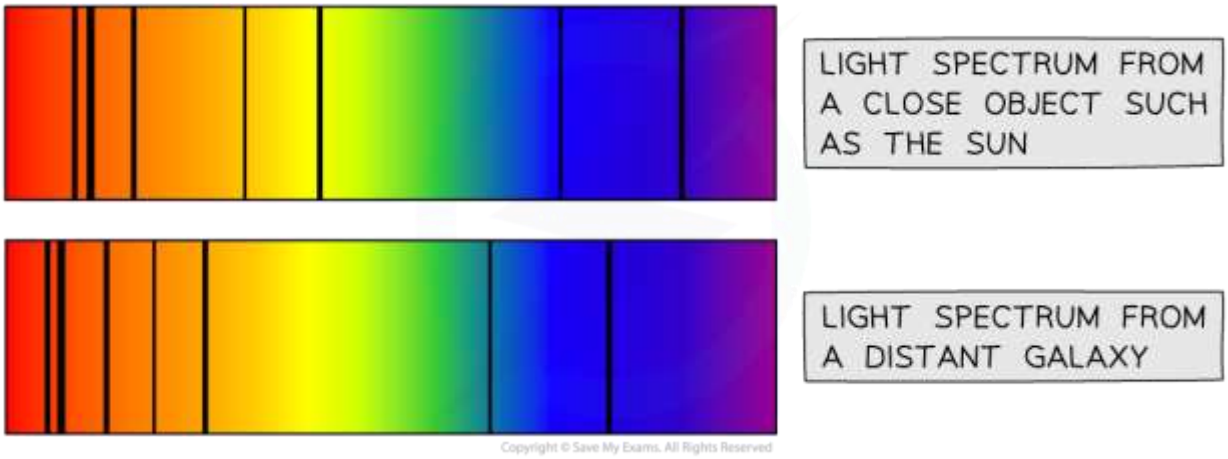
Summary Notes - Topic 16: Cosmology

16.1 Redshift and the Expanding Universe

- Light from distant galaxies is **redshifted**, meaning wavelengths are stretched.
- The farther a galaxy, the greater its redshift, indicating it is moving away.
- This supports the idea that **space itself is expanding**.
- Blue light has a shorter wavelength and means the object is moving nearer to us. These objects are said to show a **blueshift**.
- The majority of galaxies show a redshift meaning they are moving away from us and each other.
- There are some galaxies that have a small blueshift, meaning they are moving towards us. These are galaxies in our Local Group.
- **Radial velocity** is how fast an object is travelling in the direction of the line of sight.



16.2 Cause of Redshift

- **Doppler Effect**: Light waves from receding galaxies are stretched, just like sound waves from a moving ambulance.
- **Cosmological Redshift**: Space itself is expanding, stretching light waves traveling through it.

16.3 Redshift Formula

$$\frac{\lambda - \lambda_0}{\lambda_0} = \frac{v}{c}$$

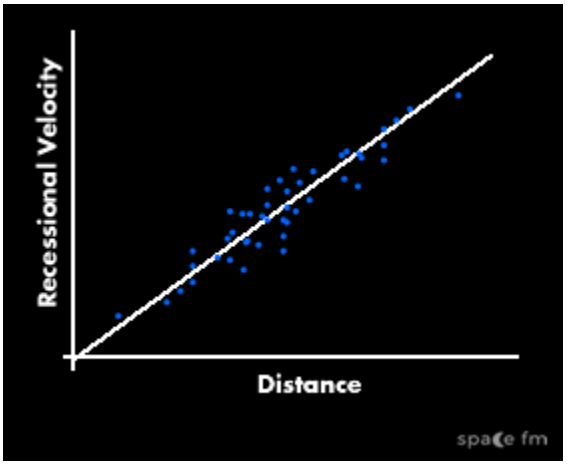
Where:

- λ = observed wavelength
- λ_0 = emitted wavelength
- v = velocity of the galaxy
- c = speed of light (300,000 km/s)

16.4 Evidence for the Expanding Universe

- **Edwin Hubble's discovery**: More distant galaxies are moving away faster.
- **Galaxies are not moving through space; space itself is expanding.**

16.5 Hubble's Law



$$v = H_0 d$$

Where:

- v = recession velocity
- H_0 = Hubble's constant (~70 km/s per Mpc)
- d = galaxy's distance from Earth

- Shows that galaxies farther away move faster.
- Used to estimate the age and size of the universe.

16.6 Estimating the Age of the Universe

- Using **Hubble's constant**, scientists estimate the universe is **13.8 billion years old**.
- **The greater H0, the younger the universe.**

16.2 Hubble's Law

- The units for H_o (km/s/Mpc) contain 2 length units.
- If we convert km to Mpc then we can cancel these out to end up with units of /s (the inverse of time).
- If we invert this then we end up with a time, the Hubble time (T).
- This is the age of the Universe.

We know that:

H_0 = 68 km/s/Mpc

and

3.1×10^{19} km = 1 Mpc

Divide both sides of the second equation by 3.1×10^{19}:

1 km = 3.2×10^{-20} Mpc

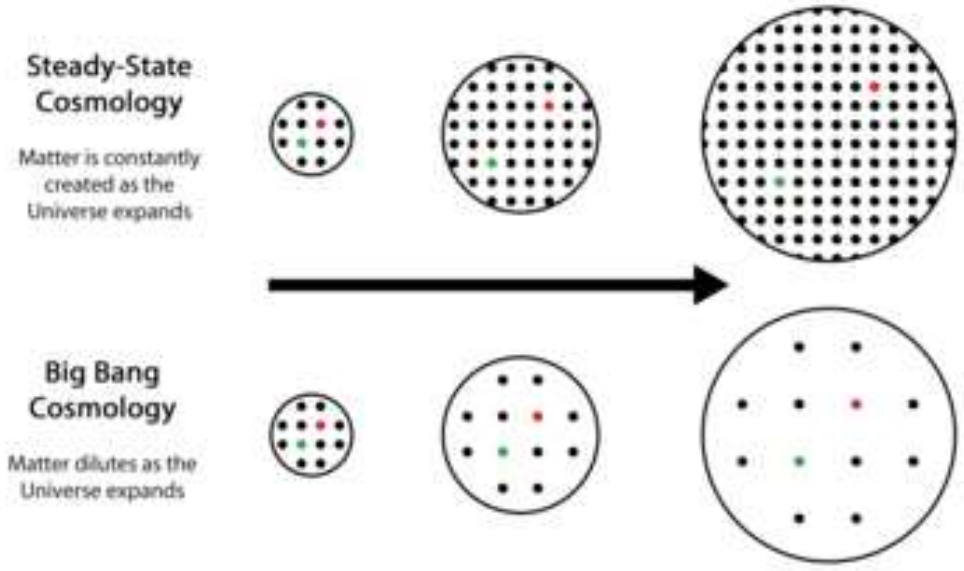
Substitute for 1 km in H_0 value:

$H_0 = 2.2 \times 10^{-18}$ /s

Invert: $T = 4.6 \times 10^{17}$ s

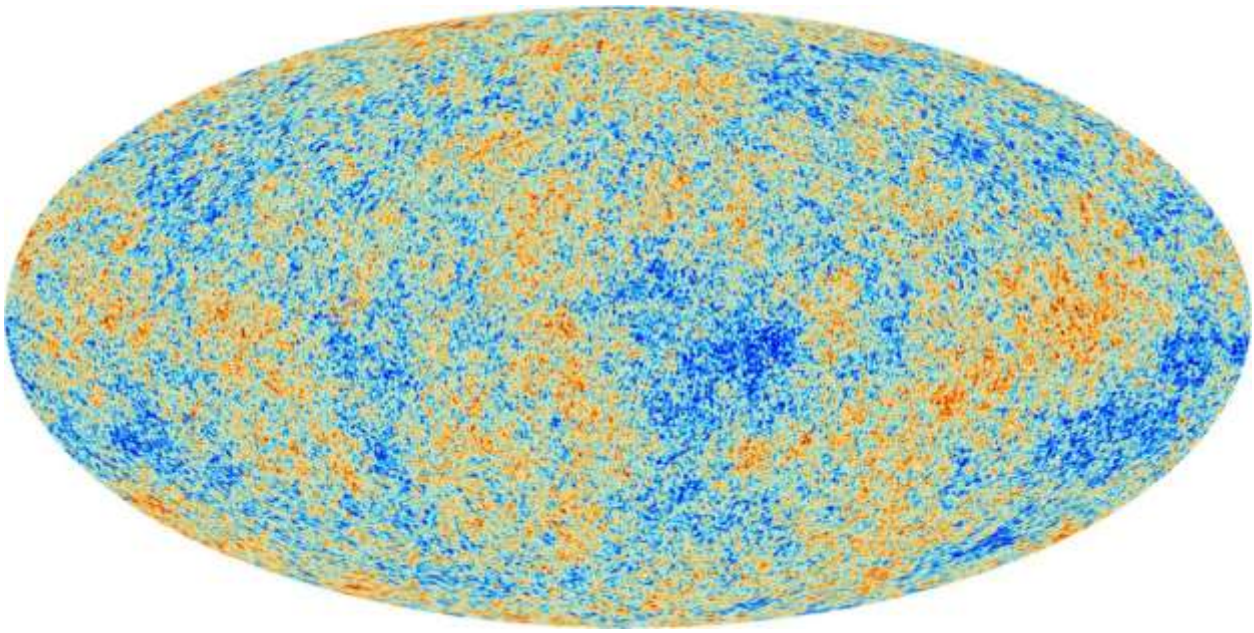
16.7 Competing Theories of the Universe

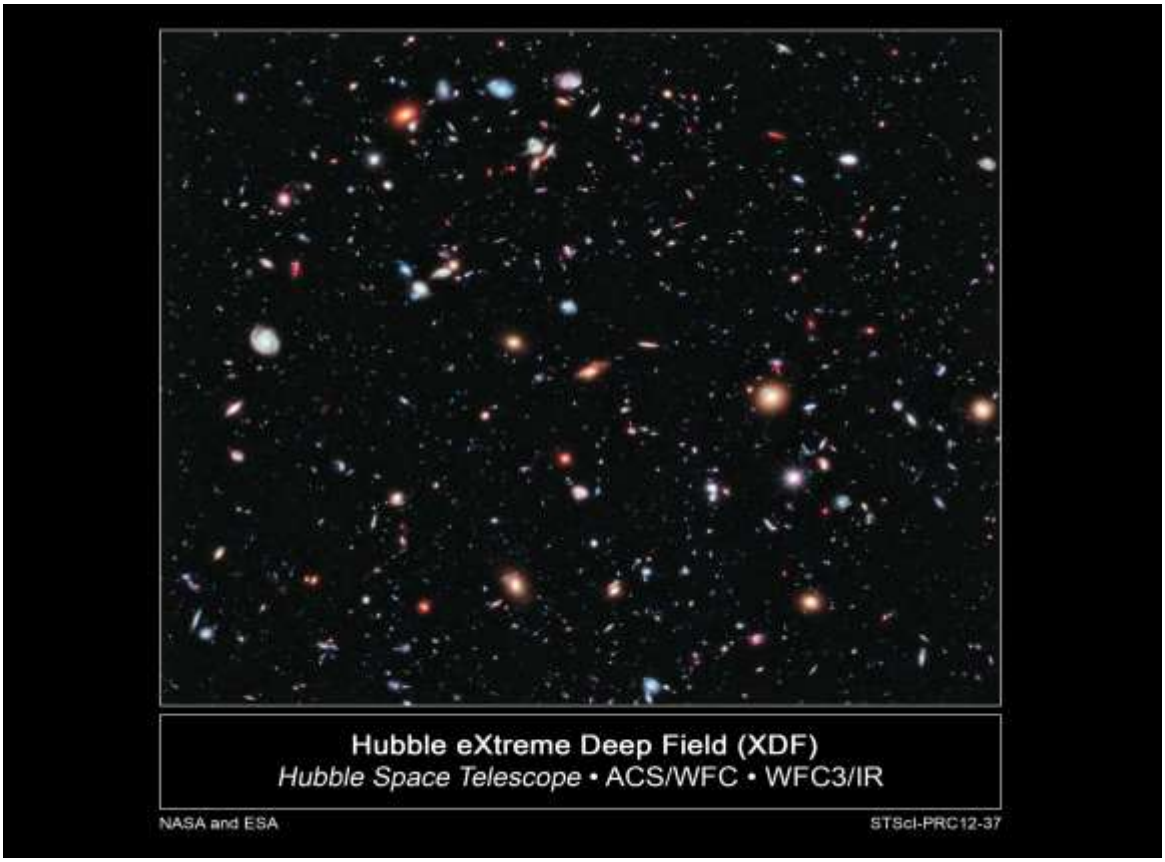
1. **Big Bang Theory** – The universe started from a single, hot, dense point and expanded.
2. **Steady State Theory** – The universe is eternal and continuously creates new matter (now disproven).



16.8 Evidence for the Big Bang Theory

1. **Quasars (QSOs)** – These stand for quasi-stellar objects. They appear like stars but are actually very different. They are believed to be galaxies that emit large amounts of x-rays, ultraviolet light and sometimes radio waves. Quasars are believed to be caused by matter falling into a black hole at the centre of the galaxies, causing jets of matter to shoot out at high speed. Bright, distant objects showing the universe's early stages.
2. **Cosmic Microwave Background (CMB) Radiation** – Leftover heat from the Big Bang, discovered by **Penzias & Wilson**. To our eyes (and telescopes) space appears black, but to a sensitively calibrated radio telescope, a background glow appears. This is consistent in any direction with very minor variations in density - the apparent 'ripples' in the radiation.
3. **Hubble Deep Field** – A deep-space image revealing galaxies from billions of years ago.




Hubble eXtreme Deep Field (XDF)
Hubble Space Telescope • ACS/WFC • WFC3/IR
NASA and ESA
STScI-PRC12-37

ARGUMENTS FOR & AGAINST

For	Against
The Universe continues to expand.	What caused the Big Bang to happen and what happened in the first milliseconds of it happening?
Cosmic Microwave Radiation is thought to be leftover heat from the Big Bang.	There does not seem to be enough mass in the Universe to account for its expansion. Dark matter may be responsible.
Hydrogen and helium are the most abundant elements in the Universe. The Big Bang would have produced these elements	

16.9 CMB Fluctuations

- Tiny temperature variations in the CMB show density differences in the early universe.
- In 2001 NASA launched **WMAP**, the Wilkinson Microwave Anisotropy Probe to take even more accurate measurements (see below).
- In 2009 ESA launched the **Planck Surveyor** to further study the CMB. In addition, extensive ground-based observations continue studies.

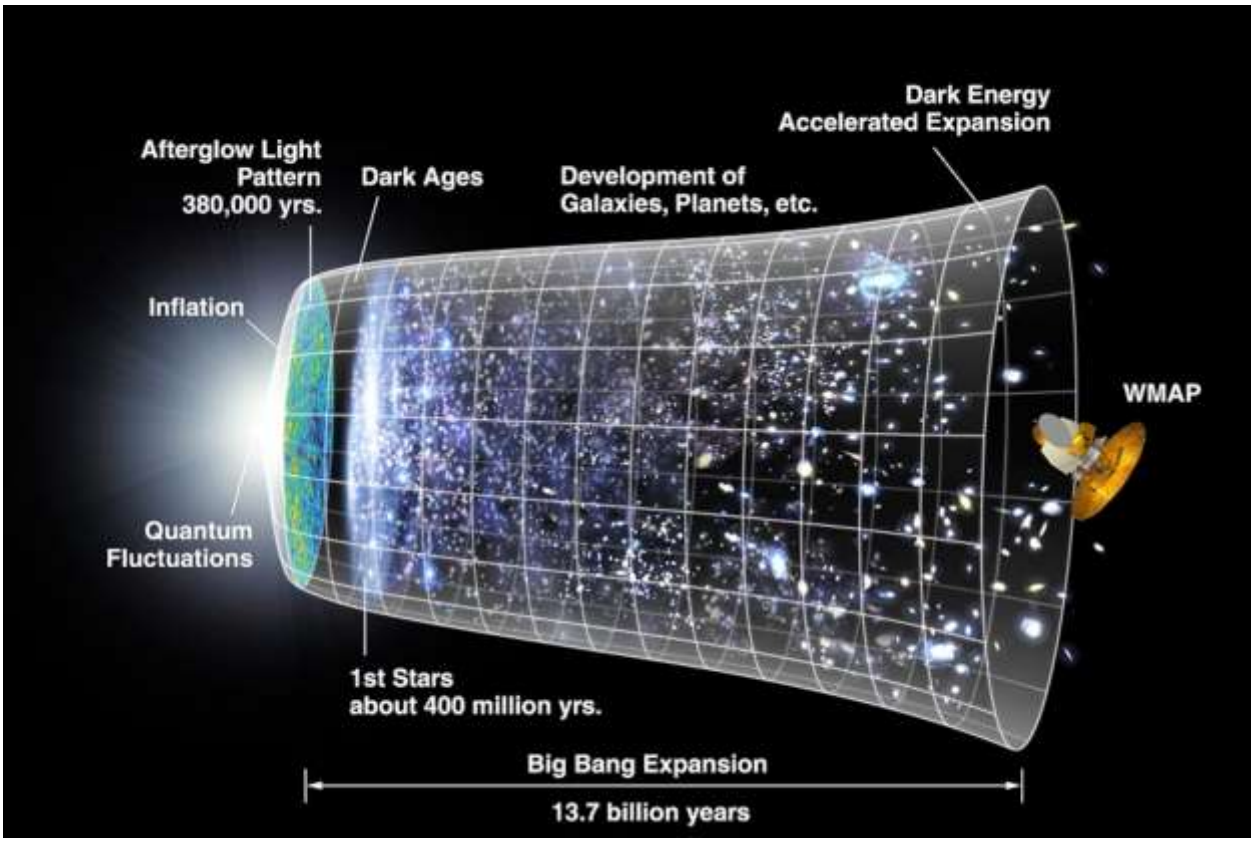
16.10 Dark Matter and Dark Energy

- **Dark Matter** – Scientists have measured the mass of galaxies (by studying the light coming from them and their velocity). It has been found that they are moving faster than they ought to for their mass. This should not be possible within other laws of physics. Their mass should be many times higher. Scientists believe that there is some invisible matter - dark matter - that cannot be directly observed that can make up over 90% of the matter in galaxies. Candidates could be dark dust, black holes, brown dwarfs, neutrinos or a new type of object or matter, yet to be observed.

- **Dark Energy** – Dark energy works differently; it appears to be a force that moves galaxies away from each other. The expansion of the Universe since the Big Bang should have slowed down the rate of movement between galaxies. The opposite is

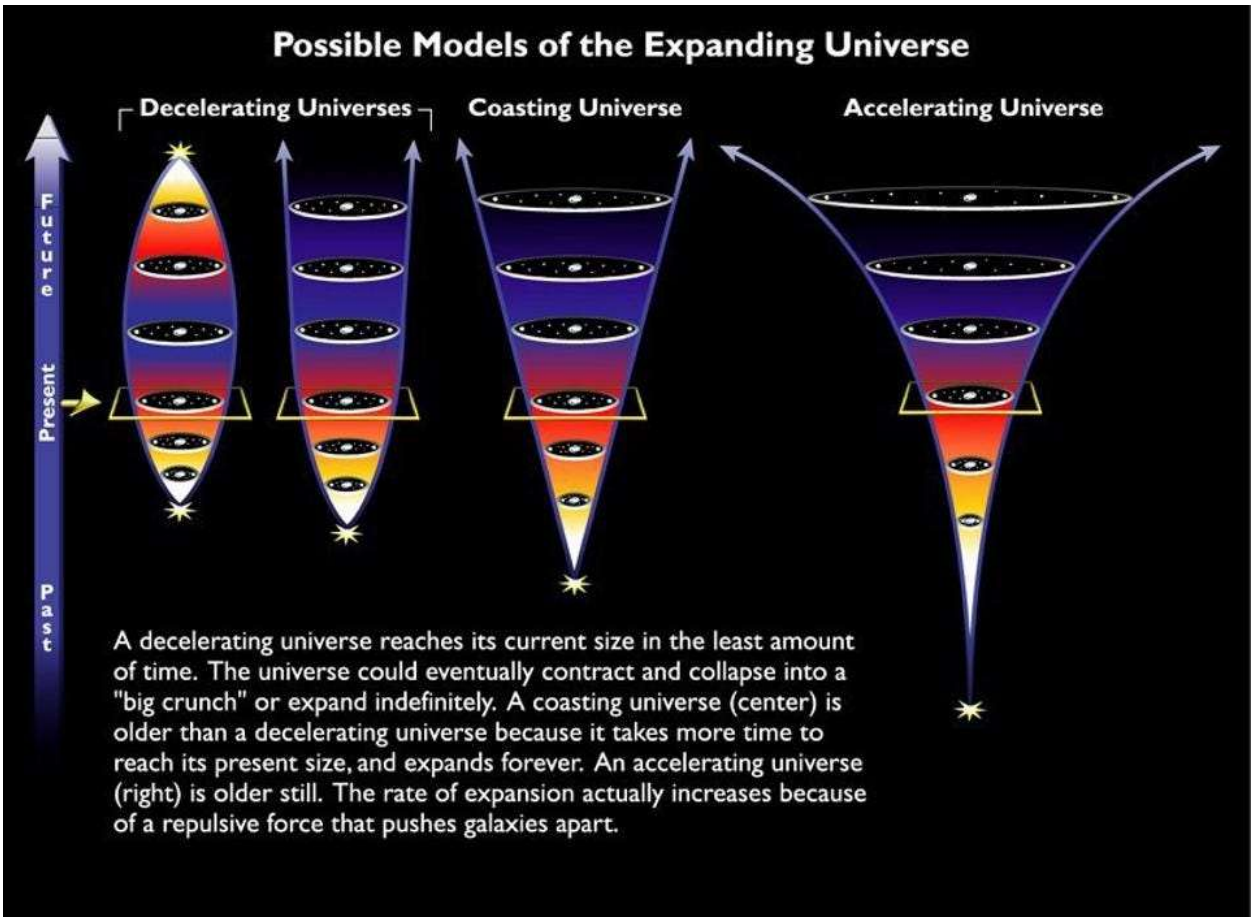
happening, however; the rate of movement is increasing. Scientists believe an invisible force – dark energy – is responsible for this.

- Makes up **95%** of the universe's mass-energy content.



16.11 Future of the Universe

- **Big Crunch** – Gravity stops expansion, pulling everything back.
- **Big Freeze** – Expansion continues, and stars burn out.
- **Big Rip** – Expansion accelerates until galaxies, stars, and atoms are torn apart.


Possible Models of the Expanding Universe
Decelerating Universes
Coasting Universe
Accelerating Universe
Future
Present
Past
A decelerating universe reaches its current size in the least amount of time. The universe could eventually contract and collapse into a "big crunch" or expand indefinitely. A coasting universe (center) is older than a decelerating universe because it takes more time to reach its present size, and expands forever. An accelerating universe (right) is older still. The rate of expansion actually increases because of a repulsive force that pushes galaxies apart.