

## Background

These SPICE resources are intended to assist teachers in teaching aspects of physics that are relatively new inclusions in the Western Australian syllabuses. They are designed to support teachers and students in their understanding of concepts related to the expansion of the Universe and Hubble's law; and fundamental cosmological concepts such as redshift, Big Bang theory and the history and future of the Universe. While it is not feasible to align each learning activity with all five elements of the 5-E model within the teaching time available, these resources include the following elements of the model where teachers may:

- **Engage** students' interest in a range of cosmological concepts, including redshift, dark matter and dark energy, and new scientific research projects such as the Square Kilometre Array, gravitational wave observatories and the Large Hadron Collider;
- provide opportunities for students to **Explore** the future of the Universe in relation to its density and the effects of gravity on its mass;
- provide opportunities for students to **Explain** the expansion, history and future of the Universe in terms of Big Bang theory and Hubble's law; and
- **Evaluate** students' progress throughout the sequence of learning resources.

The resources are designed for students studying Unit 3B Physics: Particles, waves and quanta.

## Purpose

These learning resources enable students to:

- describe and explain Hubble's law and the expansion of the Universe; and
- describe and explain fundamental cosmological concepts such as red shift, the curvature of space, Big Bang theory, and the history and future of the Universe.

## Learning pathway

### *Cosmology 1: History of the Universe*

*History of the Universe* comprises a teachers guide, fact sheet and presentation.

The presentation contains images, information and discussion points to enable students to understand and explain Big Bang theory, the evolution of fundamental interactions and matter and the formation of large scale structure (stars, galaxies etc) within the Universe. The fact sheet is a timeline summary of the evolution of the Universe since the Big Bang. See the teachers guide for detailed information on the purpose and use of this resource.

### *Cosmology 2: Evidence for the Big Bang*

*Evidence for the Big Bang* comprises a teachers guide, fact sheet and presentation.

The presentation contains information, images and discussion points to enable students to describe and explain evidence that supports Big Bang theory and the expansion of the Universe. Evidence includes the discoveries of redshift and Hubble's law; the abundance of hydrogen and helium in the Universe; and cosmic microwave background radiation. In addition, the presentation briefly looks at current searches for evidence including the Square Kilometre Array, gravitational wave observatories and the Large Hadron Collider. The fact sheet expands on the potential of these ongoing scientific research projects to lead to new discoveries. See the teachers guide for detailed information on the purpose and use of this resource.

## Cosmology 3: The future of the Universe

*The future of the Universe* comprises a teachers guide, fact sheet and presentation.

The presentation discusses the limitations to our understanding of the Universe and consequently our capacity to predict its future. It presents four different scenarios to describe and explain the possible future of the Universe, depending upon its density and the effects of gravity on its mass. Finally, the presentation explores the composition of the Universe and introduces the notions of dark matter and dark energy. The fact sheet provides a summary of the main points in the presentation. See the teachers guide for detailed information on the purpose and use of this resource.

## Cosmology 4: Shifted light

*Shifted light* comprises a teachers guide and video.

The video explains red shift through analogies with the Doppler effect and shows how astronomers use red shift to determine the recessional velocity of astronomical objects. See the teachers guide for detailed information on the purpose and use of this resource.

## Acknowledgements

Thanks to staff in the School of Physics at The University of Western Australia.

Designed and developed by the Centre for Learning Technology, The University of Western Australia. Production team: Graham Baker, Alwyn Evans, Dan Hutton, Jenny Gull and Michael Wheatley, with thanks to Pauline Charman, Bob Fitzpatrick and Wendy Sanderson.

### Video, Shifted light

Thanks to Professor Peter Quinn (Director, International Centre for Radio Astronomy Research) and Associate Professor Paul Bourke (iVEC@UWA, The University of Western Australia)

Designed and developed by the Centre for Learning Technology, The University of Western Australia. Production team: Kirsten Gottschalk (International Centre for Radio Astronomy Research), Jan Dook, Paul Luckas, Paul Ricketts, Jodie Ween and Michael Wheatley.

In preparing these SPICE resources, the resource Cosmology: The Study of the Universe from the Wilkinson Microwave Anisotropy Probe has been used as a significant source. These materials can be found at <http://map.gsfc.nasa.gov/universe/>.

## SPICE resources and copyright

All SPICE resources are available from the Centre for Learning Technology at The University of Western Australia ("UWA"). Selected SPICE resources are available through the websites of Australian State and Territory Education Authorities.

Copyright of SPICE Resources belongs to The University of Western Australia unless otherwise indicated.

Teachers and students at Australian schools are granted permission to reproduce, edit, recompile and include in derivative works the resources subject to conditions detailed at [spice.wa.edu.au/usage](http://spice.wa.edu.au/usage).

All questions involving copyright and use should be directed to SPICE at UWA.

Web: [spice.wa.edu.au](http://spice.wa.edu.au)  
Email: [spice@uwa.edu.au](mailto:spice@uwa.edu.au)  
Phone: (08) 6488 3917

Centre for Learning Technology (M016)  
The University of Western Australia  
35 Stirling Highway  
Crawley WA 6009

## Glossary

AIGO	<p>The Australian International Gravitational Observatory (AIGO) is the planned southern hemisphere link in a worldwide gravitational wave telescope. AIGO is in partnership with similar projects in USA, Germany, India, France and China.</p> <p>The AIGO research facility currently consists of an interferometer that contains a high power laser beam split into two beams at right angles. The beams reflect off mirrors at the ends of 80 m long vacuum pipes. Researchers expect to detect gravitational waves by studying interference patterns created by the superposition of the two beams.</p> <p>AIGO is located alongside the Gravity Discovery Centre at Gingin, north of Perth. For further information, see the AIGO video presentation, Discovering the Dark Side of the Universe, at <a href="http://www.aigo.org.au/aigo_video/aigo_video.htm">http://www.aigo.org.au/aigo_video/aigo_video.htm</a></p>
------	--

astrophysics	<p>Astrophysics is a branch of astronomy that deals with the physics of the Universe, including physical properties (luminosity, density, temperature, and chemical composition) of galaxies, stars, planets and the interstellar medium, as well as their interactions.</p> <p>Astrophysicists typically apply several disciplines of physics, including mechanics, electromagnetism, thermodynamics, quantum mechanics, relativity, nuclear and particle physics and atomic and molecular physics.</p>
cosmic microwave background radiation (CMBR)	CMBR is the cooled remnant of the Big Bang that fills the entire Universe. Observed today, it has an average temperature of about 2.725 K. Its spectrum peaks in the microwave frequency range at 160.2 GHz, which corresponds to a wavelength of 1.9 mm.
cosmological principle	<p>The cosmological principle states: 'Viewed on a sufficiently large scale, the properties of the Universe are the same for all observers.' This means that the part of the Universe we can see is a fair sample, and that the same physical laws apply throughout the Universe.</p> <p>The cosmological principle assumes that matter in the Universe is homogeneous (uniform density) and isotropic (the same in all directions). From Earth, the Universe looks the same as it would from any other location.</p>
cosmological redshift	Cosmological redshift is a spectral shift that occurs when a star or galaxy beyond our local group moves rapidly away from Earth. It is caused by the expansion of the Universe itself.
cosmology	Cosmology is the study of structure and changes in the present Universe.
Doppler effect	The Doppler effect occurs where there is relative motion between a source of waves and an observer. The wavelength of waves from a receding object will be longer (lower frequency); and the wavelengths from an approaching object will be shorter (higher frequency).
Doppler redshift	Doppler redshift is a spectral shift that occurs when a star or galaxy in our local group moves away from Earth. It is caused by relative motion between a source and Earth.
general relativity	Einstein's general theory of relativity (1915) is a theory of gravitation. It unifies special relativity and Newton's law of universal gravitation and describes gravity as a geometric property of spacetime.
Grand Unified Theory (GUT)	At the end of the Planck era, gravity had separated from the other three fundamental interactions. Grand Unified Theory describes relationships between these other interactions (electromagnetic, strong and weak interactions).
gravitational waves	Gravitational waves are disturbances in spacetime caused by interactions between compact masses. They are hypothesised to occur when galaxies merge or when two black holes or neutron stars orbit each other.
gravitational wave observatory	When gravitational waves travel through space at the speed of light, they pass directly through objects in their path causing everything, including space itself, to alternately stretch and shrink in different directions. Gravitational wave observatories are large-scale interferometers that consist of two arms at right angles. If a gravitational wave interacts with a detector then one arm is affected differently to the other. The variation may show up as an interference pattern produced when two identical laser beams travelling along each arm are superimposed.
hadron	See note on the Large Hadron Collider.
Higgs boson	The Higgs boson is an essential part of the Standard Model of particle physics, but has yet to be detected. It is an important component of our understanding of why some elementary particles acquire mass, and others do not.
Hubble's law	<p>Hubble's law states that the velocity at which galaxies recede from Earth is proportional to their distance from us.</p> <p>ie <math>v = H_0 D</math>, where <math>H_0</math> is the Hubble constant, <math>D</math> is the distance to a galaxy and <math>v</math> is its velocity.</p>
inflation theory	Inflation theory proposes a period of exponential expansion of the Universe during the first few moments after the Big Bang. The theory was developed in the 1980s to explain how distant parts of the Universe could once have been in close contact. It proposes that the linear size of the Universe expanded by a factor of $10^{26}$ in a fraction of a second. Inflation theory is considered to be an extension of Big Bang theory.
interferometer	See note on gravitational wave observatory.

Large Hadron Collider (LHC)	<p>The Large Hadron Collider is the world's largest particle accelerator. It comprises a 27 km circular track around which a beam of protons is accelerated to almost the speed of light before being collided with a similar beam travelling in the opposite direction.</p> <p>The LHC will be used to study sub-atomic particles and conditions that existed at the Big Bang.</p> <p>Hadrons are particles that contain quarks held together by the strong interaction. They include baryons, such as protons and neutrons, which contain three quarks; and mesons, which contain a quark and an anti-quark.</p>
Local Group	<p>The Local Group is the group of galaxies that includes the Milky Way. The group contains more than 30 galaxies, with its gravitational centre located somewhere between the Milky Way and the Andromeda Galaxy. The Local Group extends over 10 million light-year diameter and has a dumbbell shape. The two most massive members of the group are the Milky Way and the Andromeda Galaxy. The Local Group is part of a larger grouping, called the Virgo Cluster.</p>
nucleosynthesis	<p>Nucleosynthesis is the process by which heavier elements are formed from fusion of lighter elements. Nucleosynthesis resulted in the production of deuterium, helium and lithium nuclei in the first few minutes after the Big Bang.</p>
Planck time Planck era	<p>Planck time is considered to be the shortest interval of time that could be measured (approximately <math>10^{-43}</math> seconds).</p> <p>The Planck era is the interval between the Big Bang and <math>10^{-43}</math> seconds. During this period in the history of the Universe, conditions were so extreme that quantum effects dominated the Universe.</p>
redshift and blueshift	<p>The wavelength of waves from a receding object appear, to an observer, to be longer than those emitted by the source. In visible light, the wavelength has shifted closer to the red end (lower frequency) of the spectrum. This is called redshift.</p> <p>Using similar logic, light from an approaching object is shifted to the higher frequency end of the spectrum – ie it is blueshifted.</p>
Square Kilometre Array (SKA) and ASKAP	<p>The Square Kilometre Array (SKA) will be a radio telescope with a total collecting area of about one square kilometre. It comprises 3000 dishes, each 15 m in diameter, in addition to fields of static antennas. Fifty percent of the antenna collecting area will be concentrated in the core region, 15-20 km across, with the remainder in outlying stations at distances of up to 3000 km away.</p> <p>The Australian SKA Pathfinder (ASKAP) will be a new-generation radio telescope incorporating novel receiver technologies and leading-edge ICT systems. ASKAP will be a world-class telescope in its own right, as well as being a pathfinder instrument for the SKA. ASKAP will comprise an array of 36 dishes each 12 m in diameter, enabling high quality imaging across a wide field of view.</p>
Standard Model of cosmology	<p>The Standard Model of cosmology (the Big Bang model) successfully accounts for: accelerating expansion of the Universe; cosmic microwave background radiation; creation of light elements in the early Universe; and the origin of large-scale structure in the Universe.</p>
Standard Model of particle physics	<p>The Standard Model of particle physics is a theory that brings together fundamental particles of matter and three of the four known fundamental interactions that exist in the Universe. According to the model, all matter is made from six quarks, six leptons and four bosons.</p> <p>The model falls short of being a comprehensive theory of fundamental interactions because it doesn't include gravity.</p>
string theory	<p>String theory is a mathematical attempt to explain the nature of the fundamental particles of matter and the fundamental interactions in nature, including gravity. It attempts to unify general relativity and quantum mechanics.</p>
supersymmetry	<p>Some physicists attempting to unify gravity with other fundamental interactions suggest that every fundamental matter particle should have a massive 'shadow' force carrier particle; and every force carrier should have a massive 'shadow' matter particle. This relationship between matter particles and force carriers is called supersymmetry. No supersymmetric particle has yet been found, but experiments at CERN and Fermilab are underway to detect supersymmetric partner particles.</p>
WMAP	<p>The Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft was launched in June 2001 to measure differences in the temperature of the Big Bang's remnant radiant heat – the cosmic microwave background radiation – across the full sky. WMAP's measurements played a key role in establishing the Standard Model of cosmology.</p>