Cosmic Questions

Our place in space and time

EDUCATOR'S GUIDE

Harvard-Smithsonian Center for Astrophysics
Museum of Science, Boston

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EDUCATOR'S GUIDE | **grades 7–12**

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Acknowledgments

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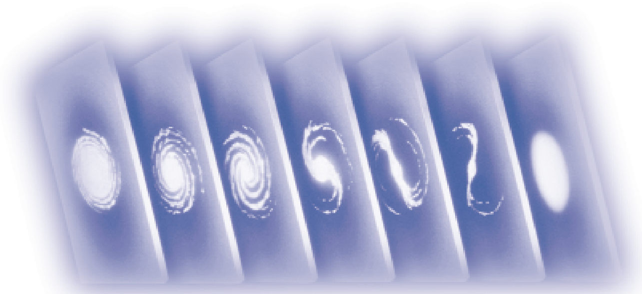
"The universe is made of stories, not atoms."

– Muriel Rukeyser
20th c. poet



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Instructions for downloading or ordering this guide can be found at **http://cosmicquestions.org**.

INTRODUCTION TO THIS GUIDE

The *Cosmic Questions* Educator's Guide is a resource for teachers of students in grades 7–12. A wealth of excellent astronomy and astrophysics curricula has been developed by many educational, research and government agencies. We have drawn from these existing resources and assembled activities that best introduce and teach the complex concepts presented in the *Cosmic Questions* exhibit. This is not intended to be a comprehensive curriculum. Resources are listed that direct you to more information. The guide was developed in conjunction with the exhibit and complements a Museum visit. However, the activities can also be used independently. The format is flexible, and you can pick and choose the materials that are most appropriate for you.

The Guide includes:

- information about the *Cosmic Questions* exhibit.
- activities to do with your class before or after you visit the exhibit.
- activities to do during a visit to the exhibit.
- additional resources for exploring your own cosmic questions.

INTRODUCTION TO THE EXHIBIT

What is the universe like?

Was there a beginning to time?

How do we fit into the cosmos?

Ancient human questions remain at the heart of modern cosmology, the study of the universe as a whole. This exhibit invites you to explore the emerging portrait of our magnificent universe. Like astronomers who observe the galaxies in awe and wonder, you too just might find yourself asking new questions about space, time and our place in the spectacular cosmos.

From interactive computer stations to stunning astronomical murals, the traveling exhibit *Cosmic Questions: Our Place in Space and Time* takes visitors behind the scenes of modern cosmological science and urges them to explore their own connection to the universe. *Cosmic Questions* has four thematic areas: Our Place in Space; Observing the Universe; Our Place in Time; and Great Cosmic Mysteries. Each area introduces new answers to old questions and inspires more questions that will further define ou place in the cosmos.

GOALS OF THE EXHIBIT

Cosmic Questions employs a diverse set of exhibit experiences and interpretive strategies that invite visitors to join the human quest to understand our place in space and time. The exhibit highlights new discoveries in astronomy while providing visitors with opportunities to:

- Learn about key astronomical and scientific concepts, including:
  - > the composition of the universe and its vast scales of space and time.
  - > "learning from light," the physical and analytical tools of the astronomer.
  - > the interplay of models, evidence and explanation in forming our understanding of the universe.
- Increase their understanding of the nature of scientific inquiry by engaging in activities that explore "how we know" about the universe.
- Encounter various human perspectives (historical, personal, cultural, artistic, etc.) on age-old cosmic questions.
- Reflect upon their own ideas about the universe and the meaning and relevancy of the ongoing human search for answers to cosmic questions.

COSMIC QUESTIONS EXHIBIT DESCRIPTIONS

Our Place in Space

In this introductory area, visitors begin at our own Milky Way galaxy and travel outward to billions of galaxies as far as our eyes can see. The question of how we fit into the vast web that is our universe has intrigued observers for many centuries. It is with modern tools and instruments that we are beginning to truly understand how vast the universe really is and how important our questions are.

Welcome Home gives scale and context for our place in our local "cosmic neighborhood" using a large mural of the Milky Way and our nearest neighbors. Explore an interactive map and a tactile bronze model with audio narration.

Mapping the Universe shows how our ideas about our place in the universe have been expanding throughout time with a display detailing the human quest to map our place in the cosmos. View the universe of galaxies in 3D using a stereo viewer; see an astrolabe, a kind of instrument used by astronomers 1000 years ago.

Wall of Galaxies illustrates that the Milky Way is just one of billions of galaxies in the universe with a photo gallery of beautiful galaxies and galaxy clusters beyond our local neighborhood. Launch from Earth and journey through the universe using state-of-the-art scientific visualizations of the cosmos.

Human Reflections connects visitors to various interpretations of cosmic themes and allows them to reflect on their own views. See artistic, spiritual and intellectual reflections on universal cosmic questions; listen in on a video of artists and scientists; use a magnetic word board to create your own cosmic poetry.

Observing the Universe

In this highly interactive section, visitors explore the universe using the tools of some of the world's foremost ground-based and space-borne observatories. With help from modern tools and the scientists who use them, we see how to piece together the story of the universe using the faint light of deep space.

Mauna Kea highlights the ways we observe the universe from Earth through a multimedia exploration of the Mauna Kea mountaintop in Hawaii, with a special focus on the Gemini Observatory. Use an interactive CD-ROM to meet scientists who use and operate Mauna Kea telescopes; see a telescope mirror in the making; view beautiful telescope images; and control a telescope yourself — request an image to be taken tonight and emailed to you tomorrow!

Chandra highlights the ways we observe the universe from space with a multi-media exploration of the Chandra X-ray Observatory. Use an interactive CD-ROM to meet scientists who use and operate Chandra; examine a model of this new space telescope; view beautiful x-ray images of the universe.

Multi-Wavelength Astronomy shows how astronomers use different parts of the electromagnetic spectrum to learn new things about the universe and the objects in it. This area is an introduction to the rainbow of light beyond what our eyes can see and an exploration of what different objects look like in those wavelengths. Use special multi-wavelength viewers to explore the night sky; compare different views of stars, nebulae and galaxies on CD-ROM with an astronomer as your guide; listen to an audio analogy for the electromagnetic spectrum.

Spectra Interactive demonstrates what light tells us about an object through a display about the information contained in a star's spectrum. Use a real spectroscope to analyze the light coming from different sources in a simulated star field.

Infrared Astronomy shows how infrared "eyes" can help us learn to observe the world around us in new ways. This multi-wavelength activity highlights the infrared band of the electromagnetic spectrum. Use a near-infrared camera to see phenomena invisible to your eyes.

Sky-watchers, Then & Now illustrates astronomical awareness throughout history and across cultures, focussing on observations of the supernova explosion of 1054 A.D. Observe a reproduction of an ancient Native American bowl thought to document the supernova's appearance.

Beyond Hubble provides up-to-date information about the latest developments in space science. Use a computer station and bulletin board to explore current astronomy news.

Our Place in Time

Anchored by the Cosmic Kitchen Theater, this area invites visitors to reflect on the notion that our human story is intimately linked to the unfolding story of the universe. Although life as we know it has only existed for a brief moment of the great cosmic history, we can look back in time and examine the expanding, evolving universe to find our own connections to the Big Bang.

Cosmic Kitchen introduces visitors to their role in the story of the universe. This short theatrical production explores the 14-billion-year history of the universe and the "recipe" for our own existence. Go deeper into Carl Sagan's quotation, "if you wish to make an apple pie from scratch, you must first invent the universe."

Cosmic Calendar highlights the major events throughout the history of the universe and how they relate to the story of life as we know it. This giant calendar shows the 14 billion year history of the universe as if it occurred in a single year. Which atoms in your body are the oldest? Find out here.

The Big Bang guides visitors in thinking about how we can examine and understand conditions at the beginning of the universe through a display about the Big Bang scenario and the evidence supporting it. Listen to Einstein guide you as you explore 3D models of "space-time"; peek into a model of the expanding universe; examine the evidence for a Big Bang; and take an interactive journey through time.

Great Cosmic Mysteries

While the other sections of this exhibit invite visitors to explore what we currently know and understand about our place in space and time, this area acknowledges that there are deep mysteries yet to be understood. A series of interconnected rooms introduces a gallery of mysteries– dark matter and energy, black holes and the possibility of life elsewhere in our universe. A fourth room invites visitors to reflect upon their own connections to the cosmos in a unique and contemplative theater.

Connecting with the Cosmos gives visitors the opportunity to make personal and aesthetic connections to the themes of the exhibit in a video mini-theater. Contemplate your connection to the cosmos through words, music and images.

What's the Cosmos Made Of? introduces visitors to the ideas of dark matter and dark energy using a display about the composition of the cosmos, both observable and invisible. View an eclectic sample of the 5% of the universe we know about; see evidence for the invisible world of subatomic particles in a cloud chamber; examine the evidence for unseen matter and energy in the universe.

Are We Alone? engages visitors' thoughts about other worlds and displays information about the search for extra-solar planets and the possibility of life beyond Earth. Explore the conditions for life in various parts of the universe using a computer interactive; enjoy historical views of other worlds and artistic visions of newly discovered extra-solar planets; compare a model of an alien solar system to ours.

What are Black Holes? familiarizes visitors with the science around and about black holes through an immersive virtual exploration of black holes. Take control of a spacecraft orbiting a black hole; launch probes into the black hole to explore its bizarre behavior; learn about the anatomy of and evidence for black holes.

What is the universe like?

Was there a beginning to time?

How do we fit into the cosmos?

NATIONAL SCIENCE AND MATH STANDARDS

The exhibit and these activities can be used to support the following **National Science Standards***

Standards	Grades 5 – 8	Grades 9 – 12
Unifying Concepts and Processes	Evidence, models and explanation	Evidence, models and explanation
Science as Inquiry	Understanding about scientific inquiry	Understanding about scientific inquiry
Physical Science	Motions and forces Transfer of energy	Motions and forces Interactions of energy and matter
Earth and Space Science	Earth in the solar system	Origin and evolution of the universe
Science and Technology	Understanding about science and technology	Understanding about science and technology
Science in Personal and Social Perspectives	Science and technology in society	Science and technology in local, national and global challenges
History and Nature of Science	Nature of science	Nature of scientific knowledge

National Council of Teachers of Mathematics Principles and Standards**

Principles and Standards	Grades 6 – 12
Numbers and Operators	Understand numbers, ways of representing numbers, relationships among numbers and number systems.
Algebra	Understand patterns, relations and functions. Use mathematical models to represent and understand quantitative relationships. Analyze change in various contexts.
Geometry	Specify locations and describe spatial relationships using coordinate geometry and other representational systems. Use visualization, spatial reasoning and geometric modeling to solve problems.
Measurement	Understand measurable attributes of objects and the units, systems and processes of measurement.
Data Analysis and Probability	Formulate questions that can be addressed with data and collect, organize and display relevant data to answer them. Develop and evaluate inferences and predictions that are based on data.
Problem Solving	Apply and adapt a variety of appropriate strategies to solve problems.
Communication	Analyze and evaluate the mathematical thinking and strategies of others. Use the language of mathematics to express mathematical ideas precisely.
Connections	Recognize and apply mathematics in contexts outside mathematics.
Representations	Use representations to model and interpret physical, social and mathematical phenomena.

* http://www.nap.edu/readingroom/books/nses/html/index.html
** http://standards.nctm.org/index.html

CLASSROOM ACTIVITIES

Cosmic Questions: Our Place in Space and Time is organized into four thematic areas. The activities in this guide have been chosen to teach concepts presented in each of these areas.

1. Our Place in Space

- What are Your Ideas About the Universe? Cosmic Survey
- Modeling the Universe

These activities lay the foundation for thinking about the size and scale of the universe. They can be used to assess students' understanding and introduce concepts before a visit to the exhibit.

2. Observing the Universe, Learning from Light

- Exploring the Spectrum
- A Multi-Wavelength Exploration of the Universe

Everything we know about the universe beyond Earth we learn from light and electromagnetic radiation. Astronomers use different parts of the electromagnetic spectrum to learn about the universe and celestial objects. These activities assume students have some prior experience with the electromagnetic spectrum. The first activity leads students through experiments with light and filters, demonstrating that the broader the range of the electromagnetic spectrum we can detect, the more information we gather. In the second activity, students work with spectacular images taken with telescopes sensitive to different wavelengths of light. These activities are appropriate before or after a visit to the exhibit. While visiting the exhibit students can see even more stunning images of the universe.

3. Our Place in Time

- Modeling the Expanding Universe
- Evidence for the Expanding Universe

What does it mean to say the universe is expanding? How do we know the age of the universe? What is the evidence for the Big Bang? Students will create conceptual models of the expanding universe and use actual galactic spectra to calculate the movement of galaxies through space. These activities could be introduced before a visit to *Cosmic Questions* and returned to in greater depth after viewing the Cosmic Kitchen Theater and other information presented in the exhibit.

4. Great Cosmic Mysteries

- Is There Life on Other Worlds? The Drake Equation
- Is There Life Out There? Community Survey

The universe is full of mysteries that have no answers yet. These activities introduce students to a framework for examining the possibility of life on other worlds, and connect to a visitor poll about these same questions.

Each activity begins with **connections** to the *Cosmic Questions* exhibit, **goals**, and a list of **materials**. **Background** for teachers offers information about the topic and tips for conducting the activity. **Suggestions for introducing** the activity are included. Depending on students' experience, some activities may require teaching or review of concepts that are not covered in this guide, such as objects in the solar system or the physics of light and electromagnetic radiation. **Procedures** provide step by step instructions for the activity. **Discussion notes** serve as the basis for group discussions and help students reflect on their learning. **Student Worksheets** and some suggested answers to the questions presented in the activities are included.

The **Resources** at the end of the guide direct you to more information to help you get started or to conduct further investigations on each of these topics.

A note about distances. We know that teachers often encourage students to use kilometers in their work. However, we have included both kilometers and miles in this guide to provide an intuitive sense about distances in the universe. Because the universe is so large, astronomers use the light year to express very large distances. A light year is the distance light travels in a year, which is equal to approximately 6 trillion miles or 9.5 trillion kilometers.

WHAT ARE YOUR IDEAS ABOUT THE UNIVERSE? COSMIC SURVEY*

Exhibit Connections: Welcome Home, Mapping the Universe, Cosmic Calendar

Goal

- to introduce the concepts of the structure and evolution of the universe

Materials

For each student

- one set of seven Cosmic Survey images
- scissors
- one copy each of the three Cosmic Survey Student Worksheets–How Big? How Far? How Old?

Background

We could live in an infinite universe. No one yet knows the true size of our universe. Our view is limited not by a physical edge to space, but by how far light has traveled since the time our universe was born. The observable universe is just a portion of the whole.

Many people, adults and students alike, are familiar with the names of objects in space, but they have an incomplete mental model of where those objects are in space, their relative size and scale, and how they fit into the cosmic scheme of things. Understanding the sizes and distances of celestial objects can be tricky because in our everyday experience, the stars all seem the same distance away, and the moon can appear close or far away depending on whether you observe it near the horizon or higher in the sky. Most people's knowledge of dim and distant objects such as nebulae and galaxies comes mainly from images in books, where all the images are about the same size with no indication of scale.

In this activity, a three-part questionnaire launches students on discussions about where objects in space are located, and when they formed. By physically manipulating images of objects in space, students represent their own mental models of space and time.

When you lead discussions with students, please keep in mind that ideas and insights about the three-dimensional organization of the universe develop gradually. Getting the "right answer" is not as important as the critical thinking skills that students develop as they confront the questions that arise as they struggle with their mental models of the universe.

This survey can serve as a great assessment activity for you to find out how your students think about the universe, and you can use it to help design follow-up activities to improve their understanding.

Suggestions for Introducing the Activity

This is an introductory activity that guides students as they begin to think about where we fit in the universe. Students should be familiar with the objects in our solar system and the terms for celestial objects beyond our solar system. Ask students to name some objects in the universe. What might we want to know about objects in the universe? What kind of information could we gather about objects in the universe?

* Images courtesy of NASA: Isaac Newton Telescope; Smithsonian Astrophysical Observatory. This activity was developed with support from NASA Grant No. NCC5-261. Universe! Education Forum. http://cfa-www.harvard.edu/seuforum.

Procedure

- Make enough copies of the Cosmic Survey images for each student to have a set of seven images. You do not need to cut these images from the book; a separate set of both the large and small images are found in the pocket at the back.

Part 1. What are your ideas?

- Hand out copies of the three data sheets and the sets of seven images. Have students cut the images apart so they can physically manipulate them as they fill out their data sheets. They should answer the survey questions in the following order: How Big? How Far? How Old? (This order represents increasing levels of conceptual difficulty for most students). Collect the students' papers so you can look over their ideas.
- Organize the class into discussion groups of three to five students. Give each group a set of survey data sheets. Explain that each team is to discuss the three survey questions and come to an agreement, if possible, on the best order of images for each question. One member of each team should record questions that arise as they order the images.
- Circulate among the groups of students, encouraging them to discuss any disagreements fully and to write down arguments in support of their answers.

Part 2: Discussion

- Lead the class in a discussion about the 3 different survey questions. Play the role of moderator, requiring each group to explain why they chose that order. (Ensure that students are also comfortable saying, "we really didn't know about these objects.") See the discussion notes for "correct" answers and frequent student ideas.
- After discussing each question, poll the students on the alternative orders of images suggested. Do not announce the correct order at this time; students should be encouraged to think for themselves.
- After getting a class consensus on all three questions, let students know the correct answers and observations of astronomers.
- Try this activity again with your students after a visit to the *Cosmic Questions* exhibit or as a post-astronomy unit assessment, to see whether their ideas and understanding have changed.

Discussion Notes

Question 1: How Big?

The correct order for the 7 images, from smallest to largest is:

Telescope	40 feet long	(12 meters)
Moon	2 thousand miles diameter	(3,200 kilometers)
Saturn	75 thousand miles diameter	(121,000 kilometers)
Sun	875 thousand miles diameter	(1,408,000 kilometers)
Pleiades	60 trillion miles across the cluster	(1×10^{14} kilometers)
Galaxy	600 thousand trillion miles across	(1×10^{18} kilometers)
Hubble galaxies	600 million trillion miles across the cluster	(1×10^{21} kilometers)

It's hard to tell the size of objects from many of the images we see because they look about the same size in the pictures. But the Sun is much larger than Saturn or any of the planets. In fact, a million Earths would fit inside the Sun. Size counts in nature. Objects much larger than Saturn or Jupiter are fated to turn into stars such as our Sun. They collapse under their own weight and grow fiercely hot as their nuclear fires are kindled.

Students may also wonder whether in the image of the Pleiades, we are talking about the sizes of the individual stars, or all the stars in the picture. For this picture and the Hubble galaxies, the challenge is to figure out the relative size of the "field of view" – all the stars or galaxies in the cluster.

Question 2: How Far?

The correct order for the seven images, from closest to Earth to farthest, is:

Telescope	350 miles above surface of Earth	(560 kilometers)
Moon	250 thousand miles	(402,000 kilometers)
Sun	93 million miles	(1.5×10^{8} kilometers)
Saturn	120 million miles (at its closest)	(1.3×10^{9} kilometers)
Pleiades	2,400 trillion miles	(4×10^{15} kilometers)
Galaxy	200 million trillion miles	(3×10^{20} kilometers)
Hubble galaxies	30 billion trillion miles	(5×10^{22} kilometers)

Figuring out the relative distances of the Sun and Saturn requires knowledge about the relative orbits of the planets. Depending on how much astronomy background students have had, the Pleiades may be placed inside the solar system or as the farthest objects in space. In general, most students (and adults) have a hard time understanding the relative distances of the last three objects.

Students often struggle with the distance of the Hubble Space telescope; after all, it takes images of very distant objects. How far away is the Hubble Space telescope? Many people believe that it is beyond the orbit of the Moon, but it's actually only 350 miles high. That's high enough for a clear view above the Earth's atmosphere, but low enough to enable it to be serviced by the astronauts aboard the space shuttle.

Many people think the beautiful Pleiades cluster of stars must be further away than a cluster of galaxies, because they look smaller. But all the stars we see in the night sky are much closer than even the nearest galaxy. A galaxy is a "city" of many billions of stars. Galaxies are so far away that we can't make out the individual stars in them. In fact, the roughly 5,000 stars we can see with our naked eyes are just among the closest of the billions of stars in our own galaxy, the Milky Way.

Question 3: How Old?

For this question, the correct order for the seven images is actually somewhat ambiguous, and the subject of much current astronomical research! In confronting this seemingly simple survey question, students are grappling with the big ideas of formation of the solar system, life cycles of stars, and evolution of the universe! A best response, one that most astronomers—but not all—might give, is:

Telescope	a few years (1990)
Pleiades	80 million years
Moon	4.5 billion years
Saturn	4.5 billion years
Sun	4.5 billion years
Galaxy	10 billion years
Hubble galaxies	10 billion years

We tend to think of stars as having been around for a very long time. In fact, our Sun is billions of years old. But new stars, like those in the Pleiades, are continually being born. The Pleiades stars are only about 80 million years old.

Which is older, the Sun or the Hubble galaxies? It depends on what you mean by "age." The Sun is about 4.5 billion years old. But the Hubble "deep-field" galaxies are among the most ancient and distant objects we can see in the sky. The light from them has taken about 10 billion years to reach us. So they were born long before our Sun. On the other hand, the Hubble deep field galaxies are young galaxies! Because of light's travel time, we see these galaxies as they were when they formed, only a few billion years after the Big Bang. Many of the stars in the galaxies in this image may be younger than our Sun, so we are looking at the "baby pictures" of objects that are now old.

STUDENT WORKSHEET Cosmic Survey—How Big?

Question 1: How Big?

You have been provided with images of seven different objects in space. Try arranging the pictures **in order of actual size** of the object (or field of objects) pictured. Order the objects so that the smallest is on the top, largest is on the bottom. Write down and keep track of questions that arise as you order the images.

When you are satisfied that you have the best order, record the names of the objects in the spaces below.

Objects Ordered by Actual Size

Smallest in Actual Size

1. ______________________________

2. ______________________________

3. ______________________________

4. ______________________________

5. ______________________________

6. ______________________________

7. ______________________________

Largest in Actual Size

Question 2: How Far?

You have been provided with images of seven different objects in space. Try arranging the pictures **in order of distance** of the object from Earth. Order the objects so that the object closest to Earth is on the top, farthest is on the bottom. Write down and keep track of questions that arise as you order the images.

When you are satisfied that you have the best order, record the names of the objects in the spaces below.

Objects Ordered by Distance from Earth

Closest to Earth

1. ______________________________

2. ______________________________

3. ______________________________

4. ______________________________

5. ______________________________

6. ______________________________

7. ______________________________

Farthest from Earth

Question 3: How Old?

You have been provided with images of seven different objects in space. Try arranging the pictures **in order of age**, beginning with the youngest (most recently formed) object and moving in order to the oldest. Write down and keep track of questions that arise as you order the images.

When you are satisfied that you have the best order, record the names of the objects in the spaces below.

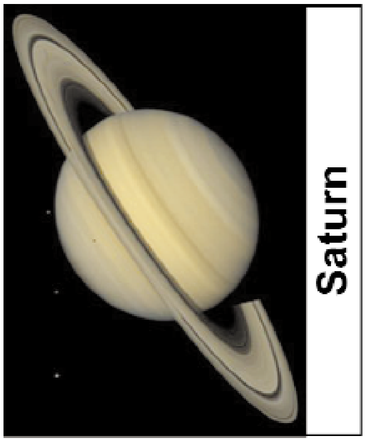
Objects Ordered by Age

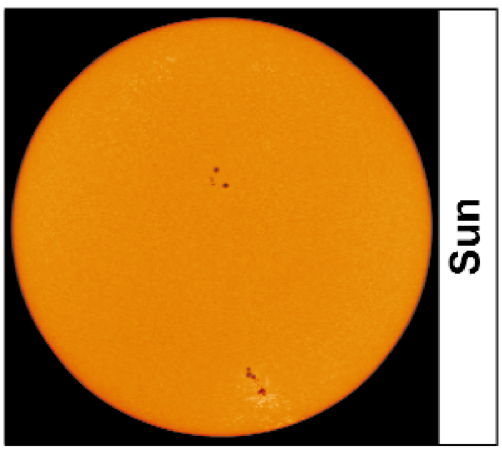
Youngest (Most Recently Formed)

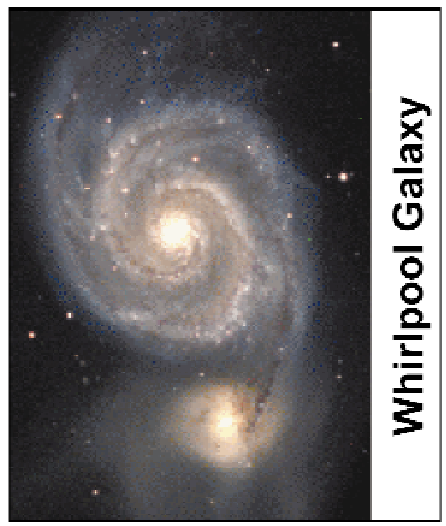
1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________
7. ______________________________

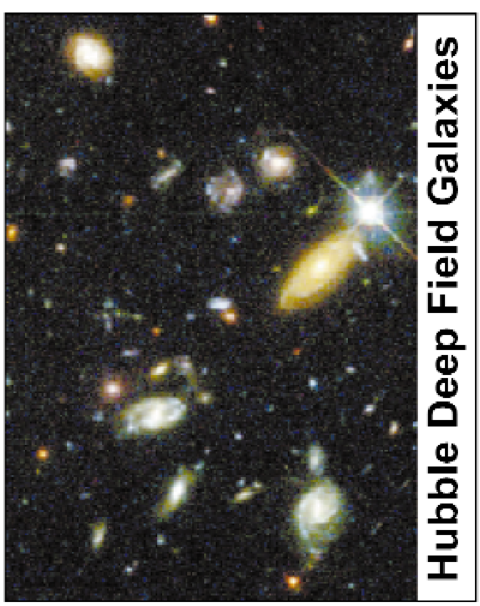
Oldest

COSMIC SURVEY IMAGES–LARGE



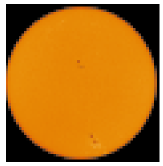






COSMIC SURVEY IMAGES–SMALL


Sun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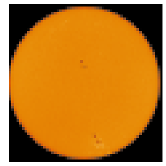
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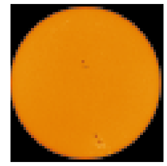
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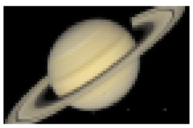
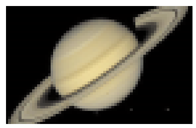

Saturn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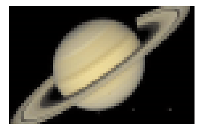
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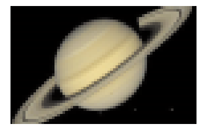
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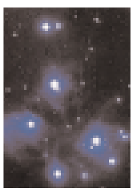
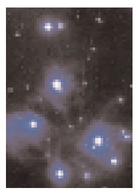
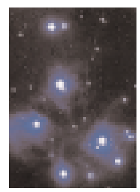
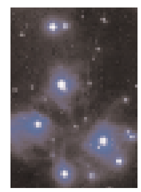
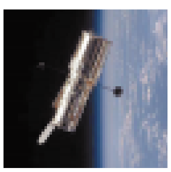
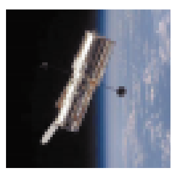

Pleiades Star Cluster


Pleiades Star Cluster


Pleiades Star Cluster


Pleiades Star Cluster


Hubble Space Telescope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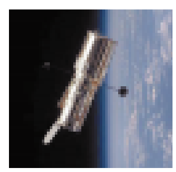
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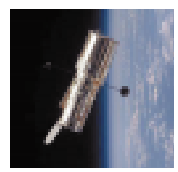
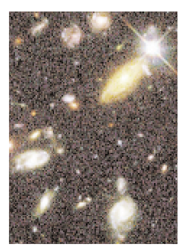
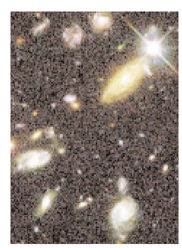

Hubble Space Telescope


Hubble Deep Field Galaxies


Hubble Deep Field Galaxies


Hubble Deep Field Galaxies


Hubble Deep Field Galaxies


Whirlpool Galaxy


Whirlpool Galaxy


Whirlpool Galaxy


Whirlpool Galaxy


Moon


Moon


Moon


Moon

MODELING THE UNIVERSE

Exhibit Connections: Welcome Home, Mapping the Universe, Cosmic Calendar

Goals

- to represent earth's physical place in the solar system and universe
- to understand astronomical size and scale
- to understand strengths and weaknesses of models

Materials

- modeling clay
- paper
- balloons
- different sized balls and marbles
- string
- markers
- scissors
- straws
- other odds and ends that might be useful in creating models
- Copies of Universe Model Analysis Student Worksheet for each group

Background

Our Milky Way is just one of countless galaxies in the universe. Our view of the universe is expanding. Less than a century ago, astronomers thought that our Milky Way galaxy of stars might be the whole universe. Today, we can observe the splendor of galaxies far beyond our own. We can see the estimated 100 billion galaxies that make up our "observable universe."

In the 1980s, Margaret Geller and John Huchra began a survey of the distances to 25,000 galaxies. To their surprise they found that galaxies are grouped in vast filaments and sheets. There appear to be great voids where no galaxies are found. Today, teams of astronomers all over the world are mapping thousands of galaxies, in search of clues about the size and shape of the cosmic web.

In this activity students are challenged to create a model of the universe in a single class period.

Getting a "big picture" of the universe as a whole is a difficult challenge — for professional astronomers as well as for students — but it's a challenge that has occupied humanity for ages. To understand the vast ranges of scale of cosmic systems, the student of the universe has to create and evaluate a variety of models against the observational evidence.

A model is a simplified imitation of something that we hope can help us explain and understand it better. Models can take different forms, including physical devices or sculptures, drawings or plans, conceptual analogies, mathematical equations, and computer simulations. In this activity, students make a physical model to represent as much of the universe as they can. They will then analyze their own and others' models with regard to what they represent, what they misrepresent, what they leave out, and perhaps most importantly, what questions they raise.

While the idea of creating a physical model of the entire universe in one class period can seem a bit daunting, this activity quickly elicits student ideas and preconceptions about the contents and organization of the cosmos. Most students will be somewhat familiar with solar system objects, but may be confused about the relationship of stars to planets, and about the relative distances. The scientist's view of the hierarchical "nested" structure of the universe—planet systems, star neighborhoods, galaxies, galaxy clusters—is not second nature to most people.

Suggestions for Introducing the Activity

This is an introductory activity that helps students think about where we fit in the universe, and model the size, shape and relative position of objects in the universe. Students should be familiar with the objects in our solar system and terms for celestial objects beyond our solar system. This activity begins with students brainstorming about objects in the universe and the concepts of models. Students with less experience with these concepts will require more time and teaching in the discussion part of the activity.

Procedure

Part 1. Discussion

- Facilitate a class discussion of what's in the universe. Ask students "What IS the universe?" Brainstorm a list of objects in the universe that can be viewed with a telescope. As students mention different objects, ask them what they know about them. What is a planet? What is a star? What is a galaxy? How far away are these things, relatively speaking? What do you think they would look like in the telescope? Which ones can we see without the aid of a telescope? How could we group the objects?
- Discuss how scientists use models to suggest how things work and to predict phenomena that might be observed. Ask students to name some familiar models, such as a globe, or a dollhouse. A model is not the real thing. It can always misrepresent certain features of the real thing. Different models may represent only part of what is being modeled.

Part 2. Modeling

- Divide students into groups of three or four. Each student can have one or more of the following roles; model maker(s), recorder of model features, spokesperson.
- Challenge students to create a model of the universe in less than 30 minutes. You may wish to have some groups choose just a part of the universe to model (such as the solar system, or a galaxy, or perhaps just the earth-moon system). One person in the group should write down the features of the model as it is built, along with questions that arise.
- Students can use the Universe Model Analysis Student Worksheet to record the features of their model as they work.

Part 3. Sharing Models with the Class

- As each group presents its model, ask the students to comment on these four questions:
  - What features of the universe does your model represent?
  - What things does your model misrepresent?
  - What things about the universe does your model omit, or not represent at all?
  - What questions came up as your group worked on your model?

Discussion Notes

After sharing all the models, discuss the following questions.

Are there any patterns that emerge?

What parts of the astronomical models do you think represented the "real thing" particularly well? Why?

What parts of the astronomical models do you think misrepresented the "real thing?" Why?

Why is representing the whole universe a difficult challenge?

What are some things you need to find out to design a better model?

STUDENT WORKSHEET Universe Model Analysis

A model is a simplified imitation of something that helps us understand it better. Because a model is not the real thing, it can always misrepresent certain features of the real thing. Different models may represent only part of what is being modeled.

After your group creates your model, you will be asked to explain your model to the rest of the class, commenting on these four questions:

What features of the universe does your model represent?

What things does your model misrepresent?

What things about the universe does your model omit, or not represent at all?

What questions came up as your group worked on your model?

Use this chart to record the features of your model as your group is working.

Features represented	Misrepresented or irrelevant features	Features of real thing omitted by model

Questions we had:

EXPLORING THE SPECTRUM

Exhibit Connections: Mauna Kea, Gemini Observatory, Chandra X-ray Observatory, Spectra Interactive, Infrared Astronomy

Goals

- to demonstrate that the continuous spectrum of white light can be broken into many colors
- to experiment with how filters change the spectrum we perceive
- to demonstrate that the greater the portion of the spectrum you can perceive, the more information you can gather

Background

What can light tell us about the universe? People tell stories. So does light. Astronomers are learning to translate the tales light brings us from deep space. Explore some of the tools that help us understand what the universe is trying to tell us.

This activity introduces students to the visible spectrum and then demonstrates what happens to an image when certain wavelengths are blocked by filters or made visible using special tools. Astronomers study the spectra of stars to learn many things, including how hot or cold stars are, whether they are moving toward or away from us, and whether they have magnetic fields.

Students will gain a basic familiarity with the electromagnetic spectrum that will be useful for the activities that follow in this guide. In the **Multi-Wavelength Exploration of the Universe**, students will move beyond images in the visible spectrum to images of astronomical objects taken with telescopes sensitive to different wavelengths of light. In **Evidence for the Expanding Universe**, students will analyze spectra to investigate galactic motion.

Materials

- overhead projector
- diffraction grating
- cardboard
- colored pencils
- masking tape
- whiteboard or large sheet of white paper
- red, blue and green filters
- transparency of three-circle RGB color diagram
- Exploring the Spectrum Worksheet

A note about the filters:
We recommend the following filters. There are other companies besides Roscolux that supply Theatrical and Stage Lighting Equipment. They will have different code numbers. Ask for pure color filters for science experiments.

Red	medium red ROSCOLUX #27
Green	dark yellow green ROSCOLUX #90
Blue	primary blue ROSCOLUX #74

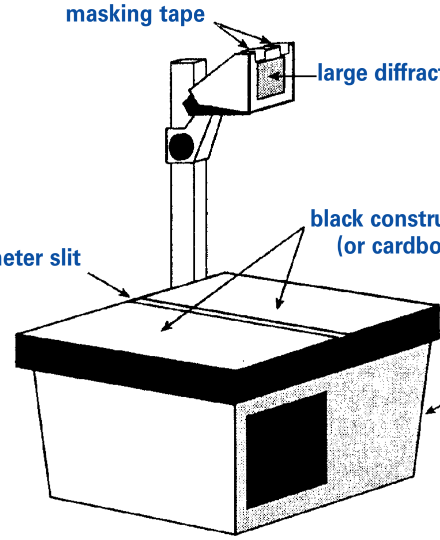
A note about the diffraction grating:
We recommend that teachers use a high-efficiency holographic diffraction grating. A more powerful grating (with more lines per millimeter) is preferred. We suggest 750 lines per millimeter, available from Learning Technologies, Inc., or Rainbow Symphony, Inc.

Suggestions for Introducing the Activity

Students should have some understanding of waves and the concepts of frequency and wavelength.

Procedure

- Find a dark space and cover windows as much as possible. This works best in a very dark room.
- Hand out copies of the Exploring the Spectrum Student Worksheet.
- Place the cardboard on the overhead so there is a slit approximately 1 cm. wide on the base plate of the projector. Turn on the projector lamp.
- Place the diffraction grating in front of the upper lens and rotate the grating until the spectrum appears on both sides of the projected slit on a large sheet of white paper or whiteboard.
- Ask students what they observe. How many colors are there in the rainbow? Can they see separate colors? Have students draw what they see at the top of the worksheet.
- Label the colors with a black marker where they are projected on the whiteboard or white sheet of paper.
- Ask students to predict what they think the spectrum will look like when viewed through a red filter. On the Student Worksheet, have them draw their predicted spectrum.



- Place the red filter in front of the light and view the spectrum. Is it as students predicted? Have them draw the actual spectrum.
- Repeat with the blue and green filters.
- Use the overhead to project the diagram of overlapping red, blue and green circles. What would it look like if you could only see red and could not see blue and green?
- Predict what the diagram will look like when viewed through different colored filters. What happens if you use two filters together?
- (Optional) Try this last exploration with photographs or other color images. If you wish, you may incorporate astronomical images.

Discussion Notes

Many students will incorrectly predict that the red filter will "turn" the whole spectrum red, and likewise for the blue and green filters. This activity can help these students understand the idea that the color is in the light, not the filter, and that the filters "subtract," or absorb certain colors of light, while letting other colors through.

Filters simulate what it is like if you can only see part of the full spectrum. In many ways humans are "color blind." Our eyes can see only the light emitted in the visible part of the electromagnetic spectrum, just as the red filter only "sees" the red part of the diagram. The entire universe emits light in every wavelength, so we must also look at it with telescopes sensitive to light that our eyes cannot see. Different wavelengths of light can give us different information about the properties and features of the object emitting that light. Continue with the next activity to investigate how astronomers use multi-wavelength images to learn more about the cosmos.

Full spectrum

Prediction: Spectrum when viewed through a red filter

Actual spectrum when viewed through a red filter

Prediction: Spectrum when viewed through a blue filter

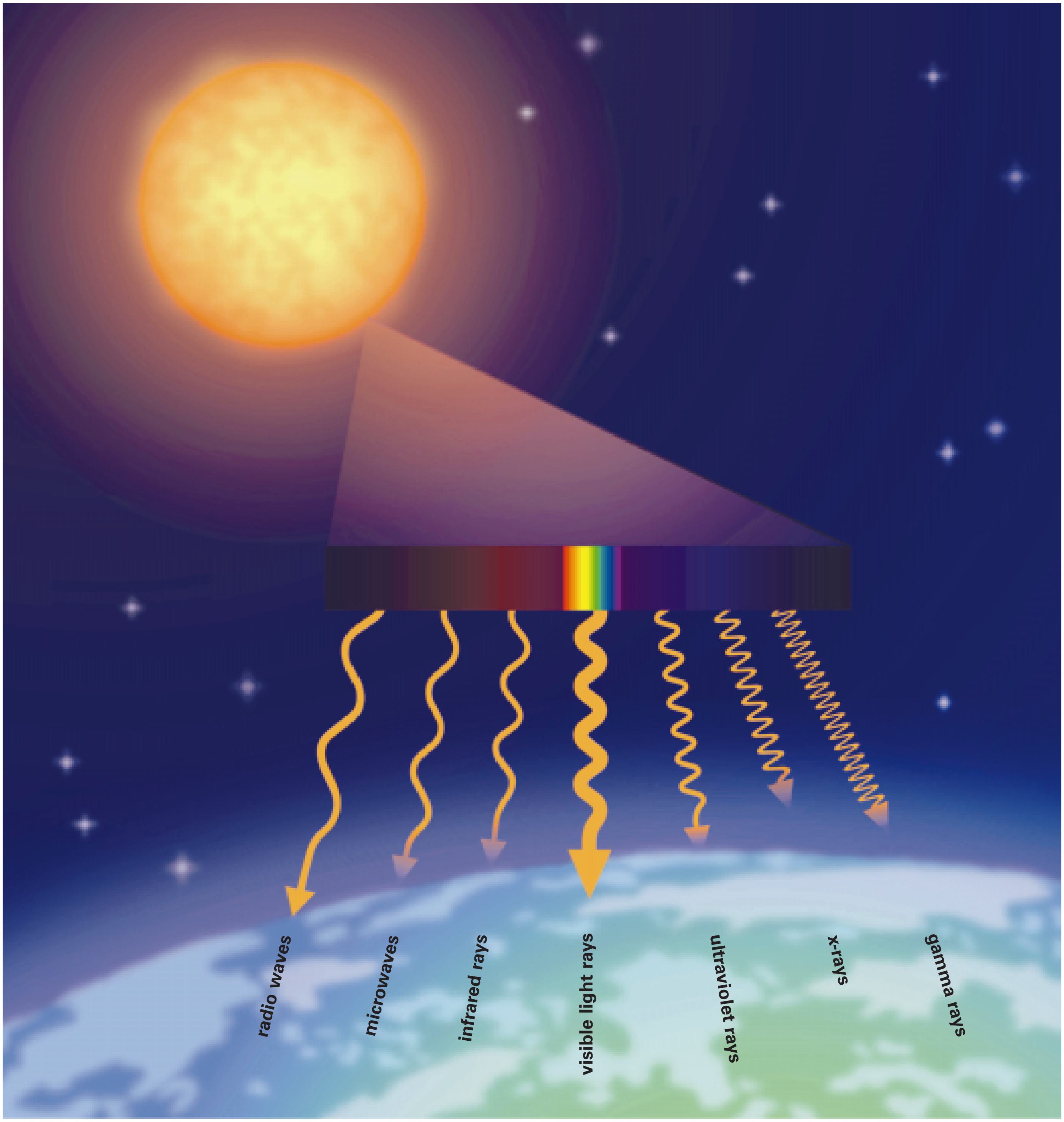
Actual spectrum when viewed through a blue filter

Prediction: Spectrum when viewed through a green filter

Actual spectrum when viewed through a green filter

RGB COLOR DIAGRAM

ELECTROMAGNETIC SPECTRUM



ELECTROMAGNETIC SPECTRUM

Type of Radiation	Description
Radio	Radio waves are at the low end of the electromagnetic spectrum. They are produced by electrons spiraling around magnetic field lines generated by stars, galaxies and black holes. Their long wavelengths allow radio waves to pass through a lot of the gas and dust in space that blocks shorter wavelength light—hence we can probe deep into the hearts of celestial objects by looking in the radio range.
Microwaves	Microwaves are the short wavelength (high energy) end of radio waves. Microwaves radiate from cool gas (cool here is close to absolute zero, -273° C!), such as the giant molecular clouds that become stellar nurseries. We also sail in a sea of microwaves, the cooled radiation that is the afterglow of the Big Bang itself. One percent of television static is from this microwave background.
Infrared	We think of infrared radiation as heat. More energy than radio but less than visible light, infrared radiation is emitted by warm clouds of dust and gas heated by nearby stars. Cool red stars, by far the most numerous type of star, emit most of their light in the infrared. In fact, almost everything in the universe, including people, is a source of infrared radiation.
Optical or visible light	A very narrow range of electromagnetic radiation is detectable by our eyes as visible light. Not only does the Sun have its peak output in this range, but our oxygen/nitrogen atmosphere is completely transparent at these wavelengths. We see planets in the visible because they reflect sunlight; stars and hot gas emit visible radiation.
Ultraviolet	Hot objects, such as the Sun radiate ultraviolet light (blocked, for the most part, by our atmosphere). Some of the hottest stars shine more brightly in ultraviolet light than in visible. The centers of many galaxies glow brightly in ultraviolet light; it's a telltale sign of gas heating up as it spirals closer and closer to the central giant black hole.
X-rays	X-rays are very high-energy radiation, with wavelengths no greater than the diameter of an atom. X-rays are only produced in extreme environments where gas temperatures are millions of degrees or particles are traveling at close to the speed of light. Colliding galaxies, supernovae and the intense gravitational fields around neutron stars and black holes are the prime sources of x-rays.
Gamma rays	Gamma rays are the very highest energy region of the electromagnetic spectrum. Just as visible light is emitted from atoms when electrons change their orbits, so gamma rays are emitted when the atomic nucleus itself changes, such as in radioactive decay. Supernovae are a main source of gamma radiation, when unstable radioactive elements created in the violence of the explosion later decay. The supernova deaths of the biggest super-giant stars create such extremes of temperature and pressure that they can release a sudden flash of gamma radiation, called a gamma-ray burst.

A MULTI-WAVELENGTH EXPLORATION OF THE UNIVERSE

Exhibit Connections: Multi-Wavelength Astronomy, Mauna Kea, Gemini Observatory, Chandra X-ray Observatory, Spectra Interactive, Infrared Astronomy, What are Black Holes?

Goals

- to introduce images taken with telescopes sensitive to different wavelengths of light
- to understand that light carries information about physical features in the universe
- to demonstrate that because light of different wavelengths comes from different physical sources, combining multi-wavelength images provides a more complete picture of the universe

Materials

This activity has several parts. Materials for each part are listed separately.

Background

New Eyes on the Skies

By using special telescopes that can detect wavelengths of light that our eyes can't see, astronomers have discovered objects in the universe we never knew were there. Stars being born, black holes, giant clouds of gas surrounding entire galaxies—all these were discovered using telescopes that could see what our eyes could not.

All telescopes collect light from objects in space. However, what we commonly perceive as light is only one type of electromagnetic radiation. Radiation comes in a range of energies, spanning the electromagnetic spectrum. The spectrum consists of radiation such as gamma rays, x-rays, ultraviolet, visible, infrared and radio. Radiation travels in waves, like ripples on a pond. The energy of the radiation depends on the distance between the crests (the highest points) of the ripple, or the wavelength. For example, low-energy radio wavelengths can range from one centimeter (0.40 inches) to longer than 100 meters (the size of a football field)! High-energy x-ray wavelengths are no bigger than a single atom. The shorter the wavelength, the greater the energy. Astronomers use telescopes that can detect different wavelengths of light in order to gain a deeper understanding of what the universe is like.

In this activity, students will have the opportunity to use actual images taken with telescopes sensitive to several of these wavelengths. Astronomers use images like these, combined with other information, to develop a complete picture of the universe and the objects in it.

Suggestions for Introducing the Activity

Students should be familiar with the electromagnetic spectrum and understand the properties of waves. See the previous activity, **Exploring the Spectrum**.

Part 1. Comparing Optical and X-ray images.

Materials

- transparencies of multi-wavelength images of the Crab Nebula and Eta Carinae cut into four separate images
- overhead projector

Procedure

- Use an overhead projector or give small groups of students the four different multi-wavelength astronomical images A, B, C, and D.
- Explain that these are actual pictures of two different astronomical objects. Two of the pictures are of the Crab Nebula, which is a supernova remnant, the remains of an exploded star that died in 1054 A.D. The other two pictures are of Eta Carinae, a massive star in the Carina nebula, that scientists believe is about to explode as a supernova. Two of the pictures were taken with optical telescopes. Two of the pictures were taken with an x-ray telescope.
- Ask students which two images they think show Eta Carinae and which two show the Crab Nebula? Which two images were taken with optical telescopes? Which two were taken with an x-ray telescope?
- Ask students to explain their choices. What evidence did they use to match the images?
- Now provide students with the following clues:
  - > The Crab Nebula optical image shows the shreds of a star that exploded.
  - > The Crab Nebula x-ray image shows a spinning pulsar within the heart of the nebula.
  - > The Eta Carinae optical image shows a central energetic star ejecting matter as an expanding bubble of gas and dust.
  - > The Eta Carinae x-ray image shows arcs of high-energy gas around the star.
- Give students an opportunity to change their choices based on this additional information.

Discussion Notes

In the discussion about these images, it is more important for students to observe features than to get the right answer. Astronomers use and compare multiple images to develop a more complete picture of the universe.

The correct answers of which images are taken of which object by which type of telescope are as follows:

A - Crab Nebula optical image
B - Eta Carinae optical image
C - Crab Nebula x-ray image
D - Eta Carinae x-ray image

All of these images are in "false" color. The colors represent different wavelengths, but not necessarily the colors we normally associate with visible light. Why would scientists use different colors? For more information on *false color* see http://chandra.harvard.edu/photo/false_color.html.

What do you notice about the shape of the different images? Optical and x-ray images will give different shapes.

These images are snapshots at one moment in time. Have Eta Carinae and the Crab Nebula always looked this way? What do you think is causing the phenomena we observe? (Student answers may vary.)

This set of images, combined with other information, can help us develop a more complete picture of the evolution of very massive stars. What else would you like to know about stellar evolution? For more information about this topic, see the resources at the end of the guide.

Part 2: Analyzing Multi-Wavelength Images as Data

Materials

- multi-wavelength images of the Crab Nebula and Eta Carinae
- Student Worksheet–Analyzing Multi-Wavelength Images
- ruler
- scientific calculator

Background

To an astronomer, an image is more than just a pretty picture of an object in space—it's data. The size and scale of images tell astronomers about the relative sizes of features in each object. The brightness of an image provides information about how hot or how abundant material in the object is. The shape and form give clues about the structure of different features and the mechanisms at work within the object.

Procedure

- Give each student a set of the images of the Crab Nebula and Eta Carinae, a ruler, and Student Worksheet. Use the images and calculators to answer the questions on the Student Worksheet.

Discussion Notes

Some questions are quantitative and answers will vary within an order of magnitude. Other questions are qualitative and ask for student opinions. Answers will vary depending on the range of astronomical knowledge students possess. The goal of this activity is for students to become familiar with the variety of information contained in multi-wavelength images. Understanding the specific cosmic phenomena shown is less important.

Suggested Answers

1. A sample chart appears below:

Image	Observations about shapes and forms	Observations about brightness	Additional observations and questions
Crab Nebula, optical (Image A)	blob-like structure strands or streaks	Streaks are brightest Edges are dark	Lots of points Busy
Eta Carinae, optical (Image B)	Like a bubble Pinched in middle	Brightest in center Dark puffs with brighter streaks	Looks like something exploding
Crab Nebula, x-ray (Image C)	Swirls with tails	Bright in center Swirls are also bright	Something may be spinning
Eta Carinae, x-ray (Image D)	Arc around a dot in center One side is rounded, the other is stretched out	Brightest in center Bright spots around edge, especially in rounded part	Fuzzy Why is it uneven?

2. 60 trillion miles (95 trillion kilometers)

3. 2003 – 1054 = 949 years ago

   949 x 365 x 24 = 8,313,240 hours ago

   60 trillion miles ÷ 8,313,240 hours ≈ 7,217,403 mph

   (11,615,284 km/hr) (3,226 km/sec)

4. Student answers will vary.
   Suggested answer: The material must have been moving much faster immediately after the explosion. It has slowed down (decelerated) over time.

5. Students may have trouble seeing the jets and may measure from different points. The full extent from tip to tip is about 3.6 light years (measured on these images using ratios), which is equal to 21 trillion miles (34 trillion kilometers).

6. Student answers will vary.
   Suggested answer: The jets extend very far beyond the star. There must be a lot of energy coming from the center of the image to generate such x-ray jets.

7. Our solar system is approximately the same size as the ejected material from Eta Carinae.

8. Student answers will vary depending on which "edge" students measure, from about 10 billion miles (16 billion kilometers) to about 20 billion miles (32 billion kilometers).

9. 10,000 hours or 417 days or 1.14 years

10. Student answers will vary.
    Suggested answer: The newly expanded material seen in the optical image would heat the gas farther out causing it to glow. An x-ray image taken 1 year later would show a larger area of heated gas, which might glow brightly in different locations than those seen in the current x-ray image.

The numbers quoted throughout this activity were taken from the following sources:

> Diameter of the material in the optical image of the Crab Nebula from http://www.seds.org/messier/m/m001.html
>
> Diameter of the material in the optical image of Eta Carinae and speed of material around Eta Carinae from http://hubble.stsci.edu/news_.and._views/pr.cgi.1996+23
>
> Diameter of Crab pulsar from http://chandra.harvard.edu/press/crabfact.html

Use the set of optical and x-ray images of the Crab Nebula and Eta Carinae and the information below to answer the following questions. For the purposes of this activity, assume all these images show these objects as they appear on January 1, 2003.

Diameter of the material in the optical image of the Crab Nebula: 10 light years

Diameter of the material in the optical image of Eta Carinae: 10 billion miles

Radius of Pluto's orbit: approximately 4.6 billion miles (7.4 billion kilometers)

1 light year = approximately 6 x 10^{12} miles = approximately 9.5 x 10^{12} kilometers

1 mile = 1.6 kilometers

1. Examine the four images and record what you see:

Image	Observations about shapes and forms	Observations about brightness	Additional observations and questions
Crab Nebula, optical (Image A)			
Eta Carinae, optical (Image B)			
Crab Nebula, x-ray (Image C)			
Eta Carinae, x-ray (Image D)			

2. A light year is the distance that light travels in a single year. How big is the Crab Nebula optical image, in miles? (Kilometers?)

3. The star that created the Crab Nebula exploded in 1054 A.D. If the material we now see originated in a single point, how fast would the gas have to be moving to have reached the distance you just calculated in Question 2. Calculate the velocity in kilometers per second. Assume no acceleration or deceleration. This gives you the average velocity.

4. Scientists now measure the gas to be moving at 1,800 kilometers per second. How does this compare with your answer above? What can you conclude about this expanding cloud of gas?

5. The optical and x-ray images of the Crab Nebula are printed at the same scale. Look for two jets coming out from the bright spot in the center of the x-ray image. How far do these jets extend, in light years? Miles? (Kilometers?)

6. Scientists believe the spinning star at the center of the Crab Nebula is now only 12 miles in diameter. Given this information, how might you explain the huge jets you see in the x-ray image?

7. The Eta Carinae optical image shows a central energetic star ejecting matter as an expanding bubble of gas and dust. How does the size of our solar system compare with the size of the ejected material in the optical image?

8. The x-ray and optical images of Eta Carinae are printed at the same scale. How far out from the central star does the arc in the x-ray image extend, in miles? (Kilometers?)

9. If the material from the center of the star is accelerating outward at 1.5 million miles per hour, how long will it take for the material visible in the optical image to reach the extent of the x-ray image?

10. As Eta Carinae continues to eject material, this material heats up the surrounding gas, causing it to glow in an x-ray image. What do you think the x-ray image will look like in one year?

Part 3: Getting a More Complete Picture Using Four Types of Images.

Materials

- transparent overlays for Centaurus A (cut the page to separate the four images)
- overhead projector

Procedure

- Use an overhead projector to display images of the Centaurus A galaxy. Show each image one at a time. Ask students what they observe, reminding them to pay close attention to relative size, shape and brightness.

  Optical Image: This shows a large galaxy with a giant dust lane across the center.

  Infrared Image: This shows the same galaxy with a very bright center.

  Radio Image: This shows two huge lobes of gas and a bright spot in the center.

  X-ray Image: This shows a bright streak, which represents a giant jet of high-energy gas and many bright spots.

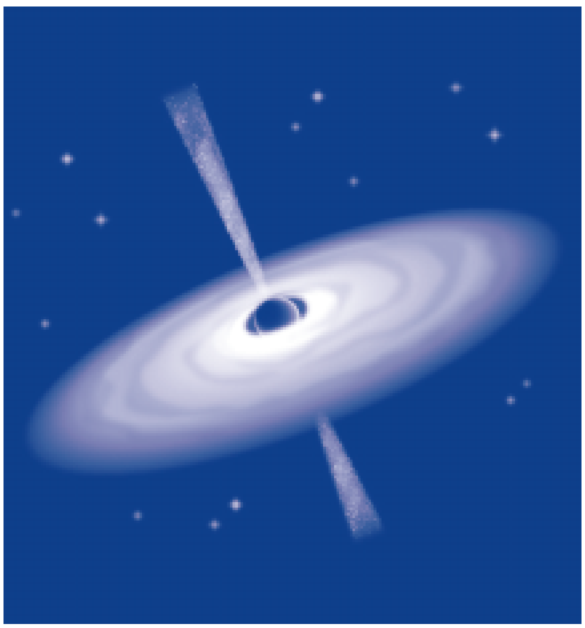
- Use the images in the following patterns to develop a more complete understanding of what is happening in Centaurus A. As you place each image, or combination of images, on the overhead, ask students what they notice. Use the symbols at the corners of the images to align the images as you lay them on top of each other.

  1. Place the Centaurus A optical image on the overhead and overlay with the infrared image. Both images show a galaxy with a dust lane across the center. The infrared image allows us to see through the dust lane to a bright spot in the center.
  2. Remove the infrared image and overlay the optical image with the radio image. The lobes of gas extend far beyond the center of the galaxy.
  3. Remove the radio image and overlay the optical image with the x-ray image. The high-energy jet runs perpendicular to the dust band.
  4. Remove all the images. Place the radio image on the overhead and overlay the x-ray image. The lobes of gas line up with the high-energy jet.

Discussion Notes

Again, the goal of this activity is for students to recognize how multiple images provide a more complete picture, rather than to identify specific astronomical phenomena. Students should not be expected to independently determine the story of the images described here. This explanation is the result of many astronomers' collaborations over many years.

The optical and infrared images of Centaurus A show a galaxy shining by starlight. Only when we view Centaurus A at other wavelengths do we realize that most of its radiation is being produced by something radically different. X-ray and radio images reveal a source of extreme power at the center of the galaxy, something very small but capable of shooting jets of radiation across millions of light years of space. The only mechanism now known to have this capability is the intense gravitational and magnetic fields of a supermassive black hole.



The current model for the anatomy of a black hole

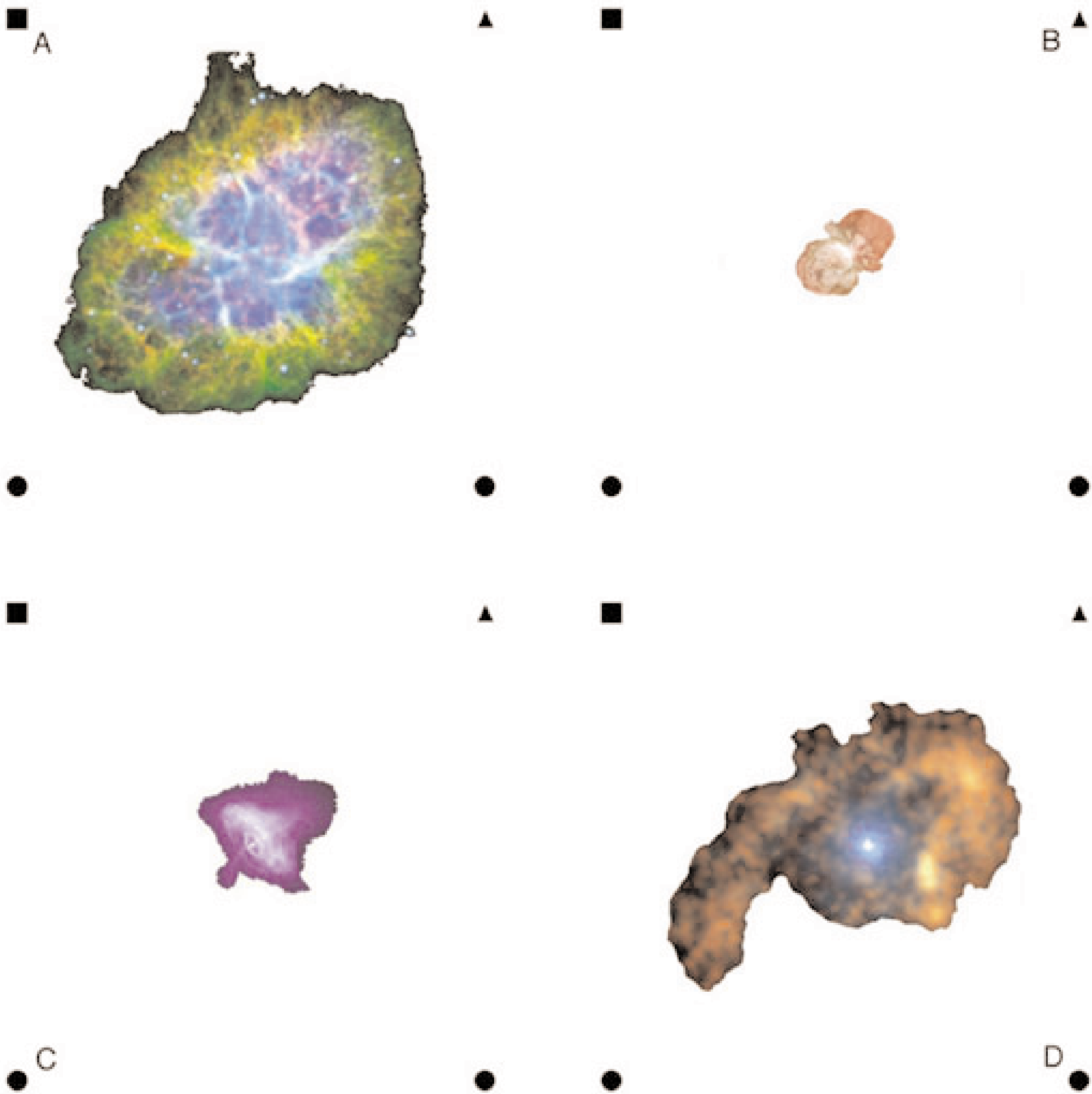
Inside a black hole the known laws of nature break down. Look for the edge of the **black hole** at the center of the illustration.

Matter approaching the black hole spirals in, gains energy and heats to millions of degrees, forming a relatively flat disk of gas and dust. Look for the flat **accretion disk** around the edge of the black hole.

Some matter near the center of the black hole is hurled outward at nearly the speed of light. Look for **jets** perpendicular to the plane of the accretion disk.

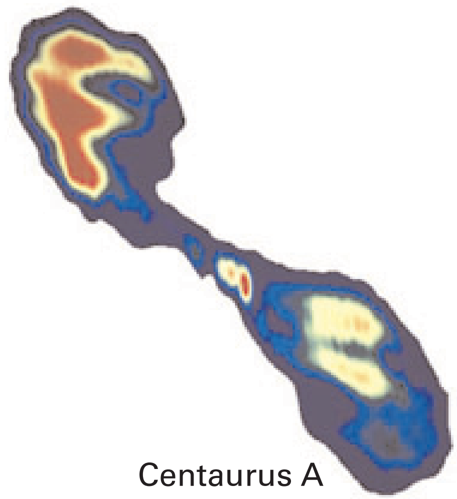
This set of images of Centaurus A, combined with other information, helps us develop a more complete picture of the structure of galaxies. Scientists now believe supermassive black holes reside at the center of most galaxies, including the Milky Way. Multi-Wavelength images provide clues about the nature of black holes and the giant jets being emitted from these powerful objects.

CRAB NEBULA AND ETA CARINAE IMAGES



CENTAURUS A IMAGES

Centaurus A
optical



Centaurus A
radio

Centaurus A
infrared

Centaurus A
x-ray

MODELING THE EXPANDING UNIVERSE

Exhibit Connections: Cosmic Calendar, The Big Bang

Goal

- to visualize a universe expanding in all directions

Materials

This activity has several parts. Materials for each part are listed separately.

Background

Before 1917, many scientists thought the universe always existed. But Einstein's revolutionary theory of gravity changed all the rules. It opened up the mind-boggling possibility that space itself—the permanence of which had never been questioned—might actually be expanding. If space is expanding, the universe we inhabit today could once have been infinitely smaller.

In 1929, astronomer Edwin Hubble made the amazing discovery that distant galaxies are speeding away from us. This means that the galaxies we see today were once much closer together—originating from a tiny region of space.

The origin of the universe remains one of the greatest questions in science. Current scientific evidence supports the Big Bang model, which states that 12 to 15 billion years ago, the entire universe began expanding from a very hot, very dense state. This sudden expansion is known as the Big Bang.

What does it mean to say the universe is expanding? The Big Bang was an expansion of space itself. Every part of space participated in it. Space is not simply emptiness; it's a real, stretchable, flexible thing. Galaxies are moving away from us because space is expanding. Galaxies are moving *with* space, not *through* space!* The models in this activity demonstrate how the motions of the galaxies reveal the continuing expansion of the universe.

In the 1920s, Edwin Hubble measured the motion of galaxies. By measuring a galaxy's distance from us and how fast that galaxy is receding (its recession velocity), he found a simple relationship: double the distance, double the velocity; triple the distance, triple the velocity. This is Hubble's Law. In equation form, it is written:

$$v = H \times d$$

Recession velocity = Hubble's constant x distance from us

The slope of the graph of distance vs. velocity represents the **Hubble Constant** for the universe.

The Hubble Constant describes how fast the universe is expanding. By measuring the rate of expansion, the size and age of the universe can be calculated. Interpreting recent observational results from space-borne and ground-based telescopes, scientists have determined different values of Hubble's constant. Determining the precise value of the Hubble constant is key to understanding the origin of the universe, and there are several factors that affect this determination. For example, the universe may not have been expanding at the same rate throughout time; that is, the expansion itself may be accelerating. Questions like these make the age of the universe a hot topic—one of the most controversial in the study of cosmology. The age of the universe is currently estimated to be between 12 and 15 billion years.

* There is also a local motion through space as galaxies interact with their neighbors, but on larger scales, the expansion of space dominates.

Suggestions for Introducing the Activity

Gather students' ideas and questions about the Big Bang. What caused the Big Bang? Was there anything before the Big Bang? What evidence do we have of the Big Bang? When we say the universe is expanding, what exactly is expanding? Students should also discuss models and the inherent flaws of any model.

In this activity, students will be using rulers to measure distances between hypothetical galaxies and using these distances to calculate the velocities of these galaxies. Astronomers do not have rulers in space, but the relationship between distance and velocity means that they can calculate distances by measuring velocities. Astronomers measure the recession velocities by looking at the spectra of the galaxies. This idea is explored further in **Evidence for the Expanding Universe**.

Part 1. Elastic band model–a one-dimensional model

Materials

- Six-foot length of one inch (or greater) wide elastic ribbon, or exercise band or bungee cord
- approximately 1/2-inch round stickers
- stapler
- tape measure
- white board or chalk board

Procedure

- Prepare the model of the universe. Stickers represent galaxies in space. The elastic band represents space.
- Start from the center and place the stickers evenly along the elastic at approximately one-inch intervals. Staple the stickers to keep them from slipping.

- Ask two students to each take an end of the elastic and hold it taut without stretching against the board. On the board, mark the points of the stickers.
- Label one sticker Galaxy A.
- To model the universe expanding, hold Galaxy A still and gradually pull on both ends of the elastic.
- Observe what happens to the distance between the galaxies.
- Measure the distance between the galaxies.
- Now choose a new sticker and label it as Galaxy B. Repeat the process, holding Galaxy B still.

Discussion Notes

Are the galaxies moving away from each other? Is there a center to the expanding universe? Are the galaxies themselves expanding? Is there any pattern to how far apart the galaxies appear to be?

This model shows how galaxies farther away from us appear to be moving faster. That is, the galaxies farthest from the reference galaxy move a greater distance in the same amount of time. Because velocity equals distance divided by time, a larger distance over a constant time corresponds to a higher velocity.

Part 2. Galaxy fields–a two-dimensional model

Materials

- Student Worksheet Galaxy Field A Transparency
- Student Worksheet Galaxy Field B Transparency
- Overhead projector
- transparency markers
- ruler

Procedure

- Project Student Worksheet Galaxy Field A Transparency for everyone to observe. This is a picture of an imaginary field of galaxies taken at one moment in time.
- Lay Student Worksheet Galaxy Field B Transparency over A. Imagine this represents the same galaxy field one second later. Choose one galaxy (it is easier to choose a large dot) and match up Worksheets A and B. It is important to keep the Worksheets square and not rotate either one, as you do this.
- What can you observe about how the other galaxies appear to have moved? (It should look as if all the galaxies are moving away from this point).
- Now choose a different point on Worksheet B to align with Worksheet A. Observe the pattern again. (It should look again as if everything is moving away from this point.)

Discussion Notes

Are we at the center of the universe? Is there a center? Is there an edge? In the universe every galaxy is moving away from every other galaxy. There is no center. From the point of view of any galaxy, that galaxy appears to be the center of the expansion. This observation is similar to observations made by a person in a moving car. Objects outside the car may appear to be moving away, but the person inside the car does not experience the sensation of movement.

Part 3. Measuring the relative motion of galaxies

In this model the imaginary galaxy fields on Student Worksheets Labeled Galaxy Fields 1 and 2 show only a few galaxies. Students will measure the distance the galaxies appear to have moved in one second.

Materials

Each student, or small group of students, should have:

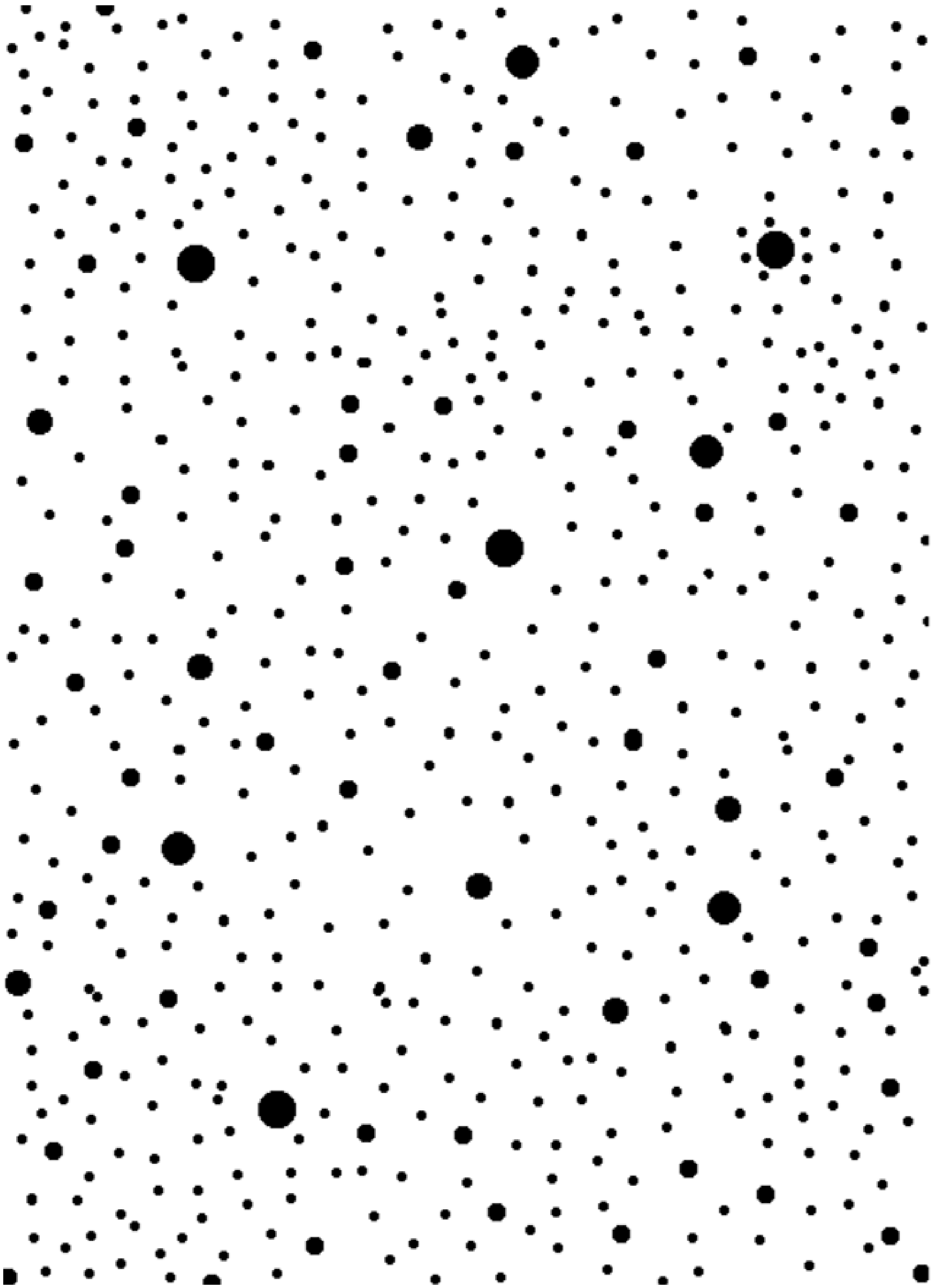
- Student Worksheet Labeled Galaxy Field 1
- Student Worksheet Labeled Galaxy Field 2, copied onto transparency
- Expanding Universe Student Worksheet
- transparency marker
- ruler

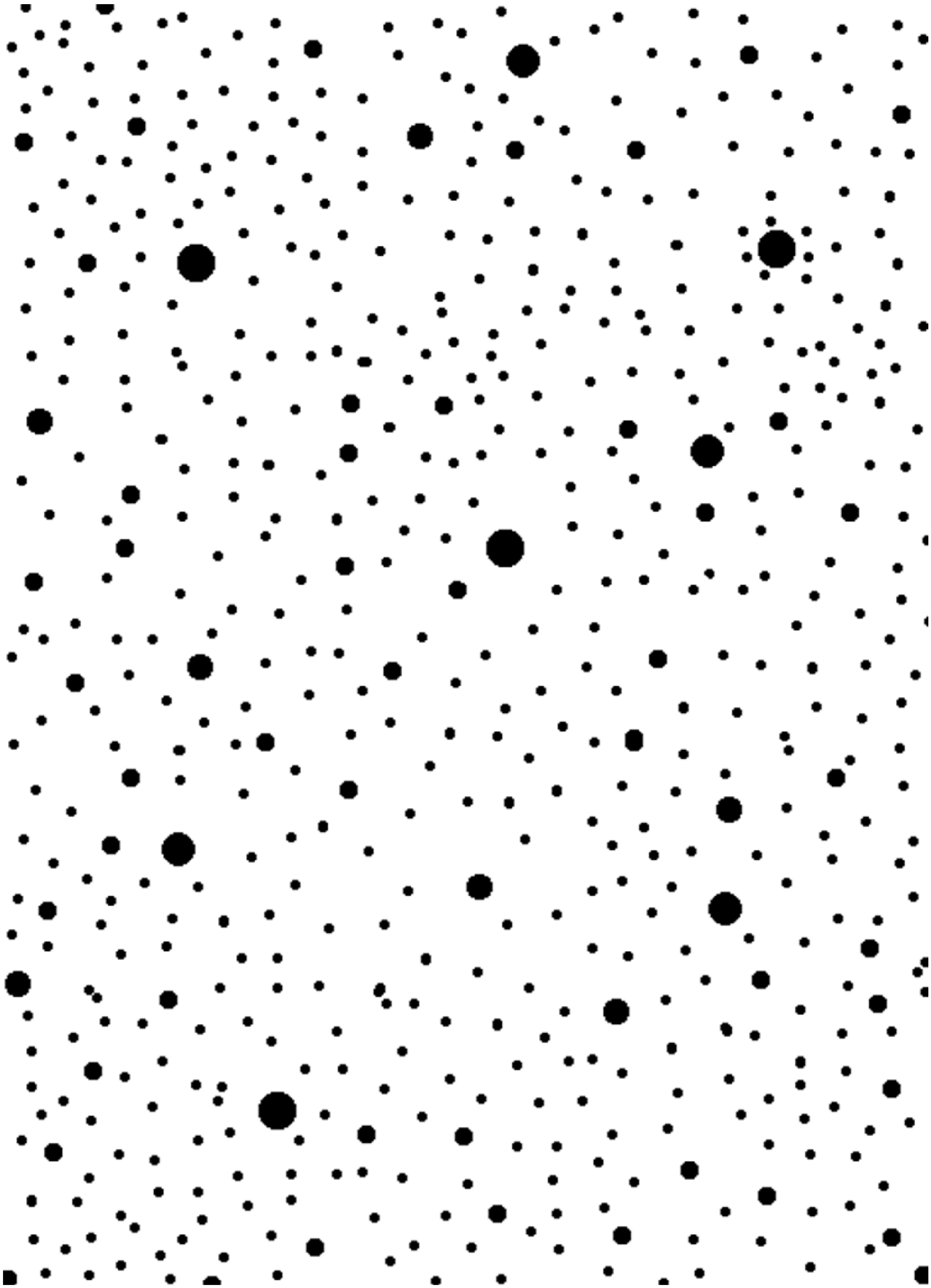
Procedure

- Each student chooses a different galaxy and locates it in the galaxy field on Student Worksheet Labeled Galaxy Field 1. Remember, this is just an idealized map. Real galaxies are neither sized this regularly nor spread this regularly throughout the universe.
- Lay Worksheet 2 over Worksheet 1 and align the two using the letter of your galaxy. This simulates one second of universal galaxy motion. Your galaxy should not appear to have moved from the top sheet to the bottom sheet.
- What can you observe about how the other galaxies appear to have moved?
- Use a transparency marker to draw an arrow from each galaxy's position at time 00:00:00 to where it has moved one second later. Record your observations and graph your data on the Expanding Universe Student Worksheet.
- Collect all the copies of the Worksheet 2 transparencies. Pile the transparencies on top of each other. You should notice that students have drawn arrows in different directions for the same galaxy. Is it possible for something to move at different speeds and direction at the same time? Is one set of data right and another wrong?

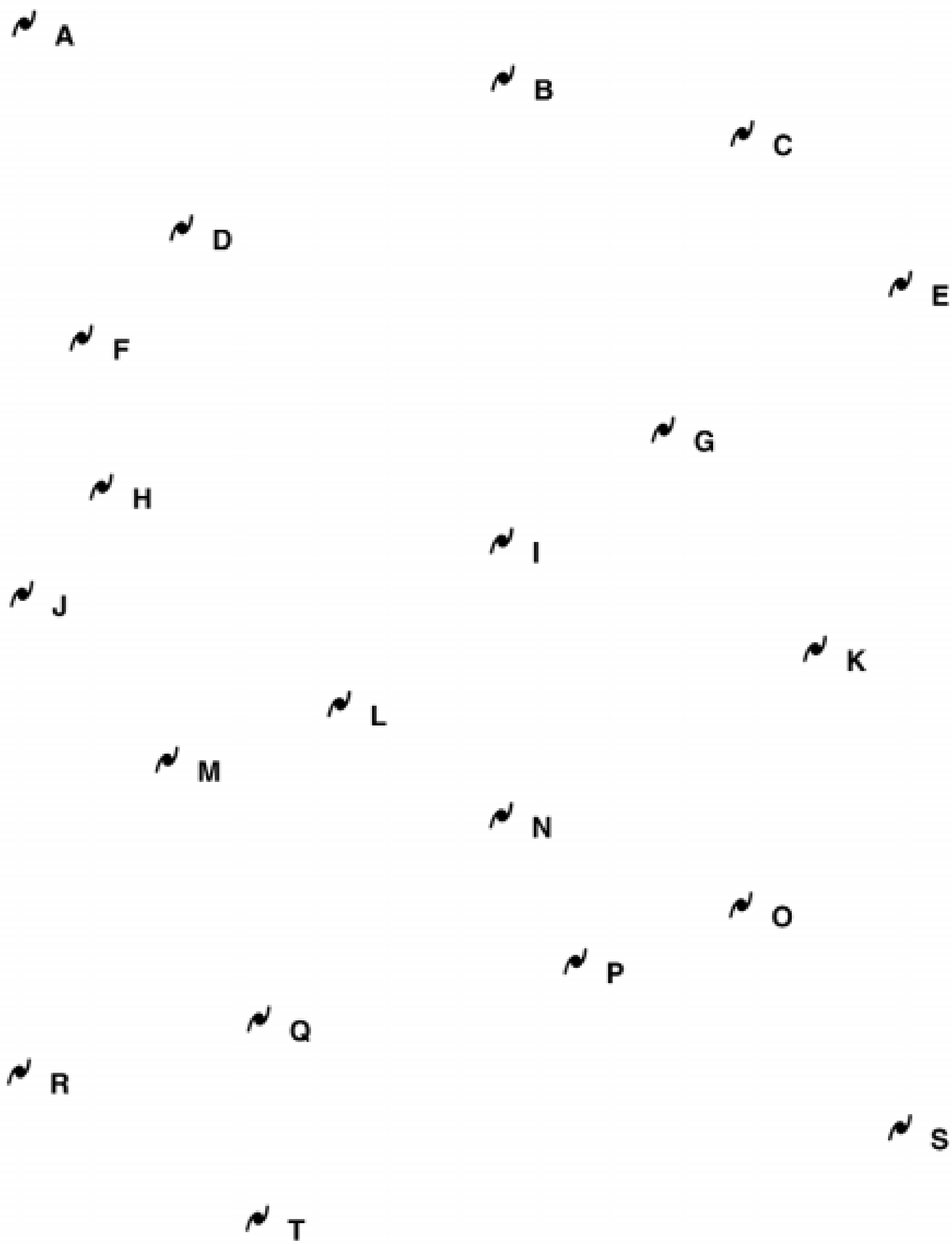
Discussion Notes

Each student's galaxy seems to be the center of the expansion. The only way this could possibly happen is if space itself is expanding because otherwise an object (such as the Sun or the Earth) would have to be moving in two directions at once. The expansion of space is the only way to reconcile the observation that from Earth everything appears to move away from us. Astronomers assume that we are not in a special place in the universe; that our place in the universe is not different from other places. This assumption is called the Cosmological Principle. It suggests that every other place should observe the expansion just as we do—a situation that would be true if space itself were expanding between the galaxies.

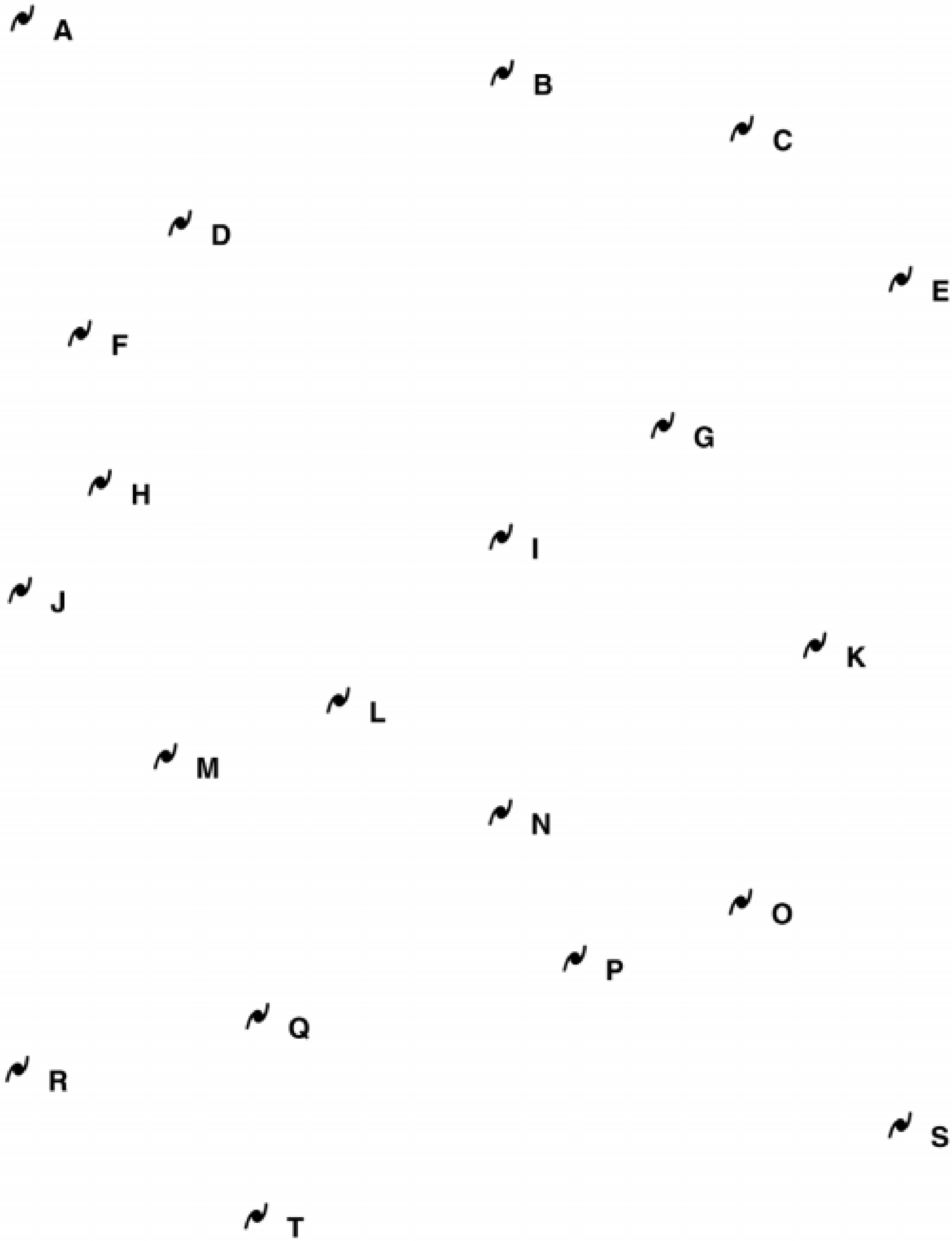




STUDENT WORKSHEET Labeled Galaxy Field 1



STUDENT WORKSHEET Labeled Galaxy Field 2



STUDENT WORKSHEET Expanding Universe

Choose a galaxy on Labeled Galaxy Field 1. Remember, this is just an idealized map. Real galaxies are neither this regularly sized nor spread regularly throughout the universe.

Lay Labeled Galaxy Field 2 Transparency over Labeled Galaxy Field 1 and align the letters of your galaxy. This simulates one second of universal galaxy motion. Align your galaxy so it does not appear to move from the top sheet to the bottom sheet. (Be careful not to rotate the papers.)

What can you observe about how the other galaxies appear to have moved?

What direction are the galaxies moving?

Have all the galaxies moved the same distance?

Using a colored transparency marker, draw arrows on Worksheet 2 to represent the motion of the other galaxies. The arrow should start at the center of each galaxy on Worksheet 1 and end at the center of that same galaxy on Worksheet 2. The arrows represent the direction and speed, or velocity, of motion of the galaxies throughout the universe.

Record how the length and direction of the galactic arrows change with their position relative to your galaxy.

Graph the relationship between the distance of each galaxy from your chosen galaxy and the length of each arrow.

EVIDENCE FOR THE EXPANDING UNIVERSE*

Exhibit Connections: Cosmic Calendar, The Big Bang, Spectra Interactive

Goals

- to become familiar with emission spectra as sources of information
- to use galactic spectra to determine galactic speed

Materials

Each student or small group of students needs a set of student worksheets:

- Looking at Spectra
- Calculating and Graphing Galactic Speed
- Images of Four Galaxies
- Spectra of Galaxies A, B, C, and D

Students should have access to color images of all spectra, including those on the Student Worksheet Looking at Spectra.

Background

The previous activity helps students to visualize a universe expanding in all directions. In this activity, students use astronomical evidence to explore this notion further. How do we know the universe is expanding?

The Big Bang model of the origin of the universe states that the universe originated in a very hot, very dense state 12 to15 billion years ago and has been expanding and cooling ever since. There are three lines of evidence that support this model.

1. We observe that galaxies are moving away from us.
2. We can detect the afterglow from this hot dense state of the early universe. The hot glowing fog that once filled all of space has now cooled to an "invisible" sea of low-energy microwaves (in the radio region of the electromagnetic spectrum). Telescopes sensitive to microwave light detect this afterglow across the entire sky and show that we are bathed in this radiation that dates from when the universe was barely 300,000 years old.
3. Spectroscopic observation of the universe shows its chemical composition to be roughly 75% hydrogen, 25% helium by mass (12 to 1 ratio of hydrogen to helium atoms). The creation of so much helium from hydrogen in nuclear reactions could only have happened if the universe was at some point in time very hot and very dense.

In this activity students examine the first line of evidence, galactic motion. Galaxies are so large, and so far away, that you could never see them move just by looking – even if you looked for a whole lifetime through the most powerful telescope! However, there is a way to detect the motion of a galaxy. By examining the spectrum of light from a galaxy, you can determine whether the galaxy is moving toward or away from us, and how fast. Students will look at optical images of four galaxies. They will then compare the emission spectra from these same four galaxies and measure the wavelength of the red hydrogen line for each galaxy. Because of the Doppler effect, the wavelength will shift as the source travels through space.

Suggestions for Introducing the Activity

Students should already be familiar with the electromagnetic spectrum and understand that atoms emit and absorb light of fixed standard wavelengths. In Part 2, students observe the red-shift of the hydrogen lines in the spectra of galaxies. You may wish to introduce the concept of Doppler shift before completing this activity, or use the activity to motivate a discussion about the relationship between motion and wavelength. For an online tutorial about the Doppler effect, visit cfa-www.harvard.edu/seuforum/galSpeed or www.pbs.org/wgbh/nova/universe/moving.html.

* This is adapted from an online activity: How Fast Do Galaxies Move? An Interactive Lab. Produced for NASA's Office of Space Science by the Smithsonian Astrophysical Observatory © 2001 Smithsonian Institution. It can be found at: http://cfa-www.harvard.edu/seuforum/galSpeed

Part 1. Looking at Spectra

Atoms emit and absorb light of fixed, standard wavelengths. An emission or absorption spectrum shows a specific pattern of lines that is a kind of "fingerprint," unique to the particular types of molecules. The emission spectrum of glowing hydrogen gas has one bright red line, a fainter blue line, and several other faint lines. The red line for hydrogen has a wavelength of 656 nanometers.

A spectrum of a galaxy is the pattern produced when the light from the galaxy is passed through a prism or similar device. The element hydrogen is the most common element in the universe, and it is plentiful in galaxies. Hydrogen is present in huge clouds of gas that fill some of the space between the stars in a galaxy. The bright red hydrogen line is an easily recognizable feature in many astronomical spectra.

Procedure

- Observe the spectrum of the Sun on the Student Worksheet.
- Observe the spectrum of the fluorescent lamp on the Student Worksheet. Have students record the colors they see and the wavelengths.
- Observe the spectrum of hydrogen gas. Have students record the colors they see and the wavelengths.
- Look again at the spectrum of the Sun and look for dark lines at these recorded wavelengths. Although these absorption lines are not as dramatic as the emission lines in the pure hydrogen spectrum, their presence tells us that the Sun contains hydrogen, and that this hydrogen is absorbing light.
- Observe the spectrum of the sample galaxy on the Student Worksheet. Determine the wavelength of the red hydrogen line in this spectrum. Note that the position of this peak is different from the laboratory sample of hydrogen.
- Discuss why the red hydrogen line would be in a different place.

Part 2. Analyzing Galactic Spectra, Calculating and Graphing Galactic Speed

As students observe the emission spectra from four different galaxies, they will observe that in each spectrum the bright red hydrogen line has shifted from its characteristic wavelength of 656 nanometers, as seen in the laboratory spectrum of hydrogen gas. This shift toward the longer wavelength part of the spectrum, which is the redder end of the spectrum, is called "redshift."

The observed redshift can be used to calculate the galaxy's velocity. The amount of the observed redshift is proportional to the speed of the source (for speeds that are not close to the speed of light). For example, light from a galaxy moving away from us at 10% of the speed of light will be redshifted by 10%. The hydrogen line that was at 656 nanometers will be redshifted by about 65 nanometers to 721 nanometers. (As speeds approach the speed of light, the principles of relativity must be used to explain the relationship between an object's redshift and its speed. However, the speeds of the galaxies in this activity are much less than the speed of light, so the simple proportion described above can be used.)

Using the galactic spectra, students will calculate how fast Galaxies A, B, C, and D are receding from us, and graph that in relation to the galaxy's estimated distance from us.

Procedure

- Give each student or small group of students optical images of the four galaxies, A, B, C, and D.
- Tell students to assume that these four galaxies are all approximately the same actual size.
- Ask students to arrange the four galaxies in order of distance from the earth. Discuss what evidence they used for their choices.
- Label the graph on the student worksheet by writing the letters of the galaxies in order of their estimated distance along the x- axis.
- Give each student or small group of students the spectra of the four galaxies, A, B, C, and D.
- Determine the wavelength of the red hydrogen line in the spectra from galaxies, A, B, C and D. Record these on the worksheet.
- Compare the wavelength of the red hydrogen line in each galactic spectrum to the laboratory sample of hydrogen gas. By how much has the line been shifted? What fraction of the original wavelength is it? At what fraction of the speed of light is the galaxy moving?
- Calculate the recession velocity of the four galaxies using the Student Worksheet.
- Plot the velocity data on the y-axis of the graph on the Student Worksheet.

Discussion Notes

In the 1920s, Edwin Hubble measured redshifts to determine the velocities of galaxies. He found that there was a linear relationship between a galaxy's distance from us and how fast that galaxy is receding (its recession velocity). This simple relationship can be described in equation form, where the slope of the graph of distance vs. velocity represents the Hubble Constant for the universe.

$$v = H \times d$$

Recession velocity = Hubble's constant x distance from us

This equation, known as Hubble's Law, states that a galaxy at double the distance will have double the velocity; at triple the distance, it will have triple the velocity. Hubble's Law is important in understanding the age and size of the universe, and is described further in the background information for the previous activity, Modeling the Expanding Universe.

Suggested Answers

These notes provide answers to some of the questions on the Student Worksheets and can be used to help guide a class discussion.

In Part 1, when looking at the pure hydrogen spectrum, students should measure peaks at 656 nanometers, 486 nanometers, and 434 nanometers. Although this third line is not visible in the color image, it can be measured on the graph. All three of these lines appear in the spectrum of the Sun and may be easier to find in the graph than in the color image.

In Part 2, we have assumed all the galaxies are all the same actual size. Therefore, Galaxy B, which appears largest in the optical image, is presumed to be closest to us. Accordingly, the smallest image (C) is farthest away. In order from closest to farthest, the galaxies are B, D, A, and then C.

Galaxy B is about 210 Mly (million light years) from the Milky Way.

Spectrum B shows the hydrogen line at 666 nanometers. This is redshifted 10 nanometers, or 1.5 %, from its original location of 656 nanometers. Therefore, the velocity of Galaxy B is 0.015 times the speed of light (300,000 km/s), which equals about 4,500 km/s. Students may measure the redshift to be between 5 and 13 nanometers, which corresponds to a recession velocity between 4,350km/s and 6,000 km/s.

Astronomers calculate the recession velocity of Galaxy B to be 4350 km/s.

Galaxy D is about 750 Mly from the Milky Way.

Spectrum D shows the hydrogen line at 690 nanometers. This is redshifted 34 nanometers, or 5 %, from its original location of 656 nanometers. Therefore, the velocity of Galaxy D is 0.05 times the speed of light (300,000 km/s), which equals about 15,000 km/s. Students may measure the redshift to be between 29 and 39 nanometers, which corresponds to a recession velocity between 13,000 km/s and 18,000 km/s.

Astronomers calculate the recession velocity of Galaxy D to be 15,400 km/s.

Galaxy A is about 1,520 Mly from the Milky Way.

Spectrum A shows the hydrogen line at 724 nanometers. This is redshifted 68 nanometers, or 10 %, from its original location of 656 nanometers. Therefore, the velocity of Galaxy A is 0.10 times the speed of light (300,000 km/s), which equals about 30,000 km/s. Students may measure the redshift to be between 65 and 73 nanometers, which corresponds to a recession velocity between 29,000 km/s and 34,000 km/s.

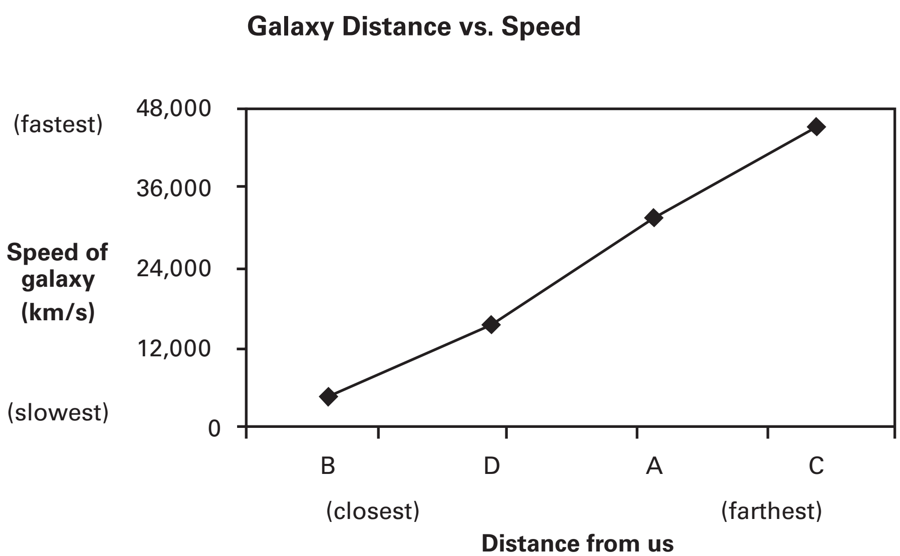
Astronomers calculate the recession velocity of Galaxy A to be 31,400 km/s.

Galaxy C is about 2,260 Mly from the Milky Way.

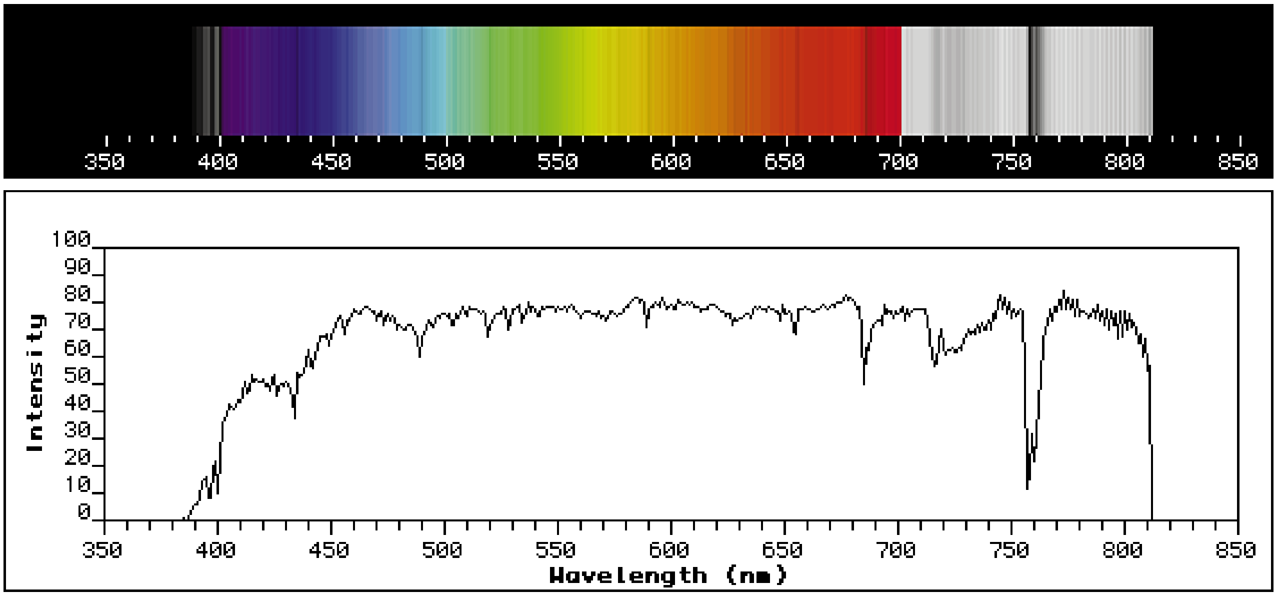
Spectrum C shows the hydrogen line at 752 nanometers. This is redshifted 96 nanometers, or 15 %, from its original location of 656 nanometers. Therefore, the velocity of Galaxy C is 0.15 times the speed of light (300,000 km/s), which equals about 45,000 km/s. Students may measure the redshift to be between 94 and 102 nanometers, which corresponds to a recession velocity between 42,000 km/s and 47,000 km/s.

Astronomers calculate the recession velocity of Galaxy C to be 44,700 km/s.

Sample Graph

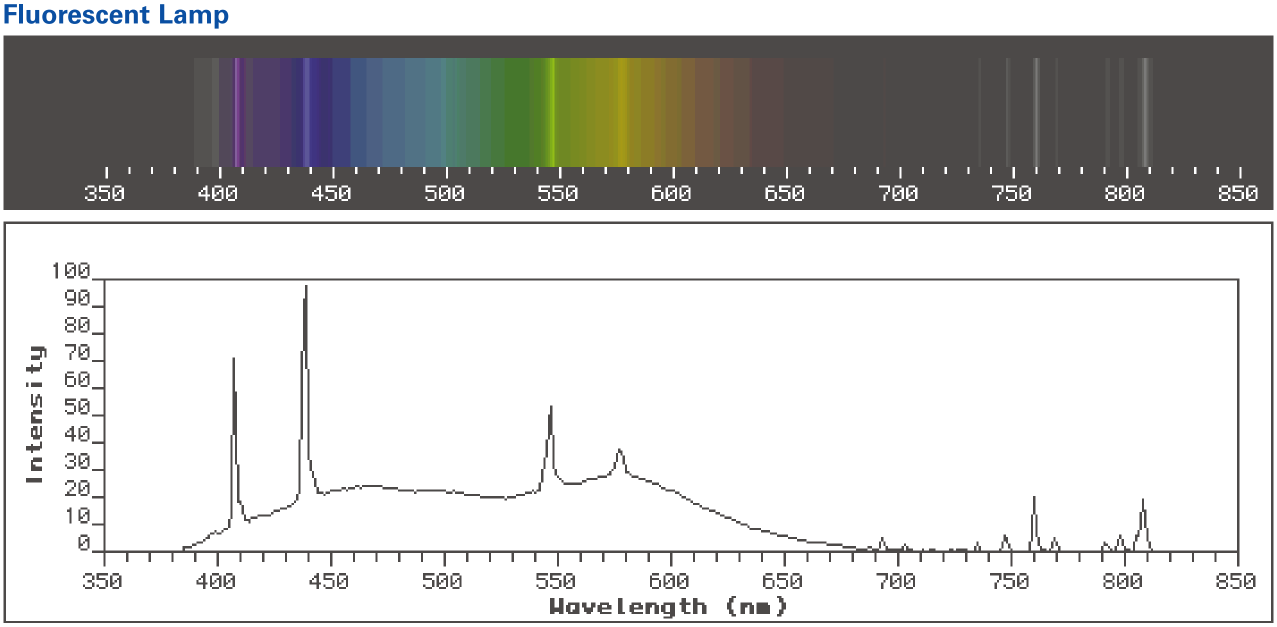


The Sun



This is the spectrum of the Sun. The pattern is created by passing light from the Sun through a glass prism, which separates the light into its component colors. In addition to the familiar rainbow of colors, notice the dark lines. These lines are produced by atoms in the Sun's atmosphere that absorb certain wavelengths of light. This dark-line pattern is called an absorption spectrum. Note that the pattern extends past the red, into the infrared region. Infrared light is not visible to our eyes. It is colored grey in this image. The grey area to the left of the blue is part of the ultraviolet region of the spectrum.

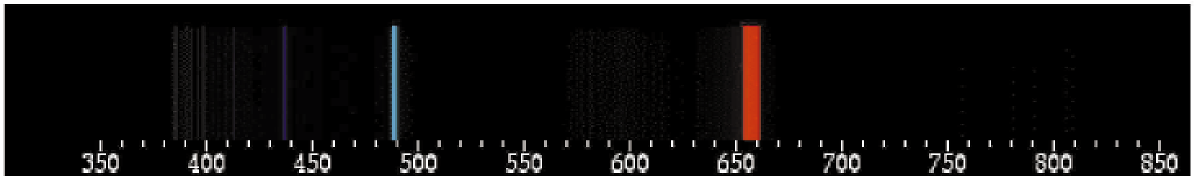
Fluorescent Lamp

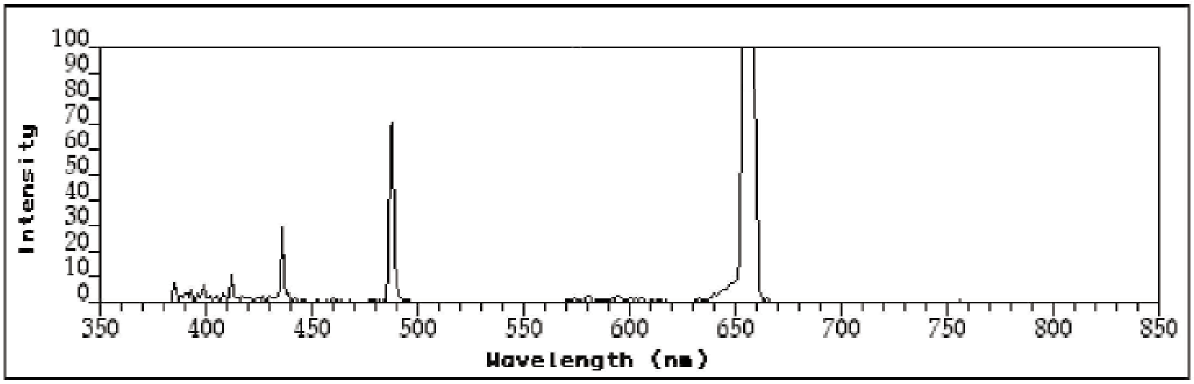


This is the spectrum of a Fluorescent Lamp. Instead of a complete rainbow, we see only certain colors of light. This bright-line pattern is called an emission spectrum. We don't see a full rainbow because rainbows are produced only by light sources that are very hot.

What colors do you see in the Fluorescent Lamp spectrum, and what are their wavelengths?

Hydrogen Gas



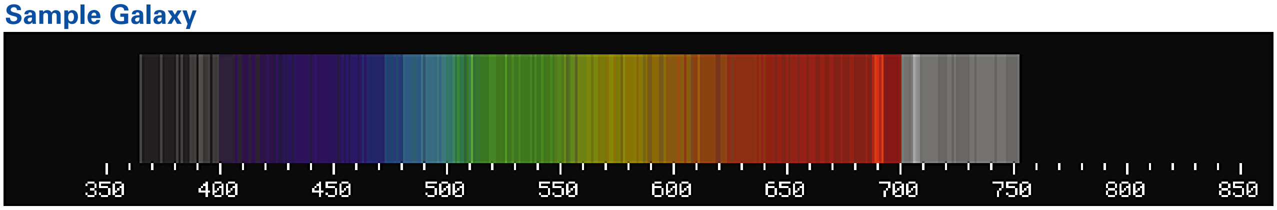


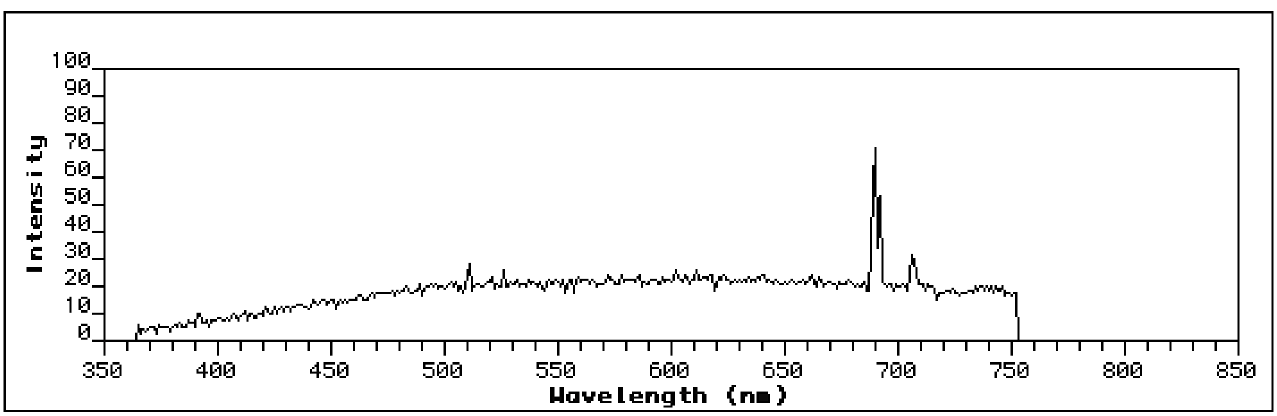
This is the emission spectrum of the element hydrogen. Hydrogen is the simplest chemical element. The pattern was produced by taking the light from a glowing tube of hydrogen gas, and passing the light through a prism.

What colors do you see in the hydrogen spectrum, and what are their wavelengths?

Look for lines at these same wavelengths in the spectrum of the Sun. Which lines can you see?

Sample Galaxy





This is the spectrum of a galaxy. The pattern was produced when the light from this distant galaxy was passed through a device similar to a prism. In addition to the rainbow, there is a bright red line. This line comes from the element hydrogen. Determine the wavelength of the red hydrogen line in the spectrum of the sample galaxy. The peak has been shifted from its characteristic wavelength (as measured above in the hydrogen spectrum) toward the longer wavelength part of the spectrum, which is the redder end of the spectrum. This phenomenon is called a "redshift."

In the sample galaxy, the red hydrogen peak is at ____________________ nanometers.

STUDENT WORKSHEET Calculating and Graphing Galactic Speed

Look at the optical images of the four galaxies A, B, C, and D. These galaxies, are all approximately the same actual size. Which galaxy do you think is closest to us? Farthest?

________	________	________	________
Closest			farthest

What evidence did you use in these choices?

Label the x-axis of the graph on page 2 with the letter of the galaxies, in order from closest to farthest.

Look at the spectra of the four galaxies A, B, C, and D. Determine the wavelength of the red hydrogen line in each spectra.

Galaxy A: ____________ nanometers

Galaxy B: ____________ nanometers

Galaxy C: ____________ nanometers

Galaxy D: ____________ nanometers

The observed redshift is proportional to the speed of the source (for speeds that are not close to the speed of light). For example, for a galaxy moving away from us at 10% of the speed of light, the light will be redshifted by 10%. The hydrogen line that was at 656 nanometers in the laboratory sample of hydrogen gas will be redshifted by about 65 nanometers, and will be observed at 721 nanometers.

By how much has the red hydrogen line been shifted in the spectra of galaxies A, B, C, and D? What fraction of the original wavelength is this? At what fraction of the speed of light is the galaxy moving?

Galaxy A: redshifted ____ nanometers =____ %

Galaxy B redshifted ____ nanometers =____ %

Galaxy C: redshifted ____ nanometers =____ %

Galaxy D redshifted ____ nanometers =____ %

Calculate the speed of each galaxy as it is receding from us, using the percentages from your answer above. The speed of light is approximately 300,000 kilometers per second (186,000 miles per second).

Galaxy A: ____ % x 300,000 km/s = ________

Galaxy B: ____ % x 300,000 km/s = ________

Galaxy C: ____ % x 300,000 km/s = ________

Galaxy D: ____ % x 300,000 km/s = ________

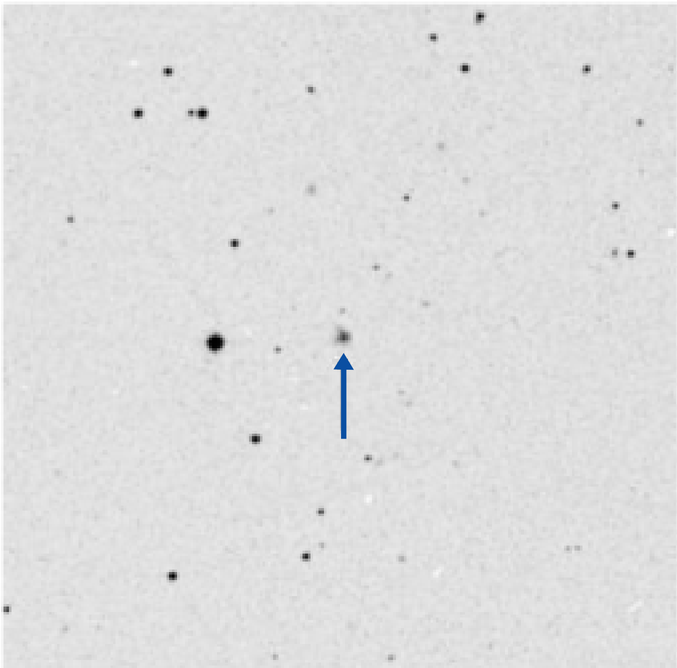
Plot the speeds of Galaxies A, B, C and D on the y-axis of the graph.

Galaxy Distance vs. Speed

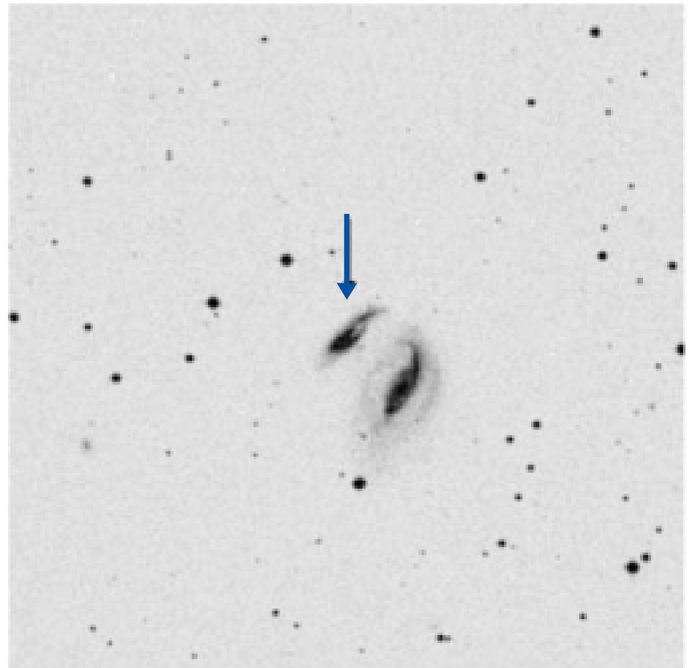
What can you conclude about the relationship between galaxy distance and redshift?

How does this evidence support the theory of an expanding universe?

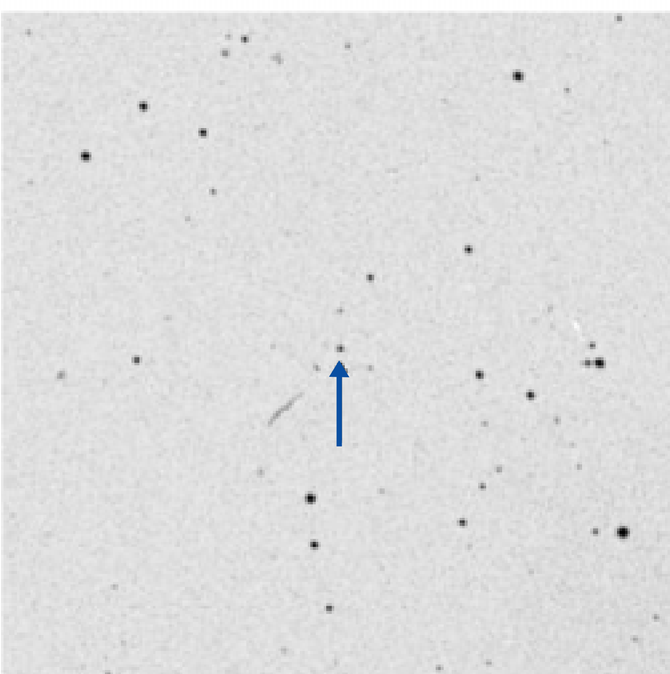
Galaxy A



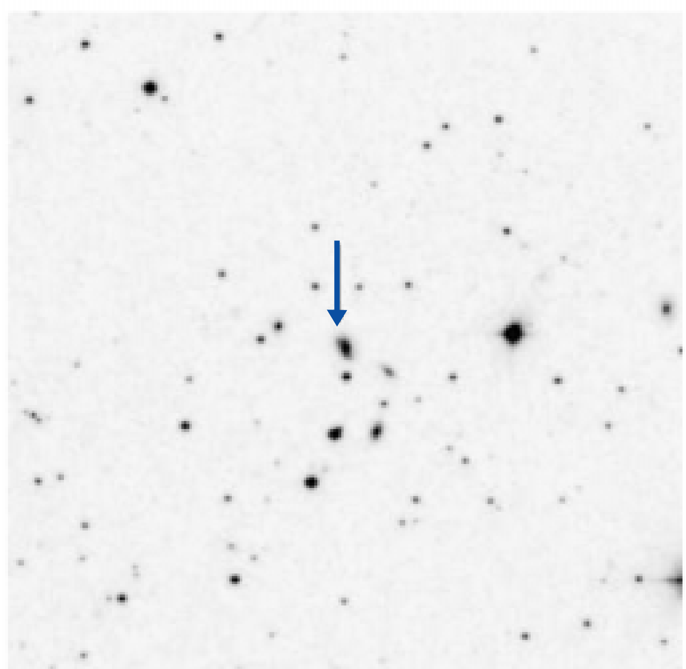
Galaxy B



Galaxy C

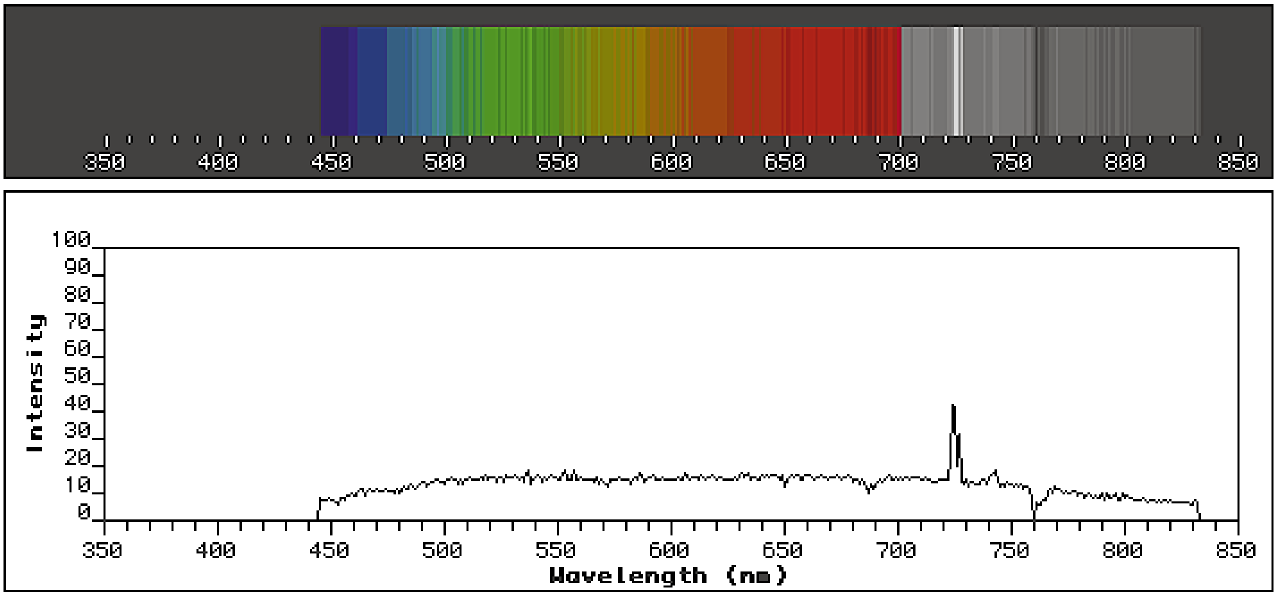


Galaxy D

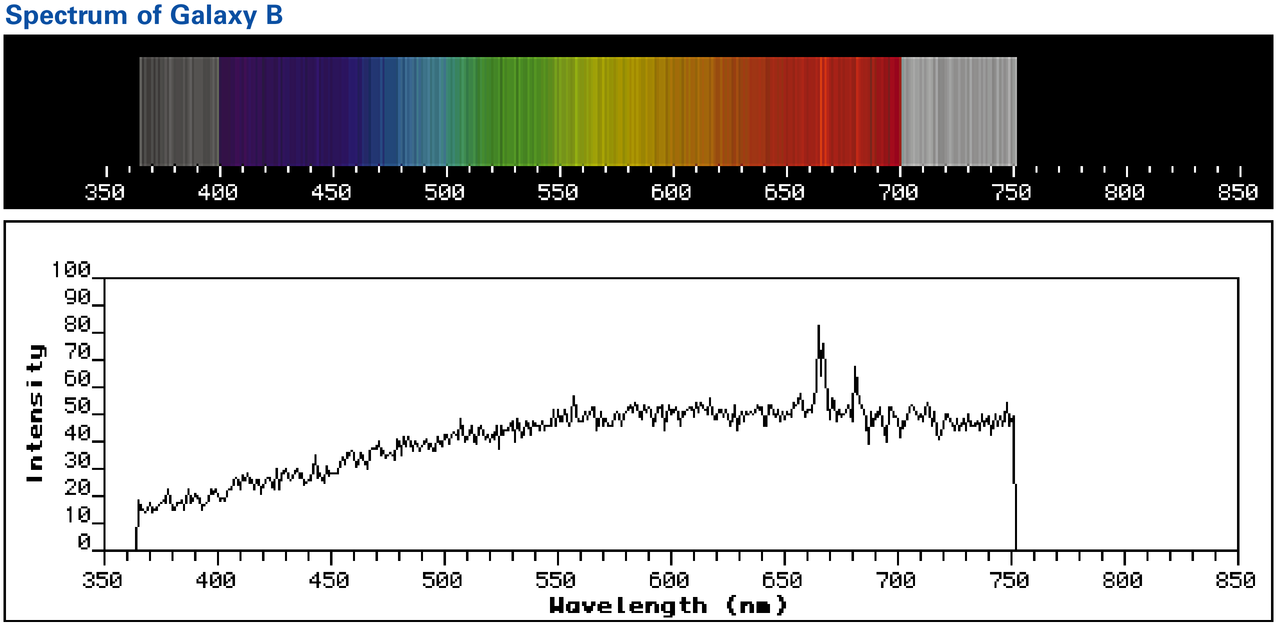


STUDENT WORKSHEET Spectra of Galaxies A and B

Spectrum of Galaxy A



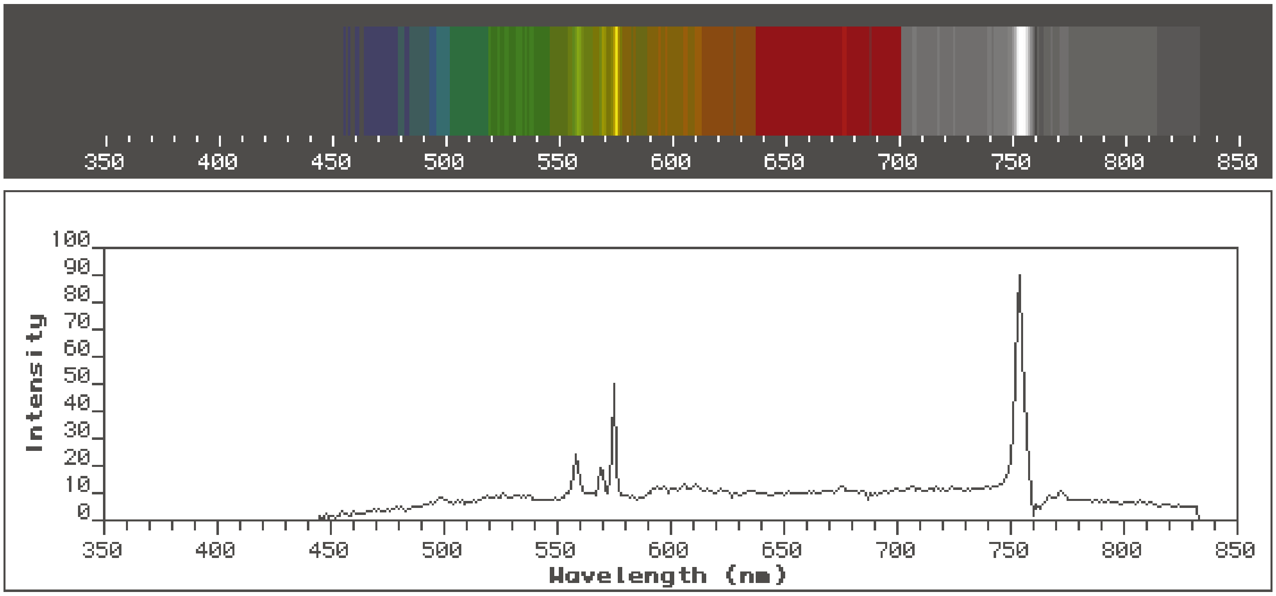
Spectrum of Galaxy B



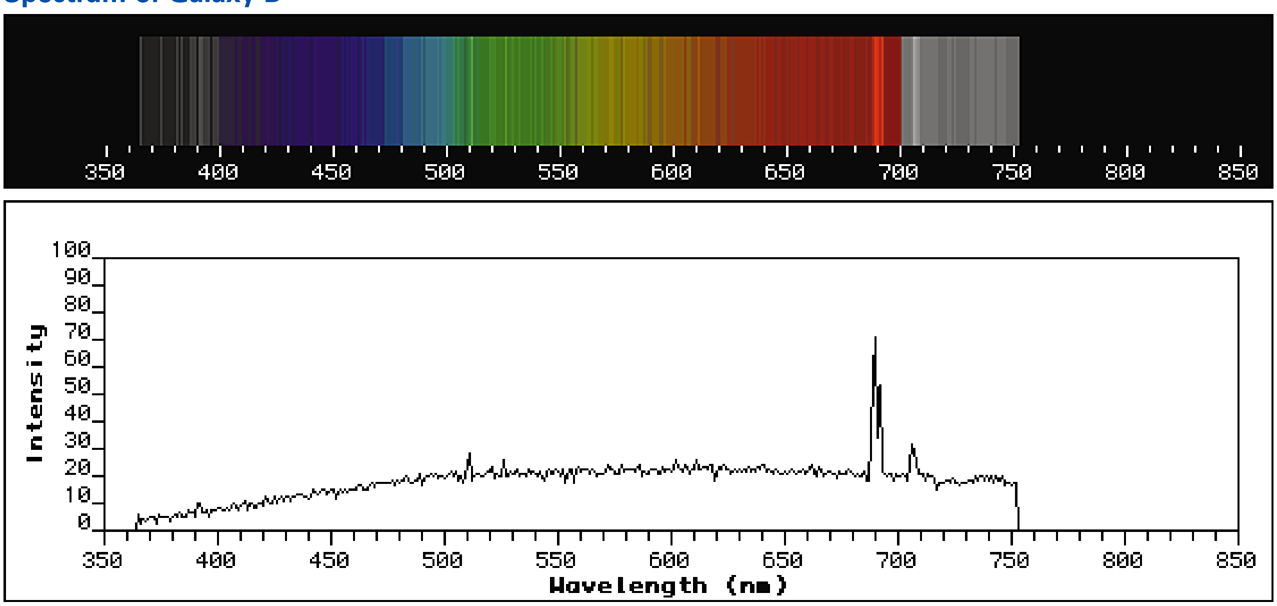
Galaxy data courtesy of Emilio Falco, Center for Astrophysics

STUDENT WORKSHEET Spectra of Galaxies C and D

Spectrum of Galaxy C



Spectrum of Galaxy D



IS THERE LIFE ON OTHER WORLDS? THE DRAKE EQUATION*

Exhibit Connections: Welcome Home, Are We Alone?

Goals

- to estimate the number of worlds in the Milky Way galaxy that have life
- to think about the size and composition of the galaxy and how it affects the possibility of extraterrestrial life
- to understand and estimate the terms of the Drake Equation

Materials

- Student Worksheets (one set per student or small group of students)
- calculators

Background

Are we alone? For the first time in history, astronomers have discovered planets orbiting stars beyond our own Sun. In fact, planetary systems seem to be widespread in the universe. Is there life, intelligent or otherwise, in any of these alien solar systems? No one yet knows. But ours may be the first generation to detect a sign of life beyond Earth. What will it mean if we find out that we are not alone?

At first, "Is there life on other worlds?" seems a simple question to answer. However, it quickly becomes a complex web of issues. What is life, anyway? How does it begin and evolve? What conditions can life tolerate? What makes a planet habitable? How do we look for and identify extraterrestrial life? To attempt to resolve these kinds of questions, astrobiologists draw on many branches of science and employ many research strategies, such as fieldwork, laboratory research, telescopic observation, and exploration with spacecraft.

Though we have not found any examples of extraterrestrial life, comparisons with certain kinds of life on Earth suggest that potential habitats for extraterrestrial life, and maybe life itself, do indeed exist. However, contrary to popular notions, if extraterrestrial life is found in our solar system, it will most likely be bacteria-like.

In 1961, the astronomer Dr. Frank Drake suggested an organized framework for thinking about life in the galaxy. Known as the Drake Equation, it provides a way to estimate the number of worlds within our Milky Way galaxy that have intelligent life and whose radio transmissions should be detectable. Drake identified a sequence of eight terms to help people think about what must occur before a world can be inhabited by a civilization with radio technology. This activity uses Dr. Drake's framework to have students consider the implications of each term and make their own estimates of life in the Milky Way galaxy.

Because we are unsure whether there is life out there, let alone intelligent life with which we can communicate, there is no correct solution to the equation—the value of each factor is open to interpretation.

* Adapted from Life on Earth...and Elsewhere. Astrobiology in your classroom. Educator Resource Guide. Developed by the NASA Astrobiology Institute (NAI), with funds from the NAI Lead Teams at NASA Ames Research Center and NASA Jet Propulsion Laboratory, and TERC's Astrobiology Curriculum Project. Fall 2000.

Suggestions for Introducing the Activity

The Drake Equation is an experiment in estimation, similar to something called a Fermi problem, in which a set of constraints is applied to figure out an unknown quantity. For example, to figure out how many people in a certain city drive blue minivans, you would start with a known quantity, such as the number of people in the city and then apply the following constraints:

> What percentage of those people have driver's licenses?
>
> What percentage of those people have families?
>
> What percentage of those families need minivans?
>
> How many car companies make minivans?
>
> What percentage of those minivans are blue?
>
> And so on, until you reach an answer.

You may wish to set up your own Fermi problem to get the students thinking about estimation in this way.

To get a sense of what your students think when they hear the term "extraterrestrial," ask them: What is the chance we are the only life in the universe? Are there such things as extraterrestrials?

Procedure

- Discuss and define the word extraterrestrial. A broad meaning includes anything from microbes to plants to intelligent creatures.
- Identify factors related to the existence of extraterrestrial life. Ask students what information they would need to determine the probability of extraterrestrial life. You might begin by saying, "Let's see if we can estimate how many worlds out there have life (or intelligent life with which we can communicate). What would we need to know?" Record the ideas.
- Introduce the Drake Equation as one scientist's effort to identify the factors in the same way students did. Have students complete the Student Worksheet Is There Life on Other Worlds and estimate values for each term. Make sure they understand that there are no right answers. The Drake Equation simply helps us think about the factors involved in determining the probability of communicating with civilizations that have radio technology.
- After making estimates for each term, have students multiply the eight terms and determine their estimate of the number of other civilizations that exist in our Milky Way galaxy that we can detect using radio technology (Question 1 on the Student Worksheet Is There Life on Earth. . . and Elsewhere?).
- Have students report their estimates and discuss the range of values and their implications.
- Use the Student Worksheet Is There Life on Earth. . . and Elsewhere? to guide a class discussion.

REMEMBER: Most, though not all, of the terms on the Student Worksheet are given as percentages, rather than numbers. Students should be careful in their calculations.

Discussion Notes

These notes provide answers to some of the questions on the Student Worksheet Life on Earth…and Elsewhere? and can be used to help guide a class discussion based on those questions. Questions 2, 3, 7, 8, 9, and 11 ask students to reflect on their own feelings, perceptions, or idea, and therefore have no background notes.

1. Based on the eight terms, what is your estimate?

While terms 5 through 8 are percentages, the final number that students obtain is a discrete number rather than a percentage or a probability. This number represents a student's estimate of the number of civilizations with radio technology that we can detect.

4. What if your answer to Question 1 were less than one?

Some scientists think that the likelihood of life arising elsewhere in the galaxy is very remote, while others surmise that life should be quite plentiful. An answer less than one would imply that the chances for life in the galaxy are very small, and the fact that we do have life on one planet, Earth, means that the chance for life on any other planet is nearly impossibly small. So an answer less than one is not "wrong"; it instead implies that Earth is something of an amazing, one-of-a-kind fluke. If students choose low probabilities for terms 5 through 8, they may come up with a number less than one. For students to increase their answer to greater than one, they may need more than the 400 billion stars in the Milky Way galaxy. One way to do this, without changing any of their estimates, would be to add another term (see discussion notes for Question 14), such as multiplying their answer by the number of known galaxies to see how many inhabited planets would be in the whole universe, instead of just the Milky Way.

5. In which terms did you have the most or least confidence?

Estimating numbers for the eight terms becomes increasingly a matter of conjecture as one goes from term 1 to term 8. There is widespread agreement only for the first two terms.

6. Are you more optimistic or conservative?

An answer of one states that Earth is the only place with intelligent life that has radio technology. There may still be life or even intelligent extraterrestrials out there, but we cannot communicate with them because they do not have radio technology. Any number larger than one implies that we may receive signals from intelligent extraterrestrials someday. However, make the distinction between detection and communication, which is a two-way exchange. With a small final number, actual communication is less likely. With a large final number, actual communication becomes increasingly likely.

10. What are the implications of discovering microbial life?

Many students express disinterest in discovering anything less than a bona fide, Hollywood-style extraterrestrial. However, no life beyond Earth has ever been found, which implies that life may be a rare accident that happened on Earth due to an extraordinary convergence of circumstances and that it is unlikely to happen elsewhere. In this context, discovering microbial life would help us understand more about how life arises and what conditions it can tolerate. Furthermore, it would help answer the question of whether life is a common process in the universe. In short, discovering microbial life beyond Earth would be a profound discovery. By multiplying terms 1 through 5, students can make their own estimate of how many worlds in our galaxy have life of any sort.

12. What is the most abundant life form on Earth?

We live in the age of bacteria. For the past three and one half billion years, bacteria have been the dominant life form in terms of numbers and biomass. They are key to many biological, geological, and chemical processes, and many scientists think that multi-cellular organisms became possible only after single-celled bacteria began living symbiotically within a cell membrane.

13. If life exists elsewhere, what do you think it will look like?

Astrobiologists feel that most extraterrestrial life will be bacteria-like, living beneath a planet's surface and using chemical energy for their needs. Animal life, and especially intelligent animal life, is probably much rarer.

14. Can you think of any other terms that might affect your estimation of life in the universe?

As mentioned in the discussion notes for Question 1, this equation only addresses life in the Milky Way galaxy. The universe is made up of many galaxies, perhaps an infinite number. Multiplying your estimate by the number of galaxies in the universe, would increase the possibility of life beyond Earth. Remember, however, that the time required for a signal to reach us from another galaxy is much longer than the time required from within our own galaxy. Other factors, such as the inclusion of habitable moons in a planetary system, may also affect the probability of detecting extraterrestrial life.

Student Extension: Exploring the already discovered planets

When the Drake Equation was first developed, scientists only had evidence for the first two criteria. Today, astronomers are able to detect planetary systems around other stars. What we know about solar systems within our galaxy is changing every day, and each new piece of information helps us refine the details of detecting extraterrestrial life. When the *Cosmic Questions* exhibit was created, there were more than 80 planets detected outside our solar system. By the time this activity guide was published, the number was more than 100. The search continues even today, not just for extra-solar planets, but for planets that might contain life. Visit planetquest.jpl.nasa.gov to learn more about the ongoing search for life beyond Earth.

NASA's Planet Quest website, planetquest.jpl.nasa.gov contains an atlas of currently known extrasolar planets. Students may wish to explore this website and learn more about specific planetary systems.

STUDENT WORKSHEET Is There Life on Other Worlds? Using the Drake Equation

Term	Background	Conservative Estimate	Optimistic Estimate	Your Estimate
1. The total number of stars in the Milky Way galaxy	These numbers are based on observations of the stars in our galaxy, the Milky Way galaxy, and of other galaxies we believe to be like our own. Most scientists believe the number of stars to be 400 billion.	100 billion	600 billion	
2. The percentage of stars that are appropriate	Many scientists believe that a star has to be like our Sun. Only about 5% of the stars in our galaxy are sun-like stars, though about 10% are closely related, either slightly warmer or slightly cooler. About 50% of stars exist in binary or multiple systems, which many scientists feel make them inappropriate.	5%	45%	
3. The average number of planets around each appropriate star	Appropriate stars may not have planets circling them. We have only just begun detecting extra-solar planets, so we don't really know how common they are.	1	10	
4. The percentage of planets within a solar system that are habitable	Our only example of this term is our own solar system. Could Earth be the only habitable place in our solar system? Is our system typical? Remember that if one system has no habitable planets and another has four, the average would be two per system.	10% On average, there is one habitable planet in every 10 systems	50% Half the planets in every system are habitable	
5. The percentage of habitable planets that develop life	Having a planet that is appropriate for life doesn't necessarily mean that life will arise. No real data are available to help us estimate this term. Earth is the only planet on which we know there is life. However, bacterial life existed on Earth shortly (geologically speaking) after its formation, possibly indicating that the development of life is easy. Many scientists believe that whether or not life arises depends on many factors.	0.000001% Life is a rare accident that is unlikely to happen elsewhere	100% Life will arise if conditions are appropriate	
6. The percentage of planets with life that develop intelligent life	On Earth, humans developed intelligence, apparently as an evolutionary advantage. However, this term depends on how you define intelligence. Are dolphins, gorillas, octopus, and ants intelligent? Furthermore, single-celled life existed on Earth very early, and multicellular life took 2.5 billion years to form (a very long time, geologically speaking). Maybe the development of complex life, let alone intelligent life, is unusual.	0.0001% or less Only one in a million planets with life will develop intelligent life	100% Any planet with life will develop intelligent life	
7. The percentage of intelligent life that develops radio technology	Communication with intelligent extraterrestrials requires that we hear from them. Given the vast distances of space, they would probably send signals that travel at the speed of light, such as radio waves. On Earth, humans have only just developed radio technology, so possibly this term should have a low value. But, we did eventually develop radio technology, so maybe this is true of all intelligent beings.	0.0001 or less Only one in 1,000,000 planets with intelligent civilizations will develop radio technology	100% All intelligent life will develop radio technology	
8. The percentage of "current" civilizations having radio technologies	Will an extraterrestrial's signals overlap with the lifespan of the receiving civilization? Extraterrestrials that sent signals a hundred thousand years ago from a world a hundred thousand light years away would still overlap with us, even if they died out long ago. So, how long do civilizations with radio technology last? A high level of technological development could bring with it conditions that ultimately threaten the species. Or maybe, once a society has radio technology, it may survive for a long time. Finally, radio signals may give way to more advanced, less noisy technologies such as lasers. No one would hear us then!	0.0001% or less One in a million civilizations with radio technology will develop it in time to detect signals from another civilization	10% One in a ten civilizations with radio technology will develop it in time to detect signals from another civilization	

Remember to convert percentages to numbers!

STUDENT WORKSHEET Life on Earth. . . and Elsewhere?

1. To find out your estimate of the number of worlds in the Milky Way galaxy that have intelligent life that we can detect using radio technology, fill out the **Student Worksheet Is There Life on Other Worlds? Using the Drake Equation**. Multiply the eight terms. Don't forget to convert percentages to numbers. Write your final answer here:

2. Based on your estimates, how good are our chances of hearing from intelligent extraterrestrials?

3. How does your answer to Question 2 compare with what you thought before you began the activity?

4. What if your answer to Question 1 were less than one? What would that mean in terms of our existence here on Earth?

5. When making estimates, in which terms did you have the most confidence? The least? Why?

6. Are you more optimistic or conservative when it comes to thinking about extraterrestrial life with radio technology in the Milky Way galaxy? Why?

7. How could you adjust the estimates in the equation to have it come out so that Earth is the only planet in the Milky Way galaxy with radio technology?

8. If tomorrow's newspaper headline read, "Message Received from Outer Space," what would it mean to you?

9. What would your reaction be if we discovered microbes on another planet? Plants? Insects? Mammals? Intelligent life?

10. If microbial life were discovered on another planet, what implications might such a discovery have?

11. How would you define extraterrestrial now? How does your current definition differ from the one that the class developed earlier in the activity?

12. What do you think is the most abundant life form on Earth?

13. If life exists elsewhere, what do you think it will look like?

14. Can you think of any other terms that might affect your estimation of life in the universe?

IS THERE LIFE OUT THERE? COMMUNITY SURVEY

Exhibit Connections: Welcome Home, Are We Alone?

Goal

- to survey other people to find out their thoughts about life beyond Earth and compare their ideas with visitors to the *Cosmic Questions* exhibit

Materials

Survey Questions
calculators

Background

Visitors to the *Cosmic Questions* exhibit have the opportunity to complete the following survey. Students can conduct their own survey before or after a visit to the exhibit and compare their answers to exhibit visitors. Students could also see whether there is any variation or pattern in answers from men and women or people of different ages. To do this, students will need to design their own method for tracking demographic data.

Procedure

- Have students survey other people in the school, their family, friends or community members. Each student should ask many different people.
- Compile the data from the entire class.
- Calculate the percentage of people who gave each response.

Discussion Notes

How do your responses compare with the general visitors to the exhibit? Are the responses similar or different? How might you explain the results?

Compare your answers to visitors to the *Cosmic Questions* exhibit while it was at the Museum of Science in Boston from September to December of 2002.

	Percentage of people who chose this response
1. Do you think there's life out there in the universe?	
No. We're all there is.	9
Maybe some forms of life.	37
Yes. Intelligent life.	31
Lots of intelligent life.	23
2. When do you think we'll find signs of life beyond Earth?	
In the next 10 years.	9
In my lifetime.	28
In 100 years.	36
In 1,000 years or more.	27
3. How would you feel if life were discovered tomorrow?	
A bit frightened.	22
Thoughtful.	29
Really glad.	26
We'll see.	23
4. What's the simplest form of life you would find exciting?	
Chemical signs of life.	20
Bacteria or lower plants.	33
Slimy or furry things.	23
Only intelligent life.	24

STUDENT WORKSHEET Is There Life Out There? Community Survey

Survey people in your school, family or community using the following multiple choice questions. Each person should choose one response for each question. Record their responses.

1. Do you think there's life out there in the universe?

	Tally	Total
No. We're all there is.		
Maybe some forms of life.		
Yes. Intelligent life.		
Lots of intelligent life.		

2. When do you think we'll find signs of life beyond Earth?

	Tally	Total
In the next 10 years.		
In my lifetime.		
In 100 years.		
In 1,000 years or more.		

3. How would you feel if life were discovered tomorrow?

	Tally	Total
A bit frightened.		
Thoughtful.		
Really glad.		
We'll see.		

4. What's the simplest form of life you would find exciting?

	Tally	Total
Chemical signs of life.		
Bacteria or lower plants.		
Slimy or furry things.		
Only intelligent life.		

Total number of people surveyed: ___________

VISITING THE *COSMIC QUESTIONS* EXHIBIT

These are some suggestions of things students can do during a visit to the exhibit.

- Watch the Cosmic Kitchen Theater presentation and experience the “recipe” to create the universe.
  - > Write a synopsis of the presentation for someone who has not seen the exhibit.
  - > At the end of the story Sophie (a character in the story) says, “Hey wait…I have so many questions!” And she asks her Dad, “What do you think came before the Big Bang? Do you think the universe will ever end? Do you believe there are people on other planets, or cows or apple pie?” How would you answer Sophie’s questions? What are your questions?

- Find two new models of astronomical phenomena, such as objects, concepts or events, in the exhibit.
  - > What physical features of the real thing do they represent?
  - > What physical features do they not represent?

- Visit the Control Your Own Telescope exhibit and request an image to be sent to your email address.
  - > Record what you request.
  - > Print this image at home or school and bring it to class.

- Visit the cosmic poetry wall.
  - > Create your own poem.
  - > Copy it down to share with other students in your class.

- Watch part of the Humans Muse video.
  - > Pick one of the questions and express your opinion about it.

- Think of your own cosmic questions.
  - > Visit http://image.gsfc.nasa.gov/poetry/ask/askmag.html to see if your questions have been answered or to submit your question to a scientist.

- Conduct *Cosmic Questions* Partner Interviews using the Worksheet on the following pages.

YOUR COSMIC QUESTIONS
Partner Interviews

Exhibit Connections: All displays

Goals
- to focus your ideas and work with a partner to learn more about the universe
- to think critically about the ***Cosmic Questions*** exhibit

Materials
Student Worksheet

Background
Cosmic Questions: Our Place in Space and Time was created to initiate a cosmic conversation with visitors about the universe. The exhibit explores three fundamental questions—What is the universe like? Was there a beginning to time? How do we fit in?—but many more questions are addressed throughout the displays and activities. Use this activity to formulate and focus your own cosmic questions as you investigate the exhibit.

Procedure
- Divide the students into pairs.
- Questions 1 and 2 should be completed before visiting the exhibit.
- Questions 3 through 6 should be completed in the exhibit hall.

STUDENT WORKSHEET Your Cosmic Questions

Your Name: ____

Your Partner's Name: ____

Answer Question 1 before visiting the exhibit.

1. What questions do you have about the beginning of the universe?
   Your questions:

2. Interview your partner about his or her cosmic questions.
   Your partner's questions:

Spend some time exploring the exhibit.

3. What question(s) from the exhibit did you find most compelling?
   Your question(s):

4. Interview your partner about the questions in the exhibit he or she found most compelling.
   Your partner's questions(s):

5. Choose an exhibit station to address one of the questions above. Which station did you choose? What does it ask the visitor to do? What do you think the designer of this exhibit component wants the visitor to learn? What would you change about this exhibit station to better address your question?

6. Interview your partner and describe the station that he or she visited.

RESOURCES

Cosmic Questions Homepage

Find out more at http://cosmicquestions.org

Our Place in Space

Universe! Education Forum: http://cfa-www.harvard.edu/seuforum

This site, hosted by the Smithsonian Astrophysical Observatory, contains information and educational activities related to NASA's space science research into the structure and evolution of the universe.

Imagine the Universe: http://imagine.gsfc.nasa.gov

Astrophysicists at NASA's Goddard Space Flight Center offer "a glimpse into the mysteries of our universe . . . what we know about it, how it's evolving, and the kinds of objects it contains."

Powers of Ten: http://powersof10.com

From the folks who created this famous film of the same name, this site offers an introduction to size and scale in the universe.

Welcome to the Universe: http://www.mos.org/sln/wtu/index.html

The Museum of Science, Boston created this site as an introduction to learning about our place in space.

Observing the Universe, Learning from Light

Multi-Wavelength Astronomy: http://www.ipac.caltech.edu/Outreach/Multiwave/

NASA's infrared data center at Caltech hosts this site full of multi-wavelength images and information.

Chandra X-ray Observatory: http://chandra.harvard.edu

Chandra's website includes an extensive photo album with multi-wavelength images.

Our Place in Time

MAP Homepage—information about cosmology and the Big Bang:
http://map.gsfc.nasa.gov/

NASA's MAP probe is studying the microwave light left over from the early universe.

An Ancient Universe—How Astronomers Know the Vast Scale of Cosmic Time:
http://www.astrosociety.org/education/publications/tnl/56/

This article from the American Astronomical Society and the Astronomical Society of the Pacific presents the evidence for an ancient universe.

Great Cosmic Mysteries

Planet Quest: http://planetquest.jpl.nasa.gov

This NASA website presents the latest data on extrasolar planets.

Black Holes and Beyond: http://archive.ncsa.uiuc.edu/Cyberia/NumRel/BlackHoles.html

This website contains information about theory and existence of black holes in our universe.

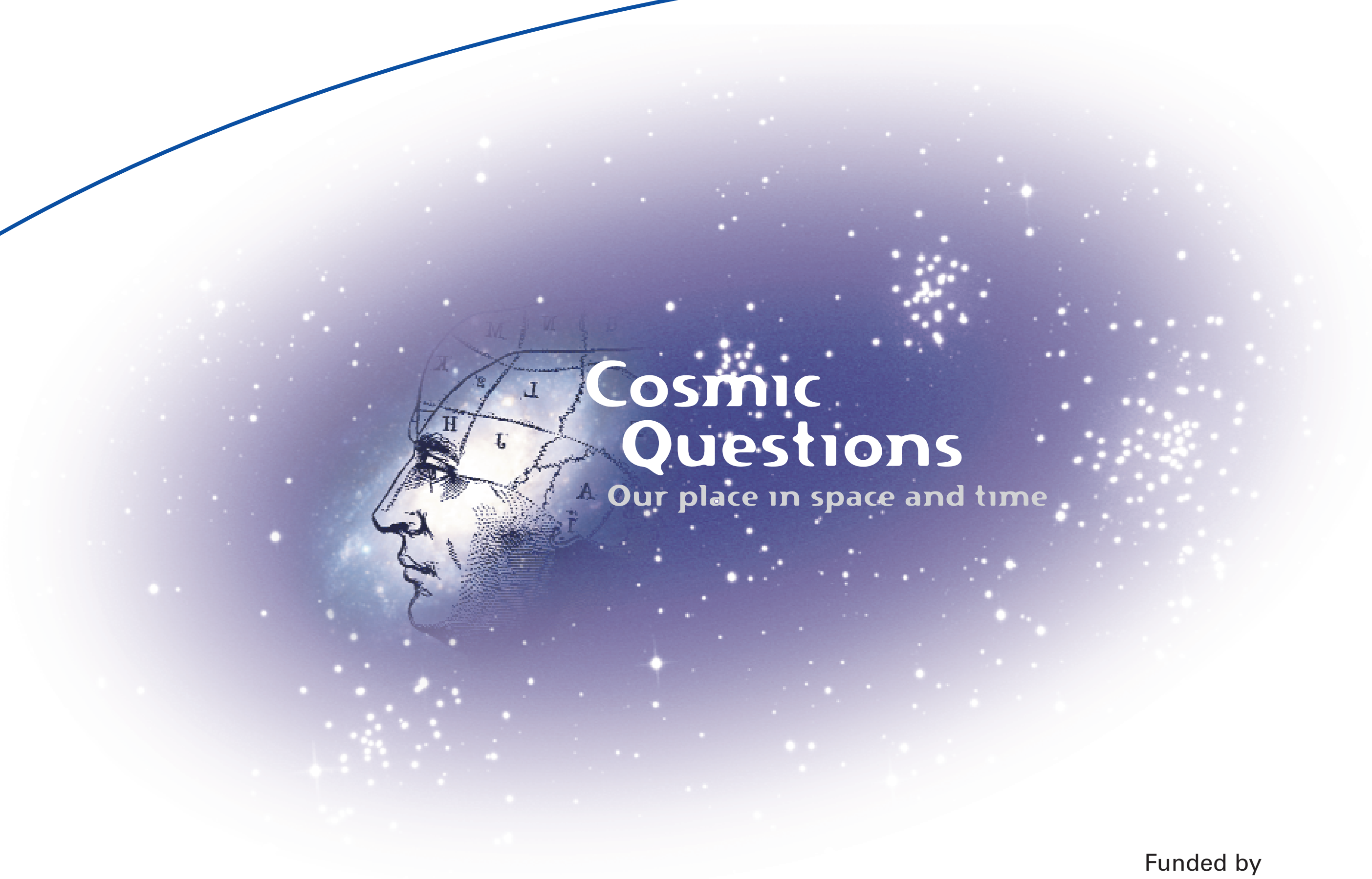
General Astronomy Resources

Space Science Education Resource Directory: http://www.TeachSpaceScience.org

A searchable database of NASA space science activities and resources.

Astronomy Picture of the Day: http://antwrp.gsfc.nasa.gov/apod/astropix.html

A gallery of astronomical photographs and images.



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