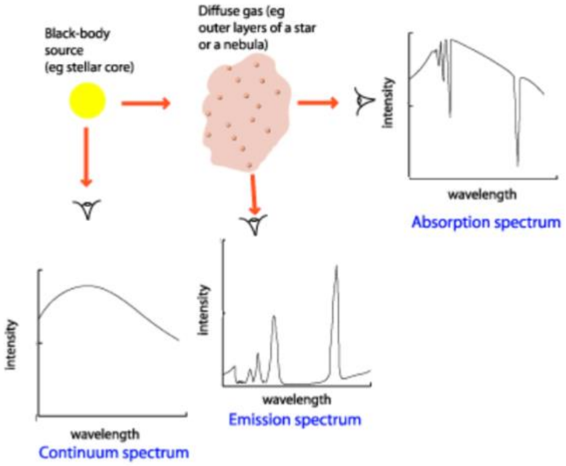
Stellar Spectra

- Electrons and orbits have distinct energy states (quantized energy states)
- Electrons can change energy between these orbitals; they can jump up to a higher state (E_2) after absorbing energy and producing absorption lines at a specific frequency ν (eg. specific wavelength λ). Or they can jump down to a lower state (E_1), releasing some energy and producing emission lines at a specific frequency ν (eg. specific wavelength λ).

$$\Delta E = E_2 - E_1 = h\nu$$

ΔE is the amount of energy required for the electron to absorb the photon

- Lines on a spectrum are formed when atoms which are in the first excited state, absorb photons and jump up to a higher excited state
- The absorption and emission lines appear at exactly the same wavelength, since the energy difference between the states needed to produce that line, is the same
- The opposite of spectra emission (spread over a range of wavelengths) is line emission (narrow band of individual spectral lines)



- The spectral curve on a graph is known as the Spectral Energy Distribution (SED)
- SED shows the energy output versus wavelength for an unknown star
- Atoms/molecules in the outer layers of a star (its 'stellar atmosphere') can absorb light at specific wavelengths
- The starlight over a range of wavelengths can indicate what particles are present in the star's atmosphere (it's chemical composition)

Stellar Classification - Hertzsprung Russel Diagrams

- Stars are classified based on their spectral features
- There are ten spectral types - O, B, A, F, G, K, M, R, N, S
- The spectral classes are O, B, A, F, G, K, M and L (broken down into R, N and S)
- Each class is sub-divided into 10 other classes, numbered from 0 to 9