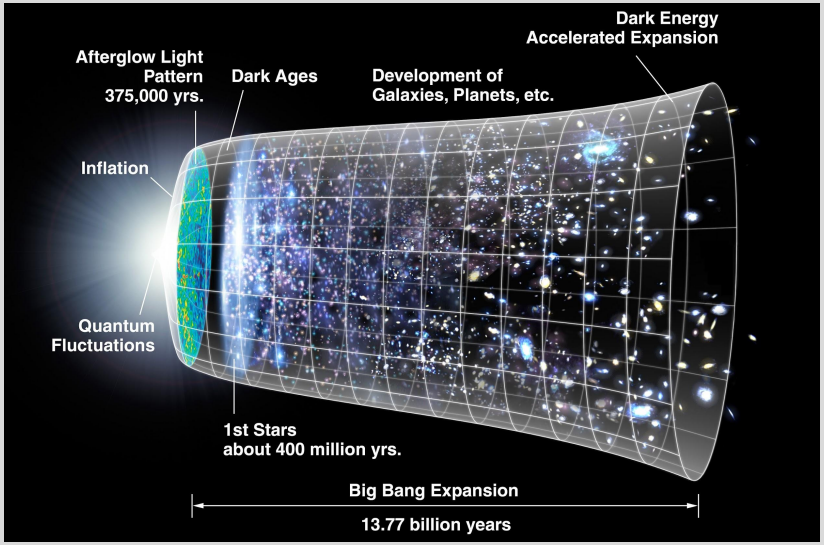
ABINGDON SCIENCE PARTNERSHIP

# 16. Cosmology

Edexcel GCSE Astronomy Course

# What is this topic about?

Students will gain an understanding of redshift and Hubble's law for distant galaxies. They will also study the evidence and explanation for the expanding Universe. Students will explore dark matter and dark energy and the possible fate of the Universe.



16.1 Know that observations of galaxies outside the Local Group show that light is shifted to longer wavelengths (redshift)
16.2 Understand that redshift is caused by galaxies receding from us

A very clear explanation of what is meant by the redshift of galaxies is given in this video (2:28):

https://www.youtube.com/watch?v=RO4i_g6gSMU&ab_channel=magipics

To consolidate your understanding study this text explanation and try the questions at the end:

https://lco.global/spacebook/light/redshift/

Remind yourself of what is meant by the Local Group here:
https://imagine.gsfc.nasa.gov/features/cosmic/local_group.html
And find out why galaxies within the local group have very small redshifts, or even blueshifts:
https://skyandtelescope.org/astronomy-resources/astronomy-questions-answers/is-it-true-that-the-andromeda-galaxy-is-blueshifted-and-moving-toward-us/

16.3 Be able to use the formula:

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

where λ is the observed wavelength, $\lambda_0$ is the emitted wavelength, v is the radial velocity of the source, c is the speed of light

Watch this video (3:31) for a further explanation of redshift and how to use this equation:
https://www.youtube.com/watch?v=MAjV7eb3j6o&ab_channel=vt.physics

Here's a typical Edexcel GCSE Astronomy question requiring use of this formula:

An absorption line has a wavelength of 625.05 nm.

When this absorption line is observed in the spectrum of a galaxy, it appears to have a wavelength of 625.65 nm.

Calculate the velocity of this galaxy in km/s.

(Speed of light c = 300 000 km/s)

Velocity = ..... km/s

# Worked solution to the question on the last slide:

Step 1 - find the equation from the Data and Formulae sheet:

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

Step 2 - substitute the known values:

$(625.65 - 625.05)/625.05 = v / 3 \times 10^8$

Step 3 - solve the equation

$(0.6/625.05) \times 3 \times 10^8 = v$

$v = 2.9 \times 10^5$ m/s

# 16.4 Understand the evidence to confirm the discovery of the expanding universe

Edwin Hubble's discovery that the universe appeared to be expanding was not definitive proof that the universe had been expanding since its formation - it could be that it just happens to be expanding right now and did something different in the past.

However, cosmologists have found several other pieces of evidence that led to the conclusion that the universe formed at a definite time in the past and has been expanding ever since. Four pieces of evidence are give here, make a note of what they are: https://www.schoolsobservatory.org/learn/astro/cosmos/bigbang/bb_evid

16.5 Be able to use the relationship between distance and redshift of distant galaxies (Hubble's law) including the formula:

$$v = H_0 d$$

where v is the radial velocity of the recession of the galaxy, $H_0$ is the Hubble constant and d is the distance of the galaxy from Earth

The exercise at this link allows you to carry out a process similar to the one Edwin Hubble followed in making his discovery that the universe was expanding:
http://astronomy.nmsu.edu/jbornak/110/hubbleslaw.pdf

I have simplified the exercise by making some of the measurements required and tabulating them here - transfer these into a spreadsheet to calculate the missing values and then plot a line graph of v vs d:

| Galaxy Cluster | Shift in nanometres (nm) | Velocity (km/s) (from redshift equation) | Distance (Mpc) | Estimated Value of $H_0$ (km/s/Mpc) |
|---|---|---|---|---|
| Virgo | 177 | 1352 | 20 | 67.6 |
| Ursa Major | 985 | | 110 | |
| Corona Borealis | 1700 | | 180 | |
| Bootes | 2900 | | 300 | |
| Hydra | 4800 | | 490 | |

You can see an explanation and a copy of Hubble's original results here:
https://www.e-education.psu.edu/astro801/content/l10_p3.html

16.6 Understand the estimation of the age and size of the Universe using the value of the Hubble constant

The equation $v = H_o d$ is a beautifully simple example of a linear relationship which can be plotted as a line graph with:

- v (km/s) for velocity as the dependent variable on the y axis
- d (Mpc) as the independent variable on the x axis
- $H_o$ as the constant of proportionality, equal to the gradient of the line

Rearranging the equation to find a value for $H_o$ gives

$$H_o = v/d$$

Its units seem strange at first as they work out to be (km/s)/Mpc

However, km and Mpc are both distances (1Mpc = $3.086 \times 10^{19}$km) so the units of $H_o$ end up being 1/seconds. So 1/Ho has units of seconds. Its value is an estimate of the number of seconds since the universe started expanding - since the Big Bang. **$1/H_o$ is an estimate of the Age of the Universe!**

# Hubble’s Law Graph

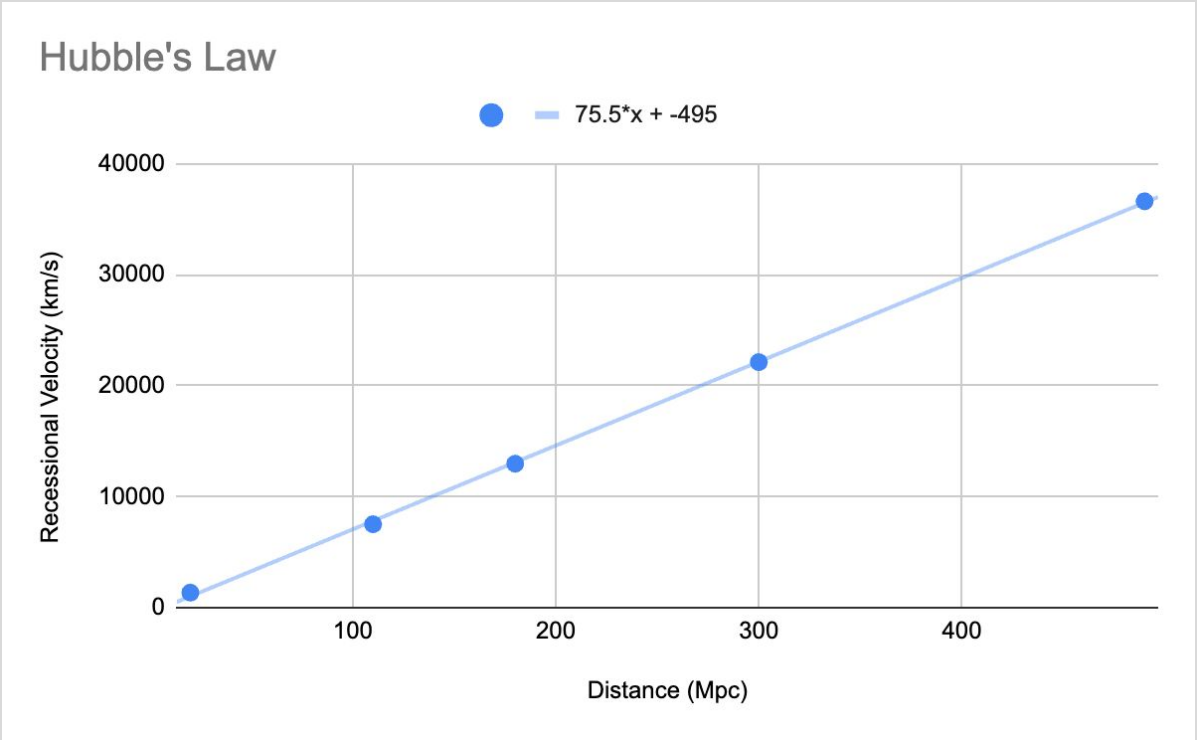
This is a graph of results obtained with the data on Slide 7.

It gives $H_o$ = 75.5

which gives

$1/H_o$ = 12.8 billion years

(when Mpc are converted to km)



16.7 Understand how the expansion of the Universe supports both the Big Bang theory and the Steady State theory

Read about where the term Big Bang came from and why astrophysicist Fred Hoyle first used it:

https://www.popsci.com/big-bang-term-origin-fred-hoyle/

Find out what the Steady State Theory is and be able to explain how it can still allow for expansion:

https://www.universetoday.com/145060/what-is-the-steady-state-hypothesis/

16.8 Understand the major observational evidence in favour of the Big Bang theory:

a quasars (QSOs)

b cosmic microwave background (CMB) radiation

c Hubble Deep Field image

16.9 Understand the significance of the fluctuations in the CMB radiation for theories of the evolution of the Universe, including discoveries by the Wilkinson Microwave Anisotropy Probe (WMAP) and the Planck mission

**a** quasars (QSOs):

The evidence provided by quasars and AGN is explained very clearly in this link. Scroll down to the section labelled '**The Short Life of an Active Galaxy'.** Make a note of what the evidence is in case you are asked to explain it - what are the reasons for the peaked shape of the graph shown here:
https://www.astronomynotes.com/galaxy/s14.htm#A3.4

Here is some extension information on how Type 1A Supernovas and quasars are used to measure the expansion rate of the universe:
https://sci.esa.int/web/xmm-newton/-/61070-investigating-the-expansion-of-the-universe-combining-type-ia-supernovas-and-quasars

**b** cosmic microwave background (CMB) radiation

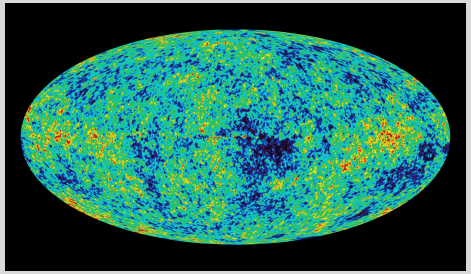
This is an excellent US PBS video that explains the CMB and its importance very clearly - it is worth taking the 7mins to watch it. Make notes so that you can explain:

1. What the CMB actually is
2. What the shape of a black body thermal spectrum is
3. What the significance of the temperature of 2.7K is
4. Why the CMB signal is the same everywhere in the observed sky
5. Why the universe is no longer orange

https://www.space.fm/astronomy/starsgalaxies/cmb.html (7:09)

Here's a very clear summary of the essential explanation for the CMB:

http://hyperphysics.phy-astr.gsu.edu/hbase/bkg3k.html#c1



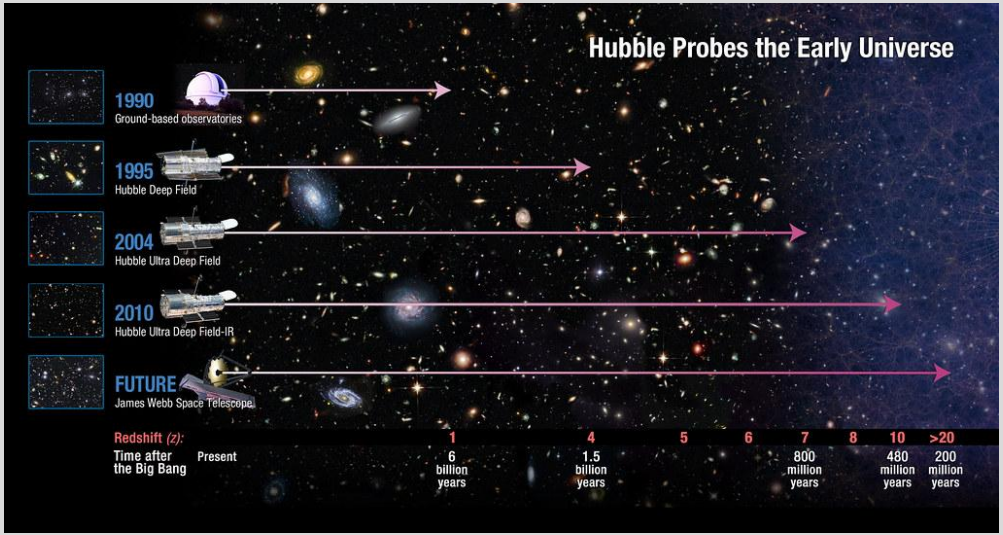
Look at images of the CMB from these three significant space missions:

COBE: https://www.nasa.gov/topics/universe/features/cobe_20th.html

WMAP: https://www.nasa.gov/feature/making-sense-of-the-big-bang-wilkinson-microwave-anisotropy-probe

Planck:
https://www.esa.int/Science_Exploration/Space_Science/Planck/Planck_reveals_an_almost_perfect_Universe

**c** Hubble Deep Field image




The above image from this site https://hubblesite.org/contents/media/images/2011/05/2815-Image.html illustrates beautifully how improvements in telescope technology allow us to see further back in time and map the evolution of structures such as galaxies in the universe.

Find out specifically what the Hubble Deep Field image was and make a note of the three bullet points explaining its significance as evidence for the Big Bang theory https://www.space.fm/astronomy/starsgalaxies/hubbledeepfield.html

# A summary of evidence for the Big Bang Theory:

Print or save this pdf for your notes:
https://www.uwa.edu.au/study/-/media/Faculties/Science/Docs/Evidence-for-the-Big-Bang.pdf

16.10 Understand the significance and possible nature of dark matter and dark energy
16.11 Understand the difficulties involved in the detection of dark matter and dark energy

First of all it is very important to understand the difference between these two concepts:

Dark Matter is explained in detail at the link below, but the important lines are as follows:

*Astronomers examining spiral galaxies in the 1970s expected to see material in the center moving faster than at the outer edges. Instead, they found the stars in both locations traveled at the same velocity, indicating the galaxies contained more mass than could be seen. Studies of gas within elliptical galaxies also indicated a need for more mass than found in visible objects. Clusters of galaxies would fly apart if the only mass they contained was the mass visible to conventional astronomical measurements.*

The explanation for this missing mass is DARK MATTER, invisible matter with properties that are different to the 'normal' matter we are familiar with.

https://www.space.com/20930-dark-matter.html#section-why-do-we-think-dark-matter-exists

Dark Energy:

Dark energy is significant on much larger scales than just within galaxies. This is the simple explanation of what it is from the link below:

*Dark energy is the name given to the mysterious force that's causing the rate of expansion of our universe to accelerate over time, rather than to slow down.*

https://earthsky.org/space/definition-what-is-dark-energy/

This link shows a graph of data showing how current data fit with different rates of expansion of the universe:

https://universe-review.ca/I02-15-accelerating.jpg

Here's a very nice Australian explanation of why we think dark matter and dark energy exist: https://www.youtube.com/watch?v=QAa2O_8wBUQ&t=8s&ab_channel=Kurzgesagt%E2%80%93InaNutshell (6:21) (Watch out for the confusion at 1:36 where the narrator accidentally says dark energy instead of dark matter!)

For a detailed explanation from one of the team awarded a Nobel Prize for their discovery of an accelerating universe, watch this longer video for enthusiasts: https://www.youtube.com/watch?v=_D6cwrl0CxA&ab_channel=LasCumbresObservatory (58:35)

16.12 Understand that current models of the Universe predict different future evolutionary paths

The diagram shows a few possible futures for the universe using popular names:

https://astronomy.com/sitefiles/resources/image.aspx?item={F017B8E6-0E1D-45EB-8BA7-9DEB5A0F437C}

This link shows how five possible fates of the universe are related to its density and the value of the cosmological constant from Einstein's theory of general relativity:

https://pages.uoregon.edu/jimbrau/BrauImNew/Chap26/7th/AT_7e_Figure_26_14.jpg

To understand what these futures may be and to explain the differences between them, watch this excellent summary video (5:55):

https://www.youtube.com/watch?v=7jA6PQACmmY&ab_channel=TheRoyalInstitution


GAME OVER
Thank you for playing