Cambridge Core Science Series: Space Science

JUST HOW BIG IS SPACE?

Cambridge Educational

Teacher's Guide

Introduction

This Teacher's Guide provides information to help you get the most out of *Just How Big Is Space?,* the third title in Cambridge Educational's eight-part *Space Science* series. Its contents will allow you to prepare your students before watching the program and present follow-up activities to reinforce the program's key learning points.

Just How Big Is Space? introduces some of the concepts astronomers use for measuring the vast distances in space. It also explores the implications of Einstein's Relativity Theory for space science.

The *Space Science* video program series consists of eight titles:

- The Planets
- The Sun and Stars
- Just How Big Is Space?
- The Invisible Universe
- Black Holes, Pulsars, and Other Odd Bodies
- Yesterday the Moon, Tomorrow Mars?
- Living in Space
- Is Anybody Out There?

Learning Objectives

By viewing *Just How Big Is Space?* students will be able to:

- Explain how scientists are able to measure the vast distances in space without going there.
- Name three measurement units used to measure distances in space and tell when each is most appropriately used.
- Describe four methods for measuring distances in space and explain how and when they are used.
- Outline the basic concepts and relationships delineated in Einstein's Special and the General Theories of Relativity.
- Describe how Relativity Theory has changed the way we view space, time, matter, energy, gravity, and acceleration.
- Identify several unusual effects predicted by Relativity Theory.
- Give an example of how Relativity Theory affects our everyday life.

Educational Standards

This program series correlates with the National Science Education Standards for grades 9-12. The content of this program has been aligned with the following educational standards from this publication:

Science as Inquiry Standards

CONTENT STANDARD A: As a result of activities in grades 9-12, all students should:

- Develop an understanding of scientific concepts
- Understand and appreciate "how we know" what we know in science
- Understand the nature of science

- Develop the skills necessary to become independent inquirers about the natural world
- Develop the dispositions to use the skills, abilities, and attitudes associated with science

History and the Nature of Science Standards

CONTENT STANDARD G: As a result of activities in grades 9-12, all students should:

- Develop understanding of science as a human endeavor
- Develop understanding of the history of science
- Develop an understanding of the nature of scientific knowledge

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English Language Arts Standards

The activities in this Teacher's Guide were created in compliance with the National Standards for the English Language Arts from the National Council of Teachers of English.

- Students employ a wide range of strategies as they write and use different writing process elements appropriately to communicate with different audiences for a variety of purposes.
- Students conduct research on issues and interests by generating ideas and questions, and by posing problems. They gather, evaluate, and synthesize data from a variety of sources (e.g., print and non-print texts, artifacts, people) to communicate their discoveries in ways that suit their purpose and audience.
- Students use a variety of technological and information resources (e.g., libraries, databases, computer networks, video) to gather and synthesize information and to create and communicate knowledge.

Standards for the English Language Arts, by the International Reading Association and the National Council of Teachers of English, Copyright 1996 by the International Reading Association and the National Council of Teachers of English. Reprinted with permission.

This program series also coordinates with the following *Benchmarks for Science Literacy* by the American Association for the Advancement of Science for grades 9 through 12:

The Scientific World View

By the end of the 12th grade, students should know that:

- Scientists assume that the universe is a vast single system in which the basic rules are the same everywhere. The rules may range from very simple to extremely complex, but scientists operate on the belief that the rules can be discovered by careful, systematic study.
- From time to time, major shifts occur in the scientific view of how the world works. More often, however, the changes that take place in the body of scientific knowledge are small modifications of prior knowledge. Change and continuity are persistent features of science.
- No matter how well one theory fits observations, a new theory might fit them just as well or better, or might fit a wider range of observations. In science, the testing, revising, and occasional discarding of theories, new and old, never ends. This ongoing process leads to an increasingly better understanding of how things work in the world but not to absolute truth. Evidence for the value of this approach is given by the improving ability of scientists to offer reliable explanations and make accurate predictions.

Scientific Inquiry

By the end of the 12th grade, students should know that:

- Investigations are conducted for different reasons, including to explore new phenomena, to check on previous results, to test how well a theory predicts, and to compare different theories.

- Hypotheses are widely used in science for choosing what data to pay attention to and what additional data to seek, and for guiding the interpretation of the data (both new and previously available).
- Sometimes, scientists can control conditions in order to obtain evidence. When that is not possible for practical or ethical reasons, they try to observe as wide a range of natural occurrences as possible to be able to discern patterns.
- There are different traditions in science about what is investigated and how, but they all have in common certain basic beliefs about the value of evidence, logic, and good arguments. And there is agreement that progress in all fields of science depends on intelligence, hard work, imagination, and even chance.
- Scientists in any one research group tend to see things alike, so even groups of scientists may have trouble being entirely objective about their methods and findings. For that reason, scientific teams are expected to seek out the possible sources of bias in the design of their investigations and in their data analysis. Checking each other's results and explanations helps, but that is no guarantee against bias.
- In the short run, new ideas that do not mesh well with mainstream ideas in science often encounter vigorous criticism. In the long run, theories are judged by how they fit with other theories, the range of observations they explain, how well they explain observations, and how effective they are in predicting new findings.
- New ideas in science are limited by the context in which they are conceived; are often rejected by the scientific establishment; sometimes spring from unexpected findings; and usually grow slowly, through contributions from many investigators.

Program Overview

Since we cannot actually go there, how do scientists measure the vast distances to the stars and other galaxies? The first half of this program discusses the size of the universe and presents several methods scientists use to estimate distances in space.

The second half of the program introduces Einstein’s Relativity Theory. It discusses how both the Special and General Theories of Relativity have changed how we define the relationships between space and time, mass and energy, and gravity and acceleration. Several unusual effects of Relativity Theory are introduced, and an example of its impact on everyday life is presented.

Main Topics

Topic 1: How Big Is Space?
With the most powerful telescopes we can see almost 14 billion lightyears into the universe. As we look out into space, we are also looking back in time to the very beginnings of our universe.

Because of the vast distances in space, scientists use more appropriate units of measurement, such as Astronomical Units, parsecs, and lightyears, rather than miles or kilometers. But how do we know how far away objects in space really are? Several methods for measuring distance to objects in space are presented, including parallax, Cepheid variables, intrinsic and apparent brightness, and supernovae. Hubble’s Law is introduced, and its implications for estimating the size of the universe are discussed.

Topic 2: Relativity Theory and Its Importance to Science
The second half of the program explores the importance of Relativity Theory to space science. Einstein's Theory of Relativity set the stage for a major shift in how we view our universe in terms of space, time, matter, energy, gravity, and acceleration. Its predictions impact virtually everything we do in space science.

The program discusses the two parts of Relativity Theory: Special Relativity and General Relativity. Special Relativity defines space and time not as distinct and separate entities, but rather as one continuous, four-dimensional fabric called "space-time." It also defines the relationship between matter and energy, which is summed up in the famous equation $E=mc^2$. At the basis of the General Theory of Relativity is the idea that gravity and acceleration are essentially the same. Gravity is defined as a distortion or curvature of the fabric of space-time. More massive objects will produce greater distortions than lower-mass objects.

Some predicted effects of Relativity Theory, such as time dilation and space contraction, are presented. Illustrative examples explain these and other relativistic effects.

Fast Facts

- The Hubble Space Telescope and others like it have allowed us to see almost 14 billion lightyears into space, and back in time to within a few hundred thousand lightyears of the Big Bang.

- Calculations based on how fast we think the universe has been expanding have given us a rough estimate of its diameter—around a hundred and fifty billion lightyears.

- "Parallax" is a way to measure the distance to closer stars. Two pictures of a star are taken, one from each side of Earth's orbit. By comparing how much the star appears to move against background objects from one picture to another, scientists can calculate the angle of apparent motion. Knowing this angle and the distance across Earth's orbit, they can calculate the distance to the star.

- "Cepheid variables" are stars that have very regular periods of fluctuating brightness—the longer the period, the brighter the star. Cepheids are used to estimate distances to other galaxies. When a Cepheid variable star is located, its period is used to calculate its intrinsic brightness. Then its intrinsic brightness and apparent brightness from Earth can be used to estimate the distance to another galaxy.

- If we know both a star's intrinsic brightness and its apparent brightness (how bright it looks from Earth) we can use these values in a simple mathematical formula called "the inverse square law of light" to find its distance.

- According to the Hubble Law, the farther away a galaxy is from us, the larger is its "red shift" (the light emitted by the star and how that light reaches us). This is explained by the fact that the distances between galaxies are constantly increasing, and that therefore, the universe is expanding. Measuring the red shift of a star helps determine how far it is from us, and the speed at which it is moving away from us.

- When Einstein presented his Theory of Relativity, it set the stage for a major shift in how scientists viewed the universe in terms of space, time, matter, energy, gravity, and acceleration.

- Special Relativity Theory defines space and time as one continuous, four-dimensional fabric called "space-time." Special Relativity also defines the relationship between matter and energy in the famous equation $E=mc^2$.

- General Relativity defines gravity as a distortion, or curvature, of the fabric of space-time. The more massive the object, the greater the distortion.

- Time dilation and space contraction are two effects predicted by Special Relativity Theory.

- The Global Positioning System (GPS) is one example of how both Special and General Relativity Theory affect our everyday lives. Without corrections for relativistic effects, within a matter of minutes the GPS system would yield incorrect positioning data. Within a matter of hours, its data would be useless.

Vocabulary Terms

apparent brightness: How bright a star appears from Earth.

Astronomical Unit (AU): A unit of length used in astronomy equal to the mean distance of Earth from the sun, or about 93 million miles (150 million kilometers).

Cepheid variables: Stars that have very regular periods of fluctuating brightness. Cepheid variables are one of the ways scientists measure the distance to nearby galaxies.

Global Positioning System (GPS): A system that provides satellite navigation for both civilian and military use.

Hertzsprung-Russell diagram: A graph of stars showing the relationship between their magnitude, luminosity, and surface temperature. Stars on this chart tend to fall into three groups: Main Sequence, White Dwarfs, and Red Giants and Super-giants.

Hubble's Law: Also called "The Hubble Law," it states that the farther away a galaxy is from us, the larger its red shift.

intrinsic brightness: The actual brightness of a star.

Inverse Square Law of Light: A formula that determines the distance to a star given its intrinsic and apparent brightness.

lightyear: The distance light travels in one year.

parsec: A measure of distance used by astronomers. A parsec is equal to 3.26 light years, or about 19 trillion miles.

space-time: A continuous four-dimensional fabric that includes the three dimensions of space and a fourth dimension—time.

time dilation: An effect predicted by Relativity Theory: that a clock runs more slowly when it is moving than when it is stationary.

wormhole: A theoretical construct derived from Relativity Theory in which two black holes meet and create a passageway to a different region of space.

Pre-Program Discussion Questions

1. How big is the universe?
2. How do we know how far away stars and other galaxies are when we can't get to them to measure the distance?
3. What is parallax, and how is it used to estimate the distance to nearby stars?
4. What is Relativity Theory? How does it affect what we do in space?
5. How did Einstein's Theory of Relativity change how we think about the universe?
6. What is the GPS? How does Einstein's Theory of Relativity affect the operation of this system?

Post-Program Discussion Questions

1. What are four methods that scientists use to measure distance in space? Discuss why and in which situations each is used.
2. How far are we able to see with the most powerful telescopes? Explain how we know that the universe is actually larger than this.
3. How did Special Relativity Theory change how we define space and time?
4. What does $E=mc^2$ mean? Give an example from our own solar system that illustrates this equation.
5. How does Relativity Theory define the force of gravity? Give an example where gravity and acceleration are indistinguishable.
6. Explain what a wormhole is.

Group Activities

Modeling the Universe
Ask students to divide into groups. Have each group focus on a different realm of the universe (see below). If the classroom is defined as your realm of the universe, how big would other objects in it be?

Realm 1: The sun is the size of the classroom.
How large would Earth be? *(A: the size of a grapefruit)*

Realm 2: The solar system out to the Heliopause (200 AU) is the size of the classroom.
How large would the sun be? *(A: a grain of salt, 0.5 mm)*
How larger would Earth's orbit be? *(A: an audio CD, 10 cm)*
How large would Earth itself be? *(A: a microscopic bacterium, 4 microns)*

Realm 3: The sun's neighborhood (65-lightyear diameter) is the size of the classroom.
How large would the solar system be? *(A: a grain of salt, 0.5 mm)*

Realm 4: The Milky Way Galaxy is the size of the classroom.
How large would the solar system be? *(A: a peppercorn, 4 mm in diameter)*

Realm 5: The Local Group of Galaxies is the size of the classroom (6.5 million lightyears in diameter).
How large would the Milky Way be? *(A: the size of a large pizza, 50 cm in diameter)*

Realm 6: The Local Supercluster of galaxies is the size of the classroom.
How large is the Local Group? *(A: the size of a basketball, 25 cm)*
How big is the Milky Way Galaxy? *(A: a button, 1.25 cm in diameter)*

Realm 7: The classroom is the size of the entire visible universe (156 billion lightyears).
How big is the Local Supercluster? *(A: a small button, 8.3 mm in diameter)*
How large is the Local Group? *(A: a small grain of salt, 0.2 mm in diameter)*

Selecting the Right Units

Divide students into groups. Ask each group to research the items in the list below and arrange them in order of scale from smallest to largest. Then have them write down, next to each item, the unit best suited for measuring it. When the list is complete, have the class discuss the tools and procedures that could be used to make each measurement.

- an electron
- the Olympus Mons (a volcano on Mars)
- the Amazon River
- the Great Red Spot (a hurricane-like feature in Jupiter's atmosphere)
- a #2 pencil
- Mt. Everest
- a school flagpole
- the Ring Nebula (estimated to be 1/2 lightyear across)
- an EP-3E reconnaissance plane
- Ganymede (the largest moon of Jupiter)
- the Empire State Building
- a grain of wild rice

Individual Student Projects

Black Holes: There's No Escape

Black holes—what are they and how do we know they really exist? Write an essay after researching the fascinating topic of black holes. Examine the concepts of escape velocity, gravity, mass, event horizon, and the speed of light as they apply to black holes. Describe the different sizes of black holes, where they are found, and how they are formed. Since light cannot escape from black holes, how have scientists "observed" them?

Before Einstein

All great scientists build on the works of those who have come before. Einstein is no exception. Without the work of earlier mathematicians, physicists, and other scientists, Einstein would not have been able to develop his revolutionary theories. Research some of the scientists and scientific discoveries that led up to Einstein's extraordinary work, then create a timeline of significant discoveries.

Hubble Now and Then

The Hubble Space Telescope has made enormous contributions to our knowledge of space. The astronomer for whom the telescope was named was also a significant force in space science. Find out who Edwin Hubble was and write a brief report on the contributions he made to cosmology.

Internet Activities

Stellar Heartbeats

Cepheid variables are one type of pulsating variable stars. Cepheids have a repeating cycle of change that is periodic—as regular as the beating of a heart. Have students visit http://chandra.harvard.edu/edu/formal/variable_stars/activity1a.html or a similar Web site to learn more about variable stars and to record their own estimations of the varying brightness of a star.

The Expanding Universe

This activity is designed to help students gain a deeper understanding of cosmology. Have students visit http://btc.montana.edu/ceres/html/Universe/uni1.html (or gather information from other Web sites) to develop authentic models and gather evidence supporting the Big Bang theory. This lesson uses observation, interactive media, and scientific models.

Assessment Questions

Q1: True or False: Astronomers use parallax to measure the distance to nearby galaxies.
A: False.
Feedback: The parallax method for finding distance only works for stars within 50 parsecs, or 160 lightyears. To measure the distance to other galaxies, scientists must use other methods, such as Cepheid variable stars or Type 1a supernovae.

Q2: Which of the following methods are used to estimate the distance to other stars in the Milky Way galaxy?

- a) The Astronomical Unit
- b) The Inverse Square Law of Light
- c) Intrinsic and apparent brightness
- d) Hubble's Law

A: b and c
Feedback: The Astronomical Unit, the distance from Earth to the Sun, is a unit of measurement most commonly used within our solar system. A star's intrinsic, or absolute brightness, and its apparent brightness (how bright it appears from Earth) are both entered into the Inverse Square Law of Light to find the distance to a star. The Hubble Law states that the farther away a galaxy is from us, the larger its red shift. The red shift is also interpreted as the speed at which a galaxy is moving away from us.

Q3: Which of the following is *not* derived from Einstein's Theory of Relativity?

- a) Time dilation
- b) Time contraction
- c) Space-time continuum
- d) Wormholes

A: b.
Feedback: Einstein redefined the universe by combining three-dimensional space and time into one continuous, four-dimensional fabric called "space-time." Time dilation and wormholes are predicted phenomena derived from relativity theory.

Q4: In lightyears, approximately how large in diameter is the universe?

a) 100 million
b) 1 billion
c) 14 billion
d) 150 billion

A: d.

Feedback: With the most powerful telescopes we can see only about 14 billion light years. However, since light left that place in space, the universe has been expanding. Calculations based on how fast we think the universe has been expanding over time have given us a rough estimate of the diameter of the universe of being about 150 billion lightyears.

Q5: True or False: The Hertzsprung-Russell Diagram is a tool used by scientists to find the distance to a star if they have its color and spectrum.

A: True

Feedback: The Hertzsprung-Russell Diagram is a chart of stars of known intrinsic brightness, temperature, and distance. Knowing a star's color gives its temperature and having its spectrum allows scientists to place the star appropriately on the diagram and determine its intrinsic brightness. Once its intrinsic and apparent brightness are known, these values can be entered into the Inverse Square Law of Light to find the distance to the star.

Q6: True or False: Prior to Relativity Theory people believed that time was absolute; clocks ticked at the same rate regardless of their location and movement.

A: True

Feedback: Relativity Theory states that time is not absolute, but relative to the motion of the clock relative to the observer. A moving clock runs more slowly than one which is stationary.

Q7: As an object like the sun gives off energy, it loses mass. This is an example of which of the following?

a) The Inverse Square Law of Light
b) $E=mc^2$
c) Hubble's Law
d) The Doppler Effect

A: b.

Feedback: $E=mc^2$, Einstein's most famous equation, defines the relationship between mass and energy. As the sun gives off energy, it loses mass. How much mass? Approximately 1,000,000 cubic yards of matter per second.

Q8: True or False: With his General Relativity theory, Einstein showed that large masses distort the space-time continuum in such a way that the motions of small masses will be affected.

A: True

Feedback: Large masses curve the fabric of space-time in such a way that the movement of smaller masses in their vicinity will be affected—the larger the mass, the greater the curvature and the greater the effect. Objects of sufficient mass can even bend the path of light when it comes within their influence.

Q9: Which of the following relationships are included within Einstein's Theory of Relativity?

a) Gravity and acceleration
b) Space and time
c) Matter and energy
d) All of the above

A: d.

Feedback: In the Special and General Theories of Relativity, Einstein defined the relationships between space and time, matter and energy, and gravity and acceleration. The predictions of Relativity Theory impact virtually everything we do in space science.

Q10: True or False: A black hole's effect, curving the fabric of space-time, is so great that light passing too close cannot escape.
A: True
Feedback: The larger the mass the more it curves the fabric of space-time. In the case of a black hole, its mass is so great that light passing too close gets caught in the distortion of space-time and spirals down into the black hole. If light is not reflected from an object, we cannot see it. That's why we call them black holes.

Additional Resources

NASA Space Science Education Resource Directory
http://teachspacescience.org/cgi-bin/ssrtop.plex

Science Teacher Lesson Plans
www.ncsu.edu/sciencejunction/terminal/imse/lowres/4/lessons.htm

The International Space Station
www.shuttlepresskit.com/ISS_OVR

SETI Institute
www.seti.org

BBC: Science & Nature: Space and the Solar System
www.bbc.co.uk/science/space/solarsystem

The Nine Planets: A Multimedia Tour of the Solar System
www.nineplanets.org

NASA Hubble Site
http://hubblesite.org

National Aeronautics and Space Administration
www.nasa.gov

European Space Agency
www.esa.int

The European Homepage for the NASA/ESA Hubble Space Telescope
www.spacetelescope.org

Additional Resources at www.filmsmediagroup.com

Available from Films Media Group • www.filmsmediagroup.com • 1-800-257-5126

Space Science Video Library

- **DVD #30964**
- **Correlates to National Science Education Standards**
- **User's Guide included**

The *Space Science Video Library* contains 19 video clips on the structure of the universe, star formation and destruction, the solar system, and space exploration. It is part of the complete Discovery Channel/Films for the Humanities & Sciences *Science Video Library*. A User's Guide is included, containing an overview; a numbered index of clips, with brief descriptions and lengths; suggested instructional strategies; and a list of additional resources. A Discovery Channel/FFH&S Production. © 2003.

How Scientists Look at the Sun

- **VHS/DVD-R #34120**
- **Correlates to National Science Education Standards.**
- **Produced in association with the Accreditation Board for Engineering and Technology and the Junior Engineering Technical Society.**
- **Viewable/printable Teacher's Guide included**

This *Science Screen Report* explores the Sun's multilayered structure, the forces at work inside it, and the methods by which scientists study it. Detailing the activities of the SOHO spacecraft, the video also explains various solar phenomena: nuclear fusion, the release of neutrinos, oscillation of the photosphere, and the processes by which the Sun may have formed as well as those that will eventually cause its collapse. A viewable/printable teacher's guide is available at www.cambridgeeducational.com. (19 minutes) © 2004.

The Complete Cosmos

- **13-part series**
- **VHS/DVD-R #8622**
- **Preview clip online at www.films.com (Search on 8622)**
- **"Best Educational Program," Radio & Television Golden Laurels, French Senate, 1999**
- **"Special Award," Jules Verne Film Festival, France, 1999**

This unique series is a visual encyclopedia of the planets, the galaxy, and the universe. Rich in awe-inspiring images and meticulous research, it presents information on everything from the reason for seasons, to the Hale-Bopp comet and black holes. A definitive introduction to the study of space and astronomy. The series includes *From Stonehenge to Hubble: Looking to the Stars; Home Star: The Sun and the Planets; Venus and Mars: Earth's Sisters; The Blue Planet and Pale Moon Above; Jupiter and Saturn: Probing the Planets; Uranus, Neptune, and the Milky Way: Dark, Deep Space; Impact! Comets and Asteroids; Celestial Wonders: Eclipses, Auroras, and Light Fantastic; Black Holes, Dark Matter; Space Explorers: A History of the Last Frontier; The Next Step: Of Robots and Space Stations; The Expanding Universe: From Big Bang to Big Crunch?; Spaceship Earth and the Search for Intelligent Life.* (20 minutes each) © 1998.

Space Frontier: The Future of Space Exploration

• VHS/DVD-R #8622

By 2019, a colony on the Red Planet—the stuff of science fiction—is expected to become scientific fact. Using computer simulations and interviews with scientists, robotics experts, and officials from NASA and the National Space Society, this program investigates the four main challenges to initiating a self-sustaining colony on Mars. An economical, single-stage, reusable spacecraft must be developed, such as the proposed Venture Star. The effects of long-term low- and zero-gravity living must be studied and counteracted, on the Moon and at the multi-national Alpha space station. The Moon must be developed as a launch platform. And robots must be sent to Mars to prepare for human habitation and create stores of fuel. Once established, a Mars colony will become the jumping-off point for exploring the rest of the solar system and the cosmos beyond. (54 minutes) © 1997.

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