teachers guide

Cosmology 2
Evidence for the Big Bang

Components

	NAME	DESCRIPTION	AUDIENCE
	Evidence for the Big Bang teachers guide	This guide contains presentation notes and questions to promote discussion about the evidence for Big Bang theory.	teachers
	Evidence for the Big Bang presentation	Evidence supporting Big Bang theory includes the expansion of the Universe; the abundance of hydrogen and helium; and cosmic microwave background radiation.	students
	Searching for the origin of the Universe fact sheet	This fact sheet provides information on three global research projects designed to reveal new evidence about the origin of the Universe: the Square Kilometre Array; gravitational wave detectors; and the Large Hadron Collider.	students

Purpose

To present evidence to support Big Bang theory.

Outcomes

Students:

- describe evidence that supports Big Bang theory; and
- explain Hubble's Law and the expansion of the Universe.

Activity summary

ACTIVITY	POSSIBLE STRATEGY
As this presentation is quite long and contains a large amount of factual information, we recommend that teachers split it into smaller sections interspersed with teacher-led discussion.	
Teacher reviews main points from the presentation in *Cosmology 1: History of the Universe*, including the Big Bang, expanding Universe, evolution of fundamental interactions and matter, and formation of stars and galaxies, and asks (rhetorically) 'How do we know these things? What evidence is there to support them?' Teacher shows slides 1–2 to introduce the sequence of the presentation.	teacher introduction
Discovery 1: the expansion of the Universe Teacher shows slides 3–7, pausing to explain Doppler redshift and cosmological redshift if required, before showing slides 8–12. Students consider the answer to the question on slide 12 (refer to slide 12 notes).	teacher explanation and/or questions
Discovery 2: the abundance of hydrogen and helium Teacher shows slides 13–16 describing predicted and observed amounts of hydrogen and helium. Teacher emphasises proportions of hydrogen to helium.	teacher commentary
Discovery 3: cosmic microwave background radiation Teacher shows slides 17–21, drawing students' attention to the map of CMBR on slide 21 showing WMAP's data after five years, and how this evidence supports the Big Bang theory.	teacher commentary
The search for further evidence Teacher shows slides 22–25 describing three new, large-scale, scientific projects, which are expected to add to our knowledge of the Universe.	teacher commentary
Teacher distributes the fact sheet, *Searching for the origin of the Universe*.	

Information for teachers

Evidence for the Big Bang is the second of three presentations that enable students to explore discoveries, and explain evidence, that support Big Bang theory.

The presentation is designed to engage students in a discussion of scientific evidence and theories that underpin modern cosmology. Presenters' notes are included to provide background information for teachers on likely discussion points and concepts where students may require more information.

The presentation contains four main sections.

SECTION	CONTENTS
Scientific ideas that underpin the Big Bang model of cosmology	
Key scientific discoveries that support Big Bang theory	expansion of the Universe, redshift and Hubble's Law relative abundance of hydrogen and helium in the Universe cosmic microwave background radiation
The search for further evidence	the Square Kilometre Array gravitational wave observatories the Large Hadron Collider
Other possible theories	string theory supersymmetry.

The fact sheet, *Searching for the origin of the Universe*, provides information on how far scientists can look back in time using the electromagnetic spectrum. Even with the best optical systems, it is impossible to see further back than 370 000 years after the Big Bang. The Square Kilometre Array (SKA), gravitational wave observatories and Large Hadron Collider are three large-scale international scientific research projects designed to further our knowledge about the formation and evolution of the Universe.

The following notes accompany the presentation, *Evidence for the Big Bang* (notes are only provided for slides that require additional information).

SLIDE	NOTES
1	This presentation has been constructed using information drawn from a number of sources. The major source is Universe 101 Big Bang Theory http://map.gsfc.nasa.gov/universe/. It is highly recommended reading for physics teachers.
4	Slipher discovered galactic redshifts. Hubble combined Slipher's redshift data and his own measurements of the distances to galaxies to discover a rough proportionality of an object's distance with its redshift.
5	For more information on Doppler shift, see *Cosmology 4: Shifted light*. Students' attention may need to be drawn to the shift in positions of the dark absorption lines on the solar spectrum. In astrophysics, redshift refers to a change in wavelength of light emitted by an object so that it appears 'redder'. That is, visible light is shifted towards the red end of the visible spectrum. Astronomical objects also emit radiation outside the visible spectrum. The term 'redshift' is also used to refer to any increase in electromagnetic wavelength, with implied decrease in frequency and photon energy.
6	There are three types of spectral shift: • Doppler shift is caused by relative motion between a source and an observer. Red and blue shifts observed from objects within the Local Group (which includes the Milky Way, Andromeda galaxy, Large and Small Magellanic clouds) are due to the Doppler effect. • Cosmological redshift is caused by expansion of the Universe itself. • Gravitational redshift is a shift in frequency when a photon moves to a lower energy state as it climbs out of a gravitational field. This presentation does not explore the concept of gravitational redshift.
7	The image shows over 1.5 million of the brightest stars and galaxies in the nearby Universe detected by the Two Micron All Sky Survey (2MASS) in infrared light. Across the centre are stars that lie in the plane of our own Milky Way Galaxy. Away from the galactic plane, the vast majority of the dots are galaxies, color coded to indicate distance, with blue dots representing the nearest galaxies in the 2Mass survey, and red dots indicating the most distant survey galaxies. Source: http://antwrp.gsfc.nasa.gov/apod/ap071211.html
9	If you look closely, the H and K lines on the chart shift towards the red end of the spectrum as the distance increases.

SLIDE	NOTES
12	Answer: The second conclusion is more likely. According to the cosmological principle, the Universe has uniform composition and density in all directions. No one location in the Universe is privileged over any other. There is no 'centre' or 'edge' to the Universe. A useful analogy is to compare the movement of galaxies to the movement of raisins in an expanding ball of bread dough. As the dough expands, raisins move away from one another. From the perspective of each raisin (galaxy), the remainder of the dough (the Universe) is the same in all directions. However, the analogy breaks down if students think about what happens near the outer edges of the dough rather than in the main bulk. Hubble's law is taken as evidence that the known Universe is expanding.
14	One second after the Big Bang, the Universe was at a temperature of about ten billion degrees Celsius and was filled with a sea of neutrons, protons, electrons, positrons, photons and neutrinos. As the Universe cooled, neutrons decayed to form protons, electrons and neutrinos. The temperature of the Universe was still so high that electrons couldn't combine with protons to form stable atoms. By the time the Universe had cooled enough for nucleosynthesis to begin, Big Bang theory predicts that the ratio of protons to neutrons was 7:1.
15	As the Universe continued to cool, protons began to combine with the remaining neutrons to form deuterium nuclei. About three minutes after the Big Bang, most deuterium combined to form helium nuclei. Trace amounts of lithium were also formed at this time. Big Bang theory predicts that the early Universe was made up of one helium nucleus (mass = 4) for every 12 hydrogen nuclei (protons, mass = 1), i.e. the ratio of the mass of helium to the total mass is 4:16 or 25%. From this, it was predicted that helium made up 25% of the mass of the early Universe.
16	The graph shows the predicted abundance of deuterium, lithium and helium in the early Universe. It is evident that the yield of helium is relatively insensitive to the density of ordinary matter, above a certain threshold. Cosmologists expect about 24% of the ordinary matter in the Universe was helium produced in the Big Bang. This agrees closely with observations and is strong evidence to support the Big Bang Theory.
18	The existence of cosmic microwave background radiation (CMBR) was first predicted by Ralph Alpher, Robert Herman and George Gamow in 1948, as part of their work on Big Bang nucleosynthesis. Arno Penzias and Robert Wilson first detected CMBR as 'noise' in a radio antenna they were building at the Bell laboratories in New Jersey. They initially thought it was interference from New York city, but eventually recognised it as cosmic background radiation – remnant heat radiation from the Big Bang. Today, the CMBR is very cold due to the expansion of the Universe - only 2.725 Kelvin above absolute zero. CMBR fills the Universe and can be detected everywhere we look. Its temperature is uniform to within one part in a thousand.
19	According to the cosmological principle, the Universe has uniform composition and density in all directions. From this, we assume that the same laws of physics that apply on Earth apply equally to all other parts of the Universe.
20	In 1992, the Cosmic Background Explorer (COBE) satellite was launched to study background radiation. It detected minute variations in the background radiation. In 2001, the Wilkinson Microwave Anisotropy Probe (WMAP) was launched to measure variations (at the parts per million level) in the temperature of CMBR. Cosmologists propose that variations in CMBR are evidence of variations in the density of matter in the early Universe that led to formation of galaxies and other large-scale structures.
21	The image shows the WMAP five-year map of cosmic microwave background radiation. Colours indicate minute temperature variations in the background radiation – red spots are 'warmer' and blue spots are 'cooler'. credit: NASA/WMAP Science Team
26	There are other theories about the origin of the Universe, but they're not explored in this presentation due to time constraints and because they aren't required in the current syllabus. Whilst Big Bang theory is considered to be our most successful theory of cosmology, two problems presented challenges to the standard theory: **The Flatness problem** The WMAP survey showed the geometry of the Universe to be almost flat. However, Big Bang cosmology predicts it to be curved. **The horizon problem** Distant regions of space in opposite directions of the sky are so far apart that they could never have been in contact under standard Big Bang expansion, because the time it takes light travel between them exceeds the age of the Universe. Yet the uniformity of the CMBR tells us that these regions must have been in contact with each other in the past. **A solution** Inflation theory, developed in the 1980s, provided a solution to these problems by proposing a period of exponential expansion of the Universe shortly after the Big Bang. By including this inflationary period, the early Big Bang spherical surface would expand to stretch the initial curvature of the Universe close to flatness. It also explains why regions of space that are now so distant were once much closer together.

Image credits

presentation, *Evidence for the Big Bang*

- 'An artist's concept of the first stars forming after the Big Bang' by NASA, science.nasa.gov/science-news/science-at-nasa/2008/22oct_missinggrbs/
- 'Andromeda galaxy', NASA/JPL-Caltech/UCLA, PD-USGOV, www.nasa.gov/mission_pages/WISE/multimedia/pia12832-c.html
- 'Vesto Slipher', Lowell Observatory, http://www.lowell.edu/Research/library/paper/vm_slipher_pict.html
- Atlas Image courtesy of 2MASS/UMass/IPAC-Caltech/NASA/NSF, antwrp.gsfc.nasa.gov/apod/ap071211.html
- Portrait photo of Edwin Hubble © The Huntington Library of San Marino, California, en.wikipedia.org/wiki/File:Hubble.jpg
- 'Spectra of galaxies' from J. Silk, The Big Bang, 2nd Ed., http://rst.gsfc.nasa.gov/Sect20/A9.html
- Hubble ultra deep field, by NASA and ESA. Source: http://hubblesite.org/newscenter/archive/releases/2004/07/image/a/warn/
- 'Robert Wilson, left, and Arno Penzias stand in front of the Bell Labs horn radio antenna', PD-USGOV, commons.wikimedia.org/wiki/File:Wilson_penzias200.jpg
- WMAP spacecraft by NASA/WMAP Science Team, map.gsfc.nasa.gov/media/990387/index.html
- 5 year WMAP image of background cosmic radiation by NASA/WMAP Science team, map.gsfc.nasa.gov/news/5yr_release.html
- 'Design of the Square Kilometre Array' by SKA program Development Office, CC-BY-3.0, www.skatelescope.org/pages/page_genpub.htm
- 'AIGO Stage II: Long Baseline Detector' by the Australian International Gravitational Research Centre, The University of Western Australia, www.aigo.org.au/stage2.php
- 'View of the LHC tunnel sector 3-4' by CERN, used by permission, cdsweb.cern.ch/record/1211045

fact sheet, *Searching for the origin of the Universe*

- 'Standard model' by Fermi National Accelerator Laboratory, PD, commons.wikimedia.org/wiki/File:Standard_Model_From_Fermi_Lab.jpg
- 'AIGO Stage II: Long Baseline Detector' by the Australian International Gravitational Research Centre, The University of Western Australia, www.aigo.org.au/stage2.php
- 'View of the LHC tunnel sector 3-4' by CERN, used by permission, cdsweb.cern.ch/record/1211045
- 'SKA overview' by Swinburne Astronomy Productions and SKA Project Development Office
- 'Laser Interferometer Space Antenna (LISA)' by NASA, PD-USGOV-NASA, lisa.nasa.gov/gallery/
- Artist's impression of ASKAP at the Murchison radio-astronomy observatory, Swinburne Astronomy Productions/CSIRO, www.atnf.csiro.au/SKA/
- 'What powered the Big Bang?' by NASA, PD-USGOV-NASA, science.nasa.gov/astrophysics/focus-areas/what-powered-the-big-bang/
- Gravitational wave detectors' by the Australian International Gravitational Research Centre, The University of Western Australia, www.aigo.org.au
- 'Simulated decay of a Higgs boson to two jets and two electrons' by CERN, cdsweb.cern.ch/record/628469

Technical requirements

The guide and fact sheet require Adobe Reader (version 5 or later), which is a free download from www.adobe.com. The presentation is provided in two formats: Microsoft PowerPoint and Adobe PDF.

Associated SPICE resources

Cosmology 2: Evidence for the Big Bang may be used in conjunction with related SPICE resources to address cosmological concepts within the broader topic of Unit 3BPHY: Particles, waves and quanta.

DESCRIPTION	LEARNING PURPOSE
Cosmology (sequence overview) This learning pathway shows how a number of SPICE resources can be combined to teach the topic of cosmology.	
Cosmology 1: History of the Universe This resource introduces students to Big Bang theory and events that have occurred since that time to create the Universe we see today.	**Engage/Explain**
Cosmology 2: Evidence for the Big Bang This resource introduces major pieces of evidence that led to the development of Big Bang theory, and discoveries that have since added further support to it.	**Explore/Explain**
Cosmology 3: Future of the Universe This resource introduces students to the principles by which scientists predict possible scenarios for the future of the Universe.	**Explore/Explain**
Cosmology 4: Shifted light A video explains red and blue-shift of light, and how it is used in astronomy to measure velocity and distance.	**Explain**

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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/.

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