Using the 'Unlocking the Universe in 3D' Virtual Reality program

YEAR 10 Unit Plan: The Big Bang and evolution of the Universe

CONTENTS:

Unit plan and associated worksheets written by Ingrid McCarthy, ANU.

All links are active as at December 2024.

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BACKGROUND

The ARC Centre of Excellence in All Sky Astrophysics in 3 Dimensions (ASTRO 3D) has created *Unlocking the Universe in 3D (U3D)*—a virtual reality teaching and learning experience to help Year 10 students better experience and understand how the Big Bang theory models the origin and evolution of the Universe.

Unit plan design

The activities completed by students in Virtual Reality have been designed by ASTRO 3D to link with the Australian Curriculum, and this unit plan provides a suggested teaching and learning sequence based on Understanding by Design/Backward Design (McTighe). The Unit Plan/Lesson sequence and the VR activities will help students understand big scientific ideas of theories (particularly the Big Bang theory) and models and supporting evidence for those theories. Teachers will be coaches by guiding students through the content and utilising the best educational design for immersive virtual reality.

Why Virtual Reality?

Simulations can provide opportunities for engaged exploration in physics teaching and learning. Beyond the two-dimensional world of screen-based simulations, abstract concepts can be visualised better in a three-dimensional virtual reality (VR) environment. These visualisations are immersive, where the user can look around and intuitively interact with objects in virtual space. VR allows students to experience scientific concepts that they cannot experience in real life or in a practical in the classroom. Research has shown that acting out physics scenarios (“embodiment”) can lead to better learning results.

The Big Bang theory and the evidence to support it are some of the most challenging concepts to teach in Year 10 Science. In the ASTRO 3D *Unlocking the Universe in 3D* VR program, the students will not just experience a 360-degree environment but will manipulate objects to collect data and evidence in virtual reality.

What will the students do?

The VR experience has been designed as a series of ‘Activities’ or ‘Modules’. Initially, the students should complete the training modules (Basic training and then Console training) to learn how to move and manipulate objects in the activities. Training takes place in the Transporter Room of the U3D Space Telescope, designed to give the students a ‘launch pad’ and a sense of place, which is essential in VR.

The Transporter Room also houses the Universe timeline, which helps students understand the Big Bang theory and shows the major changes in the Universe over time. Each of the activities is placed on the timeline.

Each activity is standalone, taking the students through different parts of the Universe timeline. Each activity links to specific evidence that supports the Big Bang theory.

Outline of activities

Training

- Basic Training – Land in the transporter room, and leave for Earth via the wristband.
- Console Training – Land in the transporter room, and leave for Earth via the wristband.

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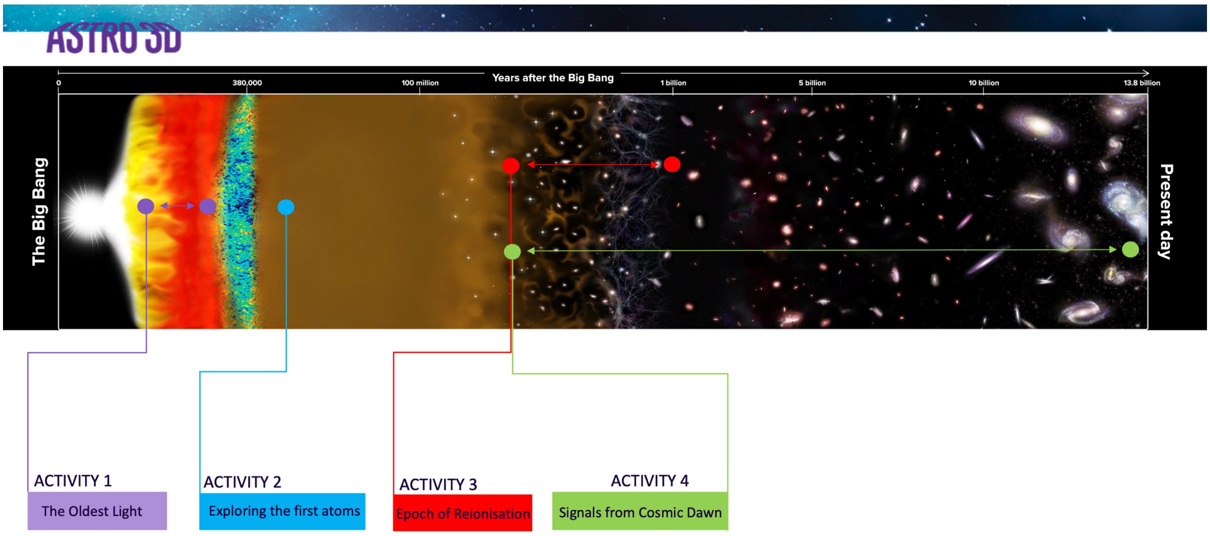
Activities

- The Oldest Light
- Exploring the First Atoms
- The Epoch of Reionisation
- Signals from Cosmic Dawn



The Oldest Light

- Land in the transporter room.
- Put on the space suit.
- Select the *Oldest Light* activity from the Universe timeline.
- Go into space to conduct tasks.
- Return to the transporter room via the wristband.
- Conduct CMB tasks.
- Return the space suit.
- Leave for Earth via the wristband.

Exploring the First Atoms in the Cosmic Dark Ages

- Land in the transporter room.
- Put on the space suit.
- Select the *Exploring Atoms* activity from the Universe timeline.
- Go into space to conduct tasks.
- Return to the transporter room via the wristband.
- Return the space suit.
- Leave for Earth via the wristband.

Epoch of Reionisation

- Land in the transporter room.
- Put on the space suit.
- Select *Epoch of Reionisation* activity from the Universe timeline.
- Go into space to conduct tasks.
- Return to the transporter room via the wristband.
- Conduct tasks.
- Return the space suit.
- Leave for Earth via the wristband.

Signals from Cosmic Dawn

- Land in the transporter room.
- Conduct tasks.
- Put on the space suit.
- Select the *Signals from Cosmic Dawn* activity from the Universe timeline.
- Go into space to conduct tasks (3x scenes).
- Return to the transporter room via the wristband.
- Conduct tasks.
- Return the space suit.
- Leave for Earth via the wristband.

Overview of program

Activity name	Summary	Level of user involvement	Size in VR
Universe 3D Transporter Room	'Waiting Room' – familiar space where users can adapt to being in VR, investigate tools, user interfaces and learn about what they need to do to complete activities. • **Induction 1 –** basic training (teleport, U3D timeline, spacesuit, wristband) • **Induction 2 –** console training	Inquiry	Real-world
The oldest light	• 10 secs – 380,000 years after the Big Bang • Sub-atomic particles • Linking the cooling and expansion of the Universe to the formation of nuclei and atoms • Standard Big Bang nucleosynthesis • Origin of Cosmic Microwave Background	Inquiry	Atomic
Exploring the first atoms in the Cosmic Dark Ages	• Standard Big Bang nucleosynthesis predicts the abundances of hydrogen and helium in the early Universe. • Atomic structure of the first stable, neutral atoms. • Origin of the first elements	Inquiry	Atomic
Epoch of Reionisation	• EoR simulation to observe new stars form and the bubbles of ionised gas getting larger and larger until the Universe becomes transparent • Modelling the evolution of the Universe. • First stars	Experiential Inquiry	Atomic and astronomical
Signals from Cosmic Dawn	• The effect of cosmological redshift on light • Radio astronomy (Australia's contribution)	Inquiry	Atomic and astronomical

ASTRO 3D has developed teacher resources in **a suggested unit plan** designed to run over approximately 11 lessons. There are lessons in VR and out of VR, designed to give the students the necessary background knowledge to fully engage with the VR activities.

The lessons and Unit Plan are suggested activities only – teachers are, of course, free to choose their own learning activities and sequence to best support their students.

We hope that both the U3D Virtual Reality Program and the Suggested Unit Plan with accompanying Teacher Resources will enhance your teaching and the student's learning of the Big Bang and evolution of the Universe.

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SUGGESTED UNIT PLAN

Curriculum links

Year/Stage: Year 10 (Stage 5)

Science Understanding: Earth and Space Sciences

Content:

Describe how the Big Bang *theory models* the origin and evolution of the universe and;

Analyse the supporting *evidence* for the theory (AC9S10U03):

- describing the **major components of the universe** using appropriate scientific terminology and units including astronomical units, scientific notation and light-years
- constructing **a timeline to show major changes in the universe** which are thought to have occurred from the Big Bang until the formation of the major components such as stars and galaxies
- examining how **stars' light spectra and brightness** is used to identify compositional elements of stars, their movements and their distances from Earth
- explaining how each different type of evidence, such as
    - **cosmic microwave background radiation,**
    - **red or blue shift of galaxies,**
    - **Edwin Hubble's observations and**
    - **proportion of matter in the universe**,
    - provides support for the acceptance of the big bang theory
- identifying the **different technologies used to collect astronomical data** and the types of data collected
- exploring **recent advances in astronomy**, including the Australian Square Kilometre Array Pathfinder, and astrophysics, such as the discovery of gravitational waves, dark matter and dark energy; and identifying new knowledge which has emerged
- identifying the **evidence supporting the Big Bang theory**
- recognising that the **age of the universe** can be derived using knowledge of the Big Bang theory
- describing how the **evolution of the universe**, including the formation of galaxies and stars, has continued since the Big Bang

Science as human endeavour:

Scientific understanding, including models and theories, is contestable and is refined over time through a process of review by the scientific community

- recognising that Australian scientists such as Brian Schmidt and Penny Sackett are involved in the exploration and study of the universe

Science Inquiry Skills:

Planning and conducting:

- Select and use appropriate equipment, including digital technologies, to collect and record data systematically and accurately

Processing and analysing data and information:

- Analyse patterns and trends in data, including describing relationships between variables and identifying inconsistencies
    - exploring relationships between variables using spreadsheets, databases, tables, charts, graphs and statistics
- Use knowledge of scientific concepts to draw conclusions that are consistent with evidence
    - using primary or secondary scientific evidence to support or refute a conclusion
    - constructing a scientific argument showing how their evidence supports their claim

Communicating:

- Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations
    - presenting results and ideas using formal experimental reports, oral presentations, slide shows, poster presentations and contributing to group discussions.

Suggested lesson sequence:

1. **The components and scale of the Universe**
2. **Modelling the Universe**
3. **VR – Basic training and console training**
4. **Basics of the Big Bang**
5. **VR – The Oldest Light (Nucleosynthesis)**
6. **Evidence for the Big Bang – Cosmic Microwave Background**
7. **The Electromagnetic Spectrum, spectra and redshift**
8. **VR – Exploring the first atoms in the Cosmic Dark Ages**
9. **VR – Epoch of Reionisation – exploring the EoR and the first stars**
10. **VR – Signals from the Cosmic Dawn (21cm line)**
11. **New technologies to uncover the answers to the big questions in modern astrophysics**

LESSON 1: The components and scale of the Universe

Time required: 50 minutes (one period lesson)

Rationale – This lesson is used to identify prior knowledge of the components of the Universe and to clear up misconceptions about size, scale distance and age of objects in the Universe.

Equipment list:

- Class sets of the 'What is the Universe?' worksheet and 'A cosmic survey: What are your ideas about the Universe?' worksheet.
- Access to the Internet to watch:
  - 'NASA – What is the Universe?' website, https://science.nasa.gov/exoplanets/what-is-the-universe/
  - 'Universe Size Comparison | Cosmic Eye', YouTube (2.59 min) https://youtu.be/8Are9dDbW24?si=VXXGaAVHsAydsUzs
- For each student:
  - one strip of seven different images (there are 4 strips on the master). Cut individual strips for each student (students will cut their own individual images).
  - A pair of scissors

Outcomes:

Students should be able to:

- identify the significant components of the Universe
- clear up misconceptions about the size, scale, distance, and age of objects in the Universe
- understand the scales of measurement scientists use in astronomy
- define a light-year and use it to describe distances in space

Prior knowledge, understandings and skills required:

Students will need:

- to have some conceptual understanding of space and the Solar System
- to be able to work in groups and use brainstorming strategies.

Background information for teachers

Many people, adults and students alike, are familiar with the names of objects in space but have an incomplete mental model of WHERE those objects are in space, their relative size and scale, and how they fit into the cosmic scheme of things.

Understanding the sizes and distances of celestial objects can be tricky since, in our everyday experience, the stars all look the same distance away, and the Moon can appear close or far away depending on whether you observe it near the horizon or higher in the sky. Of course, most people's knowledge of dim and distant objects such as nebulae and galaxies comes mainly from images in books, where all the images are about the same size—5 cm x 5 cm!

Lesson outline

These activities are based on the Harvard Smithsonian Centre for Astrophysics resource '*Cosmic Questions: Our place in space and time*', https://lweb.cfa.harvard.edu/seuforum/download/CQEdGuide.pdf

Introducing a new concept in science also includes introducing the language and symbolic jargon that accompanies it. For this reason, this introductory lesson begins with a guided activity.

1. The language of the Universe

Introducing a new concept in science also includes introducing the language and symbolic jargon that accompanies it. For this reason, the introductory lesson begins with a guided activity.

1. Using the attached 'What is the Universe?' worksheet ask the students, in groups, to brainstorm all the words they know to describe what is in the universe.
2. Once they have exhausted all their options, let them use the NASA 'What is the Universe?' website to add more components. They will need to read most of the page to expand on Earth, the Moon, stars, the Milky Way, etc.
3. Encourage them to keep going deeper and search for more answers on other websites. Encourage them to think in categories – matter, energy, time etc. Think small (atoms, protons, neutrons, quarks) and big (galaxies, stars, galaxy clusters) and things you can't see (dark matter, dark energy, photons, x-rays, gamma rays etc).
4. Sum up the activity by asking:
   - what is the smallest component of the Universe they found?
   - What is the biggest component of the Universe they found?
5. Outline that the Universe is huge and complex and goes from unimaginably small to unimaginably big.

The lesson then provides some context to introduce the concept of how big and complex the Universe is.

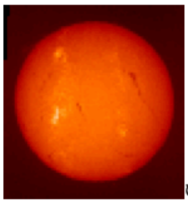
2. Cosmic Eye

Use the short video 'Universe Size Comparison | Cosmic Eye' to show the students a zoom through all well-known scales of the Universe, from minuscule elementary particles to the gigantic cosmic web.

3. How big, how far, how old

In this activity, students answer three questions about where objects in space are located and when they formed—an introduction to the concepts of the Universe's structure and evolution. By physically manipulating images of objects in space, students represent their mental models of the Universe in space and time.

1. Organise the class into eight discussion groups of 3-5 students per group.
2. Hand out copies of the 'Cosmic Survey: What are your ideas about the Universe' and the strips of images.
3. Ask the students to cut the strips into 7 separate images.
4. Explain that each group is to discuss the three survey questions and agree, if possible, on the best order of images for each question in the following order: How Big? How Far? How Old?
5. Lead the class in discussing the 3 different survey questions (notes in the Teacher's Copy). Play the role of moderator

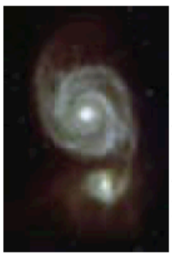

Sun


Saturn

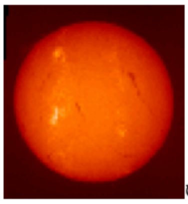

Pleiades Star Cluster


Hubble Space Telescope


Hubble Deep Field Galaxies


Whirlpool Galaxy


Moon


Sun


Saturn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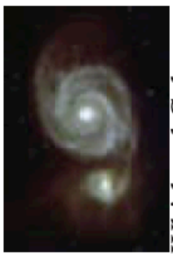
Hubble Space Telescope


Hubble Deep Field Galaxies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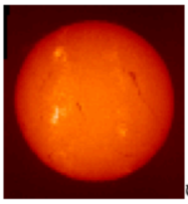
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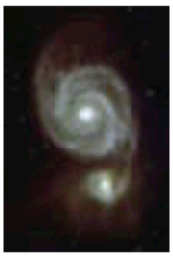
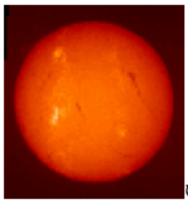

Whirlpool Galaxy


Moon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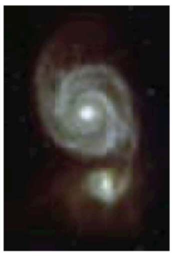
Whirlpool Galaxy


Moon

Images courtesy of NASA; Isaac Newton Telescope; Smithsonian Astrophysical Observatory

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LESSON 2: Modelling the Universe

Time required: 50 minutes (one period lesson)

Rationale – This lesson will challenge students to create a model of the Universe in a single class period. Getting a 'big picture' of the Universe as a whole is a difficult challenge — for professional astronomers and students — but it's a challenge that has occupied humanity through the Ages. To understand the vast ranges of scale of cosmic systems, the student of the Universe has to create and evaluate a variety of models against the observational evidence.

Equipment list:

- 'Modelling the Universe' PowerPoint presentation (download from the ASTRO 3D Legacy website VR page)
- modelling clay
- paper
- balloons
- different sized balls and marbles
- string
- markers
- scissors
- straws
- other odds and ends that might be useful in creating models
- Copies of the 'Universe Model Analysis Student Worksheet' for each group

Outcomes:

Students should be able to:

- understand the current *scientific model* for the structure and evolution of the Universe and the evidence that *supports* that model
- reflect on the nature of *models*, *evidence* and *explanations* in science
- represent the Earth's physical place in the solar system and the Universe.

Prior Knowledge, Understanding and Skills Required

Students will need:

- internet research skills including ability to assess the reliability and validity of sources;
- the ability to extract and collate information; and
- background knowledge of the fundamental structure of the Solar System as an example of a scientific model developed through a range of observations.

Background information for teachers

'Why Are Scientific Models Necessary?, Texas Gateway website, https://texasgateway.org/resource/scientific-models provides a straightforward explanation of the role of models in science.

The model is the most basic element of the scientific method. A model can be thought of as any simplification, substitute, or stand-in for what scientists are actually studying or trying to predict. Everything done in science is done with models. For example, it is impossible to actually 'see' the whole Universe, so models of its structure are developed.

Scientific models change as new evidence becomes available, and they are often used to make and test predictions. The intense use of models in predicting possible directions of climate change is one current example of an important use of models to guide research into phenomena.

No one has witnessed the start of the Universe, but scientists are gathering information to develop a model of the process that occurred. As more evidence is gathered, the model(s) must be adjusted accordingly. The theory of the formation of the Universe is such an example.

Ideas about the Universe have changed through time as the study of astronomy has evolved. Right up until the Dark Ages (800–1200 AD), some people still feared falling off the edge of the Earth, and many were scared by phenomena such as comets.

Aristotle (384–322 BC) was the first to speculate that the Earth was a sphere but incorrectly believed that it was the centre of the Universe. His ideas were adopted by the Church and remained untested for over a thousand years.

Aristarchus of Samos (ca. 270 BC) proposed a model for a heliocentric Solar System, which Aristotle dismissed.

Ptolemy (150 AD) developed a model for a geocentric Universe, which complemented Aristotle's beliefs, and was held to be true for many hundreds of years. It was not until 1300 years later that Nicolas Copernicus (1473–1543) built on the ideas of Aristarchus of Samos and again proposed a heliocentric Solar System. His work provided the foundations for modern astronomy.

Lesson outline

These activities are based on the Harvard Smithsonian resource 'Modeling the Universe Workshop: An Exploration of Space and Time' https://lweb.cfa.harvard.edu/seuforum/mtu/ and *Window to the Universe - The Square Kilometre Array* (A resource for teachers of students in Years 9–10), 2010, Questacon and Scitech, Perth.

What are scientific models of the Universe?

1. Show the class the PowerPoint slides on Modelling the Universe.
    a. Slide 1: What is a 'model'? Ask the class to name some familiar models (they might say aeroplanes, Lego, a globe, a doll's house, or even supermodels!).

    b. Slides 2 & 3: Discuss how scientists use models to suggest how things work and to predict phenomena that might be observed. Ask students to name some familiar models, such as a globe, or a dollhouse. A model is not the real thing. It can always misrepresent certain features of the real thing. Different models may represent only part of what is being modelled.

c. Slide 4: Discuss how scientists use models to help understand the Universe—we use the model to make a prediction. If the observations we make match the prediction, the model is a good one. If the observations don't match the prediction, then we need to refine or sometimes completely rethink our model!

d. Slides 5, 6 and 7 show the progression of understanding reflected in new models:
    i. Slide 5 – Earth as the centre of the Universe
    ii. Slide 6 – Sun as the centre of the Universe
    iii. Slide 7 – the Big Bang model (and theory).

Make your own model of the Universe?

In this activity, students make a physical model representing as much of the Universe as possible. They will then analyse their own and others' models to determine what they represent, misrepresent, leave out, and, perhaps most importantly, what questions they raise.

1. Divide students into groups of three or four. Each student can have one or more of the following roles: model maker(s), recorder of model features, and spokesperson.
2. Challenge students to create a model of the Universe in less than 30 minutes. You may wish to have some groups choose just a part of the Universe to model (such as the Solar System, a galaxy, or perhaps just the Earth-Moon system).
3. One person in the group should write down the model's features as it is built and any questions that arise.
4. Students use the *Universe Model Analysis Student Worksheet* to record the features of their model as they work.
5. After sharing all the models, discuss the following questions.
    a. Are there any patterns that emerge?
    b. What parts of the astronomical models represented the 'real thing' particularly well? Why?
    c. What parts of the astronomical models misrepresent the 'real thing?' Why?
    d. Why is representing the whole universe a difficult challenge?
    e. What are some things you need to discover to design a better model?

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LESSON 3 (VR): Basic training and console training

Time required: 100 minutes (double-period lesson)

Rationale – In this lesson, students will become familiar with using VR within the Transporter room. The students are space scientists working for the Universe 3D Taskforce, and their portal to the Universe is via the Transporter Room attached to the Universe 3D Space Telescope (U3D), which is in orbit around the Earth. The Transporter Room looks out onto the U3DST , and when a user looks down from the window, they can see Earth .

Equipment list:

- Oculus Quest (I or II) headsets – class set (one headset between 2-3 students) with the ASTRO 3D Universe in 3D (U3D) program preloaded
- Class copies of 'Console Training – Space Objects' student worksheet

Outcomes:

Students should be able to:

- use their ICT capabilities to access information, collect, analyse, and represent data, and model and interpret concepts.
- use technology to access information beyond their senses' capability. Digital aids such as animations and simulations provide opportunities to view phenomena and test predictions that cannot be investigated through practical experiments in the classroom and may enhance students' understanding and engagement with science.

Prior knowledge, understanding, and skills required:

Students will need:

- to have had an introduction to the basics of the VR experience – behaviour, safety, hygiene, wearing the headsets, what to expect, awareness of cybersickness etc. This may constitute an introductory lesson prior to starting the unit.

Lesson outline

Basic training

Instruct students to go into VR and select the 'Basic induction' option in the Training menu.

Students do not collect any information in this session. Once completing the basic training they will need to complete the basic training checklist worksheet before going back into VR to do the console training, Ensure a 'rest' between the two training modules.

Console training

Instruct students to go into VR and select the 'Console induction' option in the Training menu.

When they have completed the activity, download their data 'snapshots' and give them the student worksheet to complete.

NOTE: Depending on their capability students may need to do the VR training more than once.

LESSON 4: Basics of the Big Bang

Time required: 50 minutes

Rationale – This lesson will introduce students to the concept of a scientific theory. Understanding how the Big Bang Theory has evolved and changed over time is essential for students to understand how scientific evidence supporting theories alters our scientific understanding.

Equipment list:

- Access to the Internet to watch:
  - 'Why science is NOT 'Just a Theory' – The Royal Institution', YouTube, https://youtu.be/1uzsuCFUQ68?si=UuFs-aiYB90bkvTG (3:43 mins)
  - 'Evidence for Big Bang Cosmology – Professor Dave Explains', YouTube, https://youtu.be/zmrbjp-GDfk?si=c8v1uSAd-QXOoqfd&t=37 (12.18 min - start at 0:37s min)
- Class set of the student worksheet 'Scientific theories and evidence'.
- Printed copies of student Task Cards for the jigsaw activity (could be laminated for durability and re-use)
- Access to the Internet or printed resources on the history of cosmology

If you have not used the jigsaw teaching activity before, www.jigsaw.org/overview.htm has a good description of the strategy.

Outcomes:

Students should be able to:

- construct a timeline to show how different types of evidence support the Big Bang Theory
- recognise that scientific understanding, including models and theories, is contestable and is refined over time through a process of review by the scientific community.

Prior knowledge, understanding, and skills required:

Students need:

- to be familiar with the terms used to describe the Big Bang
- to be able to work efficiently in groups
- to be able to collaborate with other groups in a jigsaw activity.

Background information for teachers

Modern models for the formation of the Universe

The prevailing scientific theory for the origin of the Universe is the Big Bang theory. This states that the Universe began about 13.8 billion years ago with a cosmic explosion that released all matter and energy, which, until then had been compacted into a single, inconceivably dense point.

Evidence for the Big Bang was discovered by accident by Arno Penzias and Robert Wilson at the Bell Laboratories in 1963. They came across radio noise interfering with the development of communication satellites. No matter how they adjusted their instruments, they couldn't eliminate the noise. They even went as far as scrubbing the bird poo off the satellite dishes thinking that may have been the problem. They had actually discovered Cosmic Microwave Background Radiation, which is background radiation thought to be left over from the Big Bang. They received a Nobel Prize for their work.

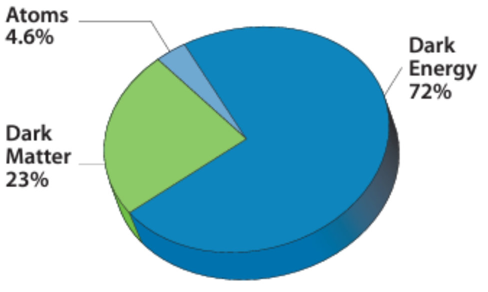
The Big Bang model is not complete. For example, it does not explain why the Universe is so uniform on the very largest scales or, indeed, why it is so non-uniform on smaller scales, i.e., how stars and galaxies came to be.

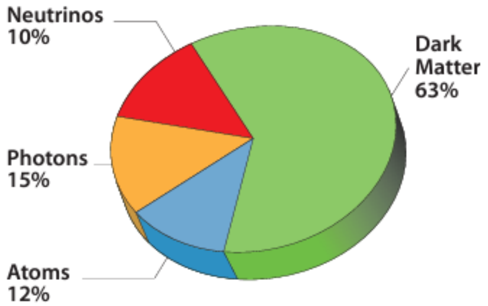
Many cosmologists suspect that Inflation Theory, which proposes a period of extremely rapid (exponential) expansion of the Universe during the first few moments after the Big Bang, may provide the framework for explaining the large-scale uniformity of the Universe and the origin of structure within it.

After the ‘explosion’, the Universe began to cool and expand, and particles formed. Until about thirty years ago, astronomers thought that the Universe was composed almost entirely of baryonic matter, that is, matter made up of protons, neutrons, and electrons. Since then, increasing evidence has accumulated that suggests there is something in the Universe that cannot be detected by traditional methods, perhaps some new form of matter.

Astronomers have had to develop a new model of matter and energy to fit their observations of the Universe. They now propose that the Universe is approximately:

- 4.6% Baryonic matter – atoms and sub-atomic particles;
- 23% Cold Dark Matter (CDM) – non-baryonic matter; astronomers are still developing models to describe this matter; and
- 72% Dark Energy – some type of force that is overcoming gravity and pushing the Universe apart.





The Wilkinson Microwave Anisotropy Probe (WMAP) is a NASA Explorer mission to measure the composition of the Universe. The left-hand chart shows a pie chart of the relative constituents today. A similar chart (right) shows the composition at 380,000 years old (13.7 billion years ago) when the light WMAP observes emanated. The composition varies as the Universe expands: the dark matter and atoms become less dense as the Universe expands, like an ordinary gas, but the photon and neutrino particles also lose energy as the Universe expands, so their energy density decreases faster than the matter. They formed a more significant fraction of the Universe 13.7 billion years ago. The dark energy density appears not to have decreased, so it now dominates the Universe even though it was a tiny contributor 13.7 billion years ago. Image and caption text from http://map.gsfc.nasa.gov/news/index.html#timeline.

Lesson outline

Introductory activity

1. Show or get the students to watch on laptops 'Why Science is NOT "Just a Theory" – The Royal Institute - https://youtu.be/1uzsuCFUQ68?si=UuFs-aiYB90bkvTG (3:43 min)
2. Get the students to fill in the answers to Q1-3 on the student worksheet 'Scientific Theories and Evidence'
3. Watch 'Evidence for Big Bang Cosmology – Professor Dave Explains' https://youtu.be/zmrbjp-GDfk?si=c8v1uSAd-QXOoqfd&t=37 – (start at 0:37s)
4. Get the students to fill in the answers to Q4-12 on the student worksheet

Timeline of scientific thinking on the Big Bang Theory

1. Divide the students into 15 groups and, if necessary, explain the system used in a Jigsaw activity.
2. Give out a task card for each discovery and ask the groups to collect the information on the card provided. They can use the Internet or any other resources at their disposal. You may want to 'pre-find' websites for less able classes or students, or to speed up the process.
3. Each group is then required to share the information collected with the rest of the class. It would be easier if the groups did this in chronological order.
4. The students can either add their information into a combined table or timeline, depending on teacher preference and time.

ASTRO 3D

Student Task Cards 1-15:

Task Card 1 – 1912 – Cepheid Variable Stars – Henrietta Leavitt
1. In one sentence, summarise the major scientific discovery. 2. How did this change astronomical thinking at the time? 3. What technology was used to collect the astronomical data?

Task Card 2 – 1912 - Doppler shift of a spiral nebula – Vesto M. Slipher
1. In one sentence, summarise the major scientific discovery. 2. How did this change astronomical thinking at the time? 3. What technology was used to collect the astronomical data?

Task Card 3 – 1917 – Cosmological considerations in the general theory of relativity – Albert Einstein
1. In one sentence, summarise the major scientific discovery. 2. How did this change astronomical thinking at the time? 3. What technology was used to collect the astronomical data?

Task Card 4 – 1924 – Evidence of galaxies outside the Milky Way – Edwin Hubble
1. In one sentence, summarise the major scientific discovery. 2. How did this change astronomical thinking at the time? 3. What technology was used to collect the astronomical data?

Task Card 5 – 1927 & 1931 – Solution to equations of the expanding Universe – George Lamaitre
1. In one sentence, summarise the major scientific discovery. 2. How did this change astronomical thinking at the time? 3. What technology was used to collect the astronomical data?

Task Card 6 – 1929 - Redshift of galaxies – Edwin Hubble

1. In one sentence, summarise the major scientific discovery.
2. How did this change astronomical thinking at the time?
3. What technology was used to collect the astronomical data?

Task Card 7 – 1948 - Steady-State Theory – Fred Hoyle

1. In one sentence, summarise the major scientific discovery.
2. How did this change astronomical thinking at the time?
3. What technology was used to collect the astronomical data?

Task Card 8 – 1948 – The Origin of Chemical Elements – George Gamow, Ralph Alpher and Hans Bethe

1. In one sentence, summarise the major scientific discovery.
2. How did this change astronomical thinking at the time?
3. What technology was used to collect the astronomical data?

Task Card 9 – 1949 – Coining of the phrase "Big Bang" – Fred Hoyle

1. In one sentence, summarise the major scientific discovery.
2. How did this change astronomical thinking at the time?
3. What technology was used to collect the astronomical data?

Task Card 10 – 1954 – Nuclear reactions in hot stars – Fred Hoyle

1. In one sentence, summarise the major scientific discovery.
2. How did this change astronomical thinking at the time?
3. What technology was used to collect the astronomical data?

Task Card 11 – 1957 – Synthesis of elements in stars (B^2FH) – Burbidge, Burbidge, Fowler, Hoyle

1. In one sentence, summarise the major scientific discovery.
2. How did this change astronomical thinking at the time?
3. What technology was used to collect the astronomical data?

Task Card 12 - 1964 - Cosmic Microwave Background discovery Arno Allan Penzias and Robert Woodrow Wilson

1. In one sentence, summarise the major scientific discovery.
2. How did this change astronomical thinking at the time?
3. What technology was used to collect the astronomical data?

Task Card 13 – 1994 - Hubble Space Telescope refines Hubble Constant – Freedman, Mould and Kennicutt

1. In one sentence, summarise the major scientific discovery.
2. How did this change astronomical thinking at the time?
3. What technology was used to collect the astronomical data?

Task Card 14 – 1998 – Accelerating Expansion of the Universe Brian Schmidt and Adam Riess, and simultaneously Saul Permutter

1. In one sentence, summarise the major scientific discovery.
2. How did this change astronomical thinking at the time?
3. What technology was used to collect the astronomical data?

Task Card 15 – 2001 onwards - WMAP measuring properties of the CMB – NASA and others

1. In one sentence, summarise the major scientific discovery.
2. How did this change astronomical thinking at the time?
3. What technology was used to collect the astronomical data?

LESSON 5 (VR): The Oldest Light activity – Nucleosynthesis

Time required: 100 minutes (double lesson). May need to go over two lesson.

Rationale – In virtual reality, students will explore the first 20 minutes after the Big Bang—the time period when subatomic particles were formed, and then nuclei and atoms wereformed. This process is known as Big Bang Nucleosynthesis (BBN) and is when the lightest elements of hydrogen, helium, and traces of lithium were formed.

Equipment list:

- Oculus Quest (I or II) headsets – class set (one headset between 2-3 students) with the ASTRO 3D Universe in 3D (U3D) program preloaded
- Class copies of the 'Oldest Light' student worksheet
- Red and dark blue colouring pencils/felt pens

Outcomes:

Students should be able to:

- start to construct a timeline to show the significant changes in the Universe which are thought to have occurred from the Big Bang until the formation of the major components of stars and galaxies
- better understand the proportion of matter in the Universe
- describe how the evolution of the Universe has continued since the Big Bang
- model the arrangement of particles in elements and compounds.

Prior knowledge, understanding and skills required:

Students will need:

- background knowledge of the evidence that supports the Big Bang Theory
- understanding of the role of scientific models in understanding phenomena
- background knowledge of the components of an atom (protons, neutrons and electrons).

Background information for teachers

Big Bang Nucleosynthesis (BBN)

BBN refers to the process by which light elements (such as hydrogen, helium, and traces of lithium and beryllium) were formed in the early Universe during the first few minutes after the Big Bang.

As the Universe expanded and cooled, protons and neutrons began to combine to form these elements through nuclear fusion. The exact abundances of these elements depend on the density of matter and radiation in the early Universe and the rate at which the Universe was expanding. This process is considered one of the key pieces of evidence supporting the Big Bang model of the Universe.

At 3 minutes, there were protons and neutrons – nuclei of all atoms. Very quickly, electrons also appeared, but they couldn't combine with the nuclei because it was too hot and dense and there was too much energy – the Plasma Universe. The nuclei clung onto photons and the Universe looked very different.

Twenty minutes after the Big Bang, the temperature fell to the point (about a billion degrees) where atomic nuclei began to form, as protons and neutrons combined through nuclear fusion to form the nuclei of the simple elements of hydrogen, helium and lithium. After about 20 minutes, the temperature and density of the Universe had fallen to the point where nuclear fusion couldn't continue.

Lesson outline

Instruct students to go into VR and select the 'The Oldest Light' on the Activities menu.

Research Task 1: Exploring subatomic particles 10-20 seconds after the Big Bang.

- Students collect information on the four subatomic particles that existed ~20 seconds after the Big Bang. This will help them complete the student worksheet.

Research Task 2: Exploring the first nuclei 2-20 minutes after the Big Bang.

- Students collect information on the nuclei which formed between 2 minutes and 20 minutes after the Big Bang.
- There are six questions on the student worksheet for students to answer. They may use textbooks or the Internet to find the answers. Spend some time discussing subatomic particles and nuclei.

Research Task 3: Formation of nuclei in the Big Bang.

- Students collect information on the order of formation of the nuclei during the Big Bang nucleosynthesis, and at what temperatures they formed.

When they have completed the activity, download their data 'snapshots' and give them the student worksheet to complete.

Additional activities:

- 'Imagine the Universe - Kinesthetic Big Bang', NASA (Goddard Space Flight Center) website, https://imagine.gsfc.nasa.gov/educators/elements/imagine/BigBang/bigbang.html

  Students will model the time after the Big Bang when the first nuclei of hydrogen and helium were created.

- 'The Elegant Universe - Sizing up Protons', NOVA – Public Braodcasting Service (PBS) website, https://www.pbs.org/wgbh/nova/teachers/activities/3012_elegant_13.html

  In this activity, find out how big a proton would be if you scaled an atom to the diameter of Earth.

LESSON 6: Evidence for the Big Bang – The Cosmic Microwave Background

Time required: 50 minutes

Rationale – During this lesson, students will examine the current scientific understanding of the oldest light in the Universe – the Cosmic Microwave Background (CMB) – and how it supports the Big Bang Theory.

Equipment list:

- Access to the Internet to watch:
    - 'Picture of the Big Bang (a.k.a Oldest Light in the Universe) – Minute Physics', YouTube, https://www.youtube.com/watch?v=_mZQ-5-KYHw&t=0s (4.00 min) (stop at 3.12 min)
- Class set of 'The Cosmic Microwave Background' student worksheet

Outcomes:

Students should be able to:

- describe why the CMB is evidence that supports the Big Bang Theory
- describe why the CMB is all around us
- extract and collate information

Prior knowledge, understanding, and skills required:

Students will need:

- the ability to listen, extract and collate information
- background information on the first 380,000 years after the Big Bang
- *data collected in Lesson 5 in VR*

Background information for teachers

The **Cosmic Microwave Background (CMB)** is a faint, uniform glow of radiation that fills the entire observable Universe. It's a remnant of the Big Bang and crucial evidence for the Big Bang Theory.

In the last VR lesson (Lesson 5), we learnt that particles combined to form nuclei and free electrons as the Universe expanded and cooled from 3 to 20 minutes after the Big Bang. The photons in this hot, dense Universe quickly scatter off the electrons, creating a dense, opaque fog.

This process of multiple scattering produces a 'thermal' or 'blackbody' spectrum of photons. According to the Big Bang theory, the frequency spectrum of the CMB should have this blackbody form. The Far Infrared Absolute Spectrophotometer (FIRAS) experiment on NASA's Cosmic Background Explorer (COBE) satellite measured this with tremendous accuracy.

Eventually, around 380,000 years after the Big Bang, the Universe had cooled sufficiently that protons and electrons could combine to form neutral hydrogen. The photons only interacted very weakly with neutral hydrogen, allowing them to travel freely in straight lines for the first time. This light has been travelling through space ever since, offering us a 'snapshot' of the early Universe.

The existence of CMB radiation was first predicted by Ralph Alpherin in 1948 in connection with his research on Big Bang Nucleosynthesis undertaken with Robert Herman and George Gamow. It was first observed inadvertently in 1965 by Arno Penzias and Robert Wilson at the Bell Telephone Laboratories in Murray Hill, New Jersey. The radiation was a source of excess noise in a radio receiver they were building. Coincidentally, researchers at nearby Princeton University, led by Robert Dicke and including Dave Wilkinson of the Wilson Microwave Anisotropy Probe (WMAP) science team, were devising an experiment to find the CMB. When they heard about the Bell Labs result, they immediately realised the CMB had been found. The result was a pair of papers in the Astrophysical Journal (vol. 142 of 1965): one by Penzias and Wilson detailing the observations and one by Dicke, Peebles, Roll, and Wilkinson giving the cosmological interpretation. Penzias and Wilson shared the 1978 Nobel Prize in physics for their discovery.

One of the most striking features of the CMB is its uniformity. Only with very sensitive instruments, such as COBE and WMAP, can cosmologists detect fluctuations in the Cosmic Microwave Background temperature. By studying these fluctuations, cosmologists can learn about the origin of galaxies and their large-scale structures and measure the basic parameters of the Big Bang theory.

Lesson outline

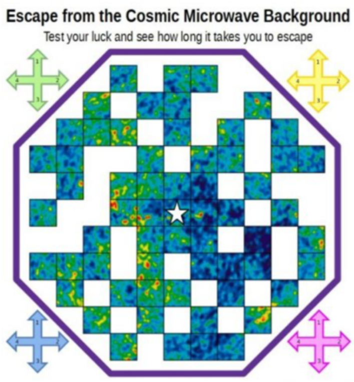
In the last VR lesson, the students investigated the formation of the first nuclei. From then until 380,000 years after the Big Bang, the Universe experienced gradual cooling as it expanded. They also collected data on the tiny variations in temperature in the CMB so they will need this data for this lesson.

1. Distribute the worksheets.
2. Students watch the video 'Picture of the Big Bang (a.k.a Oldest Light in the Universe) – Minute Physics', YouTube, https://www.youtube.com/watch?v=_mZQ-5-KYHw&t=0s (4.00 min) (stop at 3.12 min). This video also provides a review of the content of Lesson 5.
3. Get the students to complete the worksheet.

Additional (fun) activity

Escape the Cosmic Microwave Background Maze

Test your luck and see how long it takes you to escape from the Cosmic Microwave Background. An engaging boardgame for communicating the complex astrophysical concept of random chance. ASTRO 3D Legacy website, https://astro3d.org.au/education-and-outreach/escape-the-cosmic-microwave-background-maze-activity/



LESSON 7: The Electromagnetic Spectrum, spectra and redshift

Time required: 50 minutes (plus more if you want to do one/both of the practical activities)

Rationale – In this lesson, students will review the characteristics of waves and the electromagnetic spectrum (EMS). They will then build on that knowledge by exploring the EMS as 'light' and how light is used in astronomy to understand the chemistry of stars and galaxies, as well as how astronomers use redshift to understand distances and time in the Universe

Equipment list:

- Access to YouTube to watch 'Light: Crash Course Astronomy #24 – CrashCourse', YouTube https://youtu.be/jjy-eqWM38g?si=7MRjuNjfDpS0cr3t (10.33 min)
- Class set of the 'Light: Crash Course Astronomy #24' student worksheet

Outcomes:

Students should be able to:

- understand how stars' light spectra and brightness is used to identify compositional elements of stars, their movements and their distances from Earth
- explain how the red or blue shift of galaxies provides support for the acceptance of the Big Bang Theory
- identify how different technologies are used to collect astronomical data
- describe the structure of atoms in terms of electron shells.

Prior knowledge, understanding and skills required:

Yr 9 Science Understanding: Physical science

- use wave and particle models to describe energy transfer through different mediums and examine the usefulness of each model for explaining phenomena (AC9S9U04)
    - discussing the wave and particle models of energy transfer and how they are useful for understanding aspects of light and other forms of electromagnetic radiation.

Background information for teachers

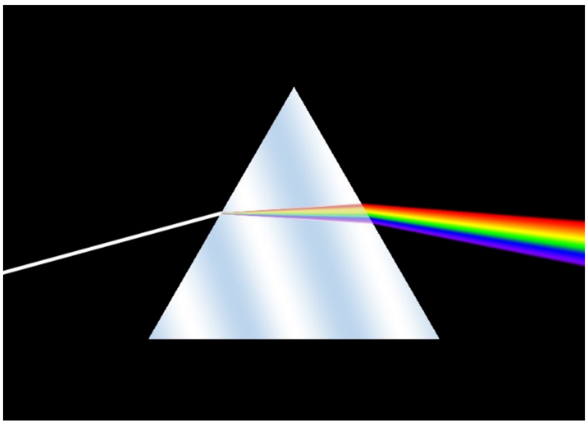
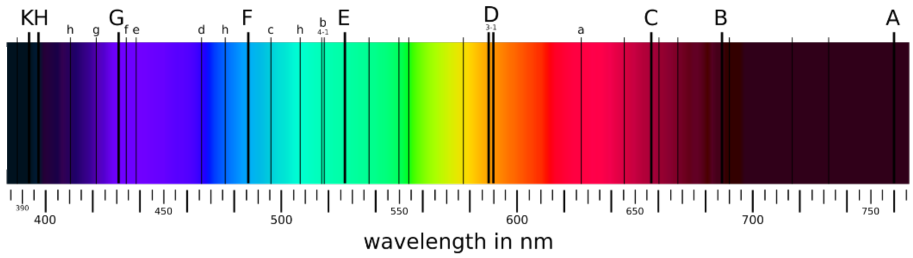


Diagram of a dispersion prism
https://commons.wikimedia.org/w/index.php?curid=102872
CC SA 1.0

In optics experiments (1666-1672), Isaac Newton demonstrated that white light could be split up into component colours using a prism and that these components could be recombined to generate white light. He also demonstrated that the prism does not impart or create the colours but separates constituent parts of the white light. As with many subsequent spectroscopy experiments, Newton's sources of white light included flames and stars, including the Sun.

In 1802, William Hyde Wollaston built a spectrometer that improved Newton's model and included a lens to focus the Sun's spectrum on a screen. Upon use, he realised that the colours were not spread uniformly but instead had missing patches of colour, which appeared as dark bands in the Sun's spectrum. Wollaston believed these lines were natural boundaries between the colours at the time.

In 1815, Joseph von Fraunhofer made a significant experimental leap forward by replacing the prism with a diffraction grating to disperse the wavelengths. The diffraction grating improved the spectral resolution and allowed the dispersed wavelengths to be quantified. Fraunhofer made and published systemic observations of the solar spectrum. However, he died before he could study this phenomenon more thoroughly.

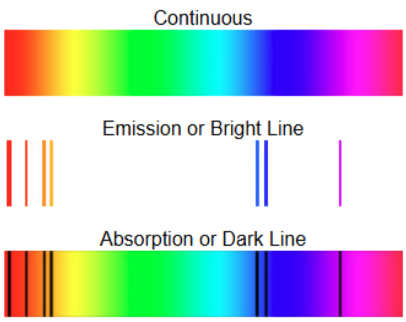


Fraunhofer lines. Wikimedia/Public Domain

In 1859, Robert Bunsen (of Bunsen burner fame!) made a totally unexpected discovery. When certain chemicals were heated in Bunsen's burner, characteristic bright lines appeared. In some cases, these were at precisely the same points in the spectrum as Fraunhofer's dark lines. The bright lines were light coming from a hot gas, whereas the dark lines showed absorption of light in the cooler gas above the Sun's surface

Coloured flames of methanol solutions of different compounds, burning on cotton wool. (Hegelrast/Wikimedia Commons CC-SA 4.0)

Together with Gustav Kirchoff, they found that every chemical element produces a unique spectrum, which provides a sort of 'fingerprint' that can confirm the presence of that chemical. They recognised this could be a powerful tool for 'the determination of the chemical composition of the Sun and fixed stars'. Throughout the 1860s, Kirchoff identified 16 different chemical elements among the hundreds of lines he recorded in the Sun's spectrum and speculated on the Sun's chemical composition and structure.



Three types of spectra: continuous, emission line and absorption (NASA's Imagine Universe)

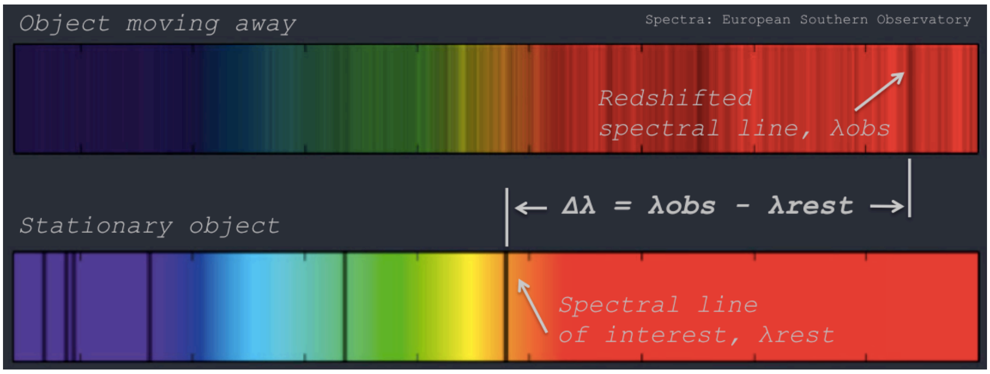
In 1885, Edward C. Pickering at the Harvard College Observatory undertook an ambitious program of stellar spectral classification using spectra recorded on photographic plates. By 1890, he had catalogued over 10,000 stars and grouped them into thirteen spectral types. Following this, Annie Jump Cannon expanded the catalogue to over a quarter of of a million stars by 1924 and developed the system of ten spectral types – O, B, A, F, G, K, M, R, N, S – that astronomers still use today.

Annie Jump Cannon (Harvard-Smithsonian Center for Astrophysics)

The first decade of the 20th century brought the basics of quantum theory, and the presence of spectral lines could now be explained by quantum mechanics in terms of energy levels in atoms, ions, and molecules. The limited set of configurations on which these elemental particles can exist (the set of quantum numbers) means that each type of atom or molecule can only absorb or emit light at specific wavelengths.

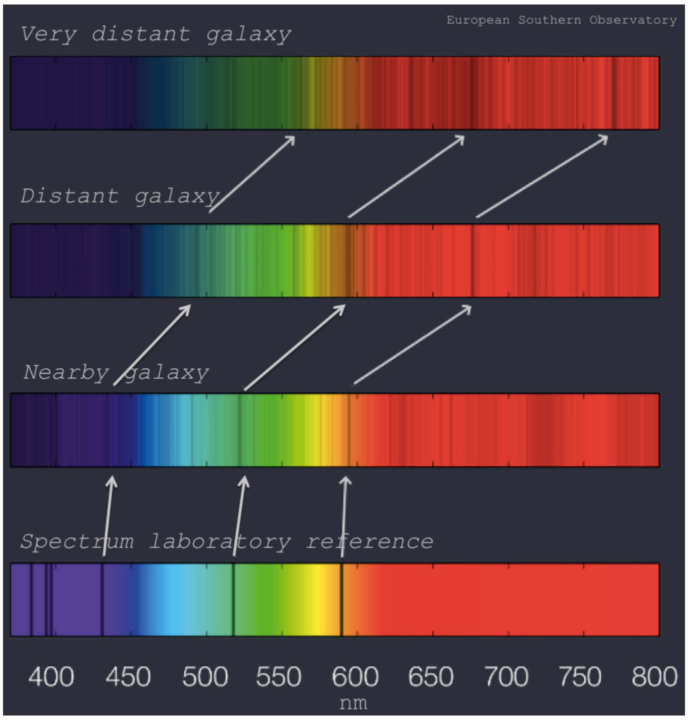
Now, astronomers can use spectroscopy to determine not only the element but also its temperature and density in the star.

They can also use spectra to determine if an object (star or galaxy) is moving away from us or towards us. The Doppler Effect is when an object emitting light moves towards an observer, the light reaching the observer will shift towards the blue end of the spectrum, decreasing the wavelength of the light and increasing its frequency. This is called *blueshift.* Conversely, if an object emitting light is receding from the observer, the light reaching the observer will shift towards the red, increasing the wavelength and decreasing the frequency. This is called *redshift.*



Spectra (ESO: European Southern Observatory)

They can also use known spectra to measure the distance to galaxies. In the early 20th century, astronomer Edwin Hubble observed that (such as below). Hubble interpreted this shift in the spectrum as a Doppler shift, postulating that these distant galaxies were travelling away from our own. Hubble eventually determined that the velocity at which these galaxies were receding was proportional to how far away they were; the further away the galaxies were, the higher their redshift was.



The spectra of distant galaxies were significantly redshifted (ESO: European Southern Observatory)

This equation, *Hubble's Law,* is written as $v = H_0 d$.

From his observations, Hubble and others were able to conclude several important facts about the nature of the Universe. The first comes from noting that all galaxies appear to be receding from our location in space. This is not because the location of the Milky Way is unique. Instead, it was realised that this is because the entire Universe is expanding; spacetime itself is stretching apart.

Furthermore, if we can look at galaxies nearby and far away and see how fast they are receding due to the expansion of spacetime, we have varying rates for the expansion of the Universe. With the speed of something moving, varying or not, we can work backward to learn when the movement began. From Hubble's observations, we can conclude how long ago the Big Bang occurred; we can estimate the age of the Universe. From this and other methods, the age of the Universe is found to be 13.8 billion years.

Lesson outline

Introductory activity

Light, spectra, spectroscopy, the Doppler Effect and redshift

1. Show or get the students to watch on laptops 'Light: Crash Course Astronomy #24 – CrashCourse', YouTube https://youtu.be/jjy-eqWM38g?si=7MRjuNjfDpS0cr3t (10.33 min)
2. Students answer the questions relating to the video on the student worksheet.

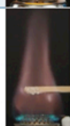
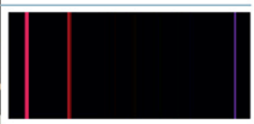
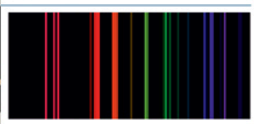
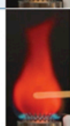
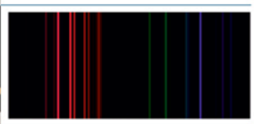
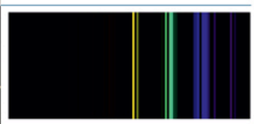
Optional practical activities

If you have time in your unit/term, there are some relevant practical activities (outside of VR) that your students can do, to help them better understand light, redshift and spectra and spectroscopy.

1. 'Tactile Electromagnetic Spectrum' – students can create an using foam board and some string. This activity is for the visually impoaried but can be adapted. Perkins School for the Blind website https://www.perkins.org/wp-content/uploads/elearning-media/Tactile%20EM%20Spectrum_0.pdf

2. In the school laboratory - Using a flame test to demonstrate the emission spectra of a variety of cations.

   The ASTA Science ASSIST website has step by step instuctions for demonstrating this activity in the lab (in a Standard Operating Procedure) and a link to a video.'SOP: Demonstrating the flame test using a PET bottle', Science ASSIST website, https://assist.asta.edu.au/resource/3950/sop-demonstrating-flame-test-using-pet-bottle

Metal Chloride	Cation	Neutral Atom Valence Level Configuration	Flame Test Color	Bright-Line Emission Spectrum
Lithium chloride Orange-red	Li^{1+}	$2s^1$		
Sodium chloride Yellow	Na^{1+}	$3s^1$		
Potassium chloride Violet	K^{1+}	$4s^1$		
Calcium chloride Yellow-orange	Ca^{2+}	$4s^2$		
Strontium chloride Red	Sr^{2+}	$5s^2$		
Copper(II) chloride Green	Cu^{2+}	$4s^23d^9$		

https://knowledge.carolina.com/discipline/physical-science/ap-chemistry/flame-tests-and-spectroscopy-get-excited-about-color/

3. Make a Smartphone Spectroscope

   ASTRO 3D has an explanatory video of how to make the spectroscope, as well as links to the template and where to buy the holographic diffraction grating. 'DIY Smartphone Spectroscope', ASTRO 3D Legacy website, https://astro3d.org.au/education-and-outreach/diy-smartphone-spectroscope/

4. 'Redshift', STEM Learning (UK) website, https://www.stem.org.uk/resources/elibrary/resource/29947/redshift

   Here is a a simple demonstration that can be used to help students understand red shift and blue shift of waves emitted by a moving object. Using the school yard, students move as if they are light waves being emitted by a star. Observers can see the apparent 'wavelength' of this light. The observers note that when the star is moving, the apparent wavelength is shifted. This demonstrates red and blue shift. Teacher notes and a video are provided.

LESSON 8 (VR): Exploring the First Atoms in the Cosmic Dark Ages

Time required: 100 minutes (double lesson suggested)

Rationale – In this lesson, students will explore, in virtual reality, the Universe after the CMB (roughly from 380,000 years after the Big Bang, to about 150 million years after the Big Bang). This period of the Universe's evolution is known as the Cosmic Dark Ages, because the neutral atoms that formed in Big Bang Nucleosynthesis have yet to clump together and form stars, so very little light is being given off.

Equipment list:

- Oculus Quest (I or II) headsets – class set (one headset between 2-3 students) with the ASTRO 3D Universe in 3D (U3D) program preloaded.
- Class set of the 'Exploring the First Atoms' student worksheet

Outcomes:

Students should be able to:

- use ICT to access information, collect, analyse, and represent data, as well as model and interpret concepts.
- use technology to access information beyond their senses' capability. Digital aids such as animations and simulations provide opportunities to view phenomena and test predictions that cannot be investigated through practical experiments in the classroom and may enhance students' understanding and engagement with science.
- describe how the evolution of the Universe, including the formation of galaxies and stars, has continued since the Big Bang.

Prior knowledge, understanding and skills required:

Students will need:

- to be able to describe and model the structure of atoms in terms of the nucleus, protons, neutrons, and electrons, as well as the mass and charge of protons, neutrons, and electrons.
- to have completed the VR Training modules (basic training and console training) and;
- to have completed The Oldest Light Activity in VR.

Background information for teachers

Dark Age (or Dark Era), from 380,000 to 150 million years:

The period after the formation of the first atoms and before the first stars is sometimes referred to as the Dark Age. Although photons existed, the Universe at this time is literally dark, with no stars having formed to give off light. With only very diffuse matter remaining, activity in the universe has tailed off dramatically, with very low energy levels and very large time scales. Little of note happens during this period, and the universe is dominated by mysterious 'dark matter'.

For the first 380,000 years after the Big Bang, all matter and energy existed as an extremely hot, dense expanding ball of ionised plasma. At this point, collisions between subatomic particles in this high-energy soup prevented the particles from acquiring electrons to form stable atoms. Once the Universe had sufficiently expanded and cooled, however, subatomic particles could acquire electrons to form neutral hydrogen atoms, and the cosmic dark ages began.

Through a combination of simulations and observations, astrophysicists have estimated that the cosmic dark ages began 380,000 years after the Big Bang. The processes thought to have brought the cosmic dark ages to an end started roughly 680 million years after the Big Bang and ended approximately 1.1 billion years after the Big Bang.

The end of the cosmic dark ages was a gradual process. Denser regions of neutral hydrogen gas in the early universe eventually gravitationally collapsed to form massive stars — the first stars in the Universe. These stars sent large amounts of ultraviolet light into the nearby Universe, but it wasn't until stars and protogalaxies were abundant in the early Universe that enough ultraviolet light was emitted into space so as to completely reionise all of the neutral hydrogen in interstellar space.

Watch this video: 'The Cosmic Dark Ages', Spacetime, PBS videos, https://www.pbs.org/video/the-cosmic-dark-ages-qkigdk/ (12.29 min)

Lesson outline

In this lesson, students will collect data in VR on the types of neutral atoms formed in the first 380,000 years after the Big Bang. They will better understand how the addition of neutrons does not change the type of element an atom is, but it does change the type of isotope of that atom.

Instruct students to go into VR and select the 'Exploring the First Atoms' on the Activities menu.

Research Task 1: The five stable atoms of the neutral Universe.

- Students collect information on the five stable elements that existed 380,000 years after the Big Bang. This will help them complete the student worksheet.

Research Task 2: Spectra of the neutral atoms.

- Students collect the spectra of the neutral atoms. This will help them complete the student worksheet.

Research Task 3: Build your own atoms.

- Students 'build' models of the five stable atoms in VR. This will help them complete the student worksheet.

Research Task 4: Where do these atoms fit on the Periodic Table – Origin of Elements.

- Students discover that an atom's identity as a specific element is determined by the number of protons in its nucleus. If possible, print out a few copies of the Periodic Table of Elements from the ASTRO 3D legacy website URL to show students and discuss.

When the students have completed the activity, download their data 'snapshots' and give them the student worksheet to complete.

ASTRO 3D

LESSON 9 (VR): The Epoch of Reionisation – Exploring the EoR and the first stars

Time required: 100 minutes (double lesson suggested)

Rationale – In this lesson, students will explore, in virtual reality, the period (about 340 million years to 1 billion years after the Big Bang) in the Universe when the slightly denser regions clumped together under gravity forming the first stars. The UV light from these stars ionised the dense fog of neutral hydrogen around them causing these regions (and eventually the whole Universe) to became transparent.

Equipment list:

- Oculus Quest (I or II) headsets – class set (one headset between 2-3 students) with the ASTRO 3D Universe in 3D (U3D) program preloaded.
- Class set of the 'Epoch of Reionisation' student worksheet.
- Internet access to watch 'What were the first stars like?', Webb Space Telescope website, https://webbtelescope.org/contents/articles/what-were-the-first-stars-like

Outcomes:

Students should be able to:

- describe how the evolution of the Universe, including the formation of galaxies and stars, has continued since the Big Bang.

Prior knowledge, understanding and skills required:

Students will need:

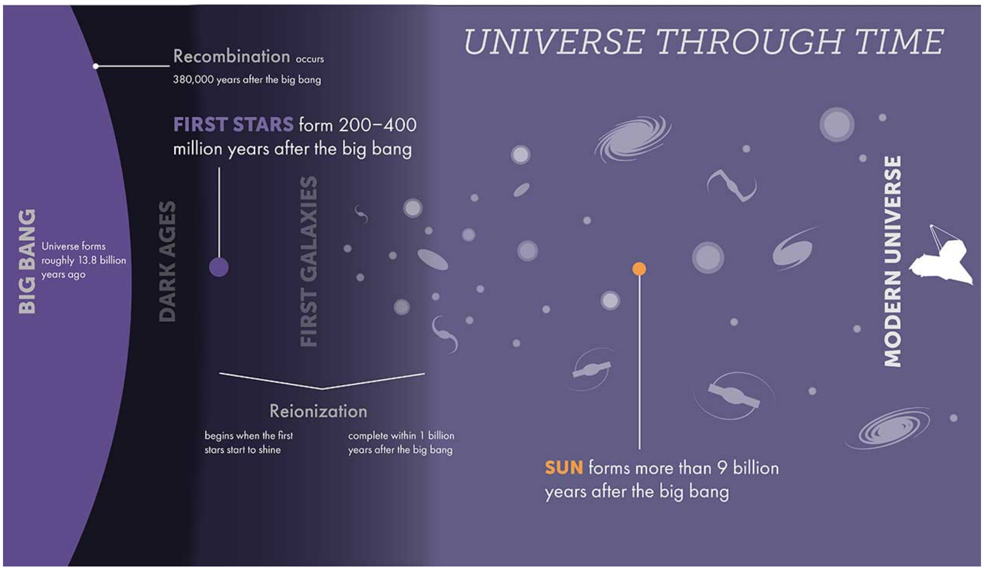
- to have completed the VR Training modules (basic training and console training); and
- to have completed The Oldest Light, and Exploring Neutral Atoms activities in VR.

Background information for teachers

The Epoch of Reionisation (EoR)

The Epoch of Reionisation (EoR) is the period in the evolution of the Universe during which the predominantly neutral intergalactic medium was ionised by high-energy radiation from the first luminous sources. These sources were stars, galaxies, quasars or some combination of the above.

By studying reionisation, we can learn a great deal about the process of structure formation in the Universe and find the evolutionary links between the relatively smooth matter distribution in the CMB and the highly structured Universe of galaxies and clusters of galaxies today.



Timeline of the Universe: Although we are not sure exactly when the first stars began to shine, we know that they must have formed sometime after the era of Recombination, when hydrogen and helium atoms formed (380,000 years after the big bang) and before the oldest-known galaxies existed (400 million years after the big bang). The ultraviolet light emitted by the first stars broke down the neutral hydrogen gas, filling the Universe with hydrogen ions and free electrons, initiating the era of Reionization and the end of the Dark Ages of the Universe. Credit: STScI

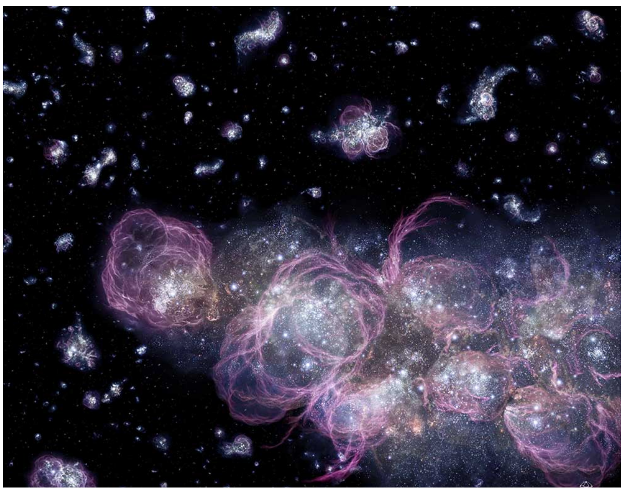
Star and galaxy formation (300-500 million years onwards)

Gravity amplifies the slight irregularities in the density of the gas around the time of the CMB. Pockets of gas become increasingly dense even as the Universe continues to expand rapidly. These small, dense clouds of cosmic gas collapse under their own gravity, becoming hot enough to trigger nuclear fusion reactions between hydrogen atoms, creating the very first stars.

These first stars are short-lived supermassive stars, about a hundred times the mass of our own Sun. They are known as Population III (or 'metal-free') stars.

Composition of first stars:

Astronomers know that Population III stars must have been made almost solely of hydrogen and helium—the elements that formed as a direct result of the Big Bang. They would have contained none of the heavier elements like carbon, nitrogen, oxygen, and iron found in stars shining today. In other words, Population III stars were metal-free. (Astronomers refer to any element heavier than helium as a metal.)



Artist's concept of early star formation: The first stars are thought to have formed as early as 100 million years after the Big Bang, when dense regions of hydrogen and helium collapsed under their own gravitational pull. Once the pressure and temperature in the centre of the cloud was high enough, hydrogen atoms began to fuse together, releasing energy in the form of UV light. Credit: Adolf Schaller for STSci

Because we haven't observed any metal-free stars, we are fairly certain that there could not have been many small ones. Small stars like the Sun last for billions of years. If small Population III stars were common, we should have detected some by now.

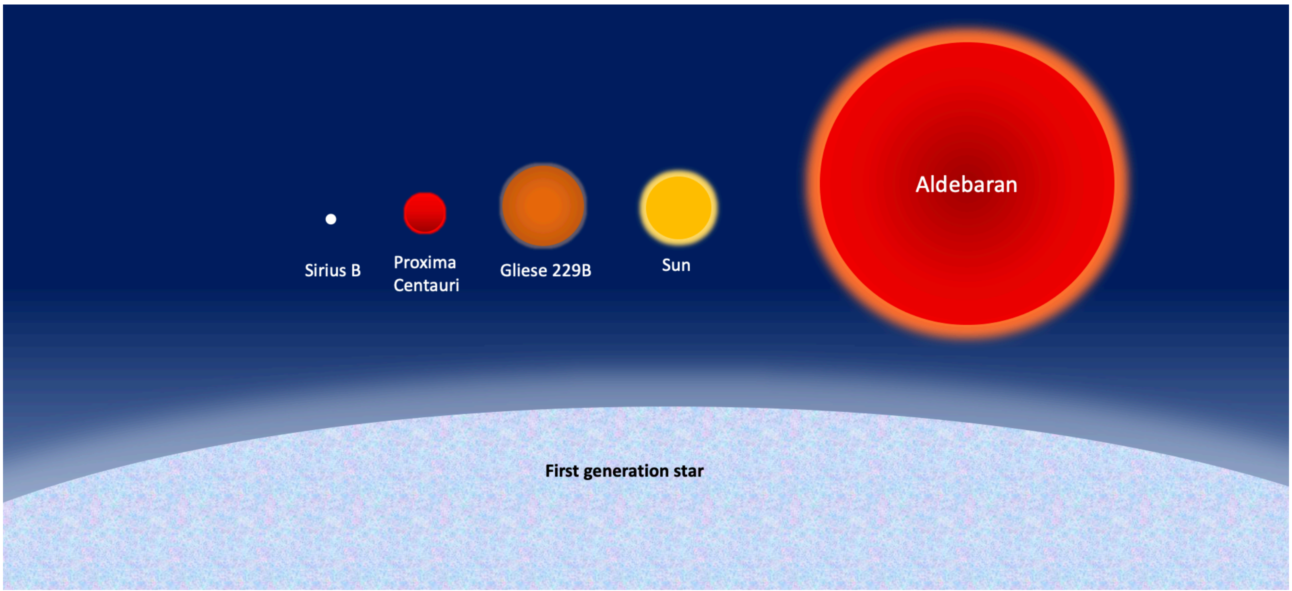
Extremely large stars, on the other hand, burn their fuel very quickly. A star 60 times the mass of the Sun lasts less than one million years. If all of the first generation of stars were extremely massive, none would still exist, and it would make sense that we have not seen any.

Temperatures and brightness of the first stars:

The temperature and brightness of a star is directly related to its mass: The more massive the star is, the hotter and brighter it is. If the first stars were very massive, they also must have been extremely hot and bright. A star 100 times the mass of the Sun, for example, would have a surface temperature around 100,000 Kelvin and would shine with the energy of 1 million Suns.

Population II and I stars:

Eventually, Population II and then Population I stars also began to form from the material from previous rounds of star-making. The larger stars burn out quickly and explode in massive supernova events, their ashes going on to form subsequent generations of stars. Large volumes of matter collapsed to form galaxies, and gravitational attraction pulled galaxies towards each other to form groups, clusters and superclusters of galaxies.



The largest stars in the present-day universe are a couple hundred times more massive than our sun. The first stars could have had as much as 100,000 times the Sun's mass. (Adapted from Merrill Sherman/Quanta Magazine)

Lesson outline

In this lesson, students will experience a fly through the 3D computer simulation of the Epoch of Reionisation and then collect data on two, first stars.

Instruct students to go into VR and select the 'Epoch of Reionisation' on the Activities menu.

Research Task 1: What happened during the Epoch of Reionisation?

The students have two opportunities to make a selection out of four options on what happens during the EoR. They confirm this in the worksheet. [**Optional:** show the students the 2D simulation they experienced in VR – 'The era of reionisation (simulation) – ESO', YouTube, https://youtu.be/aWq8ujKdRRg?si=aY9pO8eV6ITlp668 (1.06 min)].

Research Task 2: The first stars

The students collect data by measuring the attributes of two stars. This will help them complete the student worksheet.

When the students have completed the activity, download their data 'snapshots' and give them the student worksheet to complete.

LESSON 10 (VR): Signal from Cosmic Dawn – the 21 cm line

Time required: 100 minutes (double lesson suggested)

Rationale – In this lesson, students will explore, in virtual reality, the wavelength of photons emitted by neutral hydrogen. They will better understand cosmological redshift and how astronomers use radio waves to understand the evolution of the Universe.

Equipment list:

- Oculus Quest (I or II) headsets – class set (one headset between 2-3 students) with the ASTRO 3D Universe in 3D (U3D) program preloaded
- Class set of the 'Signals from Cosmic Dawn' student worksheet
- Coloured pencils or felt pens – red, green, blue, orange
- Access to the Internet to watch 'Signals from the cosmic dawn: A three minute guide – nature video', You Tube, https://youtu.be/gmIlmZ8uiOs?si=ssbETyuUgaDEcjaQ (3.28 min)

Outcomes:

Students should be able to:

- describe how the **evolution of the Universe**, including the formation of galaxies and stars, has continued since the Big Bang
- explain how red or blue shift of galaxies and light provides support for the acceptance of the Big Bang Theory

Prior knowledge, understanding and skills required:

Students will need :

- need to have completed the VR Training modules (basic training and console training) ;
- to have completed Oldest Light, Exploring Neutral Atoms, and the Epoch of Reionisation activities in U3D

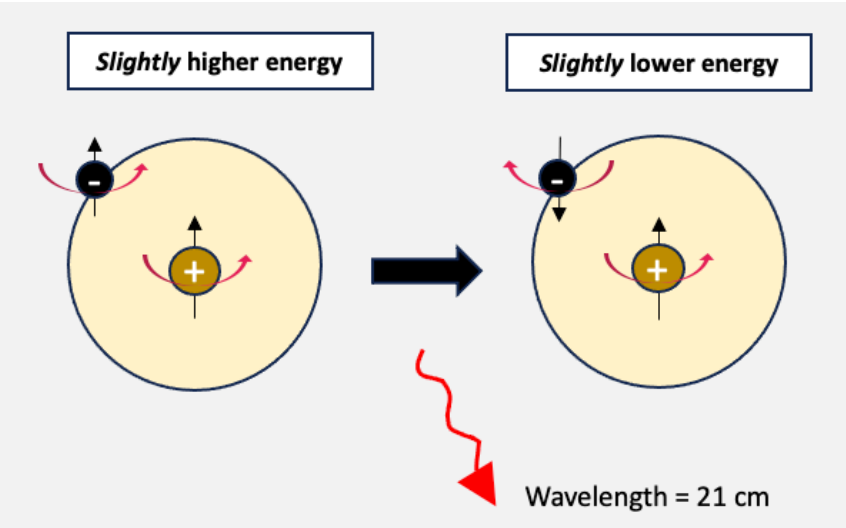
Background information for teachers

In the last lesson in VR, students learnt about the Epoch of Reionisation and how the first stars ionised the neutral intergalactic medium with high-energy UV radiation. The period of reionisation was the last time in the Universe's history that hydrogen changed its state.

Studying the reionisation process will help astronomers learn about the hydrogen gas pervading the Universe and the galaxies that drove the reionisation—even though we currently can't see them with our telescopes.

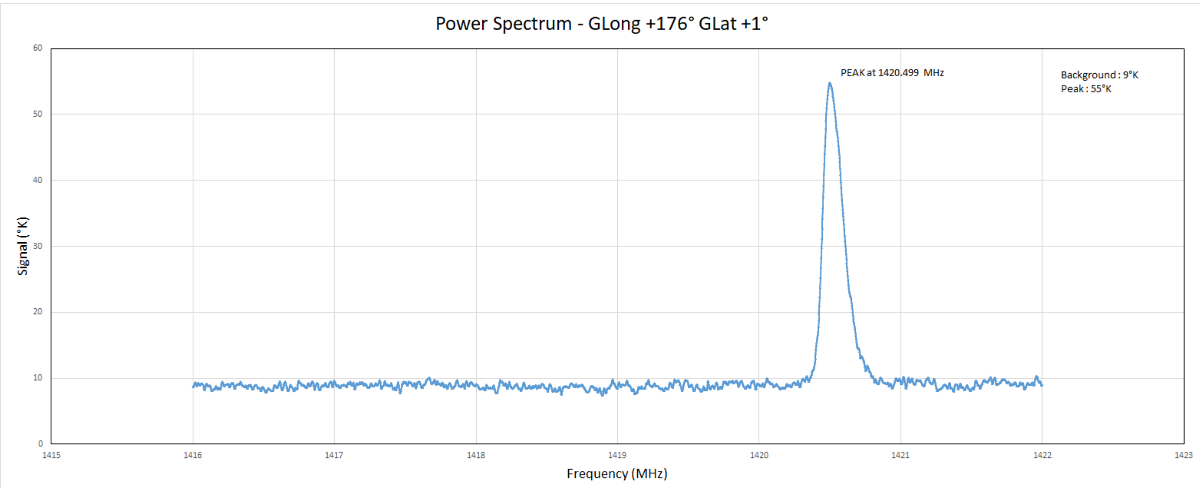
In 1944, Dutch astronomers predicted that neutral hydrogen, which at the time made up the bulk of the material in the Universe, could be detected by observing a rare transition known as the **spin-flip transition**.

If we imagine that the proton and electron in a hydrogen atom are charged balls spinning on their own axes, it has its lowest energy state when its proton and electron spin in opposite directions. However, it is possible (through collisions with electrons and other atoms) for the hydrogen atom to acquire a small amount of energy, which may align the spin of its electron with its proton.



A mildly excited electron, with its spin aligned to that of the proton, will eventually flip its spin to transition to a lower energy state. This transition releases a small amount of energy corresponding to a wavelength of 21 cm. (Adaprted from https://astronomy.swin.edu.au/cosmos/s/Spin-flip+Transition)

The slightly excited hydrogen electron whose spin is aligned with that of the proton, will eventually (roughly 10 million years) flip its spin to enter a lower energy state. The energy emitted is very small, but constant, and is equivalent to a wavelength of 21cm (1420 MHz).



It may seem that the probability of detecting this spin-flip energy of neutral hydrogen gas is very small. But there was a LOT of neutral hydrogen atoms in the Cosmic Dark Ages, and at any time, some fraction of them will be in their slightly excited state.

The spin-flip background from the Cosmic Dark Ages and the Epoch of Reionisation has not yet been observed. These 21cm wavelength photons must travel through the expanding Universe for more than 10 billion years before they reach the Earth, and this wavelength gets stretched over time. By the time it reaches Earth, the wavelengths have increased to about as much as ten times their original value – making them a couple of metres across!

Unfortunately, there are many other sources of radio waves with similar wavelengths, all of them much brighter than the spin-flip background from the Cosmic Dawn. The challenge lies in separating these various sources, which include:

- Human-made interference – FM radios, TV broadcasts, and aircraft/satellite communications;
- Atmospheric obstacles – radio waves have a difficult time passing through the ionosphere, which bends and distorts the waves, making them hard to observe; and
- Galactic noise – the cosmic rays spiralling through the magnetic fields in the Milky Way are strong radio sources which are ten thousand times brighter than the spin-flip background from the Cosmic Dawn!

For these reasons, the spin-flip background has not yet been definitively observed. But astronomers, including those from the Murchison Widefield Array *Inyarrimanha Ilgari Bundara* Telescope in Western Australia, are in a worldwide race to build radio telescopes and decipher the signals from the Cosmic Dawn.

Lesson outline

In VR, the students are challenged to answer 5 questions:
1) What created the red wave?
2) Where did it originate?
3) How far has it travelled?
4) Has it changed over time?
5) If so, what caused this change?

The data they collect in VR will help them answer the questions .

1. (Optional) Watch 'Signals from the cosmic dawn: A three minute guide – nature video', You Tube, https://youtu.be/gmIlmZ8uiOs?si=ssbETyuUgaDEcjaQ (3.28 min). This will give the students background knowledge about the 21cm hydrogen line.
2. Instruct students to go into VR and select the 'Signals from Cosmic Dawn' on the Activities menu.
3. When the students have completed the activity, download their data 'snapshots' and give them the student worksheet to complete. You may need another lesson to do this.

LESSON 11: New technologies to uncover the answers to big questions in modern astrophysics

Time required: 50 minutes (Introduction – students will need either additional class time or time at home as an assignment to complete this final task).

Rationale – Students havenow completes all the VR activities and most of the unit. This lesson/assignment provided students with the opportunity to evaluate the impact ne technologies will have on expanding our understanding of the Universe.

Equipment list:

- Class set of the 'New technologies to uncover the Big Questions on modern astronomy' student worksheet with scaffold (based on NSW DoE Stage 5 Universe Unit (November 2021)
- Access to the Internet for research

Outcomes:

Students should be able to:

- identify the different technologies used to collect astronomical data and the types of data collected.
- explore recent advances in astronomy and astrophysics.
- Ccitically analyse the validity of information in primary and secondary sources and evaluate the approaches used to solve problems
- presentsscientific ideas and evidence for a particular purpose and to a specific audience, using appropriate scientific language, conventions and representations.

Prior knowledge, understanding and skills required:

Students will need:

- to have completed the VR Training modules (basic training and console training)
- to have completed all the cctivities in U3D VR
- to have completed Lessons 1-10

Background information for teachers

Technological advancements have expanded our ability to observe the Universe and have contributed to building a better understanding of it. The advancements in telescopes and our recent ability to explore space have given us many new insights into the Universe.

The human eye was the only detector technology for thousands of years. The earliest observational tools, including the first **telescopes**, relied on an astronomer to see the astronomical body. In the 19th century, astronomers began using **photography**, as well as prisms and gratings to split light into its spectrum. Both methods opened new avenues for discovery beyond what the eye can see.

Twentieth-century astronomers built telescopes capable of observing **all types of light**, from radio waves to gamma rays. To accommodate those new ways of seeing and to improve visible-light telescopes, astronomers developed new detector technologies.

Astronomers use **spectrographs** attached to telescopes to view the spectral lines of stars and other celestial objects. A spectrograph combines a prism or diffraction grating to spread the light from a source into its spectrum. It then has a detector, usually a CCD, to record the spectrum.

A charge-coupled device (**CCD**) is a photon detector used in telescopes to create images of celestial objects. CCDs have revolutionised observational astronomy, allowing astronomers to take images that rival those from professional observatories.

Theory is how scientists fit data collected from observation into a system of understanding. However, some astrophysical systems are too complicated to be treated adequately using straightforward theoretical calculations. These include how galaxies form and organize on cosmic scales. These simulations of the large-scale structure of the universe help us understand the “cosmic web” and voids that astronomers see in galaxy surveys.. Systems like those require **computational astrophysics**, where researchers simulate the system on a computer (and sometimes supercomputers) and compare what they find with observations.

Computational astrophysics is necessary when processing massive datasets from telescopes. ‘Big data’ requires computers to process, including **new statistical algorithms** and **machine learning,** to extract meaning from the sheer amount of raw data produced by modern observatories.

Lesson outline

You have the scope to use the activities in this lesson in a variety of ways:

- In-class Internet research task
- Fill in the evaluation scaffold
- Turn the evaluation scaffold into a complete secondary source research task (essay or report).