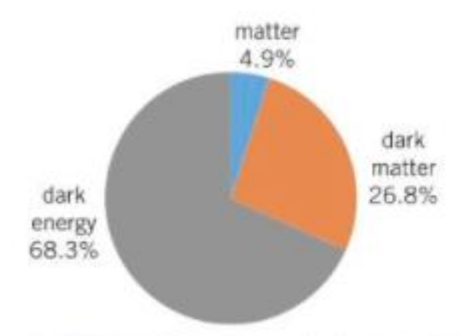
THE EVOLUTION OF THE UNIVERSE

DARK ENERGY AND DARK MATTER

The universe is expanding and at an accelerating rate. How the acceleration of expansion occurs is not yet fully understood. The most widely accepted theory is the concept of dark energy, a hypothetical form of energy that fills all of space and results in the universe expanding.

This coupled with the discovery of dark matter a few years earlier, means that at our best estimate, we currently only understand ~5% of the stuff that makes up our Universe.

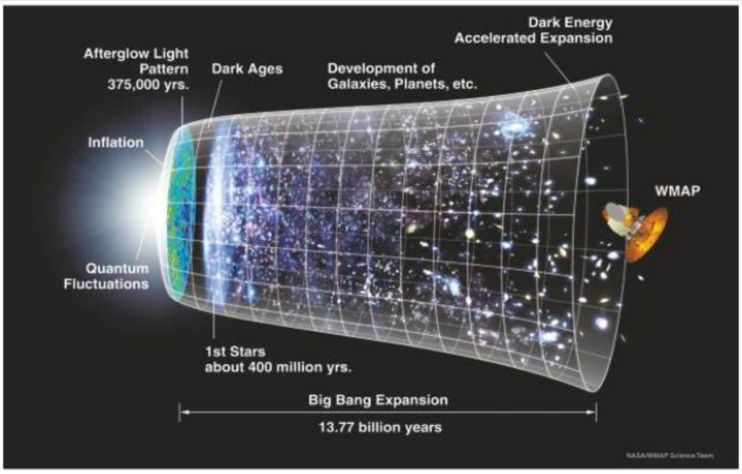
The most significant discoveries of the Universe in recent years have been on Dark energy and Dark matter.



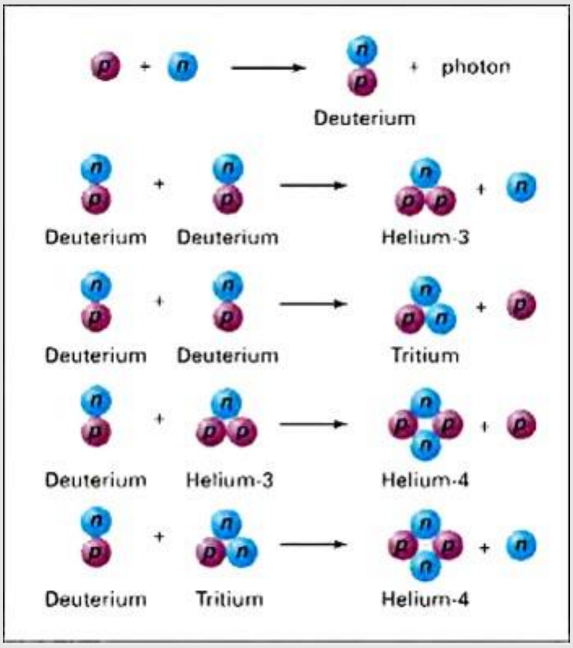
▲ **Figure 1** *Current theories indicate we do not understand 95% of what makes up our Universe*

	Time after the Big Bang	Nature of the Universe
Decreasing temperature	**The Big Bang 0 s (~13.7 bya)**	Thought to be when **time and space was created**. The Universe is a **singularity** – it is **infinitely dense and hot**.
	10^{-35} s	The universe **rapidly expands** including a phase of **incredible acceleration** known as **inflation.** There is **no matter** in the Universe, instead only **high-energy gamma ray photons (EM radiation**). The temperature is roughly **10^{28}K**
	10^{-6} s	The 1^{st} **fundamental particles** (**quarks, leptons, etc**.) **gain mass** through a mechanism that is not yet fully understood but **involves the Higgs boson** (discovered in 2013).
	10^{-3} s	The **quarks combine** to form the **first hadrons**, such as **protons and neutrons.** **Most of the mass** in the Universe was **created within the first second** through the process of **pair production** (high-energy photons transforming into **particle-antiparticle pairs**).
	1 s	The **creation of matter ceases** once the temperature of the universe drops to about **10^{9}K.**
	100 s	**Protons and neutrons fuse** forming the nuclei of **helium and deuterium** (**hydrogen-2**), along with a small quantity of **lithium and beryllium**. Expansion occurs so rapidly that no further fusion to form heavier elements occurs. ~**25% of the matter** in the universe at this stage is helium (**primordial helium).**
	380,000 years	The Universe has **cooled** sufficiently for the **formation of atoms** (nuclei **capture electrons).** The EM radiation at this stage can be detected as (Cosmic) **Microwave Background radiation**.
	30 million years	**The first stars** appear and, through **nuclear fusion**, the **first heavy elements (beyond lithium)** appear.
	200 million years	Our galaxy, the **Milky way** forms as **gravitational forces** pull clouds of hydrogen and existing stars together.
	9 billion years	The **Solar System** forms form the **nebula left by the supernova** of a larger star. **After the Sun forms**, the **remaining material** forms the **Earth and surrounding planets** (~ **1 billion years later**, 10 billion years after the Big Bang).

		It is thought that **1 billion years after the Earth** had formed (11 billion years after the Big Bang) that **life on Earth began**.
	13.7 billion years (now)	Around **200,000 years ago** the **first modern humans evolve**, and eventually study physics. The temperature of the Universe is **now 2.7K** .



▲ Figure 2 *Graphical model of the evolution of the Universe, from the earliest moment we can currently probe (to the left of the Figure). After several billion years of decelerating expansion as matter exerted gravitational force on itself, the expansion has more recently sped up again due to the dominating repulsive effects of dark energy.*

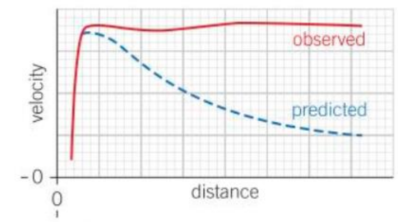


The 2011 Nobel Prize in Physics was awarded for the discovery in 1999 that the expansion of the Universe is accelerating.

Three physicists (Saul Perlmutter, Brian Schmidt and Adam Riess) were investigating the light from a distant supernovae. They were observing a particular type of supernova, called type Ia, which gives arise to a specific type of light. However, the light was less intense than predicted and the only conclusion they could make to explain this was that the Universe was expanding at an accelerating rate. This acceleration requires a source of energy which was termed 'dark energy' as it has not been discovered yet.

Dark energy is a hypothetical form of energy that permeates all of space.

It is estimated that dark energy, which remains yet undetected, or even understood, makes up around 68% of our Universe.



▲ Figure 4 *Observations of the velocities of stars in galaxies do not match predictions, leading to the idea of dark matter*

In the late 1970s, astronomers studying the light from galaxies to analyses the Doppler shift, found that the velocity of the stars in the galaxies did not behave as predicted. It was expected that their velocity would decrease as distance from the centre of the galaxy increases (from the derivation that $1/2\ mv^2 = GMm/r$).

This is the effect observed in other gravitational systems where most of the mass is in the centre, including our Solar System and the moons of Jupiter.

These unusual observations can be explained if the mass of the galaxy is not concentrated at the centre, but there must be another type of matter which we cannot see since most of the matter we do see is concentrated at the centre. This matter is termed dark matter and is spread through the entire galaxy, explaining the observations. Calculations have shown that the Universe must be made up of at least 27% dark matter.

Dark matter neither emits, nor absorbs light. Theoretical hypotheses for what dark matter could be:

Black holes, gravitinos, weakly interacting massive particles (wimps), axions, Q-balls, …

Still to this day, dark energy and dark matter are a mystery.