# *The expansion of the universe* Teaching and learning plan

## Learning intentions

Students will be able to:

* explain that red shift applies to objects that are moving away from the Earth
* identify that the amount of red shift relates to the speed of recession
* analyse the validity of claims made in secondary sources
* make accurate measurements
* construct appropriate representations that allow them to interpret and analyse the data
* identify patterns and relationships in data.

## Suggested time for this CLE

The time needed to complete *The expansion of the universe* CLE will depend on the depth of the prior knowledge of students, the time to perform the various investigations and to follow up with any extension activities. Allow 2–3 hours.

[**Planning ahead and equipment list**](http://assist.asta.edu.au/sites/assist.asta.edu.au/files/Planning%20and%20equipment%20list_Yr10_The%20expansion%20of%20the%20universe.docx)

## Safety considerations

When you and your class are completing your Risk Assessment consider the following safety points and add any other relevant ones to the list.

* The stretchy elastic band should be used carefully and safely. Ensure it is clamped securely and tension is released slowly.

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## Introduction

In this investigation, Edwin Hubble’s observations will be examined as evidence for the Big Bang theory. In 1929, Hubble discovered that the light from distant galaxies was red shifted and that the further a galaxy is from Earth, the faster it is moving away. This was evidence for the expansion of the universe following the Big Bang.

**NOTE:** *Not all galaxies are moving away from Earth. Some galaxies, such as the Magellanic Clouds, are moving towards the Milky Way and this can be seen because they are blue-shifted. This CLE will only address red shift.*

This CLE focuses on understanding and validating the observations made by Edwin Hubble as evidence for the Big Bang and links to Year 10 Australian Curriculum: Science.

### Equipment needed

Per student:

* video question sheet

### What to do

1. Tell the story: The origin of the universe remains one of the greatest questions in science. Before 1917 it was thought that the universe always existed. Einstein’s theory of relativity and the discoveries made by Edwin Hubble changed all that. In 1929, Edwin Hubble discovered that distant galaxies are moving away from us—they are receding—meaning that they were once much closer, originating from a single region of space.
2. Hand out the **video question sheet.**
3. Show students the video ‘Stephen Hawking – The Expanding Universe’, YouTube (4.13) <https://www.youtube.com/watch?v=DClEXO0pCZ4>
4. Pause at the appropriate places to allow students to answer the questions (below with answers) and for any necessary class discussion.

(Q1 at 0:05 … our ability to contemplate the Universe as a whole)

(Q2 at 1:12 … seen from Earth, all distant galaxies are slightly red in colour)

(Q3 at 1:47 … replay this section with the students’ eyes closed—the pitch rises as it approaches and the pitch falls as it goes away)

(Q4 at 2:16 and 2:25 … a) blue, b) red, c) reasoning is: higher pitch is higher frequency, shorter wavelength—blue light has a shorter wavelength than red; lower pitch is lower frequency, longer wavelength—red light has a longer wavelength than blue light)

(Q5 at 2:42 … they are all slightly red)

(Q6 at 3:22 … if we rewind far enough all the galaxies converge to a single point approximately 13.8 billion years ago which was the origin of the Universe—the Big Bang)

## Core

### Investigation 1 – Modelling the expanding Universe

In this investigation, students use a length of elastic with specified points on it to study expansion.

### Equipment needed

Per group:

* marker pen
* wide elastic band, cut and opened out to give a 16 cm minimum length
* ruler or tape measure
* spring or C-clamp

### What to do

1. Place students into small groups and distribute equipment. Instruct students to use the marker pen to place 6 dots on the elastic band at varying positions. Students will use the first dot as ‘home’ and the others as A–E in order from home. The home dot represents our Milky Way Galaxy.
2. With the elastic band laid out but not stretched, students then measure and record the distance from ‘home’ to each of the other ‘galaxies’. Students record these distances under a heading of ‘Time 1’.
3. Instruct students to clamp one end of the elastic band firmly to the bench and stretch the elastic band by a few cm. As with step 2, the students record the measurements under the heading ‘Time 2’.
4. Students repeat step 3, increasing the stretch in the elastic band three more times and record their results.

### cid:16E66DE6-6444-4D30-95E1-98BE9B98C763@gatewayExpected results and explanations

Results will depend on the initial position of the dots. Typical results obtained from a 16 cm length of elastic band. All measurements are in millimetres:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Home to … | ‘Galaxy’ A | ‘Galaxy’ B | ‘Galaxy’ C | ‘Galaxy’ D | ‘Galaxy’ E |
| Time 1 | 33 | 51 | 86 | 108 | 137 |
| Time 2 | 48 | 75 | 120 | 155 | 193 |
| Time 3 | 59 | 93 | 146 | 190 | 237 |
| Time 4 | 65 | 101 | 161 | 207 | 260 |
| Time 5 | 71 | 112 | 176 | 227 | 283 |
|  |  |  |  |  |  |
| Time 5 − Time 1 = | 38 | 61 | 90 | 119 | 146 |

By comparing the distances for each galaxy, students should find that the galaxies move further and further from home each time. Comparing time 5 – time 1 shows that the furthest galaxies (D and E) moved by the largest amounts. Of course, the distances measured at the same ‘times’ represent the relative speeds of the galaxies. The ones that travelled the furthest distances means they had the fastest speeds.

**Follow up questions for students could include:**

* When we say ‘the universe is expanding’ what exactly is expanding? (Space is expanding and taking the galaxies with it.)
* What could the universe be expanding into? (Good question – see what your students can come up with.)
* Astronomers don’t have rulers for measuring distances and speeds, so what do they use? (Astronomers measure the recession speeds of the galaxies by looking at their spectra—this is explored further in investigation 2.)
* Discuss models and the limitations with this model? (See what your students can come up with.)

### Investigation 2A – Spectra analysis

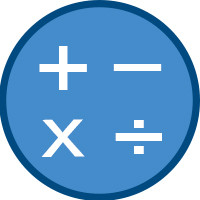
In this investigation, students examine the emission spectrum of hydrogen and compare it to the emission spectra of a sample galaxy.

### Equipment needed

Per student:

* spectral analysis student worksheet—pages 1, 2 and 4
* calculator

### What to do

1. Hand out the four-page **spectral analysis student worksheet** to each student in each group.
2. Draw students’ attention to the four galaxies shown on page 1 of the worksheet—galaxies A, B, C and D.
3. Inform students that the four galaxies are all approximately the same size and ask them to list them in order of increasing distance from the Earth on page 1 (B, D, A, C) and give a reason for their decision. Discuss what evidence they use for their choices. (The closest galaxy looks the largest and the furthest away looks the smallest.)
4. Check students’ familiarity with ‘flame tests’ where different metal ions emit a distinct colour of light when placed in a Bunsen burner flame. This light is like a fingerprint for the metal and the wavelength (or frequency) of the light corresponds to electron transitions between the energy levels within the atom. Specific wavelengths mean there are specific energy levels that identify an atom.
5. Now draw students’ attention to the spectra of hydrogen on page 2 of the spectral analysis worksheet and ask them to record the colours they can see and their wavelengths on page 4 (red at 656 nm, blue at 486 nm, and a dull line—violet at 434 nm—these figures are the exact values, students answers will be similar. Get them to adjust their red value so it is 656—they will need to use this value later).
6. Next, view the sample galaxy spectrum below the hydrogen spectrum and ask students to determine the position of the red hydrogen line either by the coloured spectrum or by the peak on the graph. (690 nm)
7. Ask students:

* By how much has it been shifted? (690 − 656 = 34 nm)
* What percentage is that of 656 nm? (34 ÷ 656 × 100 = 5.2%)

1. Find this percentage value of the speed of light which is 300 000 km/s (5.2% of 300 000 = 15, 600 km/s). This is the recessional speed of the sample galaxy—it is moving away from Earth at this speed. (These values are given as sample results in the results table on page 4.)

### Expected results and explanations

The answers appear above in brackets and as sample results in the results table on page 4 of the student investigation sheet.

The emission spectrum of hydrogen was obtained by passing the light from a hydrogen spectral lamp through a spectroscope or spectrometer. This device separates the emitted light into its individual wavelengths to provide a ‘fingerprint’ of hydrogen. There are other lines that appear beyond the visible spectrum. If your school has a hydrogen spectral lamp and spectroscopes, your students could view this for themselves.

In the spectrum of the sample galaxy, the light has been shifted towards the red end of the spectrum due to the movement of the galaxy away from Earth—we say it is ‘red shifted’. Remind students how this corresponds to what they saw (and heard) on the Stephen Hawking video. The 5.2% shift corresponds to a particular speed of 15, 600 km/s. Encourage students to record values that match their data in terms of significant figures and not just write what the calculator tells them.

If the sample galaxy were further away it would be travelling faster and its red line would be shifted further than 690 nm.

### Investigation 2B – Analysing galactic spectra

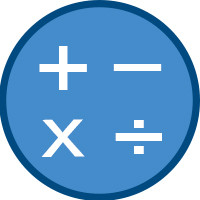
In this investigation, students observe the emission spectra from four different galaxies and analyse the shift in the red hydrogen line for each. Again, this is the red shift at work.

### Equipment needed

Per student:

* spectral analysis student worksheet—pages 2, 3 and 4
* calculator

### What to do

1. Draw students’ attention to the spectra of galaxies A, B, C and D on pages 2 and 3. They should observe that the red line in each spectra has shifted from its characteristic location of 656 nm as seen in the laboratory. Ask students why. (Again this is the red shift and since these galaxies are all moving away from the Earth their light is shifted towards the red end of the spectrum.) NOTE: *Red shift means all wavelengths of light ate shifted towards the red end of the spectrum.*
2. Tell students that the amount of red shift is used to calculate the recessional speeds of the four galaxies which was done in Investigation 2a. They are to calculate the recessional speeds and then plot this speed against the distance of each galaxy from the Earth.
3. Students then analyse each spectra and record their results and calculations in the table on page 4 of the student worksheet.
4. In the table, students will record the distance of each galaxy from the Earth when the spectra was produced—and can see if they were correct in their earlier predictions of the order (B, D, A, C).
5. Using a graphing calculator or an Excel spreadsheet, a graph of recessional speed v distance can be plotted and a trendline inserted and gradient calculated. The gradient represents Hubble’s constant and the inverse of the gradient gives the approximate age of the universe (see Teacher Background Notes). The difficulty here lies in the unit conversions.

*Teacher notes:* In a nutshell, to find the approximate age of the universe, students use 300 divided by their gradient. The reason for this is explained below. You may want to guide your more able students (or all of them) through the maths of this conversion or just tell them to use the 300 conversion factor—it is up to you.

1 million light years in km is 1 000 000 × speed of light × the no. of seconds in one year

= 300 000 000 000 × the no. of seconds in one year = 300 billion km × the no. of seconds in 1 year

and

1 billion years is 1 billion × the no. of seconds in 1 year

The 1 billion and the no. of seconds in 1 year are common to both and cancel out … leaving 300 as the conversion factor.

1. Students record their gradient value on page 4 of the student worksheet and perform a calculation to obtain an approximate age of the universe.

### Expected results and explanations

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Galaxy | Distance (million light years) | Red line position (nm) | Amount of red shift (nm) | % shift | Recessional speed (km/s) |
| A | 1520 | 728 | 72 | 11.0% | 33 000 |
| B | 210 | 664 | 8 | 1.2% | 3 700 |
| C | 2260 | 762 | 106 | 16.2% | 48 000 |
| D | 750 | 692 | 36 | 5.5% | 16 000 |

Gradient = 21.4 km/s/Mly

Age of the universe = 300 ÷ 21.4 = 14 billion years which is very close to the current accepted value of 13.8 billion years (about 1.4% difference).

## Conclusion

Determining the age of the universe is not quite as simple as explained here. There are several factors that determine the accuracy of the Hubble constant. For example, the universe may not have been expanding at the same rate, it may have sped up or slowed down at some stage in time. If the expansion of the universe is well understood how come some galaxies are blue shifted—i.e. why are they moving towards the Earth? Many questions still remain.

Australian scientist, Brian Schmidt was awarded the Nobel Prize in physics for proving that the expansion on the universe is accelerating.

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### Additional lessons and activities about the expansion of the universe and the Big Bang theory

* Students could research the discovery in 1965 of CMBR (Cosmic Microwave Background Radiation) left over from the Big Bang
* Students could watch:

‘The beginning of everything – The Big Bang’**,** YouTube (5.55 min) <https://www.youtube.com/watch?v=wNDGgL73ihY>

### Assessment opportunities

Investigation 3 provides an opportunity to assess student understanding of the concepts related to determining a value for Hubble’s constant and for the approximate age of the universe.

In addition, the level of student achievement of the science inquiry skills, **Processing and analysing data and information** and **Communicating** could be assessed.