

EDUCATOR'S GUIDE



Dorothy & Lewis B. Cullman

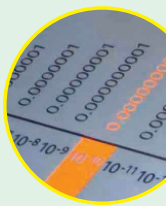
Hall of the Universe

Harriet & Robert Heilbrunn
Cosmic Pathway

Scales of the Universe

IN THE FREDERICK PHINEAS & SANDRA PRIEST ROSE CENTER FOR EARTH AND SPACE

amnh.org/education/universe



INSIDE:

- Suggestions to Help You Come Prepared
- **Essential Questions** for Student Inquiry
- Strategies for **Teaching in the Exhibition**
- **Map** of the Exhibition
- **Online Resources** for the Classroom
- Correlation to **Framework**
- **Glossary**



ESSENTIAL QUESTIONS

How do we study the universe?

Most celestial bodies are far too distant to visit, so almost all of our information comes from **light**. Just about everything in the universe — **stars, planets**, clouds of gas and dust — emits light (electromagnetic radiation). Only a fraction of this light is in wavelengths visible to the human eye. But telescopes on Earth and in orbit can capture the full spectrum. This light tells us a great deal about celestial objects and phenomena, from their chemical composition and temperature to how fast they're moving. **Astronomers** measure this light to understand how and when the universe and the galaxies, stars, and planets in it formed and have changed over time. They derive mathematical models from the fundamental laws of physics and chemistry in order to understand past events and to predict how



Willamette Meteorite

the universe will continue to change. Physical specimens like **meteorites** and Moon rocks also provide valuable information about the chemical and physical make-up of the early solar system, and even long-ago stars. Other increasingly interesting forms of evidence include **neutrinos, cosmic rays**, and **gravitational waves**.

What makes up the universe?

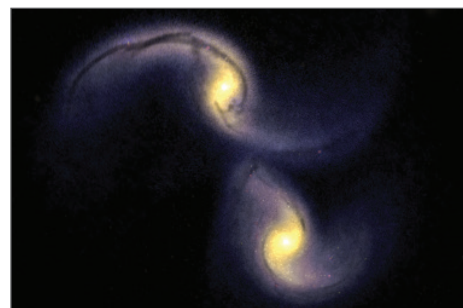
The **observable universe** contains billions of **galaxies**, but is mostly **empty space**. These galaxies range in size from thousands of times smaller to a hundred times larger than our own Milky Way Galaxy, which alone contains more than 100 billion stars. Like our Sun, many of these stars have planets, asteroids, meteoroids, and comets in orbit around them. However, all observable matter (most of which is hydrogen or helium gas) makes up only 20% of the **mass** in the universe. The other 80% is **dark matter**. Like observable matter, dark matter exerts **gravity**, but it does not emit or absorb light. Measurements show that this invisible stuff far outweighs the ordinary **matter** we see with our eyes and telescopes. Yet all the observable matter and dark matter combined still makes up less than 30% of the total mass-energy of the universe. The rest is **dark energy**, which dominates the modern universe and yet remains a mystery.

How did the universe begin?

Light tells the story of the universe. Since light takes time to travel, the farther out into space we look, the further back in time we see. When we flip a switch we see the light almost instantly, but sunlight is eight minutes old, light from nearby stars has taken years or centuries to reach us, and light from distant galaxies can be millions or even billions of years old. The history of the universe began with the Big Bang 13.7 billion years ago: smaller than an atom, the observable universe inflated to an astronomical size in just an instant. This very young universe was so dense that it was opaque: the light was trapped with the matter. As the universe continued to expand and cool, it became transparent and light slipped free. This is the moment captured in the **cosmic microwave background**. Over millions of years, the force of gravity gathered simple gas clouds into larger and more complex structures: the first stars and galaxies.

How is the universe changing over time?

Ever since the Big Bang, the universe has been expanding. It and everything it contains are in constant motion because of the fundamental physical forces of gravity and **electromagnetism**. At the same time, galaxies are colliding: smaller galaxies and surrounding gas merged to form the Milky Way, which is now on a collision course with the Andromeda Galaxy. All stars (including our Sun) are born, shine until they run out of fuel, and die. The most massive stars explode in supernovas, while all the rest fade away as white dwarves. As a star dies, it ejects matter out into space that provides raw material for new stars and planets. Puzzles remain. For example, light from distant galaxies shows that the expansion of space began to accelerate about five billion years ago. Scientists attribute this to dark energy.

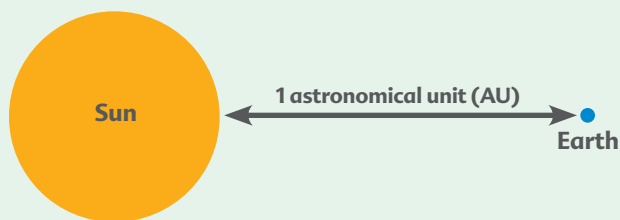


Over two billion years from now, the Milky Way and Andromeda galaxies will collide, as shown in this simulation.

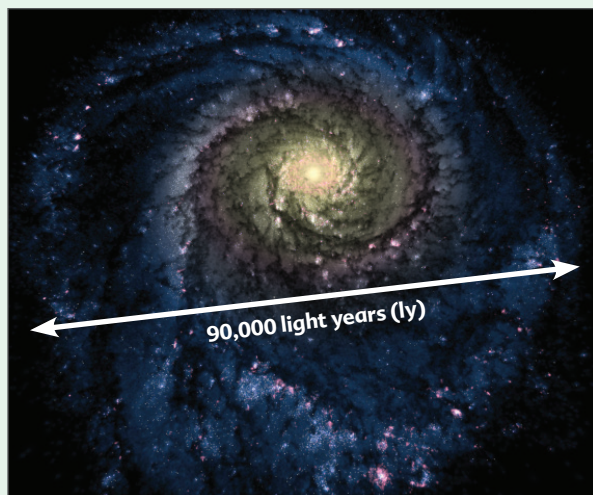
SIZE AND SCALE OF THE UNIVERSE

The observable universe is unimaginably vast. It's full of gigantic objects moving at incredible speeds and travelling enormous distances. From the nucleus of an atom to the expanse of space, its scale spans a factor of about 10^{40} — 40 orders of magnitude! We use inches and miles to measure distances on Earth, but space requires different units.

For shorter distances, astronomers use the astronomical unit (AU): the average distance between Earth and the Sun. The star closest to Earth, Proxima Centauri, for example, is over a quarter of a million AU away.



Astronomers measure longer distances in light years (ly): the distance light travels in a year. Proxima Centauri is 4.2 ly away. Our galaxy, the Milky Way, is 90,000 ly across, which is about 1/25th the distance to its closest neighbor, the Andromeda Galaxy.



Milky Way Galaxy

COME PREPARED

Plan your visit. For information about reservations, transportation, and lunchrooms, visit amnh.org/education/plan.

Read the Essential Questions in this guide to see how themes in the exhibitions connect to your curriculum. Identify the key points to cover.

Review the Teaching in the Exhibition section of this guide for an advance look at the specimens, models, and interactives that you and your class will be encountering.

Download activities and student worksheets at amnh.org/resources/rfl/pdf/universe_activities.pdf. Designed for use before, during, and after your visit, these activities focus on themes that correlate to the NYS Science Core Curriculum:

- 3-5: Explore the Moon
- 6-8: Explore Planets, Stars, Galaxies, and the Observable Universe
- 9-12: Investigate Stars and Galaxies

Decide how your students will explore these exhibitions. Suggestions include:

- You and your chaperones can facilitate the visit using the **Teaching in the Exhibition** section of this guide.
- Your students can use the **student worksheets** to explore the exhibition on their own or in small groups.
- Students, individually or in groups, can use copies of the **map** to choose their own paths.

CORRELATION TO STANDARDS

A Framework for K-12 Science Education

Science Practices

Asking questions • Developing and using models • Analyzing and interpreting data • Using mathematics and computational thinking • Obtaining, evaluating, and communicating information

Crosscutting Concepts

Patterns • Cause and effect: Mechanism and explanation • Scale, proportion, and quantity • Systems and system models • Energy and matter: Flows, cycles, and conservation • Structure and function • Stability and change

Disciplinary Core Ideas

PS1.A: Structure and Properties of Matter • PS1.C: Nuclear Processes • PS2.C: Stability and Instability in Physical Systems • PS4.B: Electromagnetic Radiation • ESS1.A: The Universe and Its Stars • ESS1.B: Earth and the Solar System

The Cullman Hall of the Universe is divided into four main zones: Universe, Galaxies, Stars, and Planets.

Each zone uses visualizations, models, images, and interactives to explore the nature and evolution of celestial bodies. The guided explorations below are designed around the theme of **gravity**. (*Possible answers follow each question.*) Before entering the hall, tell students that they will be investigating gravity and its role in forming objects made of visible matter (things that we can see).

IT'S ALL ABOUT GRAVITY

Gravity is the force of attraction between any two objects. All objects in the universe — galaxies, planets, asteroids, human beings — have gravity. The more massive an object, the more gravity it has. Gravity is one of the fundamental forces that gives the universe and the things in it their structure.

OTHER THINGS TO LOOK OUT FOR

Cosmic Address:

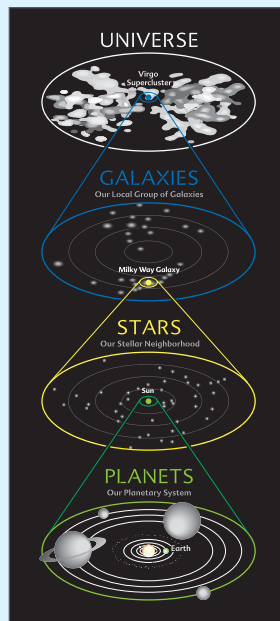
Each wall shows the location of its zone within a spatial hierarchy: our planetary system around the Sun, our stellar neighborhood in our galaxy, our galaxy in the local group of galaxies, and our group in the entire universe. This diagram can help students understand the relationships between these distant objects.

Frontiers in Science:

On the far right of each wall is a video kiosk where students can explore current research on the topic of each wall.

AstroBulletin: A large screen displays up-to-date astronomical images and discoveries.

Black Hole Theater: Short films describe astronomical topics, such as the formation of a black hole when a massive star collapses into itself.



Universe Zone

OVERVIEW: The universe is all the matter and space in existence. This zone explores the expansion of the universe and the limits of observation. Topics include the universality of physical laws, the Big Bang and the evidence for it, and how redshifted light provides evidence for the expansion of the universe.

GUIDED EXPLORATION:

- **Universe Wall:** Have students explore how our universe is changing, how gravity has shaped it, and how scientists use light to measure distance. Ask: What is the observable universe? (*The region from which light has reached us from since the Big Bang. See glossary.*) Why does this limit exist? (*Light from more distant regions has not had time to reach us.*) What is the cosmic microwave background? (*It is the oldest, most distant feature of the observable universe. See glossary.*)

Galaxy Zone

OVERVIEW: Galaxies contain dark matter, gas, dust, and billions of stars, held together by gravity. This matter orbits a common center of mass, and that orbital motion prevents the galaxy from collapsing under gravity's pull. The shape of a galaxy (spiral, elliptical, or irregular) depends on how it formed. This zone explores galactic formation and evolution, and what happens when galaxies collide.

GUIDED EXPLORATIONS:

- **Galaxy Wall:** Draw students' attention to our galaxy, the Milky Way. Have students examine the photos and animations to compare and contrast the different types of galaxies. Ask: What do the three main types have in common? (*All galaxies are collections of stars and dark matter.*) How are they different? (*They differ in shape, size, and distribution of stars.*)
- **Interacting Galaxy Cluster:** Invite students to watch the video in the center to see how gravity causes galaxies to merge and collide. Have them describe what happens when the galaxies collide. (*Gravity pulls the spiral galaxies together and scrambles the orbits of the stars to form an elliptical galaxy.*)

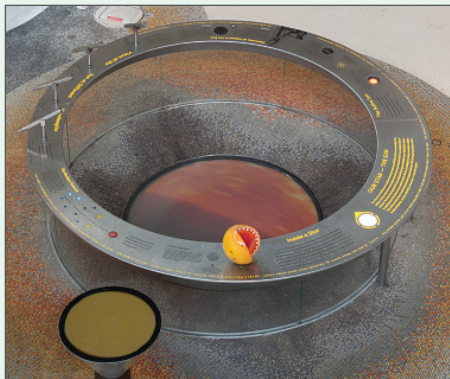
Stars Zone

OVERVIEW: A star is a huge luminous ball of hot gas, mostly hydrogen and helium, held together by gravity. Nuclear reactions in the cores of all stars, including our Sun, produce energy in the form of light. Stars shine because this light works its way to the surface and radiates out into space. This zone explores the various types of stars, their life cycles, and how stars produce the building blocks of life.

GUIDED EXPLORATIONS:

- **Stars Wall:** Tell students that all stars are born, mature, and eventually die, and that a star’s mass is the most important factor in determining its life cycle. Have students compare and contrast the different categories of stars. Ask: What role does gravity play in the birth of stars? *(If a dense cloud of gas and dust is massive enough, gravity overcomes pressure and causes it to collapse inward. Increased pressure and temperature cause nuclear fusion to ignite in its core, producing heat. This heat raises the pressure, which eventually balances gravity.)* What happens to stars at the end of their lives? *(When a star runs out of hydrogen fuel, gravity causes the star to collapse further inward. What happens depends on the size of the star. The core of most stars collapses to form white dwarfs. The highest-mass stars explode as supernovas or black holes. Their cores end up as extremely dense neutron stars.)* Point out that the life cycles of stars vary widely, and that the Sun is an intermediate-mass star. Ask students how the Sun’s life cycle compares to that of other stars. Have students explore the Supernovas Cluster.

- **Our Star: The Sun Cluster:** Invite students to explore this area and to watch clips of the Sun’s surface “in action.” Point out that heat from nuclear fusion in the Sun’s core drives the convection that powers these phenomena on its surface.



Planets Zone

OVERVIEW: Planets orbit stars, are massive enough for their own gravity to have made them round, and do not share their orbits with other bodies of similar size. This zone describes the formation and evolution of planets around the Sun and other stars, and examines the role of collisions for planets. It features the 15-ton Willamette Meteorite, the largest ever discovered in the U.S., and a self-sustaining habitat contained in a 39-inch closed glass globe, called the Ecosphere.

GUIDED EXPLORATIONS:

- **Planets Wall:** Have students explore the variety of objects in our solar system, including terrestrial and gas giant planets, asteroids, Kuiper Belt objects, moons, and comets. Ask: How do you think gravity holds the solar system together? *(The Sun is in the center. It’s the most massive object in the system so it exerts the most gravity. Its gravity holds the planets and asteroid belts in orbit around it.)* Have students imagine and describe what might happen to the solar system if gravity stopped operating. *(The planets and the Sun would fly off in straight lines and come apart. Gravity would no longer hold them together or in their orbits.)*

- **Ecosphere:** Tell students that this glass sphere is a simple example of a self-sustaining ecosystem and that it’s been sealed since 1999. Have students examine the contents and distinguish between living and nonliving. Ask: What do you think keeps the organisms alive?



(The plants and animals recycle nutrients and obtain energy from sunlight. The algae produce oxygen for the shrimp, and the shrimp produce nutrients for the algae.)

- **Willamette Meteorite & Planetary Impacts Cluster:** Have students touch the meteorite and describe how it feels. *(It feels rough, cold, corroded, metallic.)* Ask: Why do pieces of asteroids and comets crash into Earth? *(When an object in orbit around the Sun gets too close to Earth, our planet’s gravity pulls it in.)*

ONLINE RESOURCES



Astronomy OLogy

amnh.org/ology/astronomy

Hands-on activities and articles for kids 7 and up, including a Stargazing Sky Journal and Build the Big Dipper Mobile.

AstroBulletins

sciencebulletins.amnh.org

Videos, essays, and data visualizations about current research in astrophysics. Topics include the Sloan Digital Sky Survey, the Cosmic Microwave Background, and gravitational waves.

Discovering the Universe

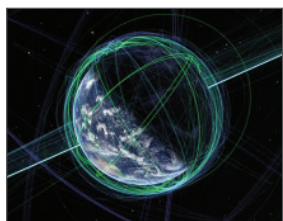
amnh.org/explore/curriculum-collections/discovering-the-universe

Curriculum materials that explore stars and other celestial bodies, and how astrophysicists study their distant light.

The Digital Universe Atlas

haydenplanetarium.org/universe/

A three-dimensional navigable map of the universe, including the Milky Way Atlas and the Extragalactic Atlas, created by the Museum's Hayden Planetarium. Includes educator's activities.



Galaxy Zoo

galaxyzoo.org

Help astronomers categorize the types of galaxies in Hubble Space Telescope images.

NASA: Solar System Exploration

solarsystem.nasa.gov

Lesson plans and activities related to NASA missions, as well as profiles of the men and women involved.

NASA: Imagine the Universe

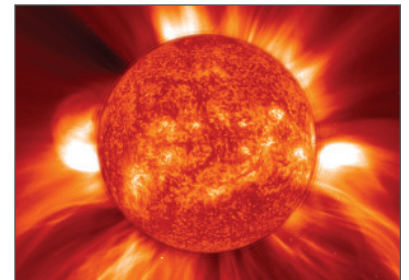
imagine.gsfc.nasa.gov/docs/science/science.html

Background information about astronomy, from basic concepts to mysteries like the nature of dark matter.

Solar & Heliospheric Observatory (SOHO)

sohowww.nascom.nasa.gov/

Images of the Sun from the SOHO spacecraft, plus a full range of classroom resources that include activities, glossary, and access to solar physicists.



Universe 101: Big Bang Theory

map.gsfc.nasa.gov/universe/

From the NASA mission that mapped the cosmic microwave background, an in-depth look at the theory of how the universe was formed.

Astronomy Picture of the Day

apod.nasa.gov/apod

Use the image of the day to explore the universe, or search by name. Captions by professional astronomers.

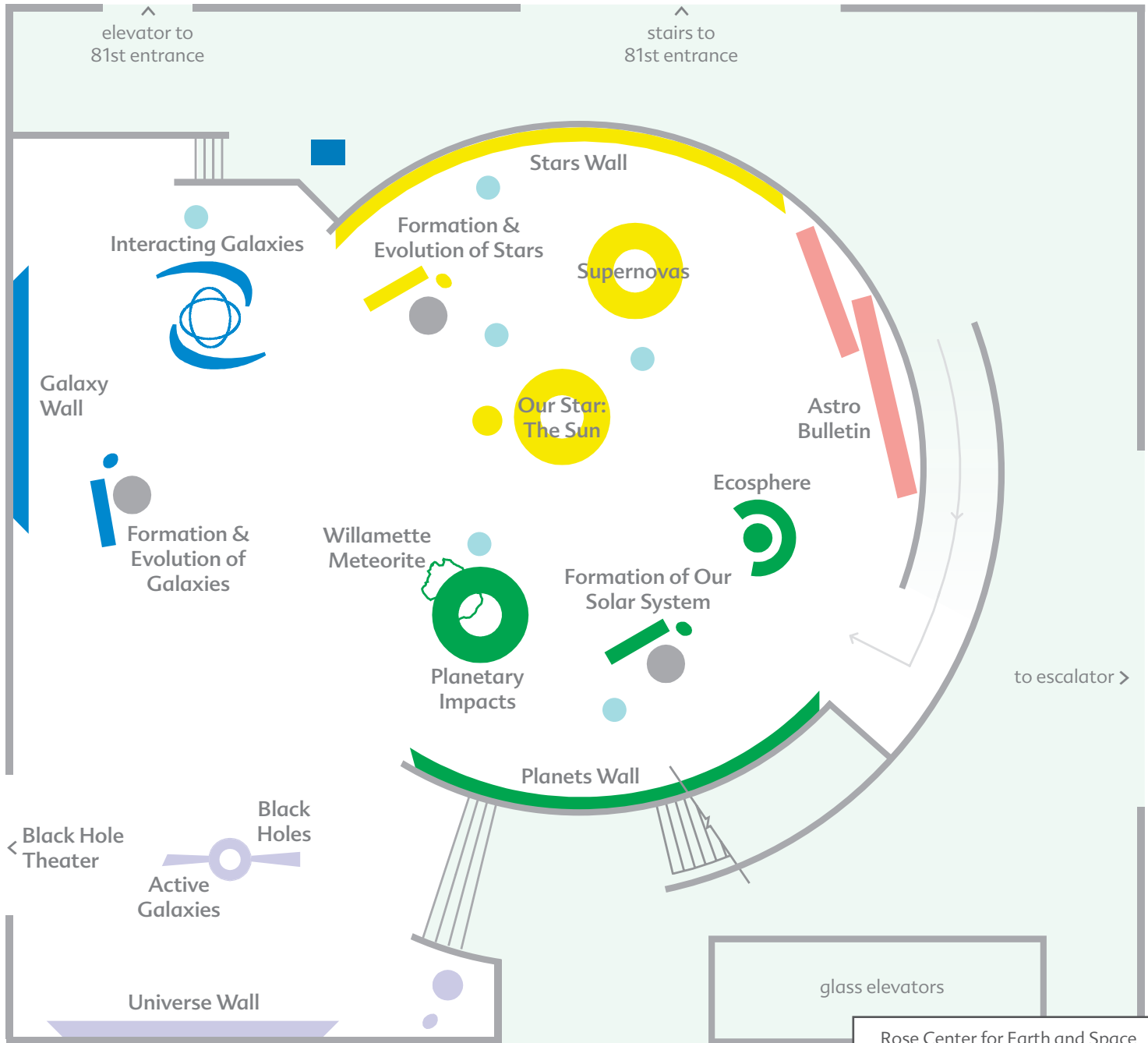
CREDITS

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MAP Cullman Hall of the Universe



KEY

- Planets Zone
- Stars Zone
- Galaxy Zone
- Universe Zone
- AstroBulletin Wall and Kiosks
- Weigh-Yourself Scales

Rose Center for Earth and Space

	SPACE SHOW EXIT	3 fl
Hayden Sphere	BIG BANG THEATER ENTRANCE	2 fl
	SCALES OF THE UNIVERSE	
	COSMIC PATHWAY EXIT	1 fl
HALL OF THE UNIVERSE		Lower Level

Glossary

astronomer: a scientist who studies the physical laws of the universe and the properties of the objects it contains. Also known as an astrophysicist.

astronomical unit: the average distance between Earth and the Sun. 1 AU = 150 million km (93 million mi).

astronomy and **astrophysics:** the study of the universe and everything in it

cosmic microwave background: a vast sea of energy left over from the Big Bang, detectable in the sky as a whisper of microwave radiation. It's the oldest light we've detected, and therefore emitted at the greatest distance from us. Slight variations in this ancient light reveal the seeds of everything in our universe.

cosmic rays: energetic subatomic particles that bombard Earth from outer space. They provide one of our few direct samples of matter from outside the solar system.

black hole: an object so dense that nothing can escape its gravity, not even light. Black holes are formed by the most massive stars at the ends of their lives, and can grow to enormous masses at the centers of galaxies.

dark energy: the cause of the acceleration of the expansion of the universe. (If gravity were the only force acting upon it, the expansion would be decelerating.) Scientists have yet to determine the nature of this mysterious phenomenon.

dark matter: an invisible substance that has existed since the Big Bang and makes up most of the mass in the universe. Although we can't yet measure it directly, its presence was revealed by galaxies spinning faster than expected.

electromagnetism: the interaction of moving electrically charged particles and objects made of them. Like gravity, this is a fundamental force at work in the universe — and it's much stronger.

empty space: there's no such thing as a vacuum, or completely empty space. The emptiest parts of the cosmos contain around one atom in a space the size of an auditorium.

energy: the ability to act upon an object. Energy can exist even without matter, in magnetic fields for example.

Mass and energy are both properties of every particle, and can be interchanged by physical processes such as nuclear fusion.

gravitational waves: ripples in the fabric of space and time caused by the motion of objects; one of the means, other than observing light, for getting information from distant objects

gravity: the force of attraction between any two masses

light: a kind of energy (electromagnetic radiation) that travels in waves. The wavelengths range from very short (high-energy gamma rays) to longer and longer (X-rays, ultraviolet light, visible light, infrared light, and microwaves) all the way to very long, low-energy radio waves.

light year: the distance that light travels in one year. One light year = 63,000 AU = 9.5 trillion km (5.9 trillion mi).

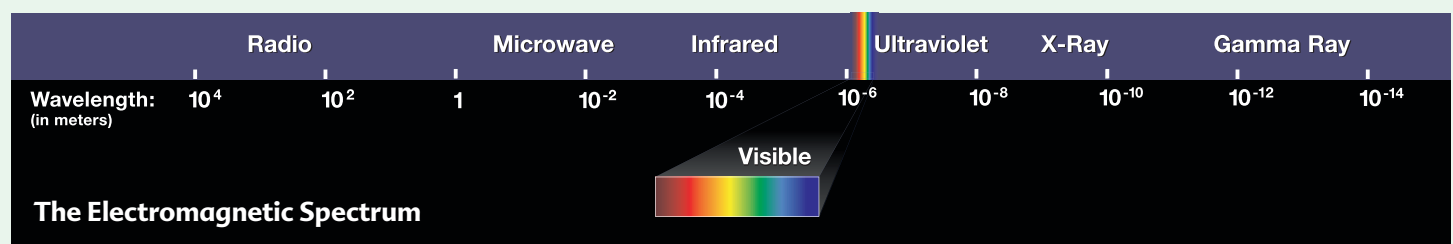
mass: the amount of matter contained within a given object, which determines how hard it is to move (inertia) and how much gravity it exerts

matter: anything that exerts gravity and moves slower than the speed of light. Visible matter is made of protons, neutrons, electrons, and other subatomic particles.

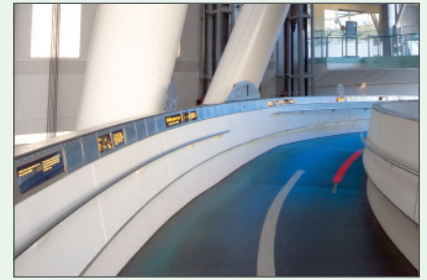
meteor: a piece of a comet or asteroid that heats up as it passes through our atmosphere, appearing as a streak of light. If it survives to land on Earth, it's called a meteorite.

neutrino: an elementary subatomic particle produced in massive numbers by the nuclear reactions in stars; another means, besides light, to observe distant objects

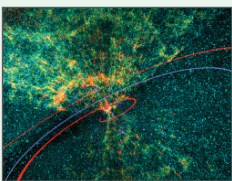
observable universe: that part of the universe from which light or other signals could conceivably reach Earth — a sphere extending more than 13 billion light years away from us in every direction. The light from objects beyond this cosmic horizon has not had enough time to reach us in the time since the Big Bang.



The history of our universe is written in light that has traveled to Earth across vast reaches of space. You and your students can start to explore this history in the Big Bang Theater, where a four-minute film takes us from the present day to the beginning of time and space. Exit onto the Cosmic Pathway. Every step on this spiral ramp represents almost 100 million years forward in time: from the Big Bang, past the emergence of the Milky Way and the formation of our Solar System, and on to all of recorded human history, contained in the width of a hair.



Big Bang Theater



GUIDED EXPLORATION:

- **The Big Bang Experience:** Before entering the theater, tell students that they are about to journey over 13 billion years into the past, to the moment when the universe began to expand from an almost infinitely dense and hot state. Point out the panels outside the theater entrance that describe the three main pieces of evidence for this incredible statement (the expansion of the galaxies, the cosmic microwave radiation, and the abundances of the light elements).

Heilbrunn Cosmic Pathway

GUIDED EXPLORATIONS:

When you exit the theater, you will be at the top of the Cosmic Pathway.

- **Introduction Panel:** Reiterate for students the concept represented by the labeled rings in the film: light emitted by distant objects takes time to reach us. For example, an image of a galaxy that's 100 million light years away from Earth shows what it looked like 100 million years ago.
- **Measure Stride Length:** Tell students that this pathway is a spiral timeline like the one they saw in the film: as they walk down they will be traveling from the birth of the universe down to the present. Encourage students to use the markings on the floor to measure how many millions of years each of their strides will transport them.

- **Photos, Videos, and Specimens:** As students walk down the pathway, have them explore the various stops (see map) to learn about how the universe evolved.
- **End of Pathway:** Draw students' attention to the human hair. Point out that its width represents the entire duration of recorded human history.

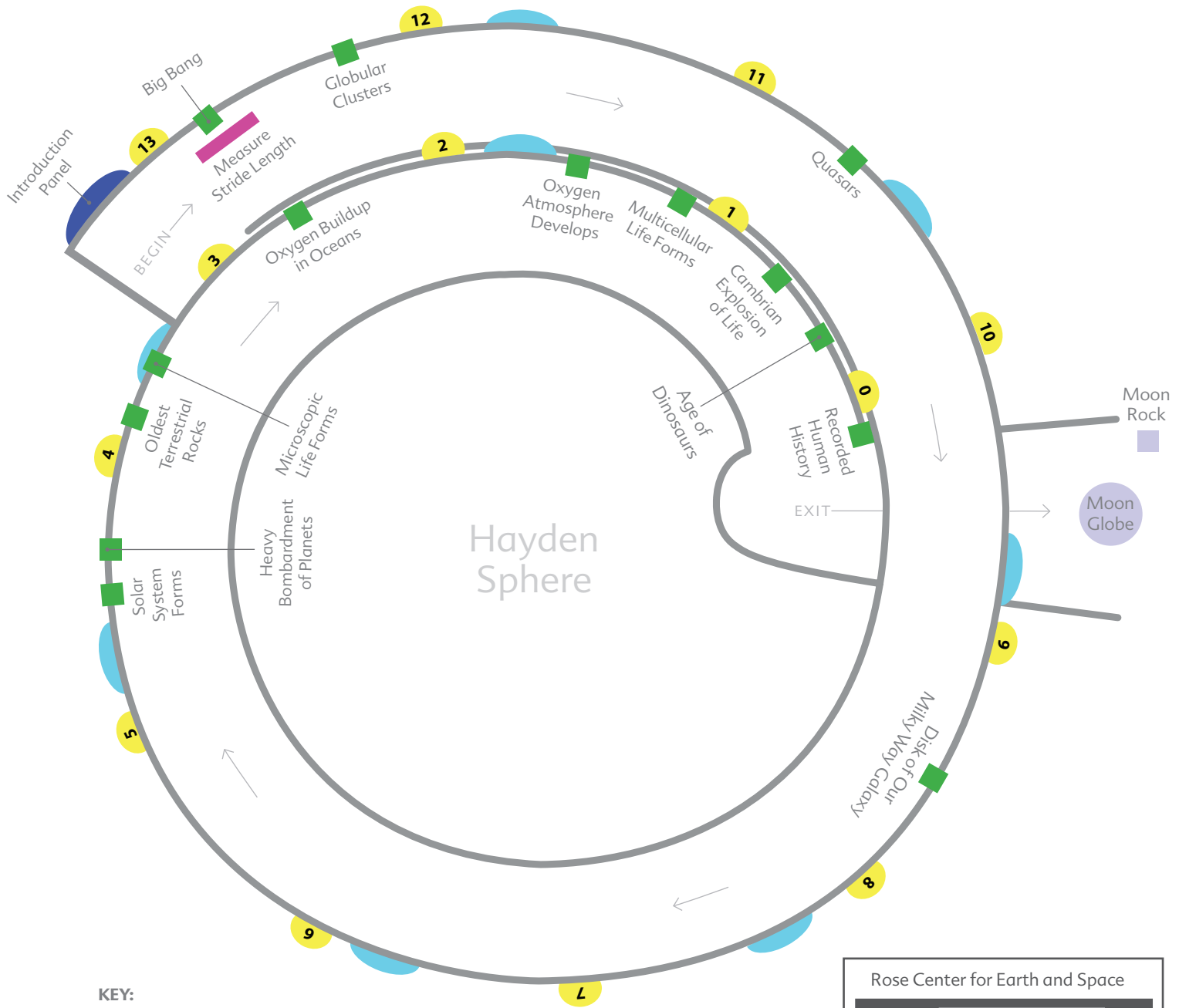
Moon Globe & Moon Rocks

At the end of the pathway, students can touch the surface of the bronze globe to feel the craters and examine how the Moon has been shaped by collisions. They can then observe a lunar rock retrieved by *Apollo 15* astronauts.



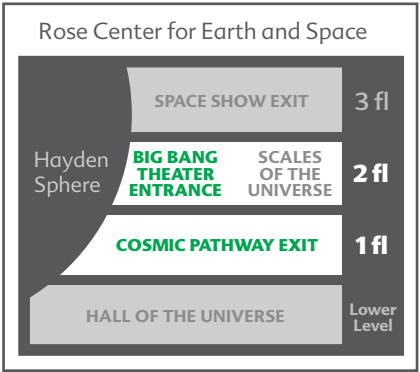
Stripes on the Floor: The common elements hydrogen, carbon, and oxygen emit ultraviolet (UV) light at characteristic colors (measured in nanometers). UV light emitted long enough ago is shifted into visible light by the expansion of the universe. The color in the stripe corresponds to the color that we observe when the light emitted by that element at that point in time reaches Earth.

MAP Heilbrunn Cosmic Pathway



KEY:

- Intro Panel
- Measure Stride Length
- Billion-Year Markers
- Events
- Videos



The Scales walkway compares the relative sizes of objects, from galaxies to atoms using the central sphere as reference. The following guided explorations around the theme of scale will help students understand the range of scales in the universe as they walk around the walkway (see map).



Scales of the Universe

Size Scale Measures Panel: Draw students' attention to the graphic. Ask: To measure your height, what units would you use? (*feet or meters*) How about the distance to another city? (*miles or kilometers*) Distance between planets? (*astronomical unit, or AU*) Between stars and galaxies? (*light years, or ly*) Explain that as they walk along the Scales, they'll be zooming in on ever-smaller objects in our universe. Tell them that they will be grappling with the vast range of distances and sizes by comparing models to the giant Hayden sphere.

Galactic Scale

- **10²⁰ Panel & Models:** Have students explore four galaxies: the Milky Way, Messier 49, Messier 101, and NGC 1365. Ask: What units do scientists use to measure their size? (*light years*) How does our Milky Way Galaxy compare with the others? (*At 100,000 ly across, it's the smallest of the four. Both the Milky Way and Messier 101 are spiral galaxies.*)
- **10¹⁸, 10¹⁶, 10¹³, and 10¹⁰ Panels & Models:** At each stop, use the Sphere as a reference to explore the relative sizes and scales of certain cosmic objects. Explain that each stop zooms in on smaller objects: the Milky Way (100,000 ly across), globular star cluster Messier 80 (200 ly), Oort Cloud (100,000 AU or 1.6 ly), Kuiper Belt (200 AU), star Rigel (70 million km or 0.5 AU).

Stellar Scale

- **10⁹ Panel & Models:** Tell students that stars come in different sizes. Explain that the Hayden Sphere represents the star Rigel and the four models above (clockwise from top left) are Alpha Centauri, Sirius, Vega, the Sun). Have them compare and contrast their sizes. Ask: How does the size of our Sun compare? (*Our Sun is a star of intermediate size.*)

Planetary Scale

- **10⁷ Panel & Models:** Draw students' attention to the planet models immediately above the panel (Mercury, Venus, Earth, Mars) and to those higher up (Jupiter, Saturn, Uranus, Neptune). Tell them that the Sphere represents the Sun and have students compare the diameters. Then look at the "Where's Pluto?" panel and explore why Pluto is now designated a dwarf planet.

Biological & Atomic Scales

- **10¹, 10⁻¹, 10⁻³, 10⁻⁶, 10⁻¹⁰, and 10⁻¹⁵ Panels & Models:** At each stop, use the Hayden Sphere as a reference to explore the relative sizes and scales of different objects: the Hayden Sphere, the human brain, raindrop, red blood cell, rhinovirus, hydrogen atom, and proton.

MAP Scales of the Universe

