Cosmic Questions

Our place in space and time

EXHIBIT INTERPRETER GUIDEBOOK

MUSEUM OF SCIENCE, BOSTON

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Acknowledgements

Cosmic Questions: Our Place in Space and Time was developed by the Harvard-Smithsonian Center for Astrophysics, a collaboration of the Smithsonian Astrophysical Observatory and the Harvard College Observatory. The tour is managed by the Association of Science-Technology Centers. Supporting educational programs and materials, including this guide, were developed by the Museum of Science, Boston. *Cosmic Questions* has been made possible by the generous support of the National Science Foundation and the National Aeronautics and Space Administration.

Cosmic Questions: Our Place in Space and Time

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 travelling 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 our 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

I. 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 or use a magnetic word board to create your own cosmic poetry.

II. 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 multi-media exploration of the Mauna Kea mountaintop in Hawaii. A special focus is 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 or 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 AD. 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.

III. Our Place in Time

Anchored by the Cosmic Kitchen Theatre, 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.

IV. 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 theatre.

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 sub atomic particles in a cloud chamber, and 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, and 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, and learn about the anatomy of and evidence for black holes.

The Role of Exhibit Interpreters

Museums are exciting and stimulating places for informal learning. Each visitor has a different reason for coming and different expectations for the experience. Our exhibits and programs present visitors of all ages with new ideas and information, and shed new light on the familiar. Museums are places where learning can take place in a context of fun and wonderment.

Museum interpreters in the exhibit halls can encourage visitors to ask questions, take a closer look, or test an idea through participatory activities. It is our hope that visitors leave the museum more excited and better informed about science, technology, and the world around them. Interpreters are at the forefront of the Museum's effort to promote active learning, develop scientific inquiry skills, and facilitate discovery.

In *Cosmic Questions*, interpreters will engage visitors with interactives on carts and use the surrounding exhibit components to excite visitors about the universe and our place in the cosmos. In conversations with visitors, interpreters will encourage inquiry; helping visitors to ask questions even when it is difficult to find explanations. We will model the process of science and the nature of technology through several themes of interpretations:

> ***Observing*** – Encourage careful, accurate, inquisitive observation. Share with visitors the importance of using tools that extend our powers of observation.
>
> ***Modeling*** – Help visitors recognize that as more information is gathered, our understanding changes and grows. Educators will enlist the use of models to help visitors better understand and become comfortable with recent discoveries in cosmology.
>
> ***Using Technology to Explore*** – Our understanding of the universe is continually improving with the use of developing technologies. Many components of the exhibition will present current technologies. Interpreters will enable visitors to feel confident in understanding the significance of technology to explore the universe.

Museum Educator Techniques

I. Who is a Museum Educator?
A museum interpreter is a host, a catalyst, and an educator. As a host, an educator invites people of all ages and levels of understanding and experience to interact with the exhibit and interpretive materials. As a catalyst, a museum educator captures the attention and stimulates the interest of each museum visitor. Finally – perhaps most importantly – each museum educator acts as a facilitator by satisfying the visitor's curiosity through the use of interactive educational materials, which makes science an activity.

The museum educator is the primary contact a visitor has with museum staff. Thus, it is very important for the volunteer to be courteous, helpful, and enthusiastic. Visitors vary in age, economic and social background, interests, experiences, values, and viewpoints. Therefore, the educator must adapt to each visitor's needs and concerns. Every effort must be made to clearly understand the reasons behind visitors' responses to the exhibition, and to see the questions, issues, or situations from their point of view. (This is a challenging job!)

II. What is an Interpretation?
An interpretation is a non-formal, hands-on interaction between a visitor and interpreter. An interpretation always involves the use of educational materials. The objective of an interpretation is to make science an activity and thereby excite visitors about science, and the role it plays in the world around them.

An effective interpretation will have a theme or objective, which is short and concise. There is a great temptation to make an interpretation lengthy and filled with all that you know, however, this will easily lose an audience. It is most effective to repeat your theme often, and develop your interpretation around this theme. A visitor who visits for only one minute should be able to walk away knowing your theme.

As an interpreter, you will know far more about the science topic than can be conveyed to the average visitor. The bulk of your knowledge will be called upon when you are asked questions.

**III.	Basic Guidelines**

1. Just be yourself: Greet visitors and introduce yourself! Smile and speak up.

2. Body language: Talk directly to the visitor and scan the group with your eyes. If you are holding a prop, or performing an activity, make sure that the material is visible to your entire audience. If you are not holding a prop, use natural gestures to explain your point.

3. Dress neatly: First impressions are incredibly important. Identify yourself as a museum interpreter and have your badge displayed prominently.

4. Use appropriate language: Define all terms in as simple a language as possible. Remain flexible and observant, and adjust what you are explaining and how you are explaining it to fit a particular visitor or group. Be sensitive to the attention span of your visitor…do not overwhelm with information!

5. Use your natural voice: Talk directly to the visitor and LISTEN to the visitor.

6. Remember your intention: Repeat your theme periodically and draw your audience back to a focus. You can change your pace, make a comparison, refer to current interests or topics, ask a question, or give an illustrative story.

7. Build confidence and self-esteem: Let the audience do as much as possible. Do not do for the visitor what they can do themselves. Do not be afraid to learn from the visitor.

8. Get participation: Be positive and enthusiastic, and get visitors involved. Most people remember what they do more than what they hear. Ask for participation, but remember never put a visitor in an embarrassing situation.

9. Do not be afraid to say, "I do not know." You are not expected to know everything. Get the answer if you can, or send the visitor to another source, such as the library.

10. Relax. No one can be instantly fascinating. If a visitor walks away before you have finished, do not take it personally.

IV. Gauging an Audience

As a museum educator, you will be challenged by the opportunity of speaking with a mixed audience almost all the time. Therefore, it is extremely important to gauge the interest and mood of your audience. Try to anticipate how a group or individual is going to react. Ask questions to find out what they know and what is important in their lives.

An educator also needs to monitor who needs to be encouraged in a group, who needs to be controlled, and what method is best to use to meet interpreting objectives. The ability to gauge an audience – analyze capabilities, skills and interests of special groups - comes with experience. Interpreting for children is a unique challenge. The outline that follows should help you to understand the abilities and interests of children of all ages.

Pre-school (ages 2-5)
Physical development: energetic and active, motor skills not well-developed, coordination poor.

Mental process: learning through senses, developing vocabulary, short memory, unexplainable fears, action precedes thought, very short attention span.

Social process: self-centered, varying degrees of independence.

Applications for interpretation: pre-schoolers require simple action oriented activities, capable of handling only one idea of concept.

Elementary school (ages 5-9)
Physical development: gross motor skills (big muscles) better developed, fine motor skills just beginning.

Mental process: interest span increases, can detect gross absurdities in statements, like to use hands, can classify objects, acquire ability of conversation.

Social process: peer relationships, strong loyalties to friends, first break from home, begins relationships with other adults.

Applications for interpretations: play games to illustrate concepts rather than talking about concepts. Incorporate activities using large muscles, and large tools. Avoid activities calling for precise coordination.

Pre-Adolescent (ages 9-12)
Physical development: wide variation in development, coordination varies, gross motor skills good, fine motor skills steadily developing, tires easily.

Mental process: concerned with things rather than ideas, ability to verbalize curiosities, has sense of historical time, begins to contrast present with past, can internally manipulate concrete information, capable of inductive reasoning.

Social process: learning to cooperate, enjoy group activities, 9-10 year old boys and girls segregate, regard each other as silly, desire to escape from too much adult domination.

Application for interpretation: desires activities using fine muscles, enjoys drawing conclusions from concrete things observed, enjoys activities comparing past with present.

Adolescent (ages 12-18)
Physical development: rapid growth and development, attains fine motor coordination, although awkward at times.

Mental process: interest in ideas, attains ability to think abstractly, long attention span, full comprehension of historical time.

Social process: needs peer group support, does not necessarily have strong self-concept, easily embarrassed, need to interact with adults as adults.

Applications for interpretation: enjoys learning highly coordinated skills, enjoys examining ideas, testing hypotheses and theories. Role of interpreter should be a supportive member of group presenting problem to be solved, rather than acting as group leader.

V. Interpreting to Visitors with Special Needs

Each year, museums are visited by large numbers of people with special needs – people with vision and hearing impairments, people in wheelchairs, people with learning disabilities. No two special needs visitors are the same, just as no two of any museum visitors are the same. However, visitors with special needs tend to require extra attention to get the most out of their visit. Their learning may be hampered by poor lighting, high exhibit cases, loud noise levels, or a lack of touchable artifacts.

As an educator, you can help turn an everyday visit into an exciting one for visitors with special needs. How? By understanding their needs, and giving them the hands-on props, clear explanations, or simplified themes that help them understand your topic. You'll find that the interpretation tips that help you work with visitors with special needs are the same tips that promote good education for EVERYONE.

Visually Impaired Visitors

Visually impairment ranges from partial vision to total blindness. Many visually impaired people can make out forms, shapes, or colors, especially up close and in the proper light, or using special magnifiers.

Here are some interpretive tips for working with visually impaired visitors:

- Use touch, descriptive phrases, and as many senses besides vision as you can.
- Be sure to orient visitors to your location and to what you have on your cart.
- Don't be afraid to use the word "see" with visitors – it's part of their vocabulary as well as yours.
- If you use a model, be sure to describe its flaws (inaccurate size or texture, lack of odor, missing context, etc.)
- Try having sighted visitors describe what they see to unsighted visitors in the group.

Hearing Impaired Visitors

Hearing impairments are also very common. You may spot some hearing impaired visitors because they wear hearing aids. Others may ask you to repeat yourself, or may lean forward as you speak. Some may lip-read you. You should realize the lip-reading is helpful, but does not solve the problem completely. Only 30% of English sounds are visible on the lips—the rest must be filled in by guessing and context. In addition, while many people are easy to lip-read, others may be very difficult.

You will also learn that some hearing impaired visitors may be reluctant to try to communicate with hearing people. Therefore, it is extremely important to be friendly and interested. Also, do not mistake the speech impairments which often accompany early deafness for low cognitive ability. Remember, hearing impairment is only a communication problem.

A few simple steps will allow many hearing impaired visitors to understand and participate in your interpretation:

- Speak slowly and distinctly. Do not shout or exaggerate your lip movements.
- Look directly at the visitor when you are talking.
- Use simple, direct sentences.
- Repeat other visitors' questions before you answer them.
- Carry a pad and pencil—if you can't make yourself understood verbally, then write.

Mobility Impaired Visitors

Many museum visitors are mobility impaired. This may mean being confined to a wheelchair for all or part of the day or being unable to negotiate steep stairs or to maneuver through crowded rooms. All new exhibits that come to the Museum are built to accommodate mobility-impaired visitors. However, these visitors may have trouble with older exhibits with high cases, narrow aisles, or poorly positioned signage.

How can you help these visitors?

- Know where wheelchair ramps and elevators are located in the museum, and use them when giving directions.
- Make sure your props are visible from wheelchair height. If they're not, bring them down off the cart top when you are talking about them.
- Ask if they have been able to see everything that they had wanted to in the exhibit cases. If they haven't, describe the artifacts or label copy.

Learning Disabled Visitors
As many as 3% of the U.S. population are learning disabled, and nearly 1 in 5 American families has a learning disabled family member.

Here are a couple general guidelines for working with learning disabled visitors:

- As much as possible, treat people with learning disabilities as if the were any other visitors.
- As for all visitors, encouragement is very important. Be sure to give positive feedback to individuals or groups for participating, answering, etc.

Cosmic Questions

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Background Information for Interpreters

Introduction to Cosmology

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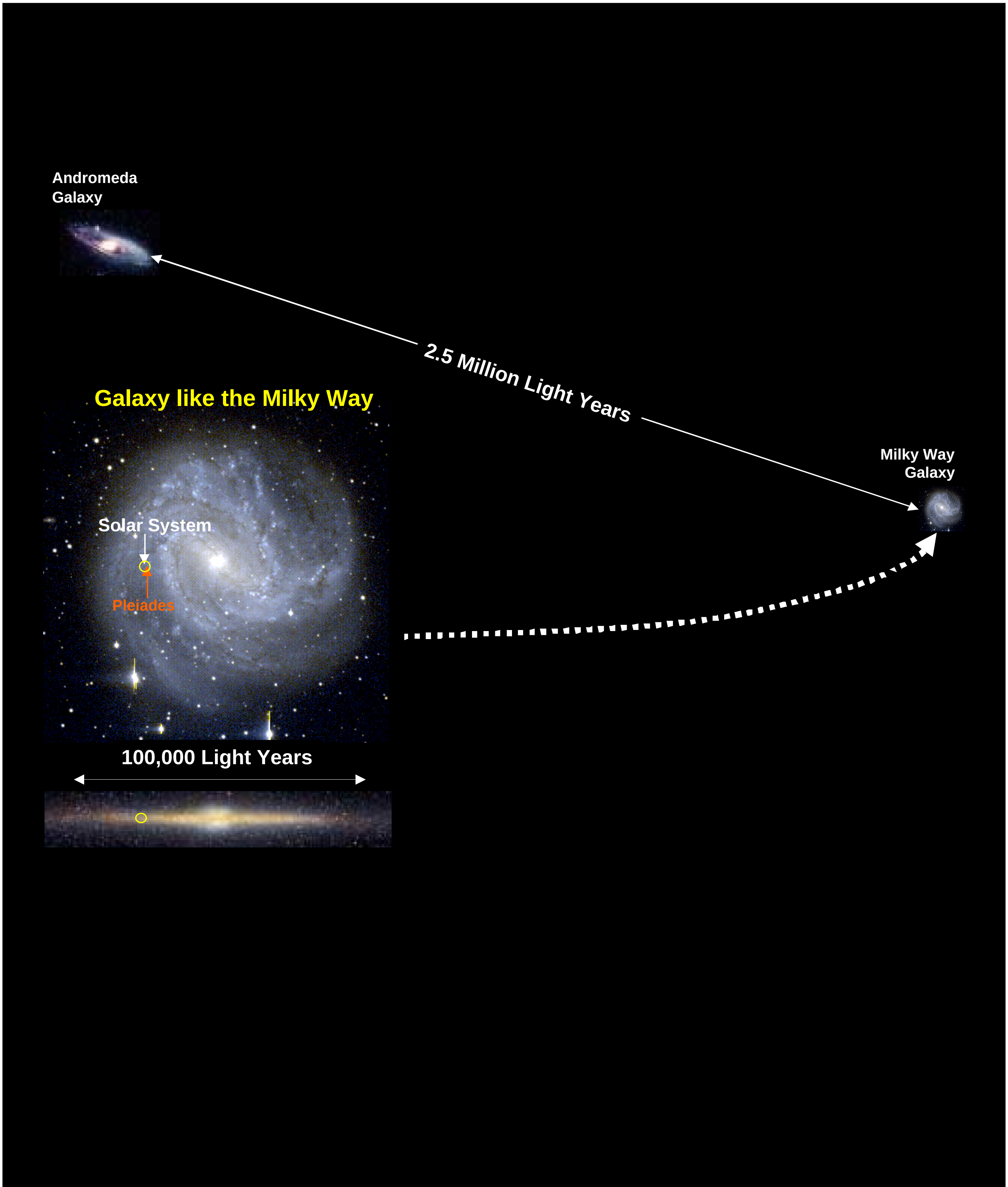
Andromeda
Galaxy
2.5 Million Light Years
Galaxy like the Milky Way
Milky Way
Galaxy
Solar System
Pleiades
100,000 Light Years

Observing the Universe: Technology to Explore

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Cosmic Questions

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Interpretation Summaries

Our Place in Space: Size and Scale in the Universe

Topic	Materials	Core Concept	Interactives
Put the Universe in Order: A Cosmic Survey	• Set of pictures of 8 celestial objects • Chart of solar system out to Saturn, showing the asteroid belt. • Chart showing the Milky Way galaxy	1. Scale and relative size of the solar system, galaxy, and universe 2. Nature of several astronomical objects, such as asteroids, galaxies, etc.	• Challenge visitors to put the universe in order from nearest the Earth to farthest away.
Modeling the Milky Way	• Play-Doh • Chart showing the Milky Way galaxy	1. Physical properties of our galaxy 2. Location and size of our solar system within the Milky Way 3. Use of models	• Challenge visitors to construct a model out of Play-Doh of the Milky Way. • Have visitors model the location and size of our solar system. • Have visitors look at the image of the galaxy and also the brass model. Have them compare size, shape, and locations with their model.
Measuring the Universe: The Bicycle Wheel	• Bicycle Wheel • String • Ruler • Tape measure • White board (or large sheet of paper)	1. Introduction to scientific measurement 2. Error in data and challenges of getting reproducible data 3. Introduction to measurement in the universe	• Use several methods of measurement to determine the circumference of the wheel. • Take each measurement a few times and record measurements. • Compare the measurements and discuss discrepancies in data. • Relate difficulties in measuring nearby objects accurately to measuring objects far away in the universe. • Introduce the idea of using light to measure.

Observing the Universe: Technology to Explore – Spectroscopy

Topic	Materials	Core Concept	Interactives
The Spectra Interactive: Spectroscopy	• *Spectra interactive* exhibit (in demo mode) • Fiber optic cable • Diffraction gratings and glasses • Multicolored spinning wheel • Maglites, desk lamp, and lasers • Colored filters • LED flashlights • Gas tubes with socket	1. Different wavelengths in the visible spectrum appear as different colors 2. There are 3 primary colors of light (red, green, and blue); together they make white light 3. Use of spectroscopy to study the properties of objects in the universe	• Experiment with diffraction gratings to explore different wavelengths of light. • Use spectroscope to look at different light sources. • Use filters with different lights and notice the results.
Laser Diffraction	• Prisms, diffraction gratings • Flashlight, green and red laser pointer • Binder clips • White board and markers • Poster of Electromagnetic Spectrum	1. What is diffraction? 2. Introduction to the Electromagnetic spectrum and the concept of wavelengths 3. How diffraction can be used for spectral analysis and imaging	• Experiment with materials to see how light can break up. • Project lasers and flashlight onto whiteboard and mark where the different wavelengths diffract.
Spectral lines	• Magnetic optical images of galaxies labeled A,B,C, and D • Magnetic spectrographs of these galaxies • Magnetic spectrograph of laboratory hydrogen	1. Use of emission spectra as sources of information to learn about stars and galaxies 2. Introduction to red shift 3. Use of galactic spectra to determine galactic speed 4. Testing ideas and making assumptions	• Put images in order first by size. • Examine spectra associated with these and notice red shift.

Our Place in Time: Modeling the Expansion of the Universe

Topic	Materials	Core Concept	Interactives
Expansion of the Universe: Latex Band Model	• Latex exercise band • Round stickers (galaxies) • Stapler • Permanent marker • Tape Measure	1. The universe continues to expand 2. As the universe expands, the “fabric” of space expands 3. Use of models	• Create a model of the universe by stapling round stickers onto a piece of latex band. • Stretch out the band and make observations about the distances between the galaxies. • Take another piece of latex band and draw a sine wave on it. • Stretch this one out and notice the difference in the wave as it stretches.
Expansion of the Universe: Balloon Model	• Balloons • Stickers (stars, rounds, etc.)	1. The universe continues to expand 2. As the universe expands, the “fabric” of space expands 3. Hubble's Law 4. Use of models	• Attach the stickers to the balloon and as you add and subtract air to the balloon notice the distances between the galaxies
Expansion of the Universe: Center of Expansion Model	• Two galaxy field acetate sheets • Ruler	1. The universe continues to expand 2. As the universe expands, the “fabric” of space expands 3. Hubble's Law 4. Use of models	• Line up the same star or galaxy on the 2 sheets. Then try another set. Are there differences? • Measure distances

Our Place in Time (continued)

Topic	Materials	Core Concept	Interactives
Curved Space & Gyroscopes: Gravity Probe B	• Gyroscopes (including one mounted in PVC) • Gravity Probe B • Bed Sheet • Basketball & tennis ball • Gravity Probe B poster and Educators' Guide	1. The nature of how gyroscopes work and what we use them for 2. Introduce the Gravity Probe B and its mission 3. Introduce Newton and Einstein and their theories 4. What is space-time curvature?	• Explore gyroscopes and examine their uses. • Investigate the Gravity Probe B. • Roll tennis ball on flat sheet and then on a sheet with the basketball in the middle.
Building the Elements	• Periodic table • Plastic bowl representing the universe • Nucleons: approximately 1 inch diameter molded from clay (red for protons, blue for neutrons) • Electrons (molded clay balls smaller than a nucleon) • Gloves (the clay can stick to and stain the hands)	1. Introduction to the atom 2. Introduction to the theory of the Big Bang 3. How the early elements formed 4. Introduction to how the remaining elements might have formed stars	• Use clay nucleons to model how elements formed.

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Interpretation Descriptions

<table>
<tr><th>Name of interpretation</th><th>Put the Universe in Order: A Cosmic Survey</th></tr>
<tr><td>Skills and concepts to be presented</td><td>1. Scale and relative sizes of the solar system, galaxy, and universe.
2. Nature of several astronomical objects, such as asteroids, galaxies, etc.
3. The overall objective is to build on and extend whatever astronomical knowledge the museum visitor already has, dispel false impressions, and, as opportunity permits, to use astronomy as an example of how science works.</td></tr>
<tr><td>Materials used</td><td>• Set of pictures of 8 celestial objects: Hubble Space Telescope, Moon, Sun, asteroid, Saturn, Pleiades star cluster, Andromeda galaxy, Hubble Deep Field (extremely distant galaxies).
• Chart of solar system out to Saturn, showing the asteroid belt.
• Chart showing the Milky Way galaxy, the location of the solar system, and the (small) region of the galaxy that we can see without optical aids. Chart (on other side) showing the distance of the Andromeda galaxy from the Milky Way.</td></tr>
<tr><td>Summary of procedure or suggested activities</td><td>Challenge visitors to put the universe in order from nearest the Earth to farthest away.

The eight objects are arranged on the cart in order of the letters on each picture (A-H). Museum visitors are challenged to first identify the pictures, and then to arrange them in order of their distance from the Earth.

Where visitors are uncertain, they can be given a hint. After they have done the five solar system objects, it is generally helpful to show the chart of the solar system, pointing out each object that has been arranged, and checking for accuracy. Then the three deep-space objects are tackled. If the visitor does not recognize the Hubble Deep Field, invite a comparison of the objects in it to the Andromeda galaxy. When all objects are ordered, the chart of the Milky Way galaxy can be shown, pointing out that the several thousand stars that can be seen with the naked eye are all in a very tiny region of our galaxy. Also be sure that they understand the nature of galaxies: "Hundreds of billions of stars, all swirling around like a whirlpool." Next, the chart of the Milky Way and Andromeda is shown, indicating the much greater distance to Andromeda than to any star we can see. Then tell them that to fit the furthest objects in the Deep Field image on the Milky Way/Andromeda chart, the paper would have to about a half-mile wide. Point out that even though this might seem to make humans insignificantly small, we humans have mostly in a the last 150</td></tr>
</table>

	years managed to make an instrument (the Hubble Space Telescope) that can see nearly to the edge of the universe, and to make theories that give us reasonable confidence that we know what we are seeing and something about how it all works. This achievement has been based almost entirely on the incredibly faint rain of electromagnetic energy (light) falling on Earth.
Questions to ask visitors during interpretation	The heart of this interpretation is answering the initial question: What is the order of these objects? Further questions largely flow out of the process, and depend on the level of knowledge of the visitor. Small children can simply be asked to identify the moon, Saturn, etc.
Extensions or connections to other topics or interpretations	Further discussions on any of the celestial objects, or general questions about astronomy. Explore how astronomical knowledge has been gained (electromagnetic spectrum, the Doppler shift, the light year and the speed of light, optics, probes that have been sent to the moon and planets, black holes, etc.)
Background material	<u>Correct Order Approximate Distances</u>: Hubble Space Telescope — 350 miles above surface of Earth Moon — 250,000 miles Sun — 93 million miles Asteroid (Ida) — 1.5 AU (occasionally closer than the Sun.) Saturn — 120 million miles (at its closest) Pleiades — 380 light years Andromeda — 2.5 Million light years (2 to 2.9 M LY) Hubble Deep Field — 10 Billion light years (for furthest objects) • When talking about light years, note that the sun is 8 light minutes away, Pluto about a light day away. • The asteroid is often identified as a meteor. This is a good opportunity to point out that it would be a meteor if it entered the Earth's atmosphere, and would be a meteorite if found on the surface. • One can point out that the asteroid belt separates the terrestrial (Earth-like) planets from the gas giants (Jovian planets). • People should be encouraged to look for the Pleiades, particularly through binoculars, where they are a very pleasing sight. Note: Image files are located in PowerPoint file named UniverseInOrder.ppt in the Cosmic Questions Interpretation folder.

	In depth descriptions of the images along with source information is located in the Appendix.
	This activity is based on one that was developed with support from NASA Grant No. NCC5-261. Universe! Education Forum. http://cfa-www.harvard.edu/seuforum/teachers/L3/survey/survey.htm

Name of interpretation	Modeling the Milky Way
Skills and concepts to be presented	1. Physical properties of our galaxy. 2. Location and size of our solar system within the Milky Way galaxy. 3. Use of models.
Materials used	• Play-Doh (also see Appendix for recipe to make your own) • Chart showing the Milky Way galaxy
Summary of procedure or suggested activities	• Challenge visitors to construct a model out of Play-Doh of their image of the Milky Way. • Have visitors model the location and size of our solar system and point out features such as the Sun, Earth, etc. • Have visitors look at the image of the galaxy and also the brass model at the entrance to the exhibit and compare size, shape, and locations with their model.
Questions to ask visitors during interpretation	What do you think our galaxy looks like? How much of the Milky Way can you see when you look up at a dark sky at night? Where and how big would Earth be on your model? What features does your model represent well? Misrepresent? What are some things that you need to know more about to make a more accurate model?
Extensions or connections to other topics or interpretations	Brass Model of Milky Way at entrance of Cosmic Questions Cosmic Survey: Put the Universe in Order interpretation
Background material	For a great introduction to galaxies and specific information about our Milky Way check out Galaxies Galore, Games and More, Teacher Page: Science Background http://amazing-space.stsci.edu/resources/explorations/galaxies-galore/teacher/scientificbackground.html

Further Reading	Soter, Steven. (2001). Section Three: Galaxies. In Soter, S., Tyson, N. *Cosmic Horizons: Astronomy at the Cutting Edge*. (pp.80-82). New York: New York Press.

Name of interpretation	Measuring the Universe: The Bicycle Wheel
Skills and concepts to be presented	1. Introduction to scientific measurement. 2. Error in data and challenges of getting reproducible data. 3. Introduction to measurement in the universe.
Materials used	• Bicycle Wheel (or another circular object) • String • Ruler • Tape measure • White board (or large sheet of paper)
Summary of procedure or suggested activities	• Use several methods of measurement to determine the circumference of the wheel. • Take each measurement a few times and record measurements on whiteboard or large sheet of paper. • Compare the measurements and discuss discrepancies in data. • Relate difficulties in measuring nearby objects accurately to measuring objects far away in the universe. • Introduce the idea of using light to measure.
Questions to ask visitors during interpretation	Why do you think that we got different measurements when we used two different tools? How did we get two different results with the same piece of string? How do you think we might measure how far away the Sun is? The moon? Pluto?
Extensions or connections to other topics or interpretations	Parallax demonstration (in demonstration boxes) Brightness flashlight demonstration (in demonstration boxes)

Name of interpretation	The Spectra Interactive: Spectroscopy
Skills and concepts to be presented	1. Different wavelengths in the visible spectrum appear as different colors. 2. There are 3 primary colors of light (red, green, and blue); together they make white light. 3. Use of spectroscopy to study the properties of objects in the universe.
Materials used	• Spectra Interactive exhibit in *Cosmic Questions* • Fiber optic cable • Diffraction gratings • Diffraction glasses • Multicolored spinning wheel • Maglites (and/or desk lamp) • Lasers • Colored filters • LED flashlights • Neon, Hydrogen, or Helium gas filled light tubes with socket (in demonstration boxes)
Summary of procedure or suggested activities	Begin by asking the visitors to look at one of the overhead lights through a diffraction grating. Ask them what they see and why. You might want to also introduce a prism (it's harder to get a spectrum, but visitors often have previously been introduced to these.) After they understand that white light is composed of different colors of light (wavelengths) mixed together, demonstrate that these colors blend to create the color white by spinning the multicolored wheel. Experiment with different light sources (desk lamp, LEDS, etc.). Turn on one of the gas light tubes and have visitors tell you what color light they see without the diffraction grating. Have them look at the tube through the diffraction grating and describe what colors appear to around the bulb. Introduce the idea that we can determine a light's composition by looking at this "barcode." Show the spectroscope fiber optic cable and explain that the spectroscope measures light and displays the wavelengths present in that light much like the diffraction gratings. Have the visitors examine different light sources with the instrument. Compare live spectroscope data of white light to the colors the visitors saw through their diffraction gratings, then compare the spectroscope data of the gas tubes to what they saw with the gratings. Introduce the colored filters and how they might be used in astronomy. Have the visitors experiment with the filters in front of different light sources and

	notice the different "barcodes." Explain how astronomers use similar methods to determine physical and chemical properties of celestial objects. For very interested visitors, you might want to introduce non-visible wavelengths.
Questions to ask visitors during interpretation	Why do you see a rainbow around the lights when you look at them through the grating? Where might you find white light split into the visible spectrum in the home and in nature? (rainbow, prisms, glass light fixtures, precious stones, etc.) Why are the colors around the gas bulb different than the colors around the white lights?
Extensions or connections to other topics or interpretations	Infrared Camera exhibit Diffraction interpretation
Background material	Chapter 2: Observing the Universe. (1999). *Unfolding Our Universe.* (pp.12-18). Cambridge: Cambridge University Press.

Name of interpretation	Laser Diffraction
Skills and concepts to be presented	1. What is diffraction? 2. Introduction to the Electromagnetic spectrum and the concept of wavelengths. 3. How diffraction can be used for spectral analysis and imaging.
Materials used	• Prisms • Diffraction gratings • Maglite flashlight, green and red laser pointer • Binder clips • Small white board with a vertical black line drawn to mark the middle • Red and green dry erase markers • Electromagnetic Spectrum poster (see source below)
Summary of procedure or suggested activities	Note: Be very careful with the laser pointers (especially the green.) Avoid getting light into eyes. • Introduce the idea of diffraction by having visitors experiment with diffraction gratings and prisms. Explore the different light sources around the room and see if there are any differences. • Clip two of the binder clips onto the bottom of one of the diffraction gratings so that it stands up on a table. • Set up a small white board about a foot away. • Turn the maglite on so that the light is going through the diffraction grating and projects onto the white board. (You might need to focus the flashlight to get a nice spectrum.) • Have visitors mark where the red and green parts of the spectrum are being projected to on the white board. • Ask them why different colors hit different parts of the white board. Talk about wavelengths of light. • Set up the red laser pointer in the same place that the maglite was. Ask visitors what is different about the two light sources and have them predict where they think that the red laser will hit the white board. (If you have the setup the same for both lights, it should end up right on top of the red marks.) Repeat with the green laser. • Introduce how astronomers might use information about wavelengths (including wavelengths other than visible) of light to help explore the universe.

Questions to ask visitors during interpretation	Why do different light sources appear different when you look through a diffraction grating? Why does the green light spread out farther from the middle than the red light? How do you think astronomers might use information such as the wavelengths of light emitted from a star?
Extensions or connections to other topics or interpretations	This is a great extension activity to do after visitors have spent some time exploring the Spectra Interactive exhibit in *Cosmic Questions.* Infrared Camera exhibit
Background material	This activity is modified from one developed by Dr. Kathryn Flannagan and Dr. Irene Porro at the MIT Center for Space Research. A poster of the electromagnetic spectrum is available for at: http://www.tufts.edu/as/wright_center/svl/posters/ems.html

<table>
<tr><th>Name of interpretation</th><th>Spectral Lines</th></tr>
<tr><td>Skills and concepts to be presented</td><td>Use of emission spectra as sources of information to learn about stars and galaxies.
Introduction to redshift.
Use of galactic spectra to determine galactic speed.
Testing ideas and making assumptions.</td></tr>
<tr><td>Materials used</td><td>Magnetic optical images of galaxies (labeled A through D)
Magnetic spectrographs of these galaxies
Magnetic spectrograph of laboratory hydrogen</td></tr>
<tr><td>Summary of procedure or suggested activities</td><td>Note: This activity works especially well after visitors have had a chance to explore the Spectra Interactive exhibit and are comfortable with the idea of spectra.
Scatter the spectrographs of the galaxies on the metal cart and invite visitors to make observations about their differences and similarities.
Now have visitors look at the hydrogen spectra and point out the large peak at 656 nanometers.
Invite visitors to determine the wavelength of the large peak in the spectra from Galaxies A, B, C and D and put these in order from smallest to largest (farther to the left to farther to the right).
Discuss why the hydrogen line would be in a different place.
Place the optical images of the four galaxies A, B, C, and D on the cart and share with the visitors that these images each match one of the spectrographs.
Let the visitors know that these four galaxies are all approximately the same actual size.
Challenge visitors to arrange the four galaxies in order of distance from the Earth so that they match their corresponding spectra.
Discuss what evidence they used for their choices</td></tr>
<tr><td>Questions to ask visitors during interpretation</td><td>What are the similarities that you notice about all of these spectra?
What could make the large peak (hydrogen) shift so far from where we know that it should show up?
How far has the line been shifted?</td></tr>
</table>

Extensions or connections to other topics or interpretations	Tuning fork demonstration (in demonstration boxes)
Background material	Galaxies are so large, and so far away, that you could never see them move just by looking at the sky; even if you looked for a whole lifetime through the most powerful telescope. However, by examining the spectrum of light from a galaxy, you can determine whether the galaxy is moving towards or away from us, and how fast it is moving. Atoms emit light of fixed standard wavelengths. An emission spectrum shows a specific pattern of lines that is a kind of "barcode" unique to the particular types of molecules. The emission spectrum of glowing hydrogen gas has a bright red line, a fainter blue line, and several other faint lines. The red line for hydrogen has a wavelength of 656 nanometers. 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 spike is an easily recognizable feature in many astronomical spectra. If you see this unique pattern in the light from an unknown source, then you can conclude that the source must contain the element hydrogen. A spectra of a galaxy is the pattern produced when the light from the galaxy is passed through a prism or diffraction grating. The emission spectra from the four different galaxies has (in addition to the rainbow) a bright red line, and a fainter blue line from the element hydrogen. However, the hydrogen peak has been shifted towards the longer wavelength part of the spectrum, which is the redder end of the spectrum. This phenomenon is called a "redshift." 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, for a galaxy moving away from us at 10% of the speed of light, its light will be redshifted by 10%. So, for this example, the hydrogen line that was at 656 nanometers will be redshifted by about 65 nanometers. It is possible to calculate how fast Galaxies A, B, C, and D are receding from us. In the 1920s, Edwin Hubble measured the redshifts of galaxies. He found that there was a linear relationship between their speed and their distance from us. That is, a galaxy at distance d away is moving twice as fast as a galaxy half as far (d/2) away. The slope of the graph of velocity vs. distance away represents the Hubble Constant for the universe, and is expressed via Hubble's law.

	v = H x d Recession velocity = Hubble’s constant x distance from us The Hubble Constant describes how fast the universe is expanding. This rate can be used to calculate the age of the universe, or how long it took for it to expand to its current size. For this reason, determining the precise value of the Hubble constant is key to understanding the origin of the universe. Although the idea is very straightforward, there are several factors that affect our understanding of the universe’s expansion. 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. These optical images and spectra are of actual galaxies. Their approximate distances and velocities follow: Galaxy A (~1520 Mly) has a recession velocity of 31,400 km/s Galaxy B (~210 Mly) has a recession velocity of 4,350 km/s Galaxy C (~2160 Mly) has a recession velocity of 44,700 km/s Galaxy D (~750 Mly) has a recession velocity of 15,400 km/s
	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. http://cfa-www.harvard.edu/seuforum/galSpeed

Name of interpretation	Infrared Camera
Skills and concepts to be presented	1. Introduction to the Electromagnetic Spectrum. 2. Visible is just one form of radiant energy. 3. Infrared is light that we cannot see. 4. Astronomers use many different wavelengths to gain further understanding of the universe.
Materials used	• Infrared Camera Exhibit in *Cosmic Questions* • Poster of the Electromagnetic Spectrum (see source below)
Summary of procedure or suggested activities	**Invite visitors to use the camera to explore the images and objects on the wall and make observations about what they see.** • Have visitors first use the camera to look at the rainbow. With the camera, they should notice a bright area past where the visible light hits. • Ask one visitor to stand behind the window and have the other visitors make observations about what they can see with their eyes and what is only visible through the camera. • Use the remote control to show a source of infrared light that we can't see at all, but the camera can detect. • Have visitors look at the stars on the far right and ask them for their thoughts as to how astronomers might be able to use infrared light to study the universe. • Introduce multiwavelength exploration and how use of different wavelengths can give us a more complete picture of the universe.
Questions to ask visitors during interpretation	How can this camera see light that is "invisible" to us without it? Why can this camera see through that window when we can't? Have you ever thought about how your remote control works? How do you think astronomers use different kinds of light to study the stars?
Extensions or connections to other topics or interpretations	Spectra Interactive exhibit Diffraction interpretation Multiwavelength Interactive exhibit Infrared thermometer (in demonstration boxes)

Background material (if any)	A poster of the electromagnetic spectrum is available for at: http://www.tufts.edu/as/wright_center/svl/posters/ems.html

Name of interpretation	Expansion of the Universe
Skills and concepts to be presented	1. The universe continues to expand; the "fabric" of space expands. 2. There is no center for expansion. 3. Use of models. 4. Hubble's law.
Materials used	• Latex exercise band • Stapler • Permanent marker • Balloons • Stickers (stars, round, etc) • Two galaxy field acetate sheets (templates in Appendix) • Ruler • Tape Measure
Summary of procedure or suggested activities	**Create several models to represent the expansion of the universe** Latex band model--one dimensional model • Create a model of the universe by stapling round stickers onto a piece of latex band. The band represents space and the stickers will represent different galaxies in the universe. • Have visitors stretch out the band and observe the distance between the galaxies. Notice that the galaxies have stayed the same size, but the distance between all of the galaxies has increased. • Now have one visitor stand at the center galaxy and hold onto the band there. Pull the two ends. Notice that all of the galaxies *appear* to be expanding from that "central" galaxy. • Try another galaxy and notice that a similar thing happens. • You may want to use another piece of latex band and draw a sine wave on it. As you stretch this, notice that the actual wavelength is stretching. As the universe expands the light wavelengths also increase.

	Balloon model--two dimensional model • Now try to visualize this expansion in a two-dimensional model, remembering that space is really four dimensions. Always be sure to point out the limitations of your models. • Place the small star or dot stickers on the balloon as close as you can to each other. These will represent galaxies. • Have visitors notice the distance between these "galaxies" before you blow up the balloon. • Now start expanding your universe--blow up the balloon a little. • Have visitors make more observations about the distances between the galaxies. • Continue expansion and have visitors make more observations about the relationships between the galaxies. Center of expansion model • Use the 2 acetate sheets with a piece of white paper behind them. • The two sheets have the same image on them except that one of the sheets has been slightly enlarged. This represents what a galaxy field might look like after one second of expansion. • Have visitors find the same galaxy on the two sheets and line them up so that they are on top of each other. • Then try another set. Have visitors notice that no matter what galaxy they pick, everything else *appears* to be expanding away from that galaxy. • Ask for observations about what is happening to the neighboring galaxies. What about the far away galaxies? • Very interested visitors might want to measure the distances that these different sets of galaxies seem to be moving apart from each other.
Questions to ask visitors during interpretation	What do you notice happening to the different galaxies? Where is the center for all of this expansion? Is there a center to our universe? Are the far away galaxies moving more?

Extensions or connections to other topics or interpretations	Red shift Spectral lines interpretation
Background material	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 between 12 and 15 billion years ago, the entire contents of the universe expanded explosively into existence from a single, hot, dense chaotic mass, and continues to expand today. What does it mean to say that 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 expansion of the universe. By measuring a galaxy’s distance from us and how fast that galaxy is receding (its recession velocity), Edwin Hubble 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 velocity vs. distance away represents the Hubble Constant for the universe. Finding the value of Hubble's constant is a current hot topic in astronomy, and has many implications for our understanding of how the universe has evolved since the Big Bang. 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. The age of the universe is generally estimated to be between 12 and 15 billion years.

Further Reading	Paul Doherty from the Exploratorium has a website with further information on this topic and additional related activities at: http://www.exo.net/~pauld/activities/astronomy/expandinguniverselecture.html

Name of interpretation	Curved Space and Gyroscopes: Gravity Probe B
Skills and concepts to be presented	1. The nature of how gyroscopes work and what we use them for. 2. Introduce the Gravity Probe B and its mission. 3. Introduce Newton and Einstein and their theories. 4. What is space-time curvature?
Materials used	• Gyroscopes (also one in PVC tube) • Gravity Probe B • Bed sheet • Tennis ball and basketball (or other large round object) • Gravity Probe B poster and Educators' Guide
Summary of procedure or suggested activities	Note: The Gravity Probe B rotor (sphere) should not be touched. It can be put into the glass display case using artifact gloves or the packing cloth. Introduce the non-spinning gyroscope and ask visitors to try to balance it without spinning. Show how spinning it makes a difference and let visitors experiment with some tricks (such as balancing the gyro on its stand or a piece of string). Ask visitors if they know why a gyroscope works. Demonstrate the resistance of a gyroscope to changing planes by having visitors grasp the non-spinning parts of the gyroscope in their hands and twist their wrists. Ask them to describe what they feel. A simple explanation (something that is spinning always wants to stay up in that plane) is generally fairly easy to understand. Introduce visitors to the Gravity Probe B. Explain that the probe is a perfect sphere and that would remove the wobble that other gyroscopes have. Talk about the forces of gravity and friction and how they impact gyroscopes on Earth. Discuss how neither would exist in a satellite in space and how that would effect the gyro (never ending rotation). Have visitors pick up the bed sheet and pull it taught. Introduce it as a model of space noting the limitations of a 2D model of a 4D concept. Roll tennis ball across the taught sheet and notice how it rolls in a straight line. Introduce Newton's theory of gravity controlling the obits, and the problem of instantaneous gravity. Drop the basketball in the middle and make sure visitors are still keeping the sheet tight. Roll the ball again, this time noting how the ball will always curve toward the

	mass. Einstein used this concept as applied to space-time to explain why the planets orbit. Return to the probe for more information about how the probe will measure the space time curvature. For very interested visitors go on to talk about the details of how the probe works or how it measures frame drag.
Questions to ask visitors during interpretation	Do you know what a gyroscope is? Why does it balance? What will happen to the tube when the gyro spins? What will happen to the gyro when...(whichever trick is being done?) What do you think that this (the gravity probe) is used for? What will happen to the ball when you roll it on a straight sheet? Why should we test Einstein's theory? Why can't we just believe him?
Extensions or connections to other topics or interpretations	Black holes Bicycle wheel gyro
Background material	Please refer to the Gravity Probe B poster and Educators' Guide (included in the Gravity Probe interpretation box) Additional copies of the Educators' Guide along with additional information and images are available at: http://einstein.stanford.edu/
Further Reading	Schwartz, Joseph., McGuinness, Michael. (1990). *Einstein for Beginners*. Pantheon Books. Couper, Heather., Henbest, Nigel. (1997). *Big Bang: The Story of the Universe*. DK Publishing. (nice curvature pictures)

Name of interpretation	Building the Elements
Skills and concepts to be presented	1. Introduction to the atom. 2. Introduction to the theory of The Big Bang. 3. How the early elements formed. 4. Introduction to how the remaining elements might have formed stars.
Materials used	• Periodic table • Plastic bowl to represent the universe • Nucleons: approximately 1 inch diameter molded from clay (red for protons, blue for neutrons) • Electrons (molded clay balls smaller than a nucleon) • Gloves (the clay can stick to and stain the hands)
Summary of procedure or suggested activities	**Introduce the concept of atoms and use the clay to model protons, neutrons, and electrons.** Ask visitors what they know about the atom. Use the periodic table and discuss protons, neutrons, and electrons. Introduce the conditions before the nucleons began to combine. Use the balls of clay to show the reactions from ^{1}H to ^{4}He, and what stopped it. Explain that stars began to form later on. Use three helium nuclei to show the reactions through ^{12}C and then extend to ^{16}O. Describe how heavy elements were released by supernovas and then introduce the theory that our solar system was formed from this leftover matter. Advice: Try to keep the explanations as simple as possible. For younger children, just introduce atoms.
Questions to ask visitors during interpretation	What is an atom? Where did all of the "stuff" of the universe come from? How do you think that the stars formed? What are the real sizes of protons, nucleons and electrons?

Extensions or connections to other topics or interpretations	Cloud Chamber
Background material	**About Atoms** Atoms are the building blocks of everything we see around us. An atom is composed of a nucleus surrounded by one or more electrons. The nucleus is composed of neutrons and protons, collectively called nucleons. A proton carries a positive electric charge of 1 unit, and a neutron is uncharged. An electron carries a negative charge of 1 unit. A neutral atom, will have an equal number of electrons as protons, and the sum of the proton and electron charges will therefore be zero. An atom doesn't always have to be neutral; it can be short an electron or two, and sometimes can have extra ones. In these cases, the atom will have a net positive or negative charge. An element can be viewed as a substance containing atoms of only one type. Here, the term is used as shorthand for the type of an atom. The type of atom is determined by the number of protons in the nucleus. Different elements have different chemical properties. The properties are determined by the number of electrons in the atom, which in turn is determined by the number of protons. When atoms combine into molecules, it is the arrangement of their electrons that binds the molecules together. Our primary focus will be the nucleus. Elements up to Oxygen (8 protons) tend to have equal numbers of neutrons and protons in the nucleus, but heavier elements tend to carry more neutrons than protons. A specific element will have a specific number of protons, but it can have differing numbers of neutrons. Nuclei with the same number of protons but differing numbers of neutrons are called "isotopes" of the same element. For example, the nucleus with the smallest number of nucleons is hydrogen. In its common form, it has one proton and no neutrons. But hydrogen has two other isotopes: deuterium, having one proton and one neutron, and tritium, having one proton and two neutrons. To specify a specific isotope, one writes the symbol for the name of the atom, preceded by a superscript giving the total number of nucleons in the atom (usually called its atomic weight or atomic mass). Common hydrogen is ^{1}H, deuterium is ^{2}H, and tritium is ^{3}H. Although isotopes of hydrogen have their own names, this is not usually the case. Isotopes of other elements are only called by their element names followed by their atomic weight (e.g. ^{16}O is called Oxygen sixteen). The second lightest nucleus is Helium, which has two protons. It has two isotopes ^{3}He and ^{4}He, having one and two neutrons respectively.

The Big Bang

Astronomers have determined that the universe is expanding and have been able to trace the expansion back to an early instant when all matter was together at one point. This instant is called the Big Bang. Physical theory can describe what the universe must have been like back to before the first nanosecond of the universe's life. The universe's temperature started out extremely high and immediately began to cool. When it was 10 milliseconds old it's temperature would have been 10^{11} Kelvin (or, 100 billion degrees Kelvin), by around the end of the first second it would have cooled by a factor of ten to 10^{10} (10 billion) Kelvin.

At about three minutes after the start of the bang, the temperature was 10^{9} (one billion) Kelvin. Space at this time was populated primarily with neutrons, protons, electrons, photons (particles of light), and neutrinos (which don't play a part here). Before this, all the nucleons were too energetic to bind together; they were just moving too fast with respect to each other. But at about three minutes, things were cool enough for protons and neutrons to begin to combine with each other.

The first stage of element building is when the very light nuclei are built. This happens fairly quickly. However, the building of these elements would not be complete until the universe had cooled down enough for the electrons to be traveling slowly enough to bind to the nuclei. That is the second stage, and this would have happened only several hundred thousand years later.

Building the lightest elements

At the three-minute mark, the universe contained isolated protons and neutrons (as well as the other particles we mentioned). At this point there would have been about 16 neutrons in existence for every 100 protons (or about 1 neutron for every 6 protons). By this time, the thermal energy was low enough that when a neutron and a proton collided, they would sometimes bind together into a two nucleon nucleus (nuclear fusion). So a proton (p), which is the ^{1}H nucleus (later it will pick up the necessary electrons) would hit a neutron (n), and form a deuterium nucleus (^{2}H), with some excess energy being carried off in a photon (of light).

p + n -> 2H + photon

When there are sufficient numbers of deuterium nuclei in existence, these will begin to collide with each other, and will produce a nucleus with three nucleons. In the following reaction, one of the deuterium nuclei is broken up and its neutron gets bound to the other deuterium nucleus to form a tritium nucleus (^{3}H). The remaining proton carries off excess energy.

$^{2}H + ^{2}H \rightarrow ^{3}H + p$

If the tritium nucleus is now hit by a deuterium, the deuterium nucleus can be broken up and its proton can bind to the tritium nucleus yielding helium 4 (^{4}He). Again, the remaining proton carries off excess energy.

$^{3}H + ^{2}H \rightarrow ^{4}He + n$

We could also get helium by going through helium 3 (^{3}He) instead of tritium:

$^{2}H + ^{2}H \rightarrow ^{3}He + n$ then $^{3}He + ^{2}H \rightarrow ^{4}He + p$

This is one of the reaction sequences that builds helium from hydrogen. There are other reaction sequences that have the same end result.

There is no stable nucleus with five nucleons, so element building tends to grind to a halt. A trace amount of the next element, lithium-7 (^{7}Li), gets made. But that is all. Conditions are not yet right for building heavier nuclei. At this point the universe consists of hydrogen and helium, with ten times as many hydrogen atoms as helium atoms. Virtually all the neutrons have been used up to build helium.

The next stage of element creation - stars

When there is a preponderance of interstellar matter in a particular location of space compared with surrounding locations, this matter will be pulled ever tighter together by the mutual gravitation of all its parts. Before the first generation of starts was formed, this interstellar matter would have been composed of the hydrogen and helium (and trace amounts of Lithium) created by the Big Bang.

As this matter pulls together it starts to collapse into a central mass. As matter is accreted onto this central mass, it heats up. Eventually it gets hot enough to start glowing. It continues to collapse and it gets hot enough, in the center of the star, to undergo nuclear fusion. This fusion starts to build helium from star’s hydrogen, and to generate energy for the star.

Eventually the hydrogen in the core of the star will have been turned into helium, and it if is a large star, it will get hot enough in the center for helium nuclei to fuse together. The first such reaction makes Beryllium:

^{4}He + ^{4}He -> ^{8}Be + photon

However, ^{8}Be is extremely unstable, and if a second helium doesn't fuse with it right away (i.e. within approximately 10-14 sec), it will break up again. Therefore it must be immediately followed by the following reaction which takes us to Carbon:

^{4}He + ^{8}Be -> ^{12}C + photon

Then, later and hotter,

^{4}He + ^{12}C -> ^{16}O gives us Oxygen.

In bigger, hotter stars we can build higher, with the reactions like the following:

^{12}C + ^{12}C -> ^{24}Mg + photon

^{16}O + ^{16}O -> ^{32}S + photon

^{28}Si + ^{28}Si -> ^{56}Fe + photon

This process stops at Iron (^{56}Fe).

Supernova

There are several mechanisms that can cause a star to become a supernova. The one most appropriate for this discussion takes place when the large star has manufactured elements up to Iron in its core and at that point has no more fuel to support the star.

The fusion reactions that take place in the star that manufactures the heavier elements produce energy for the star. This energy is what makes the star shine. This energy also keeps the core of the star hot enough to support the mass of the star above it. The elements below Iron in the periodic table produce energy when they fuse. Those above Iron require the addition of energy when they fuse together. So making elements heavier than Iron uses up energy. Therefore, once a stellar core has gone to iron, it has no energy source left, and a point will be reached when it will implode,

	then explode, creating a supernova. This explosion blows off a lot of the heavy elements that we discussed above, and also creates more elements as it proceeds. The reactions of the supernova release a lot of free neutrons into the exploding star and these neutrons are readily absorbed into the nuclei of the exploding star. Absorption of a neutron into a nucleus just increases the number of neutrons in the nucleus, but a nucleus with too many neutrons will change into a nucleus with one more proton and one less neutron (beta decay), moving it up one step (away from hydrogen) on the periodic table. Then if this nucleus absorbs a neutron, it will do the same thing and move up again. By repetition of this process, nuclei from iron up to uranium and above can be very quickly created, as well as numerous new isotopes of the lighter elements that hadn't been created previously. The remnants of the supernova are scattered about in interstellar space for use in creating the next generation of stars. After several generations of star building have passed, we could expect to have enough heavy elements for planets like ours to form. A star the size of our sun isn't expected to end up a supernova. The sun is too small for this. It won't produce any elements heavier that Helium. The stars that produce supernovae are bigger, hotter, and brighter, and they go though their fuel very quickly. They might last on the order of hundreds of millions of years in contrast to the 4.5 billion years ours has already lived. Note: This interpretation was developed by Museum of Science, Boston Volunteer George Sprott.
Further Reading	Weinburg, Stephen. (1993). *The First Three Minutes*. BasicBooks. Delsemme, Armand. (1998). *Our Cosmic Origins*. Cambridge University Press. Mackintosh, Al-Khalili., Jonson, and Pena. (2001). *Nucleus: A Trip into the Heart of Matter*. The John Hopkins University Press.

Name of interpretation	Cloud Chamber Exhibit
Skills and concepts to be presented	1. Introduction to the ideas of charged particles 2. Observation 3. Introduction to cosmic rays
Materials used	• Cloud Chamber exhibit in *Cosmic Questions*
Summary of procedure or suggested activities	• Encourage visitors to observe the paths of the charged particles in the chamber. • Explain how the chamber works • Introduce the idea of cosmic rays that are left over from the explosion of stars.
Questions to ask visitors during interpretation	What do you think those white streaks are? How do you think that they got here? Is it really possible for us to see remnants of explosions of stars here from Earth?
Extensions or connections to other topics or interpretations	Building the Elements interpretation
Background material	This cloud chamber shows that we are being bombarded by particles all of the time. The tracks reveal the charged particles that are the basic building blocks of the universe. Charles T.R.Wilson first developed cloud chambers around 1911 for experiments on the formation of rain clouds. Wilson knew that water vapor condensed around ions, atoms that have become charged by gaining or losing electrons. However, an alpha particle that had an electric charge, would leave a trail of ions as it passed through a gas. If water vapor condensed on these ions, the track of the alpha particle would become visible as a line of water droplets. Cloud chambers are today being used to detect elementary particles and other ionizing radiation, such as cosmic rays. In this exhibit, the chamber is used to detect the cosmic rays, charged particles such as alpha and beta

	particles, which originated out in space. A cloud chamber works by having a supersaturated vapor, which is in the equilibrium state between its liquid and gas phase. Usually, the vapor is water in the air. When ionizing radiation passes through the vapor, it leaves a trail of charged particles or ions. These ions serve as condensation centers for the vapor. It is this condensed vapor around these ions, which appears as tiny liquid droplets in the supersaturated vapor, which allows us to observe the path of the radiation. There are two types of cloud chambers: pulse type and diffusion. A diffusion type cloud chamber is the type used in this exhibit. The diffusion cloud chamber uses a large temperature difference that is maintained between the top and bottom of the chamber. A refrigerant is used to cool the bottom of the chamber to create the temperature difference. The air in the chamber is then saturated with a vapor, usually alcohol. The air-vapor mixture cools as it diffuses toward the cool bottom and becomes supersaturated. If the gas is kept saturated with a fresh supply of vapor, in this case a liquid reservoir, the operation of the chamber can essentially be continuous. One limitation of the cloud chamber is the relatively low density of the gas, which limits the number of interactions between ionizing radiation and molecules of the gas. Because of this, physicists have developed other particle detectors, notably the bubble chamber and the spark chamber.
Further Reading	Mackintosh, Al-Khalili., Jonson, and Pena. (2001). *Nucleus: A Trip into the Heart of Matter*. The John Hopkins University Press.

Cosmic Questions

Our place in space and time

Appendix

Put the Universe in Order Detailed Notes

Hubble Space Telescope

The Hubble Space Telescope (HST) is the largest orbiting public optical telescope in history. Its 2.4 meter diameter reflecting mirror and its perch above Earth's atmosphere allow it to create exceptionally sharp images. Originally launched in 1990, HST optics were repaired to their intended accuracy in 1993 by the first of several regular servicing missions. Astronomers using HST continue to make numerous monumental scientific discoveries, including new estimates of the age of our universe, previously unknown galaxies, evidence of massive black holes in the centers of galaxies, previously unknown moons, and a better understanding of physical processes in our universe. http://apod.gsfc.nasa.gov/apod/ap950810.html

Why put observatories in space? Most telescopes are on the ground. On the ground, you can deploy a heavier telescope and upgrade it more easily. The trouble is that Earth-bound telescopes must look through the Earth's atmosphere. First, the Earth's atmosphere blocks out a broad range of the electromagnetic spectrum, allowing a narrow band of visible light to reach the surface. Telescopes which explore the universe using light beyond the visible spectrum, such as the new ultraviolet and infrared instruments on the Hubble Space Telescope, need to be carried above the absorbing atmosphere. Second, the Earth's atmosphere blurs the light it lets through. The blurring is caused by varying density and continual motion of air. By orbiting above the Earth's atmosphere, the Hubble can get clearer images. In fact, even though HST has a mirror 15 times smaller than large Earth-bound telescopes, it can still resolve detail almost 100 times finer. It is, of course, not troubled by weather. http://apod.gsfc.nasa.gov/apod/ap970306.html

The Hubble Space Telescope is a cooperative program of the European Space Agency (ESA) and the NASA to operate a long-lived space-based observatory for the benefit of the international astronomical community. HST is an observatory first dreamt of in the 1940s, designed and built in the 1970s and 80s, and operational only in the 1990s. Since its preliminary inception, HST was designed to be a different type of mission for NASA -- a long term space-based observatory. To accomplish this goal and protect the spacecraft against instrument and equipment failures, NASA had always planned on regular servicing missions. Hubble has special grapple fixtures, 76 handholds, and stabilized in all three axes. HST is a 2.4-meter reflecting telescope which was deployed in low-Earth orbit (600 kilometers) by the crew of the space shuttle Discovery on 25 April 1990.

Responsibility for conducting and coordinating the science operations of the Hubble Space Telescope rests with the Space Telescope Science Institute at the Johns Hopkins University in Baltimore, Maryland. STScI is operated for NASA by the Association of Universities for Research in Astronomy, Inc.

HST's current complement of science instruments include three cameras, two spectrographs, and fine guidance sensors (primarily used for astrometric observations). Because of HST's location above the Earth's atmosphere, these science instruments can produce high resolution images of astronomical objects. Ground-based telescopes can seldom provide resolution better than 1.0 arc-seconds, except momentarily under the very best observing conditions. HST's resolution is about 10 times better, or 0.1 arc-seconds.

When originally planned in 1979, the Large Space Telescope program called for return to Earth, refurbishment, and relaunch every 5 years, with on-orbit servicing every 2.5 years. Hardware lifetime and reliability requirements were based on that 2.5-year interval between servicing missions. In 1985, contamination and structural loading concerns associated with return to Earth aboard the shuttle eliminated the concept of ground return from the program. NASA decided that on-orbit servicing might be adequate to maintain HST for its 15- year design life. A three year cycle of on-orbit servicing was adopted. The two HST servicing missions in December 1993 and February 1997 were enormous successes. An additional servicing missions occurred in Dec., 1999 and one is planned for mid-2002. http://www.stsci.edu/hst/

The Moon
http://www.nineplanets.org/luna.html

The Moon is the only natural satellite of Earth:

orbit:	384,400 km from Earth
diameter:	3476 km
mass:	7.35e22 kg

Called Luna by the Romans, Selene, and Artemis by the Greeks, and many other names in other mythologies.

The Moon, of course, has been known since prehistoric times. It is the second brightest object in the sky after the Sun. As the Moon orbits around the Earth once per month, the angle between the Earth, the Moon and the Sun changes; we see this as the cycle of the Moon's phases. The time between successive new moons is 29.5 days (709 hours), slightly different from the Moon's orbital period (measured against the stars) since the Earth moves a significant distance in its orbit around the Sun in that time. Due to its size and composition, the Moon is sometimes classified as a terrestrial "planet" along with Mercury, Venus, Earth and Mars.

The Moon was first visited by the Soviet spacecraft Luna 2 in 1959. It is the only extraterrestrial body to have been visited by humans. The first landing was on July 20, 1969; the last was in December 1972. The Moon is also the only body from which samples have been returned to Earth. In the summer of 1994, the Moon was very extensively mapped by the little spacecraft Clementine and again in 1999 by Lunar Prospector.

The Earth's rotation carries the Earth's tidal bulges slightly ahead of the point directly beneath the Moon. This means that the force between the Earth and the Moon is not exactly along the line between their centers producing a **torque** on the Earth and an accelerating force on the Moon. This causes a net transfer of rotational energy from the Earth to the Moon, slowing down the Earth's rotation by about 1.5 milliseconds/century and raising the Moon into a higher orbit by about 3.8 centimeters per year.

The asymmetric nature of this gravitational interaction is also responsible for the fact that the Moon rotates synchronously, i.e. it is locked in phase with its orbit so that the same side is always facing toward the Earth. Just as the Earth's rotation is now being slowed by the Moon's influence so in the distant past the Moon's rotation was slowed by the action of the Earth, but in that case the effect was much stronger. When the Moon's rotation rate was slowed to match its orbital period (such that the bulge always faced toward the Earth) there was no longer an off-center torque on the Moon and a stable situation was achieved. The same thing has happened to most of the other satellites in the solar system. Eventually, the Earth's rotation will be slowed to match the Moon's period.

Actually, the Moon appears to wobble a bit (due to its slightly non-circular orbit) so that a few degrees of the far side can be seen from time to time, but the majority of the far side (left) was completely unknown until the Soviet spacecraft Luna 3 photographed it in 1959. [Note: there is no "dark side" of the Moon; all parts of the Moon get sunlight half the time (except for a few deep craters near the poles)].

The Moon has no atmosphere. But evidence from Clementine suggested that there may be water ice in some deep craters near the Moon's South Pole which are permanently shaded. This has now been confirmed by Lunar Prospector. There is apparently ice at the North Pole as well.

The Moon's crust averages 68 km thick and varies from essentially 0 under Mare Crisium to 107 km north of the crater Korolev on the lunar far side. Below the crust is a mantle and probably a small core (roughly 340 km radius and 2% of the Moon's mass). Unlike the Earth's mantle, however, the Moon's is only partially molten. Curiously, the Moon's center of mass is offset from its geometric center by about 2 km in the direction toward the Earth. Also, the crust is thinner on the near side.

There are two primary types of terrain on the Moon: the heavily cratered and very old **highlands** and the relatively smooth and younger Maria. The Maria (which comprise about 16% of the Moon's surface) are huge impact craters that were later flooded by molten lava. Most of the surface is covered with **regolith**, a mixture of fine dust and rocky debris produced by meteor impacts. For some unknown reason, the Maria are concentrated on the near side.

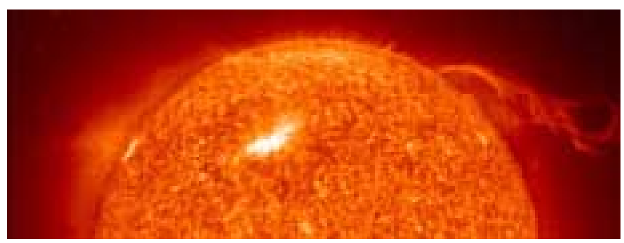
A total of 382 kg of rock samples were returned to the Earth by the Apollo and Luna programs.. Most rocks on the surface of the Moon seem to be between 4.6 and 3 billion years old. This is a fortuitous match with the oldest terrestrial rocks which are rarely more than 3 billion years old. Thus the Moon provides evidence about the early history of the Solar System not available on the Earth.

Prior to the study of the Apollo samples, there was no consensus about the origin of the Moon. There were three principal theories: *co-accretion* which asserted that the Moon and the Earth formed at the same time from the Solar Nebula; *fission* which asserted that the Moon split off of the Earth; and *capture* which held that the Moon formed elsewhere and was subsequently captured by the Earth. None of these work very well. But the new and detailed information from the Moon rocks led to the *impact* theory: that the Earth collided with a very large object (as big as Mars or more) and that the Moon formed from the ejected material. There are still details to be worked out, but the impact theory is now widely accepted.

The Sun
http://www.seds.org/nineplanets/nineplanets/sol.html

The Sun is an ordinary G2 star, one of more than 100 billion stars in our galaxy.

diameter:	1,390,000 km
mass:	1.989e30 kg
temp:	5800 K (surface)
	15,600,000 K (core)



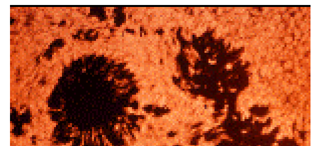
The Sun is by far the largest object in the solar system. It contains more than 99.8% of the total mass of the Solar System (Jupiter contains most of the rest). The Sun is personified in many mythologies: the Greeks called it Helios and the Romans called it Sol.

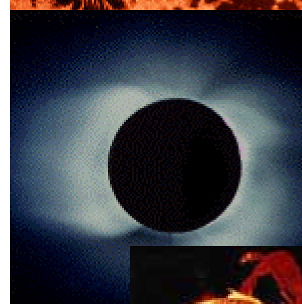
Most of the energy we receive from the Sun is the visible (white) light emitted from the photosphere. The photosphere is one of the coolest regions of the Sun (6000 K), so only a small fraction (0.1%) of the gas is ionized (in the plasma state). The photosphere is the densest part of the solar atmosphere, but is still tenuous compared to Earth's atmosphere (0.01% of the mass density of air at sea level). The photosphere looks somewhat boring at first glance: a disk with some dark spots. However, these sunspots are the sites of strong magnetic fields. The solar magnetic field is believed to drive the complex activity seen on the Sun. Magnetographs measure the solar magnetic field at the photosphere.

Because of the tremendous heat coming from the solar core, the solar interior below the photosphere (the convection zone) bubbles like a pot of boiling water. The bubbles of hot material welling up from below are seen at the photosphere, as slightly brighter regions. Darker regions occur where cooler plasma is sinking to the interior. This constantly churning pattern of convection is called the solar granulation pattern.

The Sun is, at present, about 75% hydrogen and 25% helium by mass (92.1% hydrogen and 7.8% helium by number of atoms); everything else ("metals") amounts to only 0.1%. This changes slowly over time as the Sun converts hydrogen to helium in its core. The outer layers of the Sun exhibit *differential rotation*: at the equator the surface rotates once every 25.4 days; near the poles it's as much as 36 days. This odd behavior is due to the fact that the Sun is not a solid body like the Earth. Similar effects are seen in the gas planets. The differential rotation extends considerably down into the interior of the Sun but core of the Sun rotates as a solid body. Conditions at the Sun's **core** (approximately the inner 25% of its radius) are extreme. The temperature is 15.6 million Kelvin and the pressure is 250 billion atmospheres. At the center of the core the Sun's density is more than 150 times that of water.

The Sun's energy output (386 billion megawatts) is produced by nuclear fusion reactions. Each second about 700,000,000 tons of hydrogen are converted to about 695,000,000 tons of helium and 5,000,000 tons (=3.86×10^{33} ergs) of energy in the form of gamma rays. As it travels out toward the surface, the energy is continuously absorbed and re-emitted at lower and lower temperatures so that by the time it reaches the surface, it is primarily visible light. For the last 20% of the way to the surface the energy is carried more by convection than by radiation.





The surface of the Sun, called the **photosphere**, is at a temperature of about 5800 K. **Sunspots** are "cool" regions, only 3800 K (they look dark only by comparison with the surrounding regions). Sunspots can be very large, as much as 50,000 km in diameter. Sunspots are caused by complicated and not very well understood interactions with the Sun's magnetic field.

A small region known as the **chromosphere** lies above the photosphere. The highly rarefied region above the chromosphere, called the **corona**, extends millions of kilometers into space but is visible only during eclipses. Temperatures in the corona are over 1,000,000 K.

The Sun's magnetic field is very strong (by terrestrial standards) and very complicated. Its magnetosphere (also known as the heliosphere) extends well beyond Pluto.

In addition to heat and light, the Sun also emits a low density stream of charged particles (mostly electrons and protons) known as the **solar wind** which propagates throughout the solar system at about 450 km/sec. (These particles thus reach the earth in about 3-4 days, rather than the 8 minutes for light to reach the earth.) The solar wind and the much higher energy particles ejected by solar flares can have dramatic effects on the Earth ranging from power line surges to radio interference to the beautiful aurora borealis. The solar wind has large effects on the tails of comets and even has measurable effects on the trajectories of spacecraft.

Spectacular loops and prominences are often visible on the Sun's limb. The Sun's output is not entirely constant. Nor is the amount of sunspot activity. There was a period of very low sunspot activity in the latter half of the 17th century called *the Maunder Minimum*. It coincides with an abnormally cold period in northern Europe sometimes known as the Little Ice Age. Since the formation of the solar system the Sun's output has increased by about 40%.

The Sun is about 4.5 billion years old. Since its birth it has used up about half of the hydrogen in its core. It will continue to radiate "peacefully" for another 5 billion years or so (although its luminosity will approximately double in that time). But eventually it will run out of hydrogen fuel. It will then be forced into radical changes which, though commonplace by stellar standards, will result in the total destruction of the Earth (and probably the creation of a planetary nebula).

The Asteroids (Asteroid 243 Ida)

http://www.nineplanets.org/asteroids.html

243 Ida is a Koronis asteroid orbiting the Sun between Mars and Jupiter:

orbit:	270,000,000 km from the Sun (average)
size:	58x23 km

Ida has a **satellite**! (It's the small spot to the right in the picture.) It is the first natural satellite of an asteroid ever discovered. Dactyl (right) is about 1.6 x 1.2 km, surprisingly round for such a small body. It orbits Ida at approximately 90 km.

The second of only three asteroids that have so far been observed close-up, Ida was encountered Aug. 28, 1993, by the Galileo spacecraft on its way to Jupiter.

The application of Kepler's third law to Dactyl's orbit gives a rough estimate of Ida's mass and therefore its density. That value is somewhere between 2.2 and 2.9 grams/cm3 (or perhaps a bit higher), a loose range because Dactyl's orbit is only crudely known.

Ida was originally thought to be an S-type asteroid, like Gaspra, composed of nickel-iron and some silicates. But a density of 2.9 is too low for that. Instead, Ida could well have a composition like that of ordinary chondrite meteorites, which are primitive and largely unaltered.

The surfaces of Ida and Dactyl are heavily cratered and therefore apparently quite old. But dynamical calculations indicate that the whole Koronis family is relatively young. Such calculations also indicate that objects the size of Dactyl may not be to survive for more than 100 million years or so. Perhaps the heavy cratering took place at the time of the breakup that created the Koronis family rather than the 4 billion years ago as is usually the case for such surfaces.

Galileo measured variations in the solar magnetic field as it passed by Ida (a similar effect was found at Gaspra). This indicates the Ida must contain some magnetic material, though its density is far too low for it to be similar in composition to an iron or stony-iron meteorite.

The Asteroids (In General)

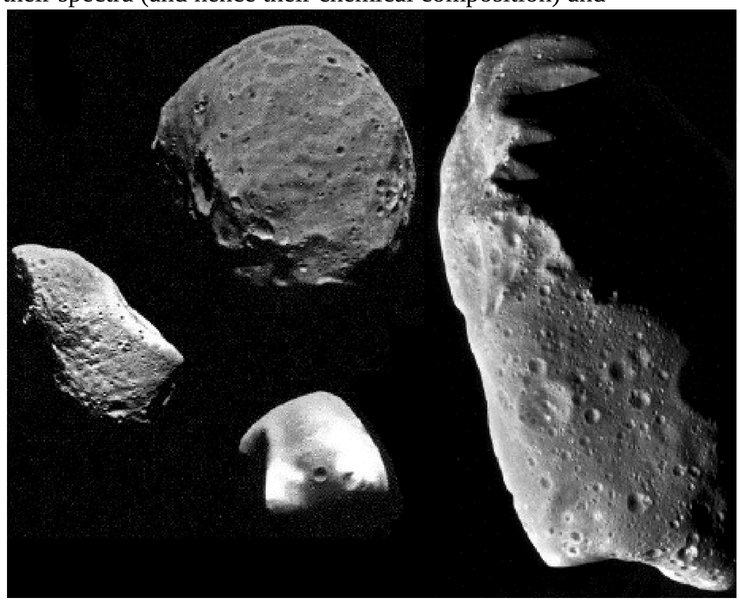
Most asteroids lie in the *Asteroid Belt*, orbiting the sun at a distance from 2.2 to 3.5 times the radius of the earth's orbit. All have a number; the larger ones also have been named (hence, 243 Ida).

On the first day of January 1801, Giuseppe Piazzi discovered an object which he first thought was a new comet. But after its orbit was better determined it was clear that it was not a comet but more like a small planet. Piazzi named it Ceres, after the Sicilian goddess of grain. Three other small bodies were discovered in the next few years (Pallas, Vesta, and Juno). By the end of the 19th century there were several hundred. Several hundred thousand asteroids have been discovered and given provisional designations so far. Thousands more are discovered each year. There are undoubtedly hundreds of thousands more that are too small to be seen from the Earth. There are 26 known asteroids larger than 200 km in diameter. Our census of the largest ones is now fairly complete: we probably know 99% of the asteroids larger than 100 km in diameter. Of those in the 10 to 100 km range we have cataloged about half. But we know very few of the smaller ones; perhaps as many as a million 1 km sized asteroids may exist. The total mass of all the asteroids is less than that of the Moon.

The largest asteroid by far is **1 Ceres**. It is 933 km in diameter and contains about 25% of the mass of all the asteroids combined. The next largest are **2 Pallas**, **4 Vesta** and **10 Hygiea** which are between 400 and 525 km in diameter. All other known asteroids are less than 340 km across.

There is some debate as to the classification of asteroids, comets and moons. There are many planetary satellites that are probably better thought of as captured asteroids. Mars's tiny moons Deimos and Phobos, Jupiter's outer eight moons, Saturn's outermost moon, Phoebe, and perhaps some of the newly discovered moons of Saturn, Uranus and Neptune are all more similar to asteroids than to the larger moons. (This composite image shows Ida, Gaspra, Deimos and Phobos approximately to scale.)

Asteroids are classified into a number of types according to their spectra (and hence their chemical composition) and albedo:



- **C-type**, includes more than 75% of known asteroids: extremely dark (albedo 0.03); similar to carbonaceous chondrite meteorites; approximately the same chemical composition as the Sun minus hydrogen, helium and other volatiles;
- **S-type**, 17%: relatively bright (albedo .10-.22); metallic nickel-iron mixed with iron- and magnesium-silicates;
- **M-type**, most of the rest: bright (albedo .10-.18); pure nickel-iron.
- There are also a dozen or so other rare types.

Asteroids are also categorized by their position in the solar system:

- **Main Belt**: located between Mars and Jupiter roughly 2 - 4 AU from the Sun
- **Near-Earth Asteroids** (NEAs): ones that closely approach the Earth
  - Atens: semimajor axes less than 1.0 AU and aphelion distances greater than 0.983 AU;
  - Apollos: semimajor axes greater than 1.0 AU and perihelion distances less than 1.017 AU
  - Amors: perihelion distances between 1.017 and 1.3 AU;
- **Trojans**: located near Jupiter's Lagrange points (60 degrees ahead and behind Jupiter in its orbit). Several hundred such asteroids are now known; it is estimated that there may be a thousand or more altogether.

Between the main concentrations of asteroids in the Main Belt are relatively empty regions known as the **Kirkwood gaps**. These are regions where an object's orbital period would be a simple fraction of that of Jupiter. An object in such an orbit is very likely to be accelerated by Jupiter into a different orbit.
There also a few "asteroids" (designated as "**Centaurs**") in the outer solar system: 2060 Chiron orbits between Saturn and Uranus; the orbit of 5335 Damocles ranges from near Mars to beyond Uranus; 5145 Pholus orbits from Saturn to past Neptune. There are probably many more, but such planet-crossing orbits are unstable and they are likely to be perturbed in the future. The composition of these objects is probably more like that of comets or the Kuiper Belt objects than that of ordinary asteroids. In particular, Chiron is now classified as a comet.

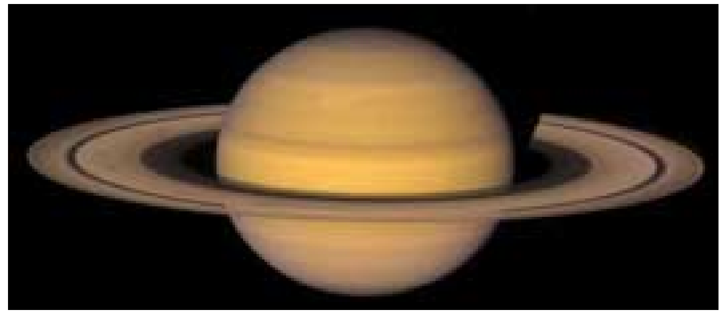
Vesta has been studied recently with HST. It is a particularly interesting asteroid in that it seems to have been differentiated into layers like the terrestrial planets. This implies some internal heat source in addition to the heat released by long-lived radio-isotopes which alone would be insufficient to melt such a small object. There is also a gigantic impact basin so deep that it exposes the mantle beneath Vesta's outer crust.

Though they are never visible with the unaided eye, many asteroids are visible with binoculars or small telescopes. A few asteroids and comets are listed below for comparison. (distance is the mean distance to the Sun in thousands of kilometers; masses in kilograms).

Saturn

http://www.nineplanets.org/saturn.html

Saturn is the sixth planet from the Sun and the second largest:



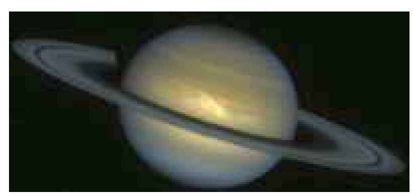
orbit:	1,429,400,000 km (9.54 AU) from Sun
diameter:	120,536 km (equatorial)
mass:	5.68e26 kg

In Roman mythology, Saturn is the god of agriculture. Saturn is the root of the English word "Saturday"

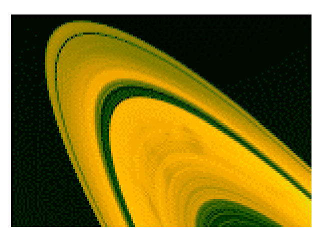
Saturn has been known since prehistoric times. Galileo was the first to observe it with a telescope in 1610; he noted its odd appearance but was confused by it. Early observations of Saturn were complicated by the fact that the Earth passes through the plane of Saturn's rings every few years as Saturn moves in its orbit. A low resolution image of Saturn therefore changes drastically. It was not until 1659 that Christiaan Huygens correctly inferred the geometry of the rings. Saturn's rings remained unique in the known solar system until 1977 when very faint rings were discovered around Uranus (and shortly thereafter around Jupiter and Neptune). Saturn was first visited by Pioneer 11 in 1979 and later by Voyager 1 and Voyager 2. Cassini, now on its way, will arrive in 2004.

Saturn is visibly flattened (oblate) when viewed through a small telescope; its equatorial and polar diameters vary by almost 10% (120,536 km vs. 108,728 km). This is the result of its rapid rotation and fluid state. The other gas planets are also oblate, but not so much so. Saturn is the least dense of the planets; its specific gravity (0.7) is less than that of water. Like Jupiter, Saturn is about 75% hydrogen and 25% helium with traces of water, methane, ammonia and "rock", similar to the composition of the primordial Solar Nebula from which the solar system was formed.

Saturn's interior is similar to Jupiter's consisting of a rocky core, a liquid metallic hydrogen layer and a molecular hydrogen layer. Traces of various ices are also present. Saturn's interior is hot (12000 K at the core) and Saturn radiates more energy into space than it receives from the Sun. Most of the extra energy is generated by the Kelvin-Helmholtz mechanism as in Jupiter. But this may not be sufficient to explain Saturn's luminosity; some additional mechanism may be at work, perhaps the "raining out" of helium deep in Saturn's interior.



The bands so prominent on Jupiter are much fainter on Saturn. They are also much wider near the equator. Details in the cloud tops are invisible from Earth so it was not until the Voyager encounters that any detail of Saturn's atmospheric circulation could be studied. Saturn also exhibits long-lived ovals (red spot at center of image at right) and other features common on Jupiter. In 1990, HST observed an enormous white cloud near Saturn's equator which was not present during the Voyager encounters; in 1994 another, smaller storm was observed.



Two prominent rings (A and B) and one faint ring (C) can be seen from the Earth. The gap between the A and B rings is known as the **Cassini division**. The much fainter gap in the outer part of the A ring is known as the **Encke Division**. The Voyager pictures show four additional faint rings. Saturn's rings, unlike the rings of the other planets, are very bright (albedo 0.2 - 0.6). Though they look continuous from the Earth, the rings are actually composed of innumerable small particles each in an independent orbit. They range in size from a centimeter or so to several meters. A few kilometer-sized objects are also likely.

Saturn's rings are extraordinarily thin: though they're 250,000 km or more in diameter they're no more than 1.5 kilometers thick. Despite their impressive appearance, there's really very little material in the rings -- if the rings were compressed into a single body it would be no more than 100 km across. The ring particles seem to be composed primarily of water ice, but they may also include rocky particles with icy coatings.

There are complex tidal resonances between some of Saturn's moons and the ring system: some of the moons, the so-called "shepherding satellites" (i.e. Atlas, Prometheus and Pandora) are clearly important in keeping the rings in place; Mimas seems to be responsible for the paucity of material in the Cassini division, which seems to be similar to the Kirkwood gaps in the asteroid belt; Pan is located inside the Encke Division. The whole system is very complex and as yet poorly understood. The origin of the rings of Saturn (and the other Jovian planets) is unknown. Though they may have had rings since their formation, the ring systems are not stable and must be regenerated by ongoing processes, probably the breakup of larger satellites.

Pleiades (M45)

http://www.seds.org/messier/m/m045.html

Distance	0.38 (kly)
Visual Brightness	1.6 (mag)
Apparent Dimension	110.0 (arc min)

Known pre-historically. Mentioned by Hesiod between 1000 and 700 B.C.

The Pleiades are among those objects which are known since the earliest times. At least 6 member stars are visible to the naked eye, while under moderate conditions this number increases to 9, and under clear dark skies jumps up to more than a dozen. The earliest known reference of this cluster is a mention by Hesiod, about 1000 BC. Homer mentions them in his *Odyssee*, and the Bible has three references to the Pleiades.

The Pleiades also carry the name "Seven Sisters"; according to Greek mythology, seven daughters and their parents. Their Japanese name is "Subaru", which was taken to christen the car of same name.

Modern observing methods have revealed that at least about 500 mostly faint stars belong to the Pleiades star cluster, spread over a 2 degree (four times the diameter of the Moon) field. Their density is pretty low, compared to other open clusters. This is one reason why the life expectation of the Pleiades cluster is also pretty low. Longer exposure photographs have revealed that the Pleiades are apparently imbedded in nebulous material.

The Pleiades nebulae are blue-colored, which indicates that they are *reflection nebulae*, reflecting the light of the bright stars situated near (or within) them.

According to new calculations, the age of the Pleiades star cluster is approximately 100 million years. This is considerably more than the previously published age of 60--80 million years. It has been calculated that the Pleiades have an expected future lifetime as a cluster of only about another 250 million years; after that time, they will have been spread as individual (or multiple) stars along their orbital path.

The Pleiades are at a distance of 380 light years.

Andromeda Galaxy (M 31)

http://www.seds.org/messier/m/m031.html

Distance	2900 (kly)
Visual Brightness	3.4 (mag)
Apparent Dimension	178x63 (arc min)

M31 is the famous *Andromeda galaxy*, our nearest large neighbor galaxy, forming the Local Group of galaxies together with its companions (including M32 and M110, two bright dwarf elliptical galaxies), our Milky Way and its companions, M33, and others.

Visible to the naked eye even under moderate conditions, this object was known as the "little cloud" to the Persian astronomer Al-Sufi, who described it 964 AD in his *Book of Fixed Stars*; it must have been observed by Persian astronomers as early as 905 AD, or earlier. It was long believed that the "Great Andromeda Nebula" was one of the closest nebulae. William Herschel believed, wrongly of course, that its distance would "not exceed 2000 times the distance of Sirius" (17,000 light years); nevertheless, he viewed it at the nearest "island universe" like our Milky Way which he assumed to be a disk of 850 times the distance of Sirius in diameter, and of a thickness of 155 times that distance.

It was William Huggins, the pioneer of spectroscopy, who noted the difference between gaseous nebula with their line spectra and those "nebulae" with continuous spectra, which we now know as galaxies.

In 1912, V.M. Slipher of Lowell Observatory measured the radial velocity of the Andromeda "nebula" and found it the highest velocity ever measured, about 300 km/sec in approach. This already pointed to the extra-galactic nature of this object. In 1923, Edwin Hubble found the first Cepheid variable in the Andromeda galaxy and thus established the intergalactic distance and the true nature of M31 as a galaxy, not a nebula. Because he was not aware of the two Cepheid classes, his distance was incorrect by a factor of more than two, though. This error was not discovered until 1953, when the 200-inch Palomar telescope was completed and had started observing.

In modern times, the Andromeda galaxy is certainly the most studied "external" galaxy. It is of particular interest because it allows studies of all the features of a galaxy from outside which we also find in Milky Way, but cannot observe as the greatest part of our Galaxy is hidden by interstellar dust. Thus there are continuous studies of the spiral structure, globular and open clusters, interstellar matter, planetary nebulae, supernova remnants, galactic nucleus, companion galaxies, and more.

Under "normal" viewing conditions, the apparent size of the visible Andromeda Galaxy is about 3 x 1 degrees (our accurate value, given above, is 178x63 arc minutes). Careful estimates of its angular diameter, performed with 2-inch binoculars, by the French astronomer Robert Jonckhere in 1952-1953, revealed an extension of 5.2 times 1.1 degrees (reported by Mallas), corresponding to a disk diameter of over 200,000 light years at its distance of 2.9 million light years, so that this galaxy is about double as large as our own Milky Way galaxy ! Its mass was estimated at 300 to 400 billion times that of the sun. Compared to the newer estimates for our Milky Way galaxy, this is considerably less than the mass of our galaxy, implying that the Milky Way may be much denser than M31.

http://apod.gsfc.nasa.gov/apod/ap000709.html

Distant Galaxies: The Hubble Deep Field Image

Galaxies like colorful pieces of candy fill the Hubble Deep Field - one of humanity's most distant optical views of the universe. The dimmest, some as faint as 30th magnitude (about four billion times fainter than stars visible to the unaided eye), are very distant galaxies and represent what the universe looked like in the extreme past, perhaps less than one billion years after the Big Bang. To make the Deep Field image, astronomers selected an uncluttered area of the sky in the constellation Ursa Major (the Big Bear) and pointed the Hubble Space Telescope at a single spot for 10 days accumulating and combining many separate exposures. With each additional exposure, fainter objects were revealed. The final result is being used to explore the mysteries of galaxy evolution and the infant universe. http://apod.gsfc.nasa.gov/apod/ap960628.html

Astronomers have been intently studying the deep field image filled with remote galaxies for clues to what galaxies and the universe looked like in the distant past. While nearby galaxies are easily detected in the image - some seen here have visible elliptical and even spiral structures - the most distant (and therefore oldest) galaxies must be identified by examining their appearance in different wavelengths of light. Based on this technique, six of the most distant galaxies in the Deep Field appear to be farther away than even quasars.

The Hubble Deep Field Project
http://oposite.stsci.edu/pubinfo/background-text/hdf.txt

A key scientific justification for building Hubble Space Telescope was to use it to measure the size and age of the universe, test theories about its origin in the Big Bang, an the emergence of large-scale structure as embodied in vast filaments of galaxies. We live within a universe that is expanding and evolving. Images of distant galaxies offer "fossil" clues to what the universe looked like when it was only a small fraction of its present age. Understanding galaxy evolution is a prerequisite to addressing even more fundamental questions about the expansion of space and ultimate fate of the universe.

The Hubble Deep Field project was inspired by some of the first deep images to return from the telescope after the 1993 HST servicing mission. These images showed that the early universe contained galaxies in a bewildering variety of shapes and also sizes. Some had the familiar elliptical and spiral shapes seen among normal galaxies, but there were many peculiar shapes not commonly seen in the local universe. Such images of the early universe are likely to be one of the enduring legacies of the Hubble Space Telescope. Few astronomers had expected to see this activity presented in such amazing detail.

Impressed by the results of earlier observations such as the Hubble Medium Deep Survey, a special advisory committee convened by Robert Williams, Director of the Space Telescope Science Institute (STScI), recommended that he use a significant fraction of his annual director's discretionary time to take the deepest picture of the universe, by aiming Hubble for 150 consecutive orbits on a single piece of sky. The research was being done as a service to the entire astronomical community.

Modeling Dough Recipe

4 Cups flour
2 Cups salt
4 Tablespoons Cream of Tartar (1/4 Cup)
2 Tablespoons vegetable oil
4 Cups water
Food coloring

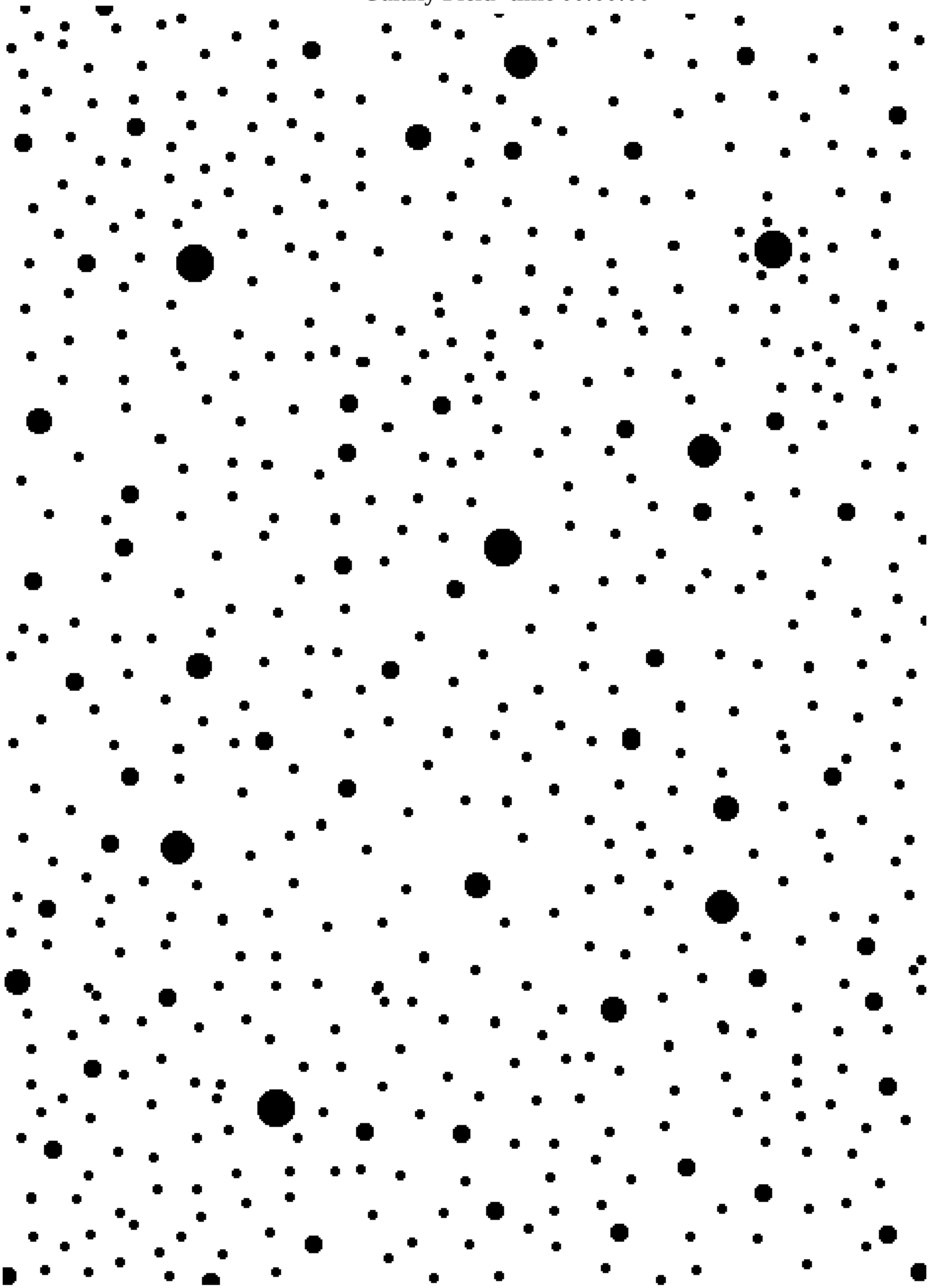
Dissolve the food coloring in the water. Mix all of the ingredients in a saucepan and cook over medium heat, stirring almost constantly. After a while, the mixture will begin to thicken; stir constantly to keep the heat distributed evenly.

When the dough has thickened and is somewhat smooth, pour it onto a floured board and knead it until smooth and no longer sticky.

You may use a few drops of peppermint oil as a preservative if you wish.

Store the cooled dough in an airtight container.

Galaxy Field time 00:00:00



Galaxy Field time 00:00:01