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ABSTRACT

This program guide is meant to help teachers assist their students in viewing the six-part pubic television series, "Stephen Hawking's Universe." The guide features program summaries that give background information and brief synopses of the programs; previewing activities that familiarize students with the subject; vocabulary that gives definitions of the terms used in each program; postviewing activities that require students to use mathematics, research, and writing skills to examine issues and ideas discussed in the program; biographies of important figures in the history of cosmology; and Web sites on related topics. The first program in this series, "Seeing is Believing," shows the radical revisions that have taken place in cosmology over the last two thousand years. The second, "The Big Bang," describes the controversies surrounding the big bang theory. The third, "Cosmic Alchemy," examines theories concerning the evolution of matter. The fourth, "On the Dark Side," views the role that cold, dark matter plays in the universe. The fifth, "Black Holes and Beyond," discusses the enigmatic objects that result from a star's catastrophic gravitational collapse. The final program, "An Answer to Everything," examines scientists' attempts to develop a complete theory of how the universe works. (WRM)

stephen hawking's universe

TEACHER'S GUIDE

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Ordering Information

Stephen Hawking's Universe is available on videocassette from PBS Home Video. To order, call 1-800-645-4727. To purchase for educational use, call 1-800-424-7963.

A companion book, *Stephen Hawking's Universe: The Cosmos Explained* by David Filkin, the series producer and a fellow student of Hawking at Oxford, is available at bookstores for $30. Published by Basic Books.

Videotaping Rights

Off-air taping rights of *Stephen Hawking's Universe* are available to educators for one year following each broadcast release.

Gordon M. Binder
Chairman and Chief Executive Of.

AMGEN

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Dear Educator,

All of us at Amgen are delighted to share with you the wonderful PBS series Stephen Hawking's Universe. *This Teacher's Guide will provide you with valuable assistance as you take your students on what we think will be the television experience of their lives.*

The English physicist Stephen Hawking is an extraordinary person. This six-part television series, full of cosmic fireworks and provocative ideas, reflects his brilliance and insight. Through Hawking's exceptional mind your students will explore the questions and theories surrounding the big bang, black holes, our model of the universe, and the technologies which have shaped our evolving vision of the cosmos.

As the world leader in biotechnology, we at Amgen are especially proud to be a part of this important educational event because our company and the biotechnology industry have a great stake in the quality of education in our country. This nation's competitive position in science and technology rests on our ability to keep a steady and reliable stream of gifted young Americans in science and technical careers. And that's why Amgen has been committed to devoting so much time, effort, and resources to education.

We are grateful to you in helping our nation's students seek the limitless opportunities and the wonders of the universe that are before them. I hope you enjoy Stephen Hawking's Universe *as much as we enjoy bringing it to you.*

Sincerely,

Gordon M. Binder

program schedule

PLEASE CHECK LOCAL LISTINGS FOR BROADCAST DATES AND ANY SCHEDULING CHANGES.

"Seeing is Believing"	Monday, October 13
"The Big Bang"	Monday, October 20
"Cosmic Alchemy"	Monday, October 27
"On the Dark Side"	Monday, November 3
"Black Holes and Beyond"	Monday, November 10
"An Answer to Everything"	Monday, November 17

Visit the *Stephen Hawking's Universe* web site at wNetStation, http://www.wnet.org, or at http://www.pbs.org.

introduction

What is our place in the universe? What existed at the beginning of space and time? Where did the universe come from — and where is it headed?

Throughout history, imaginative mathematicians and scientists have sought the answers to these fundamental questions. Copernicus, Galileo, Newton, Einstein, Hubble, and others used direct observation, reasoning, applied mathematics, and new technologies to overturn ideas about cosmology that were once deemed fundamental truths. Their breakthroughs reshaped science's understanding of the nature and structure of the universe. Their work, and that of other important cosmologists, not only provided new explanations of the universe, but also raised seemingly paradoxical questions. Did the vast variety and mass of matter that make up the cosmos evolve from nothing but energy? If so, where did the energy that created all of the matter in the universe come from?

The history of cosmology is a detective story in which each discovery leads to even more puzzles. Yet each step brings scientists closer to cosmology's ultimate goal — a single theory that takes into account all the forces shaping the universe.

Stephen Hawking's Universe is a six-part public television series that invites viewers to take part in this voyage of discovery. Hosted by renowned Cambridge University mathematics professor Stephen Hawking, the program features noted astronomers, mathematicians, cosmologists, and physicists who provide an overview of the history of cosmology and the contemporary challenges faced by astronomers.

The first program in *Stephen Hawking's Universe*, "Seeing is Believing," shows the radical revisions that have taken place in cosmology in the last two thousand years. The second, "The Big Bang," describes the controversies surrounding the big bang theory. The third, "Cosmic Alchemy," examines theories concerning the evolution of matter. The fourth, "On the Dark Side," looks at the role that cold, dark matter plays in the universe. The fifth, "Black Holes and Beyond," discusses the enigmatic objects that result from a star's catastrophic gravitational collapse. The final program, "An Answer to Everything," examines scientists' attempts to develop a complete theory of how the universe works.

How to Use This Guide

This teacher's guide offers the following components:

- Program summaries that give background information and brief synopses of the programs;
- Previewing activities that familiarize students with the subject;
- Vocabulary that gives definitions of terms used in each program;
- Postviewing activities that correspond to the program viewed, and require students to use mathematics, research and writing skills to examine issues and ideas discussed in *Stephen Hawking's Universe*;
- Biographies of important figures in the history of cosmology; and
- Web sites on related topics.

Please Note: Each page in this guide can be photocopied and distributed to students before viewing a program, or can be used as background information for developing lessons. Please tailor the use of these materials to meet your classroom needs.

Stephen Hawking's Universe can be used in both mathematics and science classes. We encourage you to share these materials with your colleagues.

contents

seeing is believing

BROADCAST DATE: OCTOBER 13, 1997 (CHECK LOCAL LISTINGS)

Vocabulary

universe: *the totality of all things.*
geocentric universe: *an earth-centered model of the universe.*
heliocentric universe: *a sun-centered model of the universe.*

Program Summary

From the dawn of civilization, humans have struggled to understand the nature of the universe. The ancients sought answers from pure reason limited by beliefs in gods and an earth-centered universe. Eratosthenes's determination of the earth's radius and Ptolemy's system of planetary motion shed no light on more fundamental issues. In the Renaissance, Copernicus, Kepler, Galileo, and Newton sparked a revolution in thought. They added measurement and the concept of universal physical law to reason and supposition. Science was born, initiating discoveries which, in 1927, brought Edwin Hubble to a California mountaintop observatory with the right question and the means to answer it. The interpretation of his results was astounding: the entire universe was expanding from an explosive moment of creation — the big bang.

Before Viewing the Program

Divide into groups of three, each group taking responsibility for researching the individuals on one of the lists below (some groups will have the same list). Each member of the class should research the dates and major achievements of one person on the list. Present your findings to the class. What do the people on the list have in common? What do the lists have in common? What is different about the historical periods represented by each list (Greek, Renaissance, modern)?

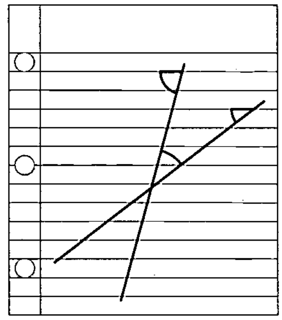
List 1	*List 2*	*List 3*
Eratosthenes	Ptolemy	Aristotle
Magellan	Copernicus	Newton
Yuri Gegerin	Hubble	Einstein

Each member of the class can also research the achievements of Galileo. Discuss what he has in common with the people on each of the lists.

Those who researched Eratosthenes can do the earth-measuring activity in advance and then act as mentors for a whole class activity before or after viewing the program.

Activity a

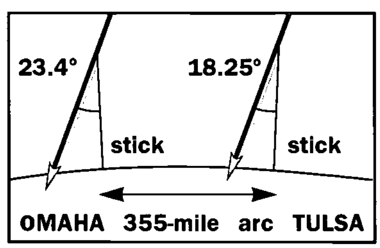
Eratosthenes (276-194 BC) measured the circumference of the earth using an ingenious technique. You can use this technique today with modern data.



1) On a piece of lined paper draw two intersecting lines.
2) With a protractor measure the angle each drawn line makes with one of the parallel printed lines. The lines represent parallel rays of sunlight.
3) Subtract one angle from the other.
4) Now measure the angle where the two drawn lines intersect. It should equal the difference between the two angles.
5) Make a general statement describing your findings.

Activity b

The sun's rays are parallel. Below are data taken when the sun was highest in the sky on August 1st in Omaha, NE and in Tulsa, OK, 355 miles directly to the south. In both cities a stick was driven straight into the ground, and the angle that the sun's parallel rays made with the top of each stick determined. The sticks are extensions of the earth's radii. From the data and knowledge that there are 360 degrees in a circle, you can use a simple algebraic equation to calculate the circumference of the earth.



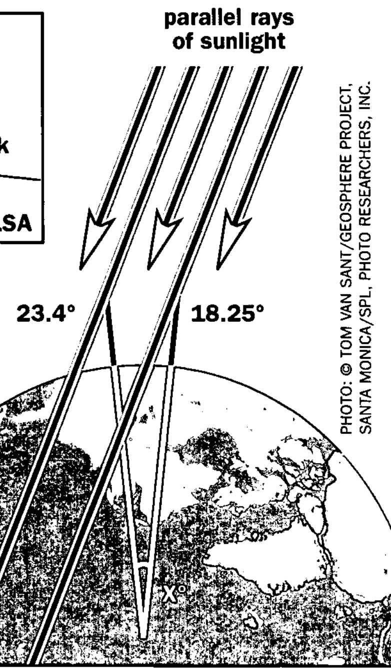


PHOTO: © TOM VAN SANT/GEOSPHERE PROJECT, SANTA MONICA/SPL, PHOTO RESEARCHERS, INC.

Web Sites

Galileo: http://www-groups.dcs.st-and.ac.uk/~history/Mathematicians/Galileo.html
Newton: http:// www-groups.dcs.st-and.ac.uk/~history/Mathematicians/Newton.html
Einstein: http:// www-groups.dcs.st-and.ac.uk/~history/Mathematicians/Einstein.html
Hubble: http:// www-groups.dcs.st-and.ac.uk/~history/Mathematicians/Hubble.html

the big bang

Vocabulary

astronomy: *the study of the universe beyond the earth.*
cosmology: *the study of the large scale structure and origin of the universe.*

Program Summary

Many scientists of the early 20th century, including Albert Einstein, found the idea of an expanding universe with an abrupt origin unpalatable. They viewed the universe as static and eternal. Ironically, the most vocal advocate of the expanding universe was Father LaMaitre of the Roman Catholic Church, the institution that had once strenuously resisted Galileo's ideas. Were the same human constraints that plagued earlier astronomers present in modern times? To a certain extent they were, but now there was a difference. All scientists agreed that the controversy could only be settled by direct and precise measurements. What measurements? For almost 40 years a debate raged until Robert Dicke proposed that the big bang would have produced a flash of light still present everywhere as a glow of radio waves. In 1965 Arno Penzias and Robert Wilson unmistakably found that glow, now called the Cosmic Microwave Background Radiation (CMBR). The debate was over. Our universe, the totality of all things, had a fiery beginning about 15 billion years ago.

Before Viewing the Program

In preparation for the viewing of "The Big Bang," discuss what you believe about an origin to the totality of all things. In viewing the program, try to identify the fundamental nature of the debate described. How was the controversy settled?

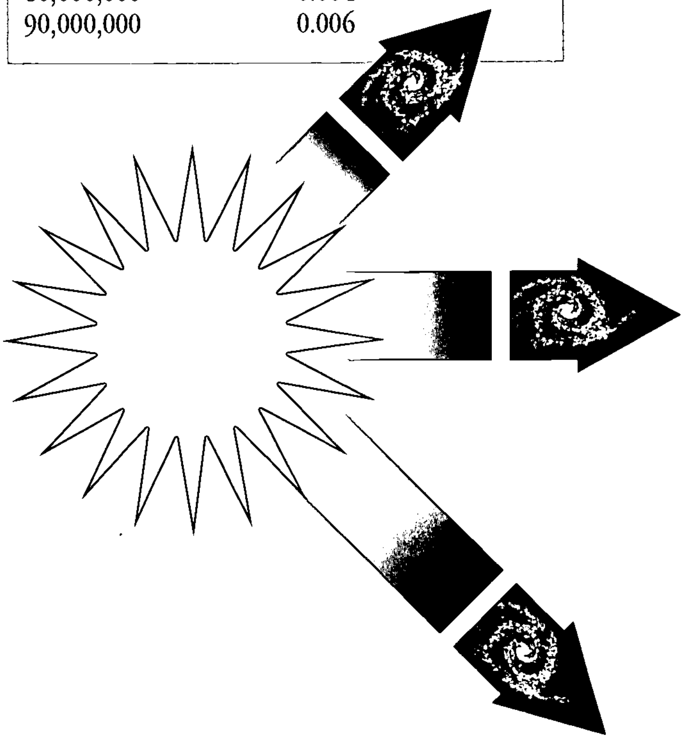
After Viewing the Program

Continue discussing the origins and the history of our view of the universe. Hold a conversation on the Hubble measurements and their interpretation. Then do the following activity and discuss the 15-billion year result. This result assumes that the galaxies have been traveling at a constant velocity. What if gravity has been slowing them down? (The universe would appear to be younger than calculated in the activity.)

Activity

Between Newton and Hubble, astronomers came to realize that the sun was not in the center of the universe. It was just one of billions of stars in our galaxy. Then Hubble found that our galaxy was one of billions of galaxies in the universe. With his colleagues, he also found that every other galaxy was speeding away from us, and that the speed seemed to be proportional to its distance. That is, if one galaxy is twice as far away as another, it is moving twice as fast, three times as far, three times as fast, and so on. This leads to a startling conclusion. You can arrive at the same conclusion by looking at the following data.

Distance (light years)	*Speed (light years/year)*
30,000,000	0.002
60,000,000	0.004
90,000,000	0.006



If we know how far an object is away from us, and how fast it is speeding away, then we can calculate how long ago it left our neighborhood. We do it by dividing the distance by the speed. Do it now for all three galaxies. Record your results. Hubble believed that the universe, of which our galaxy is a part, was in a general state of expansion. From a result similar to yours, the big bang origin of the universe was conceived. Write a brief paragraph on how your result could lead to the idea of a beginning of the universe at a single point in time.

Web Sites

MAP Introduction to Cosmology Page: http://map.gsfc.nasa.gov/html/web_site.html
Cosmology and the Big Bang: http://csep1.phy.ornl.gov/guidry/violence/cosmology.html

cosmic alchemy

BROADCAST DATE: OCTOBER 27, 1997 (CHECK LOCAL LISTINGS)

Vocabulary

hot big bang: *theory supported by Edwin Hubble that the universe originated at a single point in space and time.*
spectroscope: *a device that divides light into its component wavelengths (colors), used to determine the chemical makeup of a distant object.*

Program Summary

What is the universe and everything in it made of? Where does it all come from, and how do we know? Discoveries in the late 19th century revealed that the entire observable universe is made of the same elements as those on earth. With knowledge of the dual nature of matter and energy, scientists began to fit the pieces of the macroscopic and microscopic world together. This program covers the discovery of the nature of matter, its initial creation from the primordial conditions in the big bang, the building up of elements in stars, and the way this might affect the end of the universe.

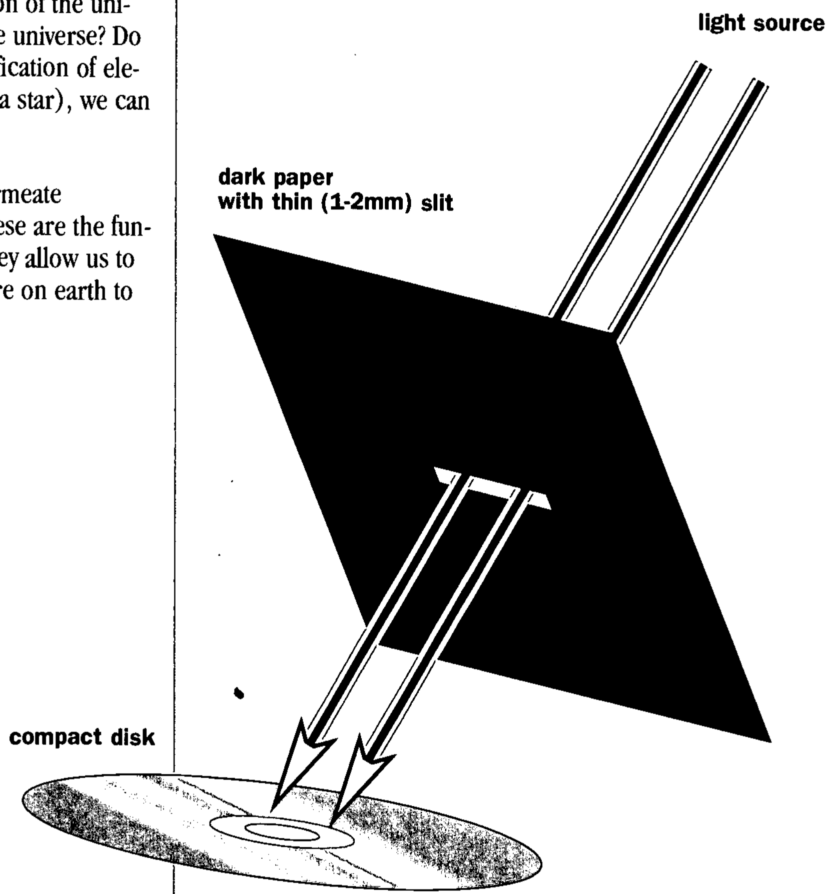
Before Viewing the Program

Discuss the question of the elemental composition of the universe. How do we know what elements are in the universe? Do the spectroscopy activity and focus on the identification of elements from a distance. If the matter is glowing (a star), we can determine its composition.

The same laws governing atoms on the earth permeate throughout the universe, just as gravity does. These are the fundamental assumptions of modern astronomy. They allow us to theoretically apply the results of experiments here on earth to the entire universe.

Activity

Each element gives off a unique pattern of light colors (wavelengths) by which it can be identified. Scientists use a device called a diffraction grating to observe the pattern. Its surface is similar to the reflective surface of a CD, except the grooves are parallel. You can see the component wavelengths of light by holding a CD at just the right angle — you see a rainbow. You can actually analyze some light sources in the following way. First, cut a slit in a piece of dark construction paper about 2 millimeters wide and 3 centimeters long. Holding a CD under the slit paper at about a 30 degree angle (some adjustment needed), you will see a spectrum (rainbow) reflected on the CD. The spectrum you get depends upon the light source. Point it at the sun or at a normal incandescent light, and you will see a continuous spectrum. If you point it at neon signs in store windows, you will see the line spectrum of whatever gas or gases are in the tubes (except for red, most have mercury for brilliance).



Web Sites

WebElements: http://www.shef.ac.uk/uni/academic/A-C/chem/web-elements/web-elements-home.html
What is the Periodic Law and how was it formulated?: http://edie.cprost.sfu.ca/~rhlogan/periodic.html
A Little Nut: http://www.xmission.com/~dparker/nucleus.html
The Day the Universe Went All Funny:
http://www2.ncsu.edu/unity/lockers/users/f/felder/public/kenny/papers/relativity.html

7

on the dark side

Vocabulary

dark matter: *matter in space known to exist only from indirect observation of its gravitational effects.*

radio telescope: *device used to collect radio waves — a nonvisible form of light — emitted by distant objects.*

Program Summary

According to the observational research of Vera Rubin on the velocities of stars around galaxies, there is a great deal of matter exerting a gravitational force that we simply cannot see. This matter appears to be of an entirely different nature from the ordinary matter we experience, observe, and interact with in everyday life. There is no spectral evidence of its presence. This "dark matter" makes up roughly 90 percent of the stuff in the universe, and it has important gravitational implications for the future of the universe. Specifically, will the universe keep expanding forever, or will it someday stop and start collapsing upon itself on the way to a big crunch? Perhaps there is just enough matter for the expansion to be halted by gravity, but not enough to collapse. For science there are two problems here: What is the mysterious dark matter? How much of it is there?

Before Viewing the Program

1. Here are the levels of organization of observable matter in the universe.

1. subatomic particles
2. atomic nucleus
3. atom
4. molecule
5. planets or stars
6. solar systems
7. galaxies
8. galaxy clusters
9. galaxy superclusters

Do research in pairs on each with regard to size and the force holding the matter together.

After Viewing the Program

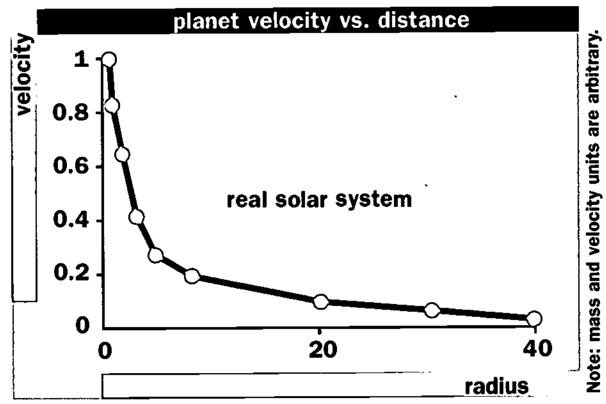
Do the following activity to examine the dark matter problem in galaxies. What Vera Rubin found was that even beyond the edge of the galaxies, velocity was constant, indicating large amounts of unseen mass.

Activity

The velocity of an orbiting object is controlled by the amount of matter (mass) within the orbit and the radius of the orbit: the greater the mass, the more gravity, the higher the velocity. The greater the radius of the orbit from the center, the lower the velocity. This relationship is described by Newton's equation

$$\boxed{V_{orb} = \sqrt{\frac{MG}{R}}}$$

where V_{orb} is orbital velocity, **M** is mass, **G** is the constant of gravity, and **R** is the radius (distance) from the center. More than 99 percent of the mass in the solar system is concentrated in the sun. Therefore, the sun's gravity controls the orbital speeds of the planets. Here is a graph of the orbital speeds of the planets against the distance of the sun.



Within the whirling disk of the galaxy the velocities of orbiting stars remain roughly constant with increasing distance from the center. This is because the mass of the galaxy is spread out (as **R** increases, **M** increases as well because more and more mass is included in the orbits.) But when we come to the edge of the visible mass in the galaxy, we expect the orbital velocity of outlying stars and satellite dwarf galaxies to get smaller. Vera Rubin found that that was not the case.

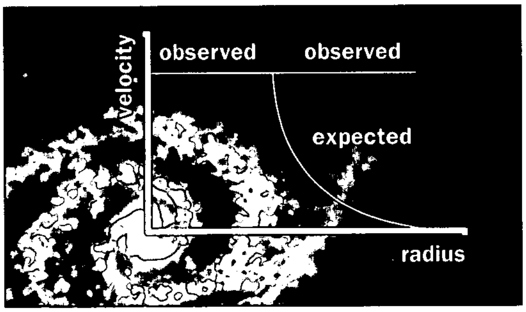


PHOTO: NATIONAL RADIO ASTRONOMY OBSERVATORY/SPL, PHOTO RESEARCHERS, INC.

Using the equation and your knowledge of dark matter, propose an explanation for the observed high orbital velocities.

Web Sites

A Primer on Dark Matter: http://csep1.phy.ornl.gov/guidry/violence/darkmatter.html

Cosmic Hide and Seek: The Search for Missing Mass: http://www.gti.net/cmmiller/drkmttr.html

black holes and beyond

Vocabulary

black hole: *gravitationally collapsed object from which not even light can escape.*

quasar: *stands for "quasi-stellar" object; energetic galactic nuclei.*

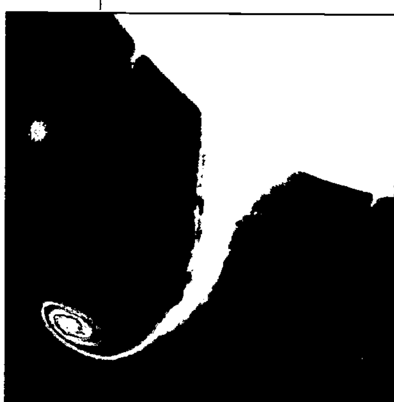
Program Summary

The universe is a strange and violent place, full of regions spewing out energy on an unimaginable scale and objects so massive not even light can escape from them. With the discovery of quasars (extremely luminous, compact objects in the hearts of ancient galaxies), the picture of the universe became more complex. Though the mechanism responsible for such enormous outputs of energy is not completely established, one answer was found in a part of Einstein's theory of relativity — black holes, specifically supermassive black holes at the centers of distant galaxies. These objects consume enormous amounts of matter. As the matter falls inward, it releases a large amount of observable energy. Einstein didn't think black holes were possible, despite the fact that his own theory implied their existence. Robert Oppenheimer thought otherwise and set out to prove the presence of collapsed stars so massive not even light can escape them. Black holes seem to be a reality.

Before Viewing the Program

Black holes are so strange, they almost seem to be from science fiction. While understanding the details of space and time in the neighborhood of a black hole requires knowledge of general relativity, their essence is relatively easy to grasp.

Review the introduction to the black hole activity, then do a thought experiment. "Suppose, in our imaginations, we squeeze the earth down to half its present radius. What happens to the surface gravity? What happens to the velocity required to escape?" They both increase. Now squeeze it to half again, and again. At some radius the velocity required to escape will exceed the velocity of light (c). The earth will be a black hole.



Artist's illustration of matter from a red giant star being pulled toward a black hole.

Activity

Any mass, if squeezed down small enough, can become a black hole. To make the earth into a black hole it would have to be squeezed down to a radius of .86 centimeters, about half the size of a golf ball. To calculate the radius of the black hole for the mass of the earth, the equation used is:

$$\boxed{R=\frac{2MG}{c^2}}$$

where for the earth **$M_e=5.8*10^{27}$grams, $G=6.67*10^{-8}$, $R_e=6.4*10^{8}$cm** and **$c=3*10^{10}$cm/sec.**

If you could weigh a thimbleful of the black hole/earth, how much would it weigh?

Classical physics predicts that the radius of a black hole increases in exact porportion to an increase in mass (if an object is twice the mass of the earth, it would have twice the earth's black hole radius). What would the black hole radius of the sun be, given its mass of 334,672.02 units of earth mass?

At the center of each galaxy, a black hole with a mass of a million to a billion (10^6-10^9) times the mass of the sun is believed to reside. What black hole radius would such massive objects have? There are 160,000 centimeters in a mile.

The radius of our solar system is roughly $6*10^{14}$ centimeters, or about $3.75*10^{9}$ miles. How do the radii of these massive black holes compare to the radius of the solar system?

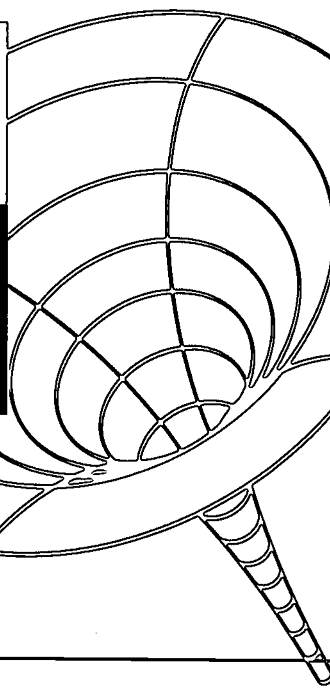


PHOTO: JULIAN BAUM/NEW SCIENTIST/ SPL, PHOTO RESEARCHERS, INC.

Web Sites

What Feeds the Monster?: http://zebu.uoregon.edu/1996/ph123/qso.html

Hubble Surveys the "Home" of Quasars: http://www.xs4all.nl/~carlkop/quasars.html

Beyond the Event Horizon: An Introduction to Black Holes: http://bradley.bradley.edu/~dware/blkhole.html

an answer to everything

BROADCAST DATE: NOVEMBER 17, 1997 (CHECK LOCAL LISTINGS)

Vocabulary

quantum mechanics: *theory describing the properties of the atomic and subatomic particles.*
relativity: *Einstein's theory of space and time describing gravity and the large scale operation of the universe.*

Program Summary

Scientists generally agree on the big bang origin of the universe as we see it today. Fifteen billion years ago there was a momentous event whose nature is uncertain. But as we track the expansion backward, toward that moment of seeming creation, the details blur. Is our universe a minor event in an endless series of universes (or multiverses)? Our physics seem inadequate to explain the early times in a way that is consistent with the conditions existing today. That is a crucial requirement of science — no gaps should exist in the cause-and-effect chain linking two moments in a physical history. If our physics fails, understanding on the most fundamental level weakens; we have a crisis in science. New tentative and remarkable theories uniting relativity and quantum mechanics have been proposed — inflation theory and superstring theory. They are strange, not yet worked out, but seem to shed light on the earliest times. They hold the promise of providing a simple and elegant way to explain everything in universe and how it all works.

Before Viewing the Program

Discuss the following: If all the matter and energy in the universe are packed into a very small volume, the result fits the characteristic profile of a black hole. Then how could it expand? (While physicists have been able to explain this using mathematics, there is no simple, clear verbal explanation for it yet.)

Activity

Select one or more of the topics below, and write an essay on the topic, citing examples from *Stephen Hawking's Universe*.

1. Nature stands mute on itself; progress toward explaining even the simplest process in the universe begins with a proposal. Describe the role of imagination in science in general and in the history of cosmology in particular.

2. What makes science, science? As bizarre theories on the early history and ultimate fate of the universe appear, some have asked if physics is moving toward metaphysics. Describe the role of measurement in science and why it applies to all new views of the universe.

3. Mathematics is an abstract subject. But from Galileo and Newton to today's cosmologists, advances toward understanding the fundamental aspects of the real universe could not have been made without mathematics. Describe the role of mathematics in science in general and how it connects to the real physical world.

Select all of the above topics and, incorporating the notions of observation and/or experiment, describe how science is done.

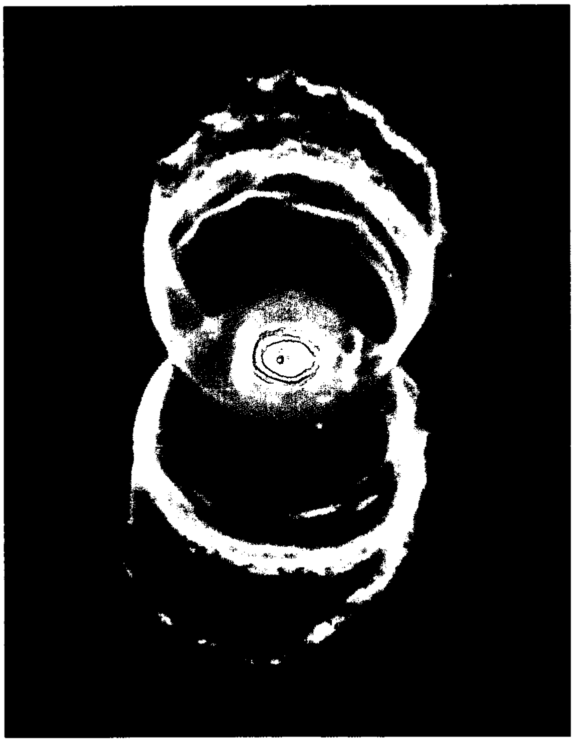


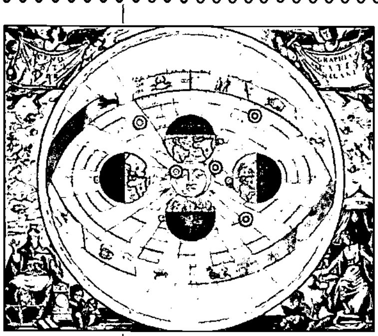
PHOTO: RAGHVENDRA SAHAI AND JOHN TRAUGER (JPL), THE WFPC2 SCIENCE TEAM, AND NASA

Hourglass nebula

Web Sites

Measurement in Quantum Mechanics FAQ: http://www.mtnmath.com/faq/meas-qm.html
Beyond the Big Bang: http://www2.ari.net/home/odenwald/anthol/beyondbb.html
Mathematical Breakthroughs Establish God's Extra-Dimensional Might: http://www.surf.com/~westley/4q95faf/4q95dmsn.html
Superstring Theory: http://www.lassp.cornell.edu/GraduateAdmissions/greene/greene.html

Biographies



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Nicolaus Copernicus

Copernicus, born February 19, 1473 in Toruń, Poland, first proposed that the sun, rather than the earth, was at the center of the universe. This revolutionary idea completely contradicted the teachings of the Roman Catholic Church, which dominated scholarly and religious thought in Europe at the time. His proposal was suppressed. Copernicus's heliocentric universe (pictured) was a giant leap forward in our understanding of our place in the cosmos. He died May 24, 1543 in Poland.

Galileo Galilei

PHOTO: CORBIS-BETTMAN

Galileo, born February 15, 1564 in Pisa, Italy, helped bring Copernicus's heliocentric universe into wide acceptance, despite the protests of the church. Using the recently invented telescope, he discovered the phases of Venus, the cratered and mountainous surface of the moon, Jupiter's moons, and sunspots. He used these observations to support the Copernican view, for which he faced the Inquisition. Galileo's application of mathematics to describe the motion of objects was seminal in setting the course of modern science. He died under house arrest January 8, 1642.

Sir Isaac Newton

Almost exactly one year after Galileo died in Italy, Sir Isaac Newton was born January 4, 1643 in England. He is considered to be the founder of modern science. Newton engaged in a wide range of experimental and theoretical activities, including mathematics, optics, the nature of light, alchemy, and the creation of a set of laws to describe motion. His crowning achievement was his law of universal gravitation. He proposed that the same gravity causing objects to fall on the earth held the moon in orbit. Then he made the great conceptual leap: that the laws of physics were the same everywhere in the universe. He died March 31, 1727 in England.

PHOTO: CORBIS-BETTMAN

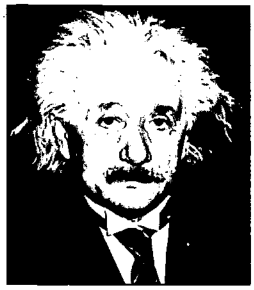


PHOTO: CORBIS-BETTMAN

Albert Einstein

Einstein, born March 14, 1879, is most famous for his general theory of relativity and the equation $E=mc^2$. Published in 1915, it proposed a new way to look at gravity and the operations of the universe on a large scale in relation to space and time. In addition to his theories of special and general relativity, he also established the quantum nature of light, for which he received the Nobel Prize in 1921. His theories changed our view of the universe from that of the Newtonian "straight line" physics to that of a curved, warped space-time with many bizarre implications. He ended his career at Princeton University and died on April 18, 1955. Until the end of his life he was devoted to discovering a theory that could describe everything in the universe, large and small, but he never realized this dream.

Edwin Hubble

Edwin Hubble was born November 20, 1889. His contributions to our understanding of the universe came in two parts. He was the first to determine by precise measurement the distances of galaxies, establishing that they were great but comparable galaxies in their own right, not objects in the Milky Way. With colleagues he went on to measure the velocities of these galaxies and found that they were all moving away from us. The further away a galaxy was, the faster it moved. This velocity-to-distance ratio was a straight-line proportion. Using Einstein's prediction that nothing in the universe can move faster than the speed of light, he arrived at the conclusion that at some point in space and time there was a physical beginning to the universe, the big bang, and that the universe had been expanding ever since.

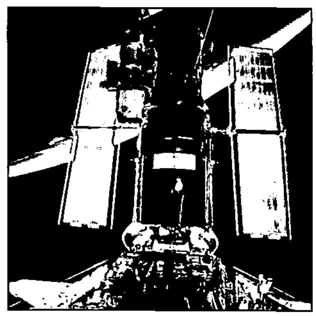


PHOTO: NASA

Hubble Space Telescope

He found the velocities of the galaxies to be in exact proportion to their distances, which he interpreted as evidence of the general expansion of the universe. Looking backward in time, one arrives at the inescapable conclusion that all the matter in the universe was concentrated at a single point. Hubble's work underlies all of modern theory of cosmology. He died September 28, 1953.

PHOTO: © BBC WOLRDWIDE LTD.

Stephen Hawking

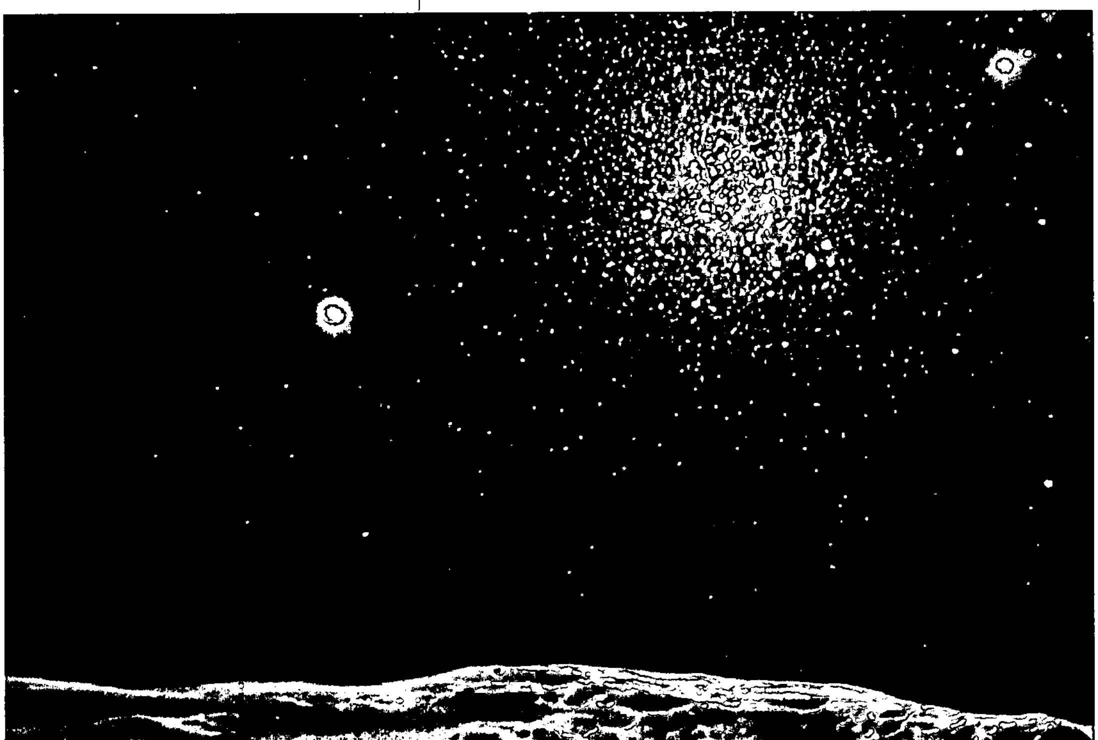
Stephen Hawking was born January 8, 1942 in Oxford, England, into a scientific family; his father was a prominent research biologist. He decided early to enter science but rejected biology for mathematics and physics. After receiving his bachelor's degree from Oxford, Hawking briefly considered a career in astronomy but resolved instead to study cosmology at Cambridge. He was drawn to cosmology, he has said, because it asked "the really big question: Where did the Universe come from?"

While studying at Cambridge, Hawking developed amyotrophic lateral sclerosis, more commonly known as Lou Gehrig's disease. The illness attacks and disables skeletal muscles and affects such basic functions as speech and swallowing. Today Hawking depends on a motorized wheelchair for mobility and, because a tracheotomy injured his vocal chords, "speaks" through a voice-processing program that responds to words he keys into a specialized portable computer.

He received his Ph.D. from Cambridge in 1966 and collaborated with his colleague, Roger Penrose, to refine the mathematical approach to black holes they had already developed. Working alone, with Penrose, and with other collaborators, Hawking developed a series of papers on related topics, such as the beginning of time and the theory of "supergravity," which has clarified certain issues surrounding the development of the so-called grand unified theory, the "theory of everything." The discovery in the past few years of apparent black holes (including one at the center of our own Milky Way galaxy) have helped to focus public attention on Hawking's work.

Professor Stephen Hawking holds the post of Lucasian Professor of Mathematics at Cambridge, a chair once held by Isaac Newton. His calculations regarding the nature of black holes — collapsed stars so massive they absorb whatever light they emit and devour the matter that surrounds them — are generally acknowledged to have increased science's understanding of how the universe began and to have advanced the prospect of a unified field theory that will unite the interactions of the four basic forces in the universe.

His 1988 book, *A Brief History of Time,* sold more than eight million copies worldwide. Stephen Hawking has received many honors, including the Albert Einstein Award and the Maxfield Medal.



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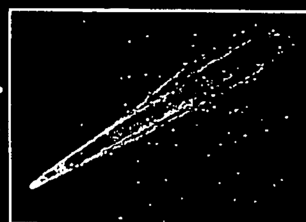
"Where did we come from? How did the universe begin?

Where are we going?



Why is the universe the way it is?

...The questions are clear and deceptively simple,

but the answers have always seemed well beyond our reach —

until now."

— **Stephen Hawking**

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