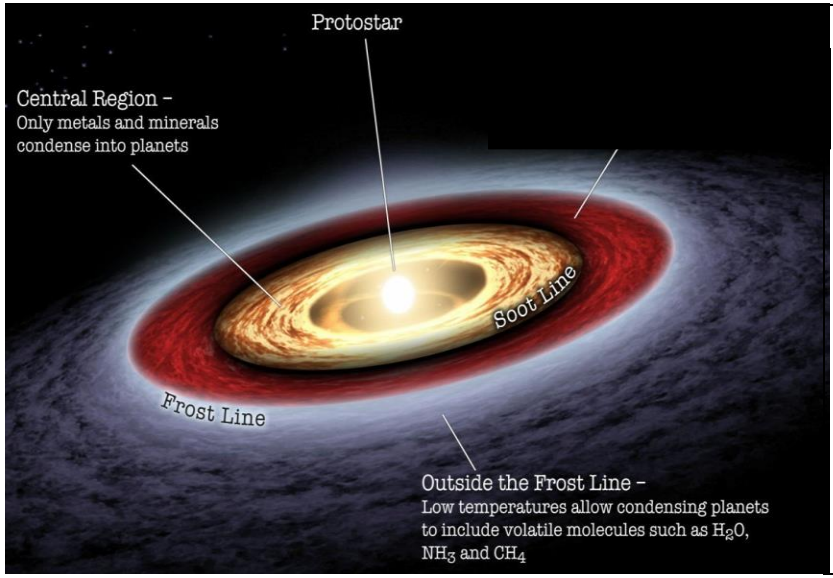
Astronomy **Summary Knowledge Organiser** – Chapter 12 (Topic 12) **Formation of planetary systems (i)**

GRAVITATIONAL ATTRACTION has produced the <u>regular motion</u> that we see in out Solar System, including the fixed orbits of both planets and moons. It is also responsible for the original <u>formation</u> of those planets and moons.
4.6 BILLION YEARS AGO a cloud of dust and gas collapsed to form a **PROTOPLANETARY DISC** of **75% Hydrogen**, **23% Helium** & 2% other elements such as Oxygen, Silicon, Carbon, Iron & Nickel. The Sun formed at the center of this chaotic swirling disc and as **distance from the Sun increased temperature decreased**.

The planets and moons we see today formed due to **ACCRETION** of the material in the protoplanetary disc. Firstly **electrostatic attraction** pulled tiny particles together and then their **gravitational attraction** pulled other particles to them forming ever larger ones. These processes continued for 100 million years, until eventually the **metallic and rocky (silicate) planetary cores of the 4 inner planets formed**.
There may have been as many as <u>50 bodies</u> (planetesimals) <u>originally formed</u> in the Solar System but **collisions** and then **reformation** eventually produced the 8 planets we have today. **EVIDENCE of these collisions** includes **Mercury's iron core** making up a massive **60% of its total volume** (Earth's core is only 20% of its volume), the **large axial tilt of Uranus**, the '**backward' (retrograde) spin of Venus**, the formation of **the Moon** and large **impact craters** observed throughout the Solar System.



Mercury – high temp. & low 'g' =practically no atmos'.

Venus – despite high temp, has enough 'g' to retain a dense atmos'.

Saturn's large moon **Titan** – low temp. & enough 'g' to retain Nitrogen rich atmos'.

Neptune – low temp. & high 'g' so retains a deep atmosphere of H & He.

<u>'g' = gravitational field strength</u>

The **FROST LINE** is an imaginary boundary **about 5AU from the Sun**. At distances **<5AU** from the Sun, the **high temperatures** meant that **only metals & silicates could CONDENSE** to form firstly **TINY GRAINS,** then **LARGER FLAKES and finally the METALLIC-ROCKY CORES** of **Mercury, Venus, Earth & Mars**..
Beyond the frost line, the **low temperatures** allowed even the **VOLATILE COMPOUNDS (water, methane & carbon dioxide)** to **condense into solid grains**. The result of this is that the gas giants are found in the **outer Solar System** <u>because</u> they **formed outside the frost line**. The <u>elements</u> of Hydrogen & Helium remained gaseous inside and outside of the frost line but were largely blown outwards by the solar wind.

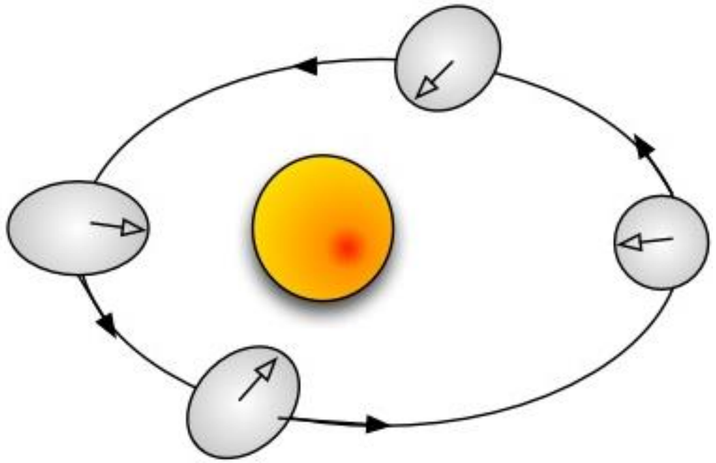
All planets are **SPHERICAL** but <u>not</u> all moons/asteroids. Whether moons/asteroids are spherical depends on **what they are made of** (composition) and their **size**. If a moon or asteroid is made of **ICE** it will have **WEAK RESISTIVE ELASTIC FORCES** and will only need to be <u>**400km**</u> in diameter before its **attractive gravitational forces** are able to pull it into a spherical shape. **ROCKY** moons and asteroids have **STRONGER RESISTIVE ELASTIC FORCES** and so won't be pulled (deformed) into a spherical shape unless they are > <u>**600km**</u> in diameter.

Gravitational forces also affect the **ORBITS** of moons! Most **LARGER MOONS** (such as the 4 Galilean moons of Jupiter) **formed at the same time as their host planet** and so they **orbit in the same plane** and **spin in the same sense**(clock-wise/anti-clockwise) as the planet. However, other moons that **orbit at a different inclination** or **spin in the opposite direction** of their host planet were probably **CAPTURED** from the **Asteroid (AB) or Kuiper Belts (KB)** eg. Mars-Deimos (AB), Saturn-Phoebe (captured Centaur(half-comet half-asteroid)) & Neptune-Triton (KB) .

Planetary **atmospheres** are <u>determined</u> by two factors, the **distance from the Sun** (**temperature**) and the **mass of the planet** (**gravity**). A planet closer to the Sun will naturally have a higher surface temperature so the **average kinetic energy of the gas molecules** within the atmosphere will be **higher**. If the gas molecules <u>exceed the escape velocity</u> of the planet then they can and will eventually '**escape**' that planet. Therefore, for a planet to maintain the lighter elements (H, He) it must be **relatively cold** (a large distance from the Sun) <u>and</u> have a **relatively high mass**.

Astronomy **Summary Knowledge Organiser** – Chapter 12 (Topic 12) **Formation of planetary systems (ii)**

Moons have **TIDAL FORCES** inflicted upon them due to the inverse square nature of gravity. Due to the **nearside** of a moon being pulled towards its planet with a **stronger force** compared to its far side (which is further away from the planet), moons are '**stretched'(elongated) directly inline with the planet**. This effect causes moons to have a **TIDAL BULGE directly inline with the planet** at all times in its orbit, even as the moon spins on its own axis. As the moon spins whilst orbiting its planet **the tidal bulge MIGRATES across its surface causing INTERNAL TIDAL HEATING.**



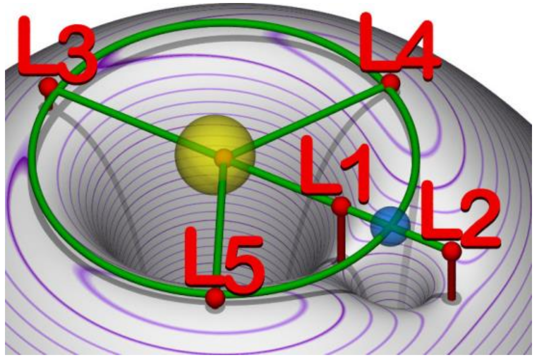
As the moon spins in orbit, the continual migration of the tidal bulge across the moons surface causes **INTERNAL FRICTION** that has a **HEATING EFFECT** on the moons interior.
The **thermal energy** that is generated within the interior of moons is **transferred** from the **kinetic energy store** of the moon. This means the moon will **spin slower over time** and eventually its **rotational period** will slow enough to match its **orbital period**, it will now be locked in **SYNCHRONOUS ROTATION** with its host planet. Large moons that are close to large planets are most likely to have synchronous rotation due to the large tidal forces applied to them!
*Once synchronous rotation is achieved **tidal heating does not stop** because orbits are elliptical, so orbital speeds are not constant, meaning tidal bulges still move(oscillate about a mean position).

Tidal heating and changes to orbits can also be caused by **MULTI-BODY INTERACTIONS** such as seen with Jupiter's moons Ganymede, Europa & Io. The **orbital periods** of these 3 moons are in the exact **ratio of 4:2:1** (see below).

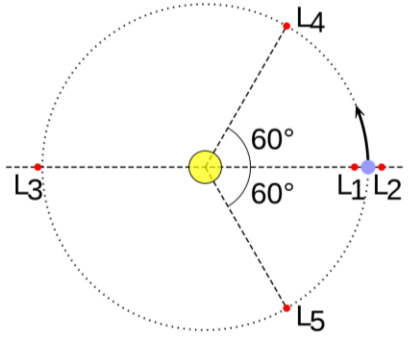
This **ORBITAL RESONANCE** is caused by regular gravitational tugs from **Ganymede** and **Jupiter** on **Europa** and **Io** that happen when the 3 moons line up. The continual tugs have caused the orbital resonance ratio to become fixed and cause tidal heating, hence Io has many erupting volcanoes on its surface today! **Icey moons** such as Saturn's moon Enceladus and Uranus' Miranda can also undergo internal tidal heating that causes **cryovolcanoes** (ice volcanoes).

TIDAL GRAVITATIONAL FORCES try to tear moons apart, internal-resistive **ELASTIC FORCES** try to hold them together. If a moon is either made of a material that generates a weak elastic force or is close to its host planet and so experiences strong tidal gravitational forces it may get ripped apart or never form in the first place, leaving a **RING SYSTEM** instead of a moon!

The **ROCHE LIMIT** is the **minimum distance a moon can form from its parent body without being torn apart by tidal gravitational forces.**
The Roche Limit (for bodies of similar composition) is *x 2.5 the RADIUS* *of the parent body*



LAGRANGIAN POINTS occur in any **2 body system** due to the effects of their combined gravity. There are **5** Langrangian Points where the **combined gravitational forces** of the 2 bodies (eg. Sun & Earth) is **exactly equal to the force needed to keep a satellite in orbit** around one of the bodies (Earth).
L1, L2 & L3 are UNSTABLE and if we place satellites in those positions they need to be continuously maneuvered to maintain their orbit (this requires using fuel).

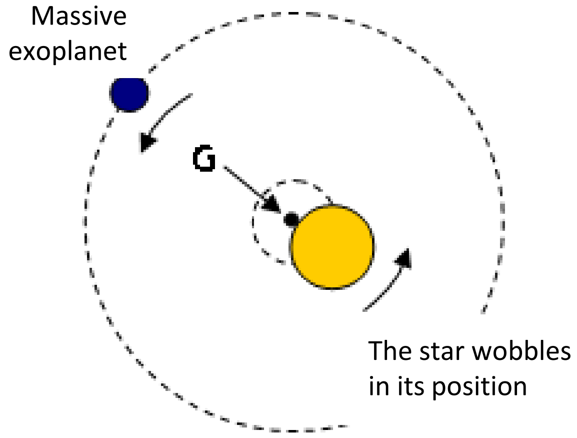


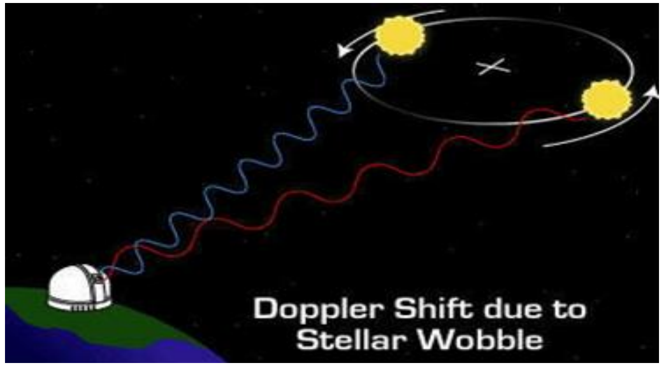
L4 & **L5** are **STABLE** and found **60°** **ahead of** and **behind Earth**.

Astronomy **Summary Knowledge Organiser** – Chapter 12 (Topic 12) **Formation of planetary systems (iii)**

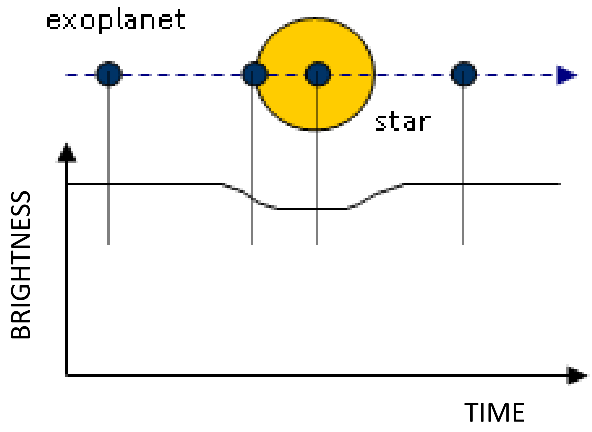
Since the first discovery of an exoplanet system in 1995 by Mayor & Queloz, three methods have been used to find more ……..

ASTROMETRY (below) – this method finds **massive exoplanets** when their **gravitational pull causes the parent star to move or 'wobble'** around a common center of gravity. We measure the stars 'wobble' very precisely and indirectly find the exoplanet(s).



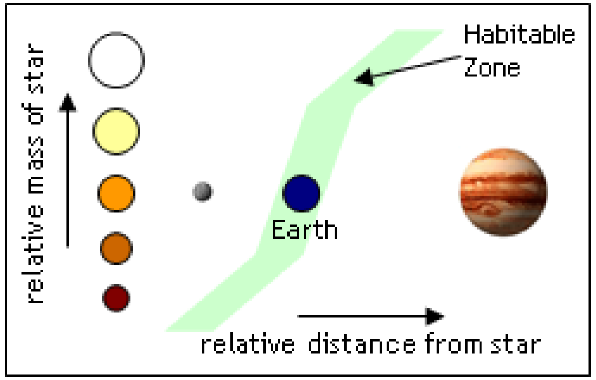


TRANSIT METHOD (below) – if the **orbital plane** of an exoplanet matches our '**line of sight**' we will see the star **dim** every time the planet passes in front of it. When the exoplanet transits the disc of the star we see it reduce in brightness by a very small amount (1%). **Observing** the star over a **long period of time** and **plotting its brightness** allows the stars exoplanet system to be uncovered.



RADIAL VELOCITY METHOD (see left) – sometimes called the ***Doppler-shift method*** this method also involves the '**wobbling**' of the parent star as the gravity of large exoplanets pull on it. The host star will **move towards and away from the observer** as it moves around its own orbit and so the light it emits will be **blue-shifted** or **red-shifted**. Astronomers use ***spectroscopy*** to measure the amount of Doppler-shift and can then deduce the presence of exoplanet systems from it.

EXTRATERRESTRIAL LIFE requires a source of **ENERGY** (from tidal heating or radioactive decay in the planets core) , **CARBON** (an element that can make compounds such as amino acids which are the small building blocks of larger organic molecules) and **LIQUID WATER** (an excellent solvent and transport mechanism for moving nutrients around).



The **HABITABLE ZONE** is sometimes called the **Goldilocks Zone** and is the **range of distances a planet must be from its host star** if liquid water is to exist on its surface.

The **DRAKE EQUATION** allows us to <u>**estimate**</u> the **number of <u>intelligent civilisations</u> in our own <u>galaxy</u>** (the Milky Way).

$$N = N_s \times f_p \times n_{HZ} \times f_l \times f_i \times f_c$$

- N: number of civilizations in our Galaxy that might communicate
- N_s: number of stars in our Galaxy
- f_p: fraction of stars with orbiting planets
- n_{HZ}: number of Earth-like planets in Habitable Zone
- f_l: fraction of Earth-like planets on which life actually evolves
- f_i: fraction of planets where life is intelligent and develops communication technology
- f_c: fraction of planet's life for which intelligent civilisations live