Core Knowledge® SCIENCE

Earth in Space:
How are we connected to the patterns we see in the sky and space?


Science Literacy

Science Literacy Student Reader


Skywatching


Lunar eclipse

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Earth in Space

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Core Knowledge®

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Earth in Space

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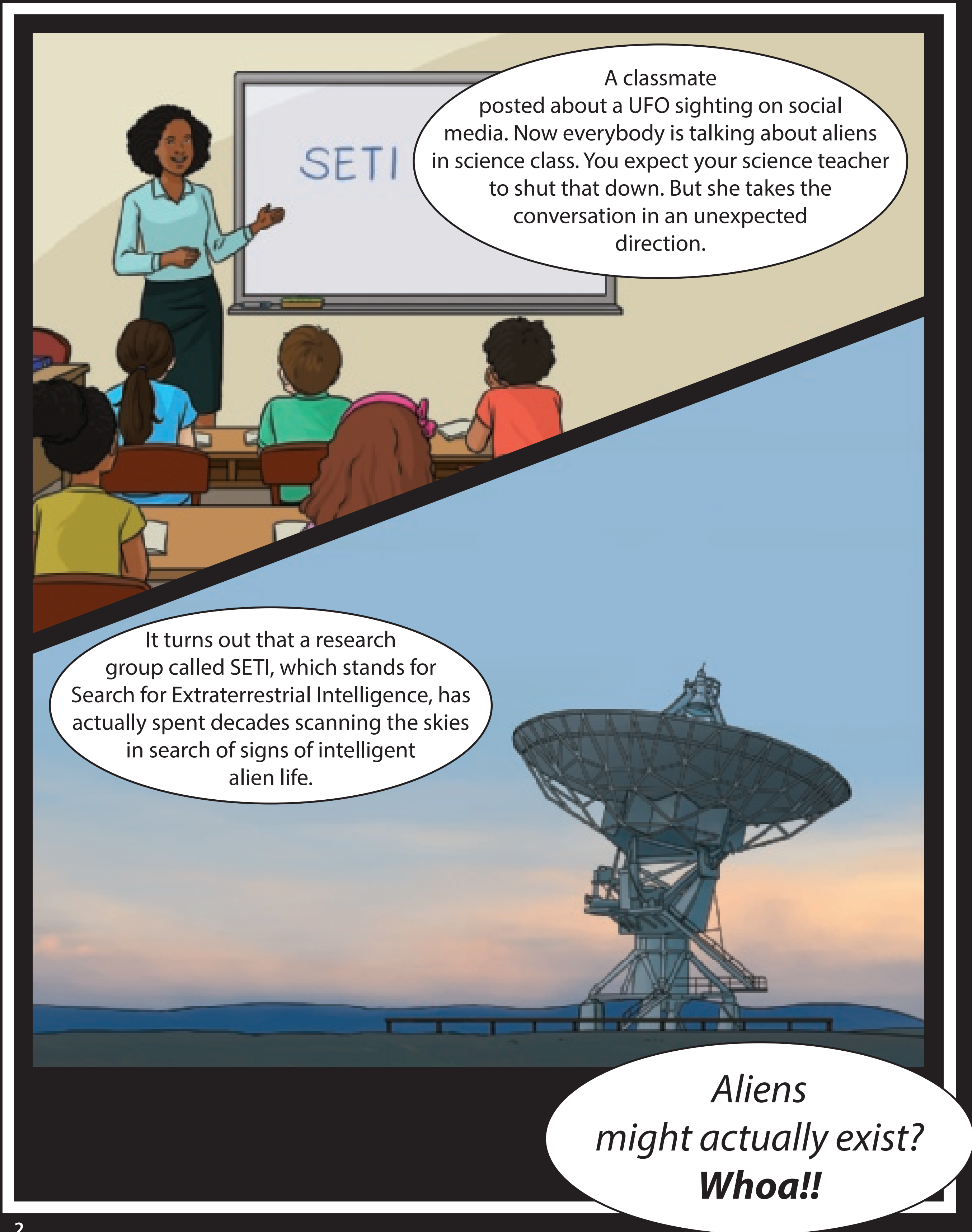
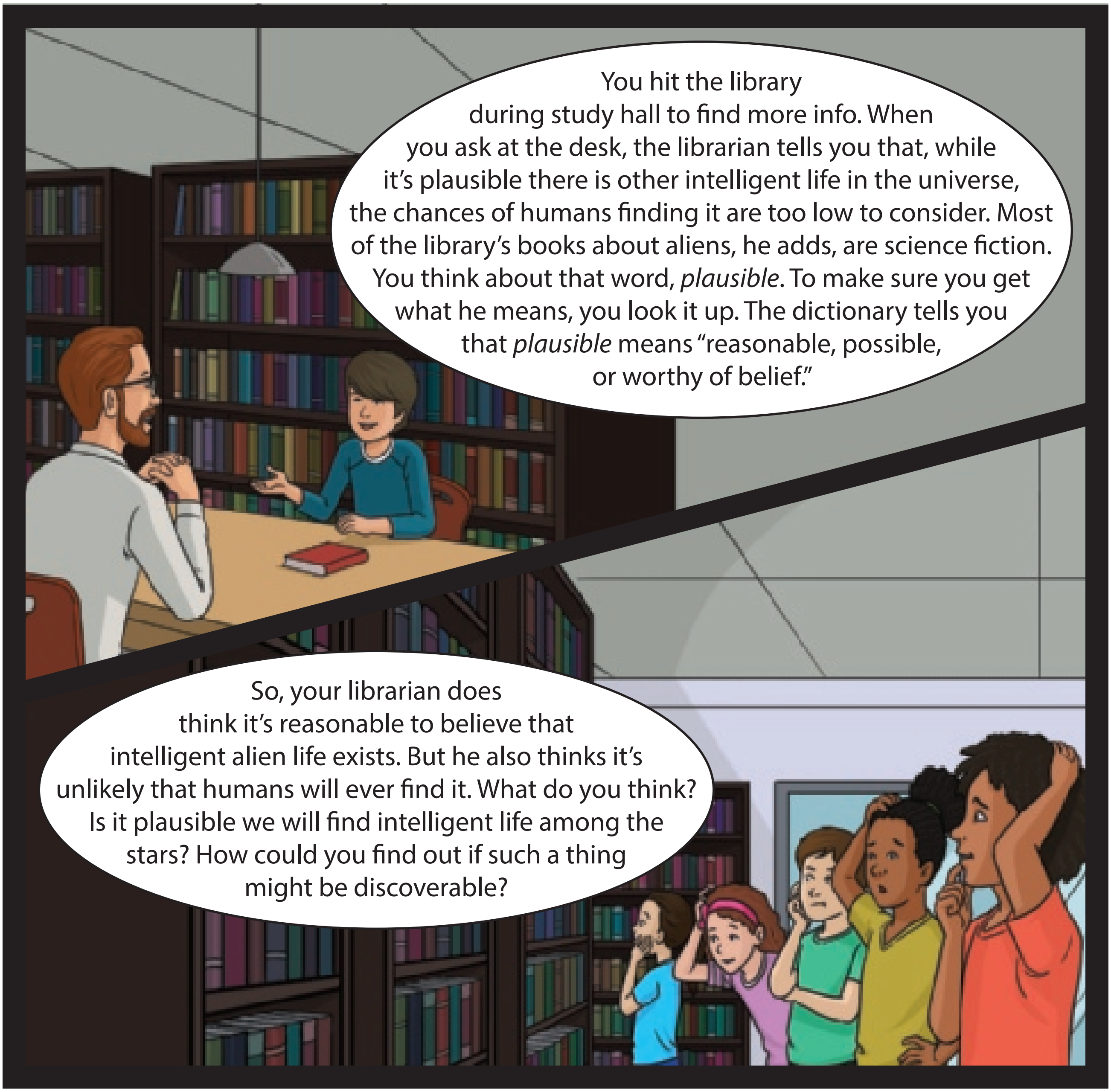
Put Yourself in This Scene





This book is about scientific literacy, which means knowing how to think about science topics that you read or hear about. Our world has 24–7 news, social media, and too many websites to count. The amount of information we must sort through is overwhelming, and all the information is not reliable. In the internet age, sources of information are often obscure or not trustworthy. It is good to process information with a healthy degree of skepticism. We will make our way through several topics related to Earth's place in space through this book. Along the way, the series of reading selections and the writing exercises that go with them will help you flex your mental muscles and sharpen your science literacy skills. The ability to read about science, understand the information, and tell truth from fallacy or misrepresentation is important. Science literacy helps you as an individual and as a consumer (of both products and information), and it shapes the ways you affect the community in which you live.

Celestial Stories

Throughout history and around the world, humans have told stories. People gazed at the sky and wondered about the things they saw there. They told stories about the sun, the moon, and the stars and passed the stories down from generation to generation. These are just a few of those stories from various cultures.

Ngalindi, the Moon Man

Yolngu

The Yolngu people of the indigenous lands of Australia called the moon "Ngalindi." Ngalindi was a Moon Man. He was once slim and in good shape. But then he became lazy, round, and fat (referring to a full moon). Ngalindi had many wives, and his wives grew angry with him for losing his fit figure. So they chased after him and began chopping pieces of him off until he was slim again (referring to the waning moon).

Vocabulary

celestial, adj. positioned in or related to outer space, observed in the sky

Sköll and Hati

Norse

Fenrir, the fearsome wolf, was born to the god Loki and the giant Angrboda. Fenrir had two wolf pups named Sköll and Hati. These two pups grew into mighty, vicious creatures. They began to roam the realm of the gods, looking for prey. Sköll spotted the shining moon and chased after him, while Hati spied the bright sun and chased after her. The sun and moon now run endlessly across the sky, fleeing the great wolves. But at Ragnarok, the end times, Sköll and Hati will finally catch their prey, and the moon and sun will be swallowed up and shine no more.

The Barque of Ra

Egyptian

Ra, the king of all the gods, brings the light of the sun with him everywhere he goes. His light brings warmth and light to the people of the world, so he travels each day by boat, his barque. Every morning, Ra boards his morning barque, the Manjet. He sails the Manjet across the sky, bringing light to the living. Each evening, Ra boards his evening barque, the Mesektet. He sails the Mesketet across the sky of the underworld, bringing light to the dead. Therefore, we have light only during the daytime.

The Moon Rabbit

Aztec

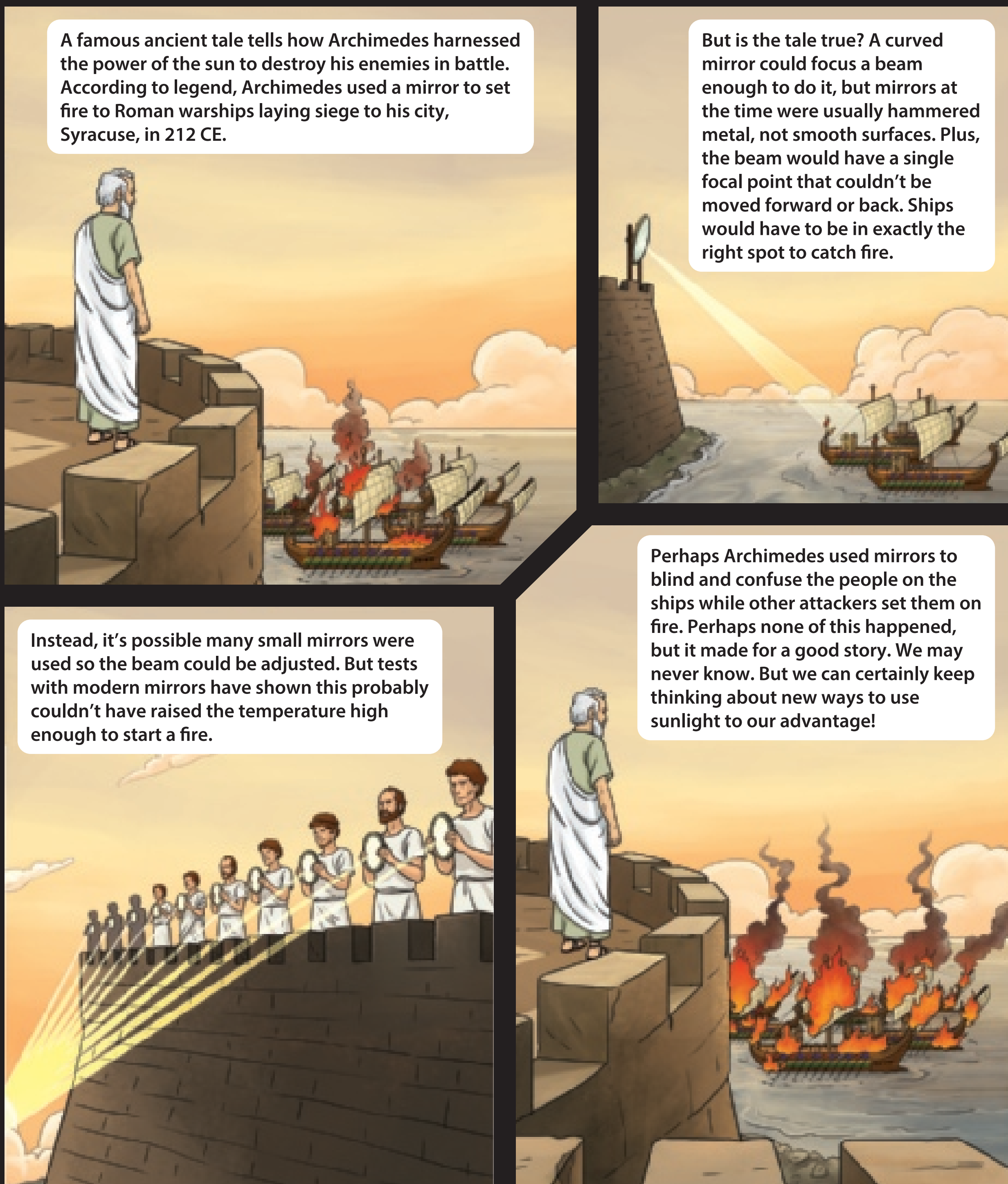
Quetzalcoatl, the god of the sun, began walking on a long journey. For many days he walked, until he found himself in a dry, barren desert, far from food or water. Thirsty and hungry, Quetzalcoatl collapsed and feared he would die. But a rabbit happened by and, seeing Quetzalcoatl in such distress, offered herself to him as food so that he would not starve. Quetzalcoatl was so deeply moved by her offer of sacrifice that he lifted her to the moon, where her image became stamped on its face. "Little rabbit," he said, "though you are small and humble, you will forever be remembered each time anyone looks up into the sky, for they will see you there and be reminded of your selfless act."

The Seven Boys and the Pines

Cherokee

Long ago, seven boys were playing with their stone wheel, running and laughing. Their mothers called to them to stop playing and help prepare supper, but the boys refused to listen. So their mothers said, "If they like stones so much, let them eat stones," and made a soup of stones. The boys were so angry they began to dance, whirling in a circle. They danced faster and faster, until they began to rise into the air. Their mothers tried to grab them, but only one succeeded. She pulled him so hard he sank into the Earth. The other six rose into the sky, and we can still see them shining as the Anitsutsa (the Pleiades) today. The mother of the seventh boy wept every day, watering the ground with her tears, until finally a tall tree grew from the ground. And that is how the pine forest came to be.

Archimedes's Mirror



Make Your Own Sundial

Long before there were ticking clocks or digital watches, there were sundials. People used the interaction of the sun and Earth to keep track of the hours throughout the day. Follow these steps to make your own sundial!

Step 1

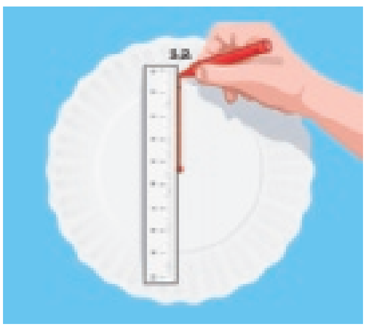
Gather your materials:

- Paper plate
- Markers or crayons
- Ruler
- Pencil
- Drinking straw
- Compass or compass app
- Accurate clock, watch, or clock app

Step 2

Write the number 12 on the edge of the plate. Use the pencil to poke a hole through the center of the plate.

Step 3

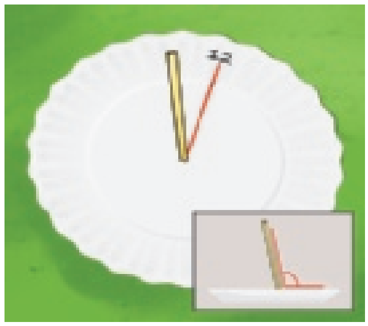


Draw a straight line from the hole to the number 12. This line represents 12:00 noon.

Step 4

Take your materials outside on a sunny day shortly before noon. Using your compass or compass app, determine which direction is north (assuming you're in the Northern Hemisphere).

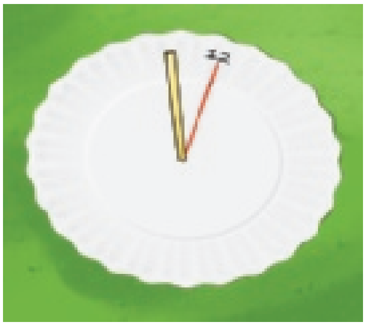
Step 5



Place the straw through the hole in the center of the plate, and place the plate on the ground. Using your compass, angle the straw slightly in the direction you identified as north.

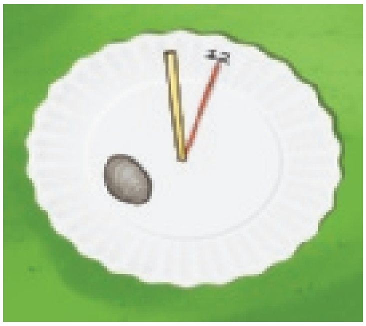
Step 6

At exactly noon, rotate the plate so that the straw's shadow lines up with the line you drew to number 12.



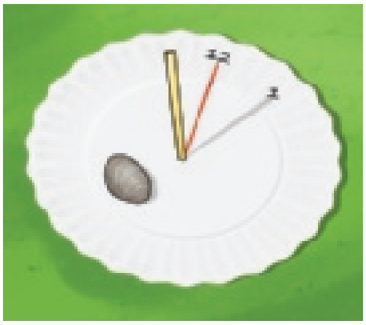
Step 7

Secure the plate to the ground with a rock or other weight. Take a break for the next hour, until 1:00.



Step 8

At exactly 1:00 p.m., return to the plate and mark a number 1 in the spot on the edge of the plate where the straw's shadow falls.

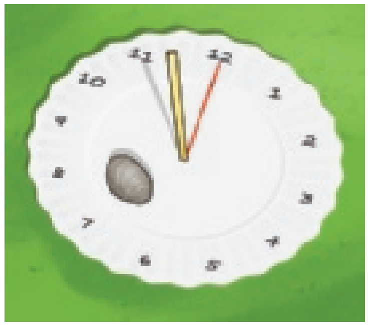


Step 9

Every hour on the hour until sunset, return to the plate and mark the next number on the edge. Take a break overnight.

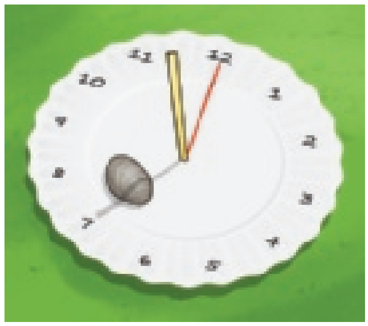
Step 10

Beginning at dawn the next day, return to the plate each hour on the hour and mark the number on the edge. Continue this until you have all 12 numbers marked.



Step 11

Your sundial is now complete! Return to it anytime to check the time of day.



Connection

Does the shadow move clockwise or counterclockwise around the plate? Why?

How might you modify the sundial to tell the minutes in addition to the hours?

What would happen if you moved the sundial from the spot where you made it?

Around the World

Space-related innovations have originated all over the world.

United States, 2012: Voyager 1 is the first spacecraft to journey beyond the edge of the solar system.

United States, 1926: Robert Goddard launches the first rocket propelled by liquid fuel.

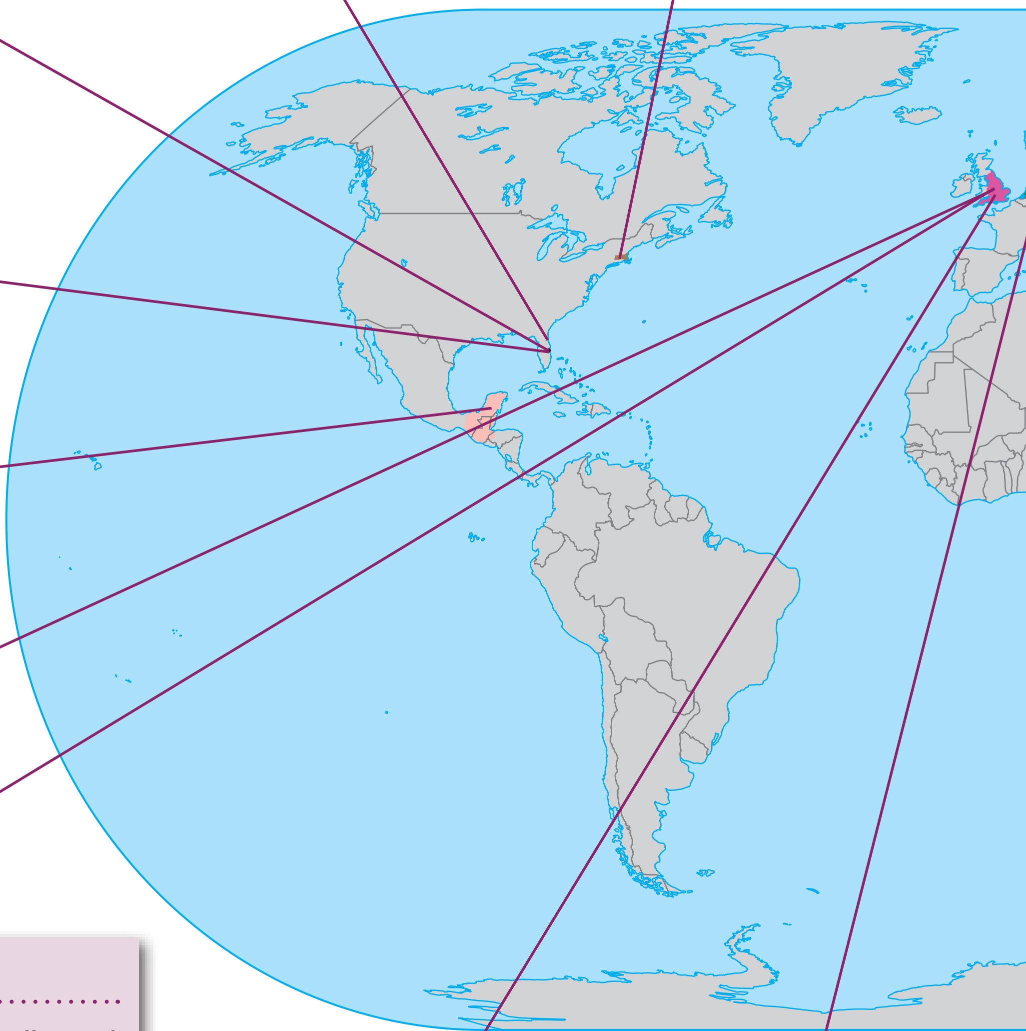
United States, 1969: Neil Armstrong and Edwin "Buzz" Aldrin are the first people to walk on the moon, with Michael Collins staying in lunar orbit.

United States, 1990: The Hubble Space Telescope, a large and versatile space telescope, launches into Earth orbit.

Mayan Civilization, ca. 750 BCE: A system of interrelated astronomical calendars is developed. is developed.

England, 1668: Isaac Newton builds the first reflecting telescope.

England, 1800: William Herschel discovers infrared light.



England, 1868: Norman Lockyer discovers helium in the sun.

Dutch Republic, 1608: Hans Lipperhey files a patent for the first refracting telescope.

Vocabulary

orbit, v. to travel around in an elliptical path

reflect, v. to bounce or send back

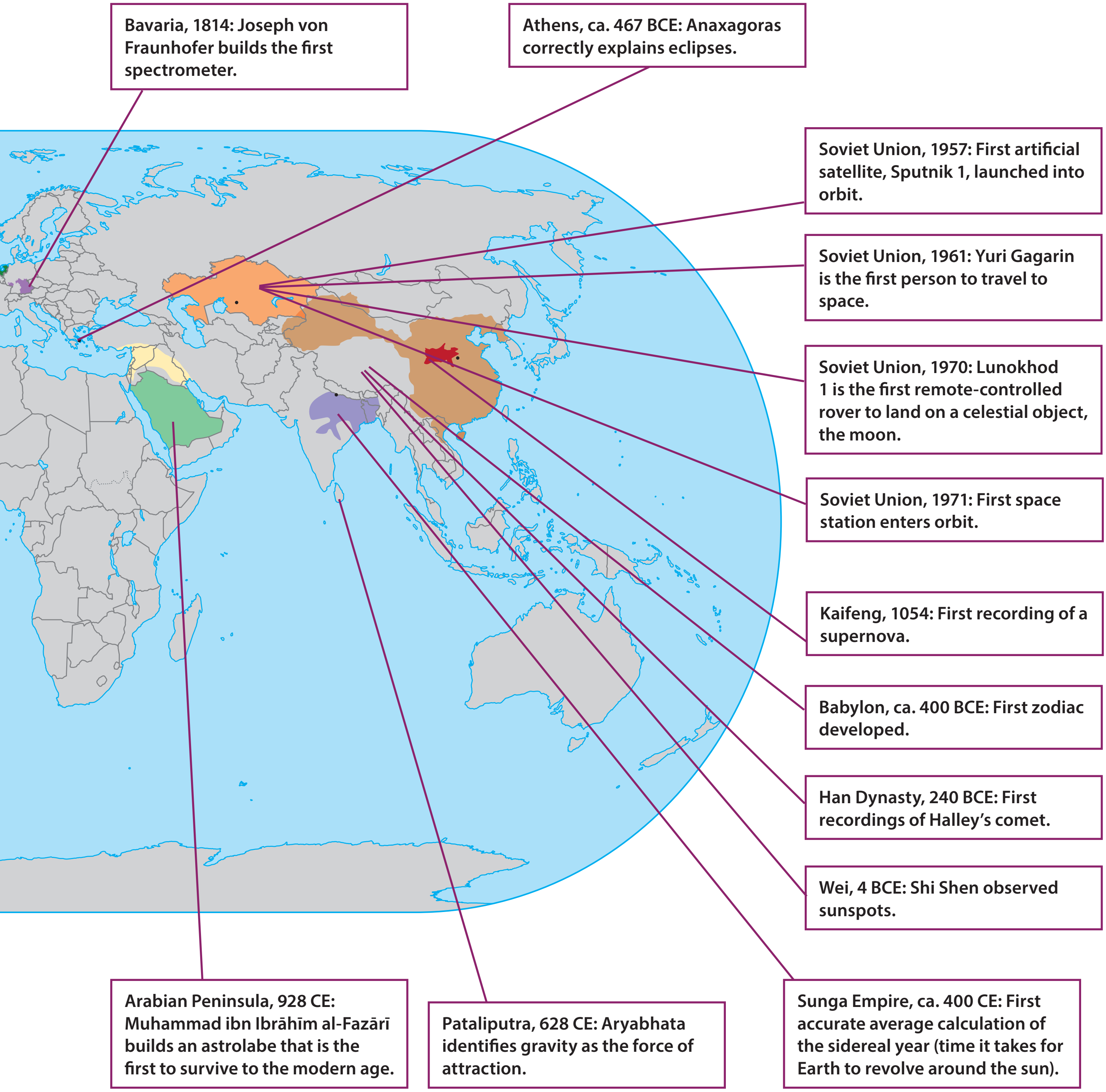
refract, v. for energy waves, to change direction as a result of passing through a material or other disruption

Word to Know

A *zodiac* is a region of the sky that is divided into twelve astrological signs that are found along the plane of Earth's orbit. Aries, Leo, Virgo, and Scorpio are examples of some of these zodiac signs.

Connection

Inventions and discoveries that happened before the ones shown here may have existed, but records of them have been lost or destroyed.



Across Time

People have observed space for thousands of years.

Sky watchers before the 1600s looked with the unaided eye. Astronomy then consisted of recording observations and patterns and making mathematical calculations.

An astrolabe is an instrument that was used to make measurements of the altitudes of celestial bodies.

Zodiacs involve identifying constellations and noticing repeating patterns in where and when they appear in the sky.

- **750 BCE** Mayan calendars
- **467 BCE** First correct explanation of eclipses
- **400 BCE** First zodiac
- **240 BCE** First recordings of Halley's comet
- **4 CE** First record of observed sunspots
- **400 CE** First accurate average calculation of the sidereal year
- **628 CE** Identification of gravity as the force of attraction
- **928 CE** First astrolabe built to survive to the modern age
- **1054** First recording of a supernova
- **1608** Patent filed for first refracting telescope
- **1668** First reflecting telescope

The first telescopes were optical telescopes, meaning they work by focusing visible light.

A spectrometer is a device that detects and analyzes wavelengths of electromagnetic energy. Each type of matter has its own electromagnetic "signature." A spectrometer allows astronomers to determine the chemical makeup of planets, stars, and other objects in space.

Human space travel now routinely carries people into low Earth orbit and has taken a few people as far as the moon. However, uncrewed spacecraft are traveling farther into space and sending back much more information from which we can learn.

1800 Discovery of infrared light

1814 First spectrometer

1868 Discovery of helium in the sun

1926 First launch of rocket propelled by liquid fuel

1957 First artificial satellite launched into orbit

1961 First person to travel to space

1969 First people to walk on the moon

1970 First remote-controlled rover to land on a celestial object

1971 First space station enters orbit

1990 Hubble Space Telescope in orbit

2012 First spacecraft to journey beyond the edge of the solar system

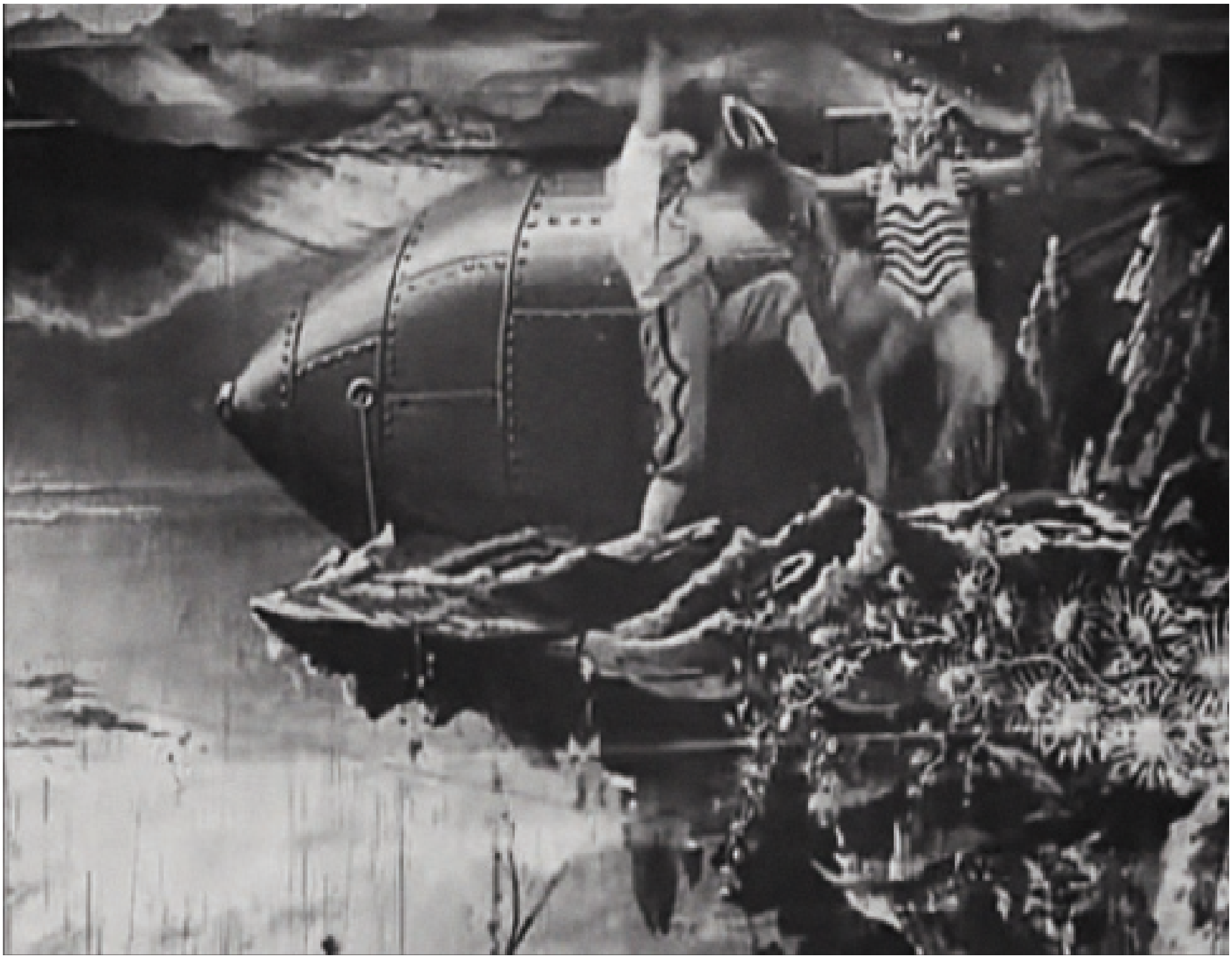
Le Voyage dans la Lune

Science fiction films about space travel are common today, but that wasn't always the case. After all, films were being made long before spaceflight became a reality.

The first film ever made about spaceflight was a French film titled *Le Voyage dans la Lune* (*A Trip to the Moon*), which was released in 1902. The film was greatly inspired by two novels by Jules Verne: *From the Earth to the Moon*, published in 1865, and *Around the Moon*, published in 1869.

The film version features a group of astronomers who journey to the moon in a capsule fired out of a cannon. The "man in the moon" in the film has an actual face, and the capsule lands in his eye, creating a classic image in early science fiction cinema.

This scene from *Le Voyage dans la Lune* became iconic.



This scene shows an alien grabbing onto the back of the space capsule, and plants hang over the cliff in the foreground.

Once on the moon, the astronomers have no need of spacesuits. Plants grow on the ground of the moon. Aliens attack and capture the astronomers as they sleep and take them to their king. The astronomers fight back and escape and speed back to Earth in their capsule, but one of the aliens grabs on and flies back to Earth with them. Back on Earth, the capsule with the astronauts, as well as the alien, lands in the ocean, and they are rescued by a ship. They are then given a parade, where they display the alien as a captive.

The film was meant to be satire, making fun of scientists whom the filmmaker thought had ridiculous ideas. At the time of the film's release, the Wright brothers had not even flown a plane in the sky for the first time. The idea that humans could visit the moon was laughable. Yet fewer than seven decades after the film's release, humans really did walk on the moon.

The Space Race

Space-related innovations have originated all over the world.

08/02/1955:
The Space Race officially begins when the USSR responds to a statement by the US that they intend to launch an artificial satellite into orbit.

11/03/1957:
The USSR launches the first mammal, a dog named Laika, into orbit. They did not have plans to return the craft safely to Earth, so Laika died in orbit.

08/19/1960:
The USSR is the first to send mammals into orbit and recover them alive. The mammals are two dogs, named Belka and Strelka.

1955 1956 1957 1958 1959 1960 1961 19

10/04/1957:
The USSR launches Sputnik 1, the first artificial satellite in orbit. In Russian, ***sputnik*** means "traveling companion."

01/31/1958:
The US launches Explorer 1, an artificial satellite, into orbit.

07/29/1958:
The US government officially creates NASA.

01/31/1961:
The US launches a chimpanzee named Ham into orbit and recovers him alive.

04/12/1961:
The USSR launches the first person, Yuri Gagarin, into space.

The Space Race was a competition between the Soviet Union (USSR) and the United States (US) to achieve landmark milestones in spaceflight. The race was both scientific and political, as it was thought that superior spaceflight capability would result in military dominance. The Space Race pushed both nations through great advancements in engineering and innovation.

05/05/1961:
The US launches Alan Shepard into space. Although he was not the first human in space, Shepard was the first to control his spacecraft himself, as Gagarin's spacecraft flew in automatic mode.

07/21/1961:
The US launches John Glenn into orbit for the first time. Although Shepard was the first American in space, he did not achieve orbit.

07/31/1964:
The US lands a robotic lunar probe, Ranger 7, on the moon.

10/12/1964:
The USSR sends the first multiperson crew aboard a single spacecraft into space: Vladimir Komarov, Konstantin Feoktistov, and Boris Yegorov crew the Voskhod 1.

11/12/1966:
The US achieves EVA, with Edwin "Buzz" Aldrin spending a total of 5.5 hours outside the Gemini 12 spacecraft.

62 1963 1964 1965 1966 1967 1968 1969

03/18/1965:
The USSR achieves the first extravehicular activity (EVA), also called a spacewalk, by Alexei Leonov aboard the Voskhod 2.

03/23/1965:
The US sends its first multiperson crew into space: Gus Grissom and John Young crew the Gemini 3.

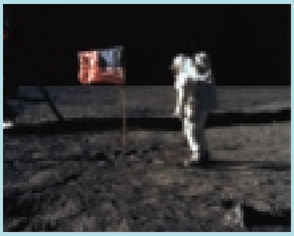
12/21/1968:
The US sends the first people out of Earth's orbit, also the first to orbit a celestial body. Frank Borman, James Lovell, and William Anders orbit the moon on the Apollo 8 spacecraft.

07/20/1969:
The US sends the first people to land on the moon. Neil Armstrong is the first person to set foot on the moon, followed by Buzz Aldrin, while Michael Collins remains in the command module in lunar orbit.

Consider the Evidence

NASA Fan1

July 20! Today we celebrate the anniversary of the moon landing! On this day in 1969, Neil Armstrong became the first person to set foot on the moon. He made the famous declaration: “That’s one small step for [a] man, one giant leap for mankind.”



Andy Jameson

This is nonsense. Don’t fall for it! Humans never went to the moon. Just look at that photo. Do you see any stars in the sky? No, because they couldn’t have shown any, or people could compare their positions and figure out the photos were taken on Earth, either in a desert or in a studio.

Michaela Kirk

Of course you can't see stars in the sky in the photos on the moon. The camera's light settings were set to capture the images of the people and objects on the surface of the moon, not tiny points of light in the sky. Don't let the dark sky fool you. It's only dark because the moon has no atmosphere. The photos were taken during the day, in bright sunlight.

Danica Weiss

If you don't believe your own eyes about the stars, believe them about the shadows. Just look at the ground. The shadows point all kinds of directions! Shadows from the sun would point only one way. These shadows were clearly cast because of studio lighting.

Dr. K.S. Field

Although some shadows may seem to be pointing different directions, this is due to the uneven surface of the moon, as well as the high degree of reflectivity of the rocks and dust. Unlike on Earth, rocks on the moon are not subject to weathering, so their jagged, shiny surfaces never get worn down.

Wendy Lu, M.D.

Explain, then, how the astronauts survived exposure to the huge amounts of radiation in the Van Allen belts, the zones of ionizing radiation from the sun trapped in Earth's magnetosphere. No one could survive the harmful radiation levels there.

Alicia Cortez

You're right, no one could survive the levels of radiation in the Van Allen belts, that is, if they were floating outside in space. But the Apollo 11 spacecraft was very well shielded for exactly this reason. As an engineer, I can assure you that there were plenty of radiation dosimeters recording exposure on board the spacecraft, which showed the astronauts were exposed to about 1 rem, the same as you'd receive from a CT scan in a doctor's office.

NASA Fan1

Debate is good! But about this tremendous scientific achievement, it would have been much more difficult to simulate landing on the moon than it was to simply go there. There would have been no way to keep all the insiders from talking about it. Plus, NASA didn't go there just once; they went back five more times!

Spot the BS

Heads up! There is **b**ad **s**cience being used to support some of the arguments. Can you detect where the reasoning and science don't quite add up?

Consider the Source

Of the various responders, who constructs theories from their own personal viewpoints, and who provides more credible information?

Script versus Transcript

How does the dialogue from a movie dramatization of Apollo 11 compare to the transcript of the actual events?

Screenplay Excerpt for a Movie About the Apollo 11 Mission

FADE IN

EXT. MOON

The LUNAR LANDER touches down. We see it hovering, blowing fine dust away from the bottom as it gently lands. Dust begins to settle.

ALDRIN speaks on radio, with slight distortion, to CAPCOM, also radio distorted.

ALDRIN
Houston, the Eagle has landed.

CAPCOM
Roger. Congratulations on a successful landing, Eagle.

ALDRIN
We're suiting up to go out. Can you see us? Video is good?

CAPCOM
Roger, video is good. The world is watching. Good luck, gentlemen.

CUT TO

INT. LANDER

ALDRIN and ARMSTRONG both stand up. They look at each other, their faces serious. ALDRIN gives a thumbs-up and raises his eyebrows, silently asking if ARMSTRONG is ready. ARMSTRONG returns the thumbs-up, nods, and lowers the sun visor on his helmet. He spins the door crank and pushes the door open as ALDRIN lowers his visor as well.

CUT TO

EXT. MOON

We see the door of the lander push open, and a ladder is lowered. ARMSTRONG steps down slowly. At the end he turns and makes the final jump, a small puff of dust rising around his feet.

ARMSTRONG
That's one small step for man, one giant leap for mankind.

Transcript Excerpt from Apollo 11 Mission

Timestamps represent time since launch.
CC: CAPCOM, Mission Control
LMP: Lunar Module Pilot (Aldrin)
CDR: Commander (Armstrong)
(TRANQ) refers to Tranquility Base, the lunar landing position.

LUNAR SAMPLING -- Apollo-11 commander Neil Armstrong gathers samples of the lunar soil soon after he made his historic first step on the surface of the Moon on July 20. Program scientists planned this as his first task in case the lunar visit was cut short. This picture was taken by Edwin Aldrin from inside the landing vehicle. Part of the vehicle's shadow is visible in the foreground. (69-3088)
Photo from IPS

04 13 22 00 CC
Roger. We're getting a picture on the TV.

04 13 22 09 LMP (TRANQ)
You got a good picture, huh?

04 13 22 11 CC
There's a great deal of contrast in it, and currently it's upside down on our monitor, but we can make out a fair amount of detail.

04 13 22 28 LMP (TRANQ)
Okay. Will you verify the position—the opening I ought to have on the camera?

04 13 22 34 CC
Stand by.

04 13 22 48 CC
Okay. Neil, we can see you coming down the ladder now.

04 13 22 59 CDR (TRANQ)
Okay. I just checked getting back up to that first step, Buzz. It's—not even collapsed too far, but it's adequate to get back up.

04 13 23 10 CC
Roger. We copy.

04 13 23 11 CDR (TRANQ)
It takes a pretty good little jump.

04 13 23 25 CC
Buzz, this is Houston. F/2—1/160th second for shadow photography on the sequence camera.

04 13 23 35 LMP (TRANQ)
Okay.

04 13 23 38 CDR (TRANQ)
I'm at the foot of the ladder. The LM footpads are only depressed in the surface about 1 or 2 inches, although the surface appears to be very, very fine grained, as you get close to it. It's almost like a powder. Down there, it's very fine.

04 13 23 43 CDR (TRANQ)
I'm going to step off the LM now.

04 13 24 48 CDR (TRANQ)
THAT'S ONE SMALL STEP FOR (A) MAN, ONE GIANT LEAP FOR MANKIND.

. . . and Postscript

People have not returned to the moon in the more than 50 years that have passed since the Apollo missions. Despite the great drama and excitement of the actual Apollo missions and the many movie adventures they inspired, real human space travel remains extraordinarily dangerous and expensive. It is simply much safer and viable to do most of our explorations of space using uncrewed probes.

However, planning has been underway for multiple missions to return humans to the surface of the moon once again.

To be continued . . .

Sparking the Imagination

"The Star"

by Jane Taylor

TWINKLE, twinkle, little star,
How I wonder what you are!
Up above the world so high,
Like a diamond in the sky.

When the blazing sun is gone,
When he nothing shines upon,
Then you show your little light,
Twinkle, twinkle, all the night.

Then the trav'ller in the dark
Thanks you for your tiny spark,
He could he see which way to go,
If you did not twinkle so.

In the dark blue sky you keep,
And often thro' my curtains peep,
For you never shut your eye,
Till the sun is in the sky.

'Tis your bright and tiny spark
Lights the trav'ller in the dark:
Tho' I know not what you are,
Twinkle, twinkle, little star.

Connection

The poem "The Star" by English poet Jane Taylor was first published in 1806 in a collection of poems and nursery rhymes by her and her sister Ann. It's a whimsical rhyme that prompts a couple questions with real science answers.

Why do pinpoints of starlight "twinkle"?

Twinkle refers to a light varying repeatedly between brighter and fainter. Why do stars do that? Because their light bounces through moving layers of air at different temperatures as it passes through Earth's atmosphere. That causes the star's appearance to wobble and flicker.

Why do stars appear in the sky only when the sun does not?

The light from stars is reaching Earth all the time. Sunlight scattered throughout Earth's atmosphere makes the sky bright so that the light from stars becomes indistinguishable by our limited eyes during periods of daylight. But it is possible to see stars during the day with the aid of a well-aimed telescope.

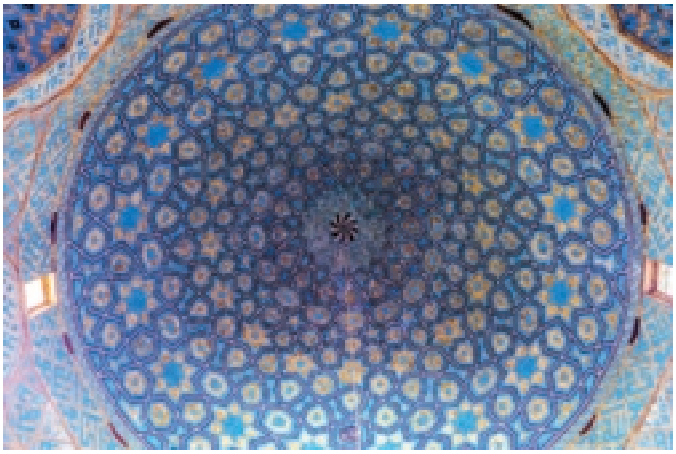
The Moon Over a Waterfall

by Utagawa Hiroshige

Connection

The Moon Over a Waterfall by Utagawa Hiroshige showcases the moon appearing large behind a tree that is growing at a cliff's edge. The tree and cliff create perspective that places the moon at the horizon and makes it appear large. In everyday experience, the moon does look larger (or closer) to our eyes at the horizon than it does when it appears higher overhead in the sky. This is an illusion produced by the way our brains process visual information. However, it is not an illusion that the moon appears whiter overhead but sometimes in pink or orange hues nearer to the horizon. When you view the moon near the horizon, its reflected light travels through more atmosphere from that angle before reaching your eyes than when the moon is overhead. That little bit more distance in the atmosphere filters out more of the light with shorter wavelengths, the blue light.

Ceiling Murals of Mosques and Synagogues



Connection

Many mosques and synagogues have elaborate murals on the ceiling that resemble the sky and draw the eye up. Stars are glowing orbs of gas, but the shapes of stars have long been depicted in art as many points radiating from a bright center. We see the dots of light with pointy spikes because of limitations in our eye structures that prevent perfect focus.

The Starry Night

by Vincent van Gogh

Connection

The Starry Night by Vincent van Gogh is one of the most famous and recognizable paintings in the world. The artist takes the "out of focus" nature of stars to the extreme. He was almost certainly moved more by emotion than science or realism in creating this work. Yet he notably distinguished the planet Venus from the stars, by apparent brightness and size, as they are distinguishable in the night sky by the unaided eye.

Taking a Long Look

When Vincent van Gogh painted *The Starry Night*, he had no idea of the swirling images of the night sky that would one day come not from a paintbrush but from a camera.

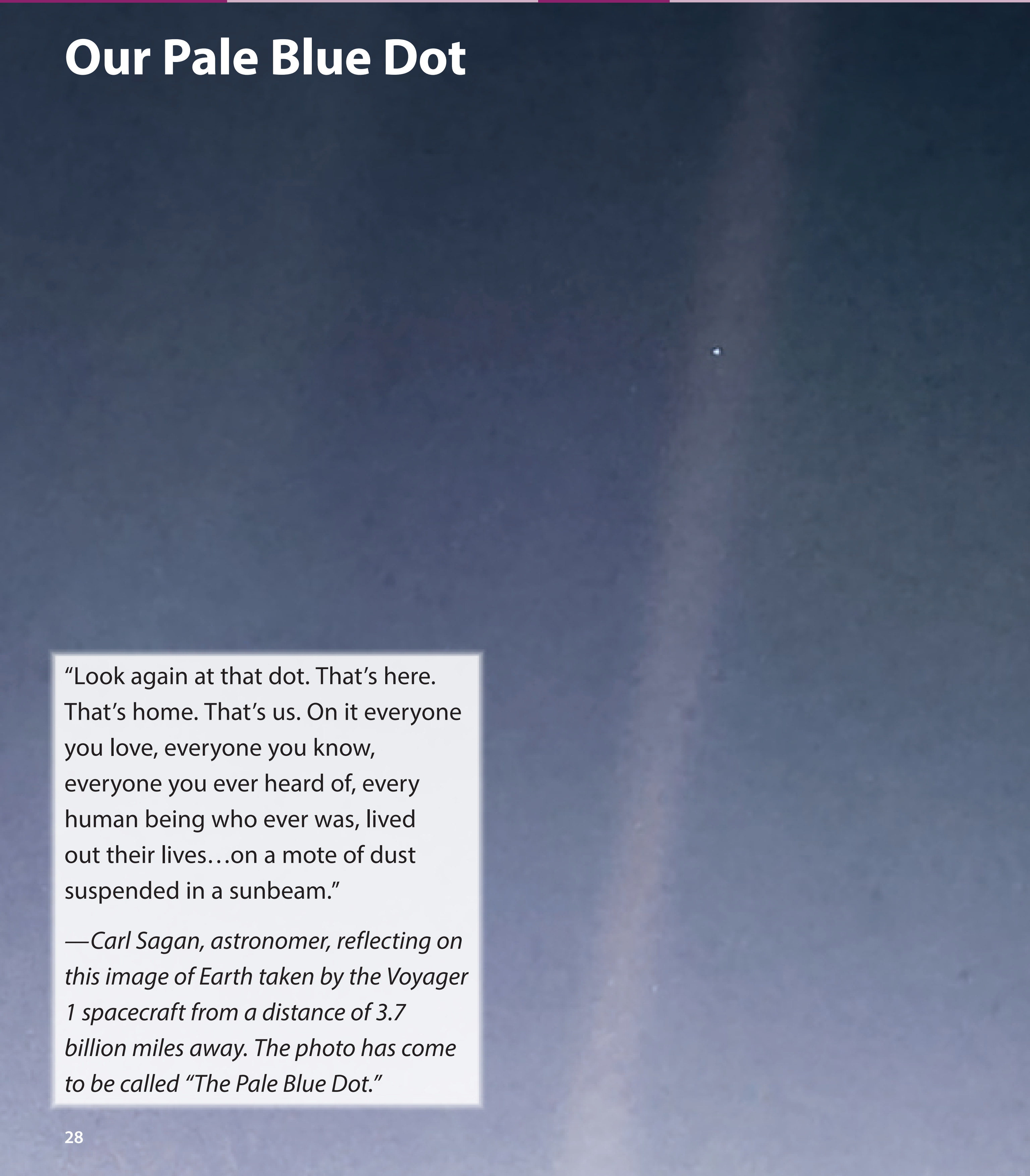
Star trail photos show the motion of the stars in the sky at night. They are easy to take with the right setup and equipment. This is what happens when light is allowed into the camera for longer than the usual snap of the shutter—a long enough period of time that the stars move along their patterned course in the sky while the shutter is open.

Here's what it takes:

DSLR camera
Tripod
Cable release

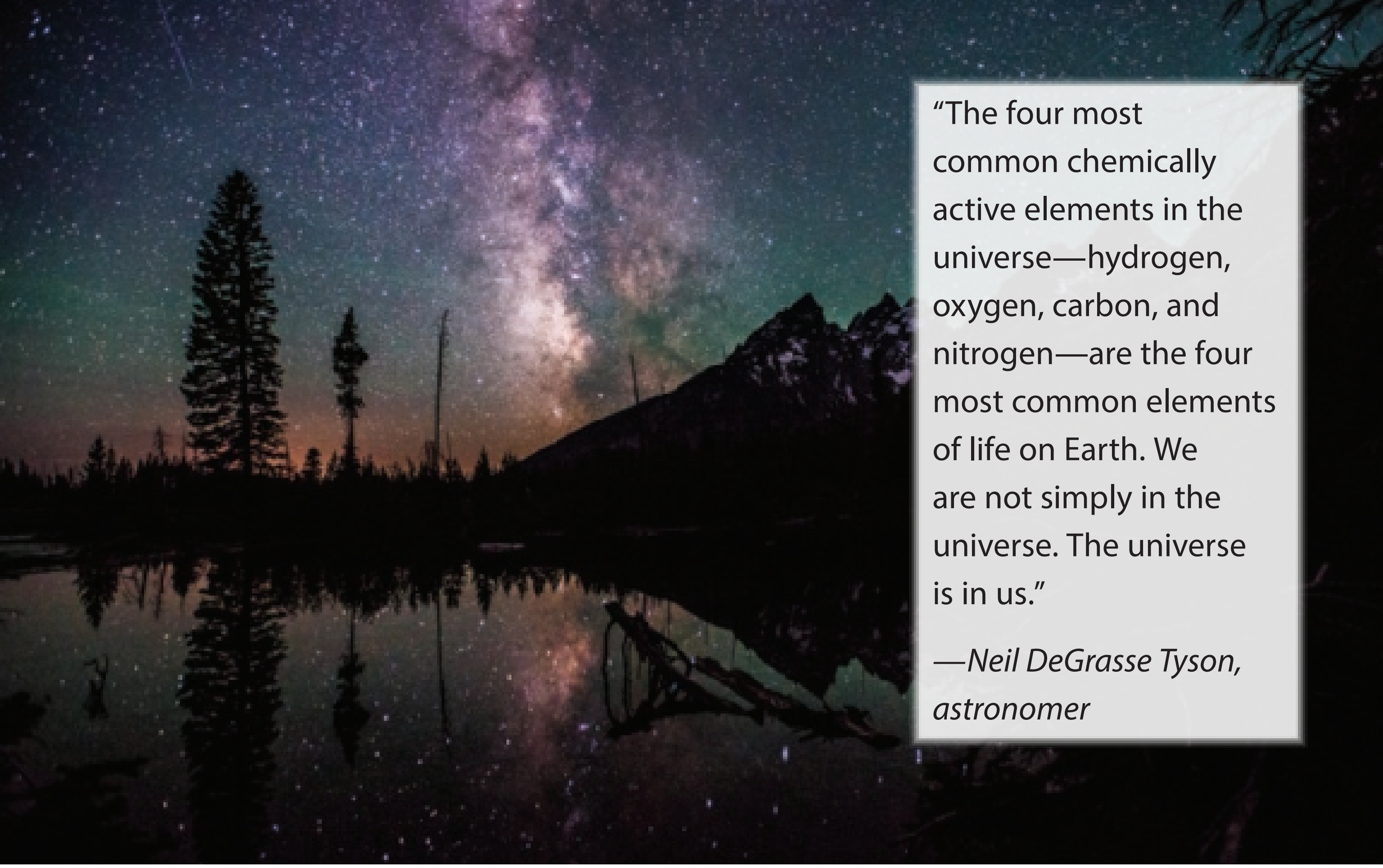
1. Set up the camera on the tripod. Use the viewer to adjust the camera to frame the image you want. Most photographers include a bit of scenery, such as trees or buildings, to add a point of reference to the photo.
2. Focus the lens to infinity.
3. Ensure your cable release is plugged in. This is extremely important because any shaking of the camera will ruin the shot.
4. Set the camera to "Bulb" shooting mode. Set the aperture between f/2.8 and f/4. Generally, higher aperture settings will give photos with edges that are smoother, while lower ones give sharper edges. You may need to experiment with your camera and the shot you want to find the best aperture setting.
5. Set ISO to the lowest setting (100 on newer cameras, 200 on older ones).
6. Press the button on the remote to open the shutter.
7. After the desired length of exposure, press the remote again. Photos that show star trails may have exposures from as little as 15 minutes to as much as several hours.

Our Pale Blue Dot



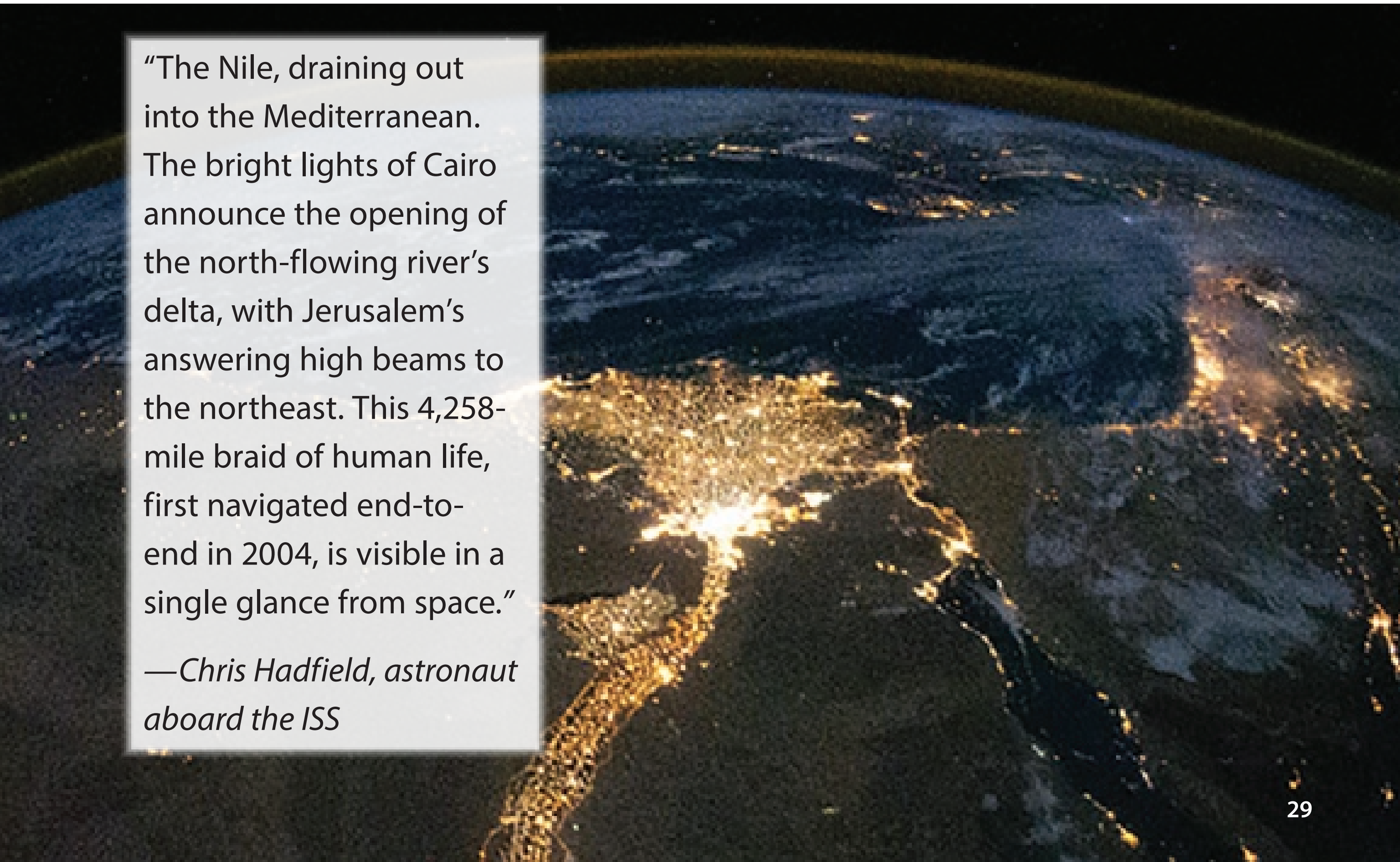
"Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives…on a mote of dust suspended in a sunbeam."

—Carl Sagan, astronomer, reflecting on this image of Earth taken by the Voyager 1 spacecraft from a distance of 3.7 billion miles away. The photo has come to be called "The Pale Blue Dot."



"The four most common chemically active elements in the universe—hydrogen, oxygen, carbon, and nitrogen—are the four most common elements of life on Earth. We are not simply in the universe. The universe is in us."

—Neil DeGrasse Tyson, astronomer

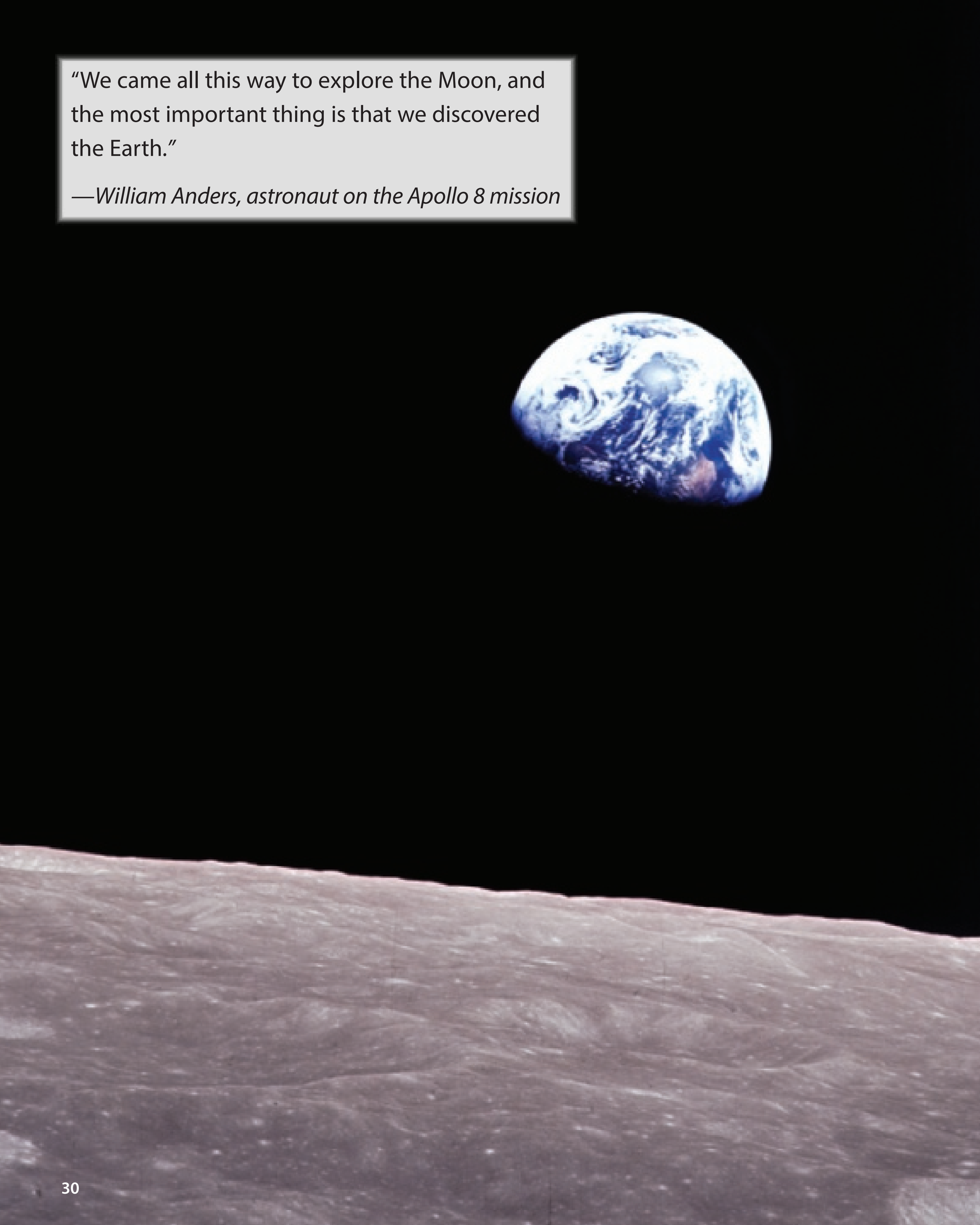


"The Nile, draining out into the Mediterranean. The bright lights of Cairo announce the opening of the north-flowing river's delta, with Jerusalem's answering high beams to the northeast. This 4,258-mile braid of human life, first navigated end-to-end in 2004, is visible in a single glance from space."

—Chris Hadfield, astronaut aboard the ISS

"We came all this way to explore the Moon, and the most important thing is that we discovered the Earth."

—William Anders, astronaut on the Apollo 8 mission



Beyond Photography

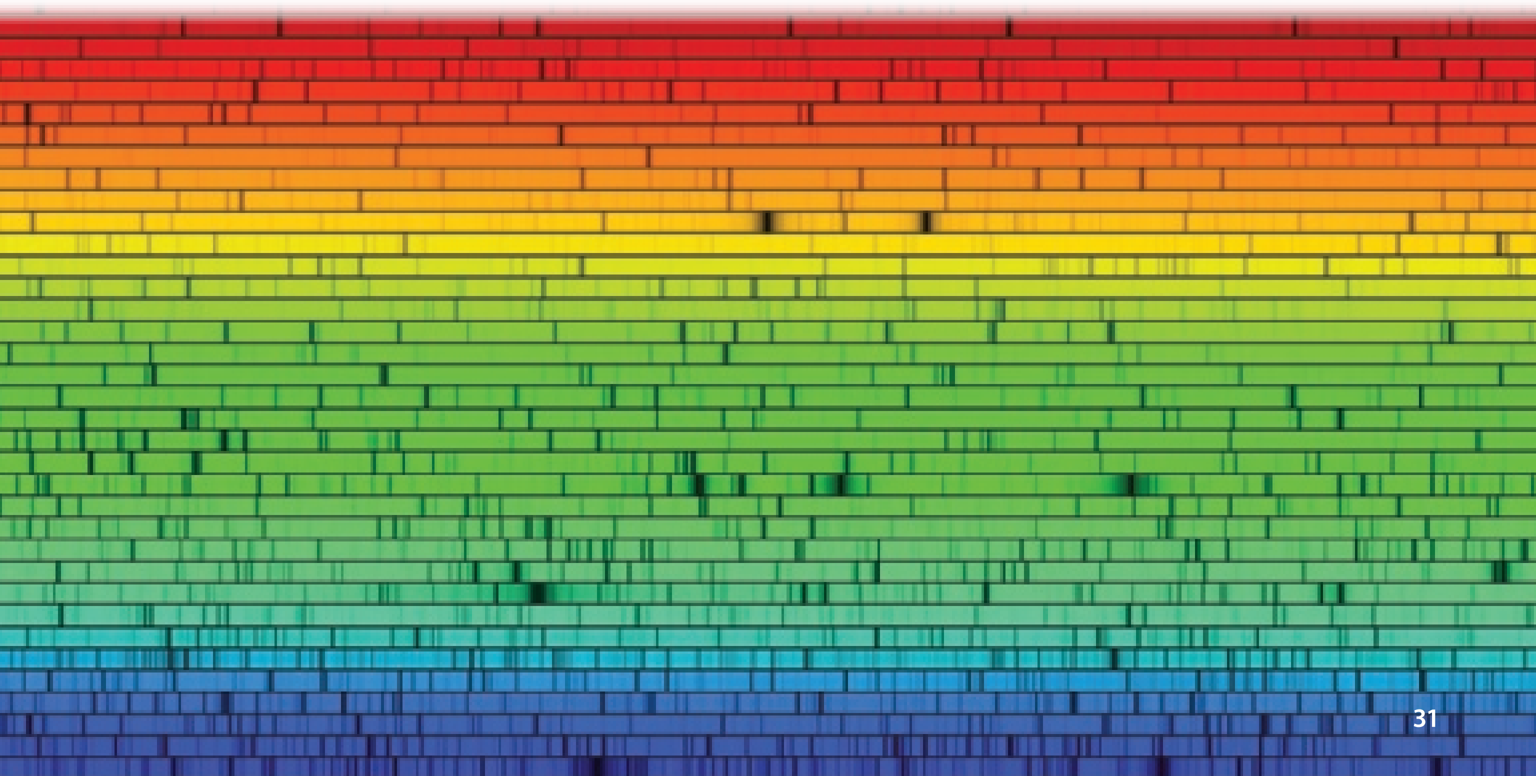
Photos of the night sky can be inspiring, but not too much can be learned about a star by looking at it with our eyes or even through optical lenses. Still everything we can learn about a star comes from techniques related to "catching light." Or, more accurately, from studying electromagnetic spectra.

Stars emit electromagnetic energy. The visible light portion of the **spectrum** can be seen with the eyes and with the aid of optical telescopes and camera lenses. Radio telescopes "listen" for waves outside the visible light range and can detect objects whose light we cannot conventionally see. X-ray detection catches X-ray emissions of stars. Collection of data beyond the range of visible light is used to render beautiful composite images of celestial structures we cannot see with our eyes from Earth.

But how can we tell what stars are made of? Different gases absorb different wavelengths of light. This provides a "fingerprint" (spectral absorption lines) that reveals chemical elements at a distance. Astronomers use spectrometers to look at chemical fingerprints and determine the composition of stars and the atmosphere of planets. Spectral absorption lines provide a way to classify stars.

This is the spectrum of the sun. The dark lines reveal which chemical elements are present in its gases. Those elements absorb specific wavelengths of energy, leaving a gap in the spectrum.

A star's temperature can be determined by its spectrum. The sun is a yellow star with surface temperatures of 5,000–6,000 K. Cooler stars (such as Betelgeuse, which has a surface temperature of T = 3500 Kelvin) emit more red and orange light than blue and violet light. Thus, cool stars are red. Temperature and color provide data by which stars can be described and classified.



Seeing Stars

When you think of a telescope, like most people you probably picture a tube with glass lenses at both ends. That's just one kind of telescope. Scientists view space using different telescope technologies to make pictures.

Visible Light Telescopes

Optical telescopes capture images using visible light. There are three main types of optical telescopes. Refracting telescopes use lenses to focus light. Reflecting telescopes use mirrors to focus light. And catadioptric telescopes use both lenses and mirrors. The Yerkes Observatory in Wisconsin has a large refracting telescope and two smaller reflecting telescopes. It houses physics and chemistry labs in addition to the telescopes and is considered the birthplace of modern astrophysics.

The Yerkes Observatory has several optical telescopes.

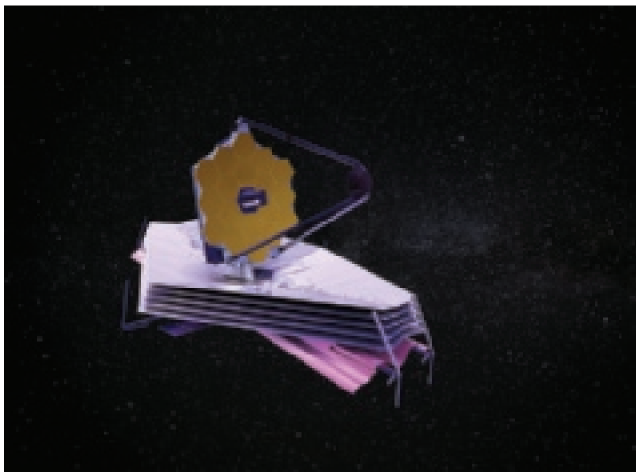
Radio Telescopes

The Very Large Array in New Mexico is the largest collection of radio telescopes in the world. Each dish is mounted on tracks and can be moved independently of the others, although they are often used together to obtain detailed images. Radio telescopes detect radio waves, lower energy than visible light. The collected energy data are often translated into digital pictures, which can be combined with images taken by telescopes that capture other wavelengths of light into composite photos.

The Very Large Array is a collection of radio telescopes in New Mexico.

Infrared Telescopes

Infrared telescopes detect invisible light from the infrared region of the spectrum. Some infrared telescopes also gather light in the visible wavelengths. The James Webb Space Telescope, launched into orbit in December of 2021, is an infrared telescope that also gathers red visible light. It orbits outside Earth's atmosphere, which both absorbs and reflects light. This helps the telescope take higher-resolution images. Previously, the Spitzer Space Telescope captured images in the infrared region, but its mission ended in 2020 after it ran out of coolant.



The James Webb Space Telescope images space from infrared light.

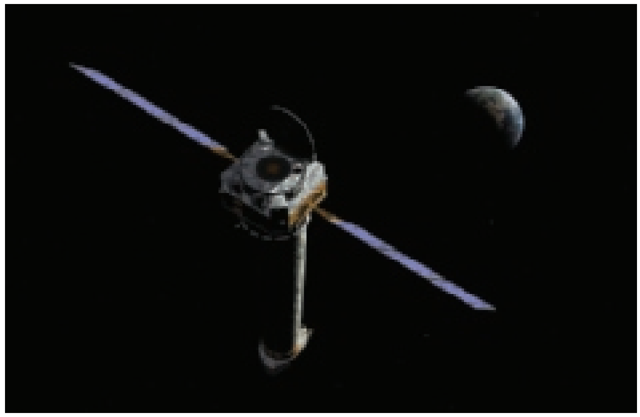
Ultraviolet Telescopes

Some telescopes capture ultraviolet light. These telescopes are generally located on satellites or other spacecraft because most ultraviolet light is absorbed by Earth's atmosphere. The Hubble Space Telescope captures light in the ultraviolet range, as well as visible and some infrared light. The Hubble Space Telescope, like the James Webb Space Telescope, orbits Earth outside of the atmosphere so that it can capture detailed images without distortion from the atmosphere.

The Hubble Space Telescope was launched into orbit in 1990.

X-Ray Telescopes

Capturing X-ray energy is no easy feat. All X-rays emitted by cosmic objects are absorbed by Earth's atmosphere, so X-ray telescopes must be launched into space. The Chandra X-Ray Observatory orbits Earth more than 80,000 kilometers above the surface. X-ray data are analyzed using computers and also are translated into digital pictures.



All X-ray telescopes, like the Chandra X-Ray Observatory, must be launched into space.

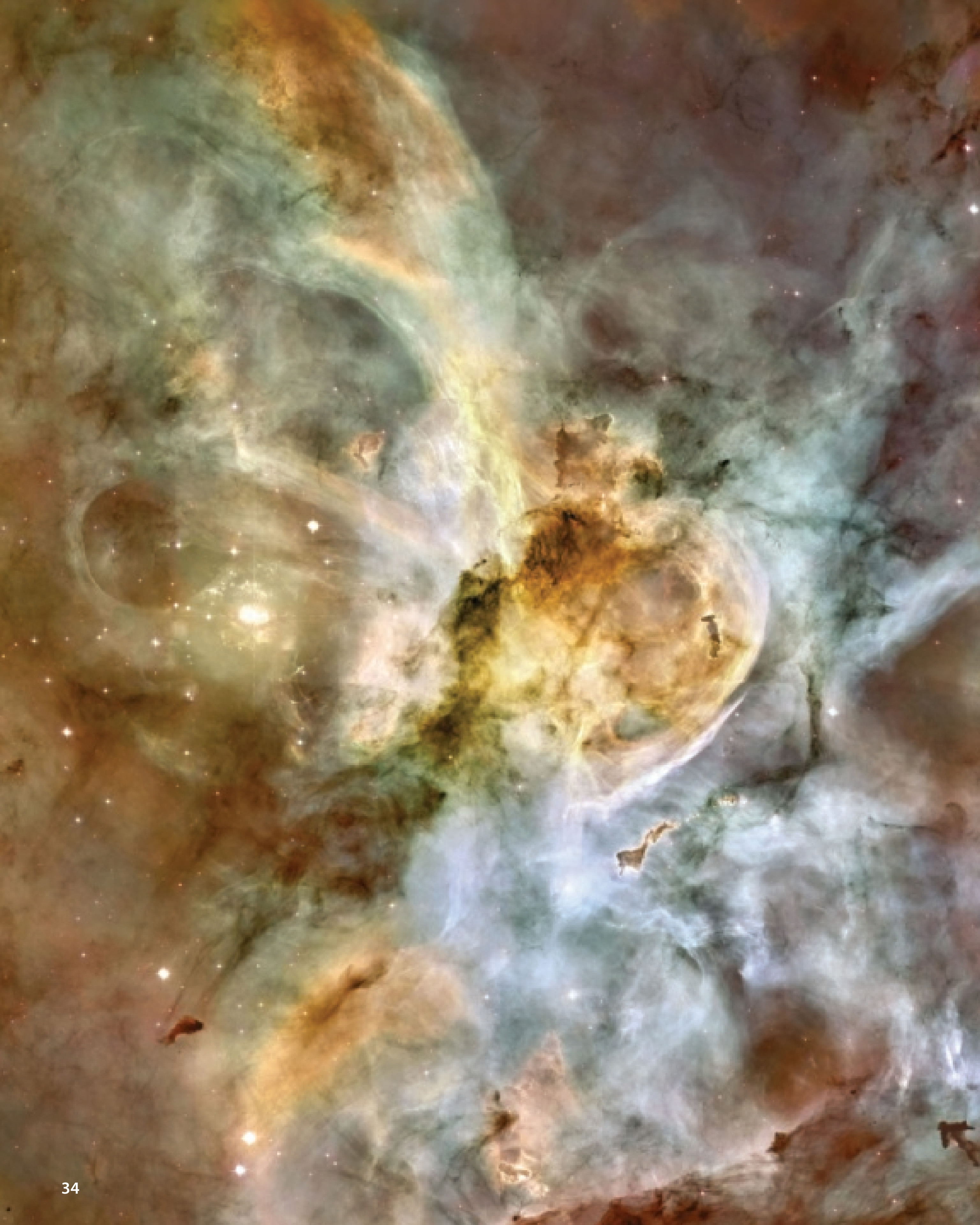
Gamma Ray Telescopes

Gamma ray telescopes detect the highest-level electromagnetic energy emitted by cosmic objects. Unlike other types of telescopes, gamma ray telescopes do not capture the energy directly. Instead, they detect light in space that results from the interaction of gamma rays and Earth's atmosphere. When gamma rays strike Earth's atmosphere, they generate charged particles. Telescopes like the MAGIC telescope in the Canary Islands reflect the flashes of charged particles into tubes that increase the signal.

The MAGIC Observatory is on La Palma in the Canary Islands.

Vocabulary

spectrum, n. a continuous sequence or range, as of color or electromagnetic energy



Art joins science in the making of a Hubble Space Telescope image such as this one. This picture of the Carina Nebula shows a celestial structure almost too large to comprehend. The image is 50 light-years wide, a composite of 48 frames. The frames are not simple camera snapshots. Hubble's devices detected the spectra of each point of sky that the telescope was aimed at. Then a computer compiled the data about the chemical makeup of those locations. The data create a false-color, digital image of hundreds of millions of pixels using red for sulfur, green for hydrogen, and blue for oxygen emissions. If the computer were programmed to assign different colors to the elements, the image would look different.

Out of the Shadows

You might have noticed that astronomy timelines and lists of achievements tend to feature mostly men. In the 1800s and early 1900s, fewer women than men went to college, so not as many women as men were active in the space-related sciences. And the women who did work in astronomy did not get the recognition of their male counterparts. However, the space science story is incomplete without several key contributions made by scientists who were women. Star classification systems, the mathematical equation to calculate the distance to stars, the discovery of the composition of stars, the discovery of pulsars, and the first images of a black hole are all space science achievements made by women.

Williamina Fleming, born in 1857, was a Scottish-born astronomer who worked in the United States. Working at the Harvard Observatory, she examined photographs of stars and began to catalogue them. She developed a classification system that grouped stars based on their spectral absorption lines. She also discovered the first white dwarf star.

Annie Jump Cannon was an American astronomer and mathematician born in 1863. She began working in the same Harvard Observatory as Williamina Fleming in 1896. She modified Fleming's classification system in order to group stars based on their temperatures. This system classified stars as O, B, A, F, G, K, or M and is still in use today.

Henrietta Swan Leavitt was an American astronomer born in 1868. Like Fleming and Cannon, she worked at the Harvard Observatory classifying stars. She examined Cepheid variables, which are pulsating stars that vary in size and temperature. She noticed a pattern between the period of a star's pulse and its brightness, or luminosity. Using these data, she devised what became known as Leavitt's law, which is the mathematical formula that can be used to measure intergalactic distances.

Cecilia Payne-Gaposchkin, born in 1900, was a British astronomer who worked in the United States. She worked at the Harvard Observatory as well, where she studied the absorption spectra of stars, especially the sun. She determined that stars are composed mostly of hydrogen and helium.

Jocelyn Bell Burnell is a Northern Ireland astronomer born in 1943. Working at the University of Cambridge, she studied radio waves generated by stars. She discovered pulsars, which are neutron stars that spin rapidly, sending out radio emissions that are received as short bursts.

Director Spotlight

In SciScreen Monthly, our quest continues to get you behind the scenes looking at science productions, fact and fiction, in cinema and television. This month we sat down with director Angela Houseman to talk about her new streaming series, *Infinite Universe*.

SSM: Thank you for speaking with us, Angela. We're very excited about your new series. What can you tell us about it?

AH: I'm so happy to finally be bringing this series to the public! It's been my dream ever since I was a little girl. I used to watch *Cosmos*, the TV series by Carl Sagan. I was fascinated by the show and started filming my own short snippets about the universe in my backyard.

SSM: So was that why you decided to become a filmmaker?

AH: Oh yes! [laughs] Those old home movies of mine were cute but so technically terrible! I had no idea what I was doing, either as a filmmaker or as a science communicator. It took a long time for me to learn how to make films and even longer to understand enough about science to begin to make *Infinite Universe*.

SSM: You've mentioned Carl Sagan. Was he one of your inspirations? It seems like he's influenced *Infinite Universe* very strongly.

AH: I adore Sagan. I can't say enough good things about him. He was a sound scientist, but he was also just an incredible

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communicator. He could make any topic interesting and easy to understand, even the really tricky stuff, like relativity and evolution. With *Infinite Universe*, I wanted to sort of pick up where he left off. Science has advanced a lot since 1980, and I think that storytelling is worth revisiting.

SSM: While Sagan's influence is clear in your series, you've definitely made it your own. I'm especially impressed with your visual effects. Or rather, lack of them.

AH: Yes, this is where *Cosmos* and *Infinite Universe* really differ. *Cosmos* was a pioneer in using special effects to send Sagan journeying through galaxies. These days, CGI makes effects like that commonplace. I wanted to do something very different—something you don't see every day. So we scouted the most interesting and unusual locations and shot as much of our footage outdoors as possible.

SSM: The locations truly are beautiful. You've really used the natural wonders of Earth to highlight how special we are in the galaxy.

AH: [smiles] I'm so glad you think so! That was really the point. The more we are able to look into space and learn about what's out there, the more we realize how astonishingly unique and fragile our planet and the phenomenon of life are. Being in nature always makes me feel very connected to the cosmos, though. "Out there" and "down here" are governed by the same physics. We tried to let that feeling come through on-screen. We also took great care to disturb those beautiful natural settings as little as possible. Over eons, gravity will inevitably end all of it, but in this time, we are so lucky to have the world that we do.

SSM: Thank you so much for speaking with us! We'll be watching as soon as the show premiers on November 9th.

The *Infinite Universe* crew on location in Canada

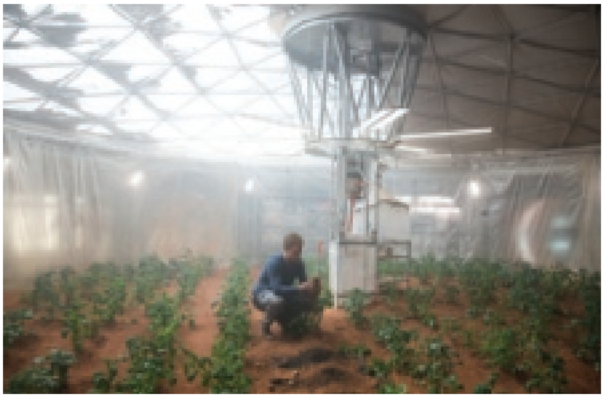
Facts in the Fiction

The film *The Martian*, released in October 2015, is a science-fiction adventure movie based on the novel of the same name by Andy Weir. In the tale, astronaut Mark Watney is stranded alone on Mars during a dust storm. He must survive until he can be rescued.

The movie is, to be sure, an excellent adventure film, with action-packed scenes, a riveting storyline, and a character whose fate you really do care about. The movie is also crammed full of science. So, let's examine how plausible the science of the film really is.

First, let's look at the dust storm that causes all the problems. While winds on Mars can reach 100 miles an hour, the extremely thin atmosphere means these winds aren't comparable to winds of the same speed on Earth. Although dust storms do sometimes present a problem for the rovers NASA has actually landed on Mars, this is due to dust obscuring cameras rather than winds damaging components. The idea that Martian winds would be so bad a mission would need to be abandoned stretches to unlikely.

However, much of the science in the movie following the storm is not only plausible but was discussed with consultants from NASA to ensure it was as correct as possible. There is water on Mars, although most of it is in the form of ice at the poles. Watney makes drinking water by causing a chemical reaction in leftover rocket fuel, which is doable, if very dangerous. And Watney, a botanist, grows potatoes by planting potato slices in an improvised garden and fertilizing them with his own waste.



The ability to grow crops on Mars has, of course, not been tested. But it's very likely it could be done, especially if the right nutrients and microbes were added to the soil, as Watney does. However, it would probably take longer for crops to grow than the timeline of the film allows.

Watney makes frequent use of duct tape to repair holes in his suit and the life pod in which he lives. Provided the tape seals properly, this solution works quite well. In fact, it was an improvised air filtration device held together with duct tape that saved the lives of the astronauts aboard NASA's Apollo 13 mission when disaster struck.

To be rescued, Watney must journey weeks in a rover to meet his rescuers. The risks here are probably understated: Martian temperatures are, on average, –62°C, so cold that NASA's rovers on the planet are equipped with heaters to warm their core systems. Watney briefly considers disabling the rover's heater, which, in reality, would be a death sentence.

The most scientifically accurate idea in the movie is the gravity assist on which the rescue mission relies. Also known as a gravity slingshot, a gravity assist uses the **gravitational force** of a massive object, such as a planet, to change the trajectory of a spacecraft. It is a technique often employed by NASA in missions throughout the solar system, including the Apollo missions, which went to the moon.

Overall, despite a couple of exaggerations, *The Martian* is highly scientifically accurate and almost entirely plausible. At no point is the science outright false; it merely takes a few liberties with degree of disaster or length of time needed to accomplish a task. This makes it one of the most scientifically accurate science-fiction movies ever produced.

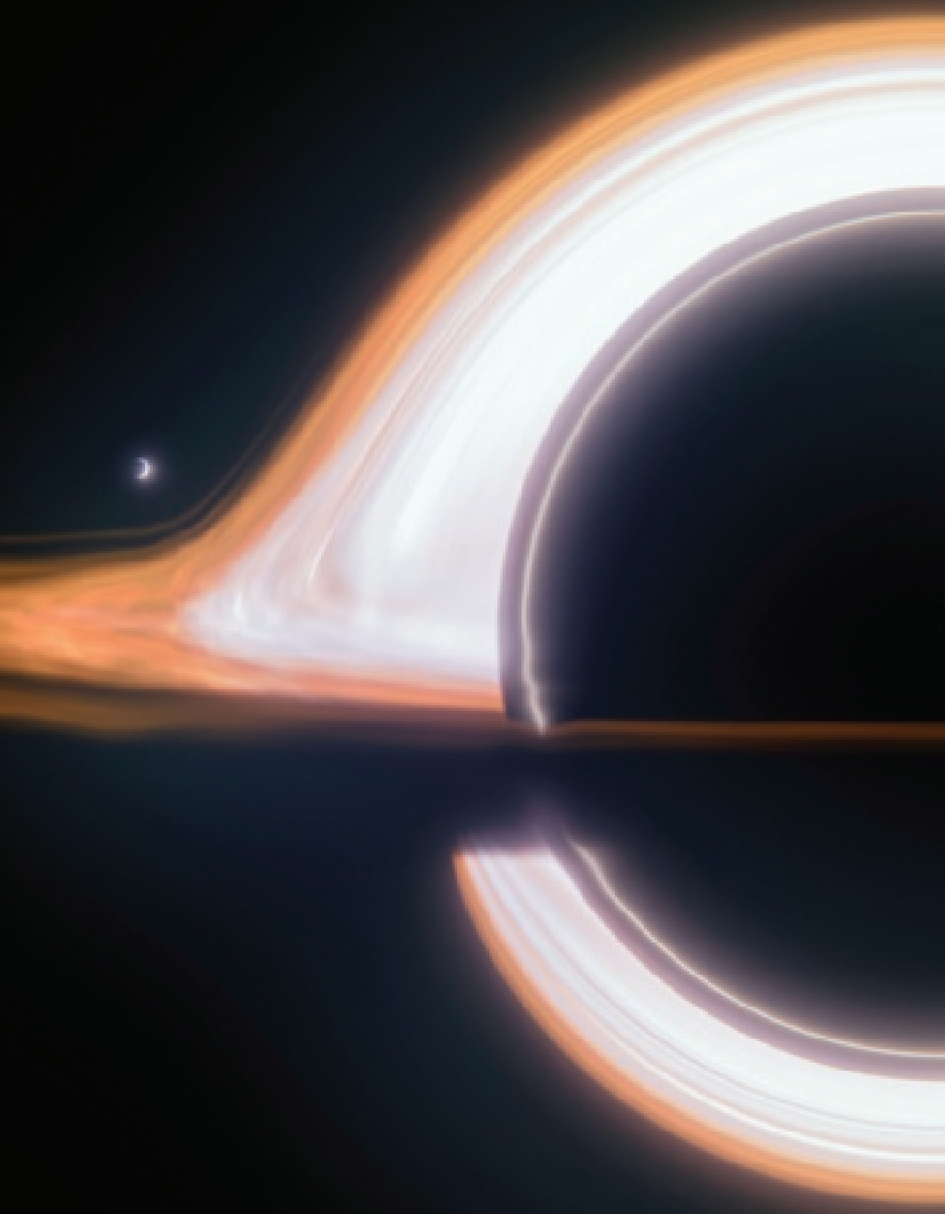
Vocabulary

gravitational force, n. a fundamental physical force of attraction between masses

Science from Fantasy

In 2014, the film *Interstellar*, directed by Christopher Nolan, hit theaters. While it was popular with audiences, it was also, rather remarkably, important for science.

Interstellar tells a story that relies on its characters interacting with a black hole. Plenty of science fiction movies have toyed with black holes in the past, but most of them played very loose with the science, usually opting to show black holes as enormous black patches in space.

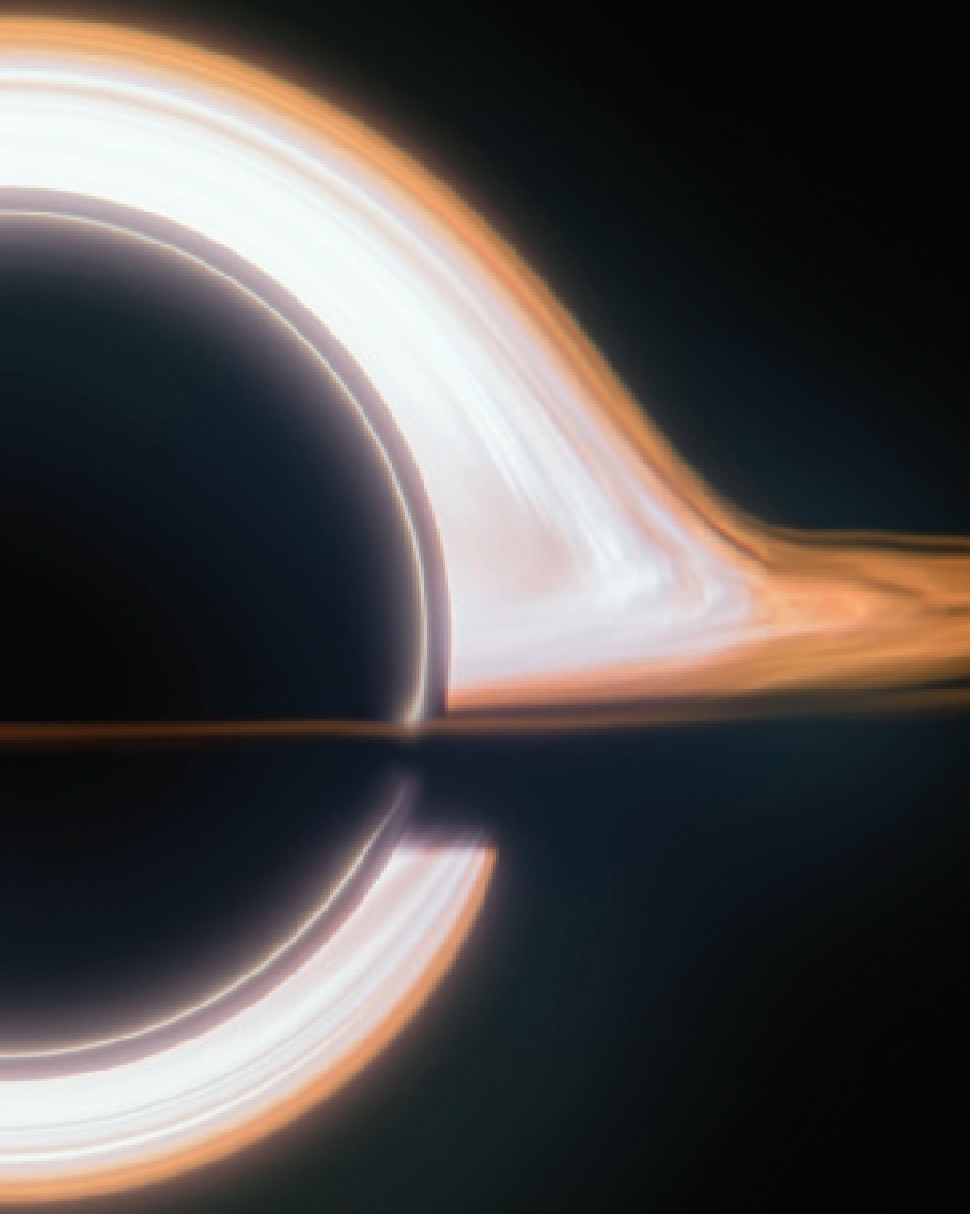


The team behind *Interstellar* chose a different approach. They wanted audiences to feel the enormous size of a black hole, and they wanted it to be as real as possible. Their first computer simulations rendered the typical black dot. It wasn't at all what they wanted.

A team of computer graphics artists, physicists, engineers, and astronomers designed and refined a computer algorithm based on the physics involved in actual black holes. Their final computer program used research from dozens of academic papers, plugging in the physics equations that describe black holes and their interactions with light and matter.

This time, their computer simulation gave them something spectacular. Not only did it accurately show what astronomers have observed around black holes, the up-close and personal view provided by the simulation gave new insights into the way light and matter behave near the event horizon, which is the edge beyond which light cannot escape the black hole's gravitational force. In fact, these insights were so new and unusual, they provided the basis for two new academic research papers!

In *Interstellar*, not only did science inspire art, but art gave rise to new science. It is truly an incredible achievement.



Black hole depiction from *Interstellar*, 2014

Is There Anybody Out There?

Carl Sagan's work included much more than his treasured show *Cosmos*. He was also a renowned science fiction novelist. In 1985, Sagan published *Contact*, which went on to become a major motion picture in 1987. The story explores the theme of contact between present-day humans and extraterrestrial beings that are far more technologically advanced. How much fact was in that volume of fiction? Does intelligent alien life exist?

In 1961, American astronomer Frank Drake formulated the Drake equation, meant to calculate the probability of intelligent life on other planets. The equation includes some numbers known with a high degree of certainty (such as the rate of the formation of stars) and others known with hardly any certainty (such as the fraction of planets that are home to living organisms). However, even the most conservative estimates suggest that at least 1,000 planets in the Milky Way Galaxy alone could be home to other intelligent life-forms.

Consider this sentence.

If intelligent alien life-forms exist, why do we have no evidence of them?

The conflict between the high estimates for its existence and the lack of obvious evidence for extraterrestrial life is called the Fermi paradox. It is named for Enrico Fermi, who is rumored to have first framed the question this way. Seeking answers, philosophers and scientists have come up with four possible solutions to explain the Fermi paradox.

1. **We're the first to exist.** In this explanation, we're the lucky ones to have evolved first. After all, *someone* must be first. That first civilization wouldn't be able to find any others because they simply don't exist yet. Unhappily for us, we're that first one, all alone (so far) in the universe.
2. **We're all too different.** In this explanation, multiple intelligent civilizations exist, but we're so different we have no way of recognizing each other or communicating. Perhaps these other life-forms live on scales much faster or slower than our own, so we don't interpret their signals correctly. Or perhaps their technology is so much more advanced than ours that we can't even recognize it. After all, would we recognize attempts by snails to communicate with us?
3. **Intelligent life is doomed.** This rather pessimistic explanation states that all civilizations advanced enough to have technology to explore space either destroy themselves or destroy each other the moment they come into contact. In other words, intelligence leads to extinction.
4. **We're just not there yet.** This explanation suggests that our technology simply isn't yet advanced enough or hasn't existed long enough to pick up alien signals, which are, by definition, very far away. After all, humanity only just began discovering the full spectrum of electromagnetic radiation in 1887. While this seems like a long time ago to us short-lived humans, on a cosmic scale, it's only a moment. Even if another civilization is out there right this minute looking for us as we're looking for them, if they're thousands of light years away from us, our signals won't reach each other for thousands more years. And that's supposing we're using the same means of communication in the first place!

There is also, of course, the rather implausible notion that aliens are already here among us, disguised or hiding or being deliberately kept away from the public. Speculation about flying saucers, crop circles, alien abductions, and government infiltration is the fun realm of science fiction but has little following among those truly seeking intelligent extraterrestrial life.

The Search Is On

In 1992 NASA initiated a formal program for the search for extraterrestrial intelligence (SETI). However, Congress canceled the program after less than a year. The nonprofit research organization called the SETI Institute picked up part of that work and continues to explore the question of whether or not we are alone.

The Allen Telescope Array (ATA) in California is the first radio telescope to be designed and used specifically for SETI searches.

Glossary

accretion, n. the pulling together and cohesion of matter because of gravity

annual, adj. occurring every year

artificial satellite, n. a human-made device placed into orbit around Earth or another celestial object

black hole, n. a cosmic body with gravitational force so great that light cannot escape it

celestial, adj. positioned in or related to outer space, observed in the sky

diurnal, adj. occurring daily

eclipse, n. the obscuring of one celestial body by another

electromagnetic radiation, n. energy, including light, in the form of electromagnetic waves

elevation, n. the angular distance of a celestial object above the horizon

focal point, n. the point at which rays or waves meet after refraction or reflection

galaxy, n. a very large group of stars and associated matter

gravitational force, n. a fundamental physical force of attraction between masses

lunar phases, n. the repeating pattern of differing appearances of the moon from Earth

orbit, v. to travel around in an elliptical path

pattern, n. a reliable sample of observable attributes

perspective, n. the appearance to the eye of objects in respect to their relative distance and positions

plausible, adj. appearing reasonably worthy of belief

Polaris, n. the North Star, so named for it's constant position over Earth's North Pole

reflect, v. to bounce or send back

reflecting telescope, n. an optical device that magnifies distant objects through the use of mirrors to focus light

refract, v. for energy waves, to change direction as a result of passing through a material or other disruption

refracting telescope, n. an optical device that magnifies distant objects through the use of lenses to focus light

scatter, v. to spread out in random directions

science literacy, n. the ability to read, hear, and comprehend information about scientific topics and demonstrate understanding in discussion and through writing

social media, n. websites and applications that allow users to participate in sharing content on the internet

solar, adj. related to the sun

solar system, n. the system of celestial objects bound by the sun's gravity or by the gravity of objects orbiting the sun

spectral absorption lines, n. dark lines seen on the electromagnetic spectra emitted by objects indicating the presence of specific gases

spectrum, n. a continuous sequence or range, as of color or electromagnetic energy

telescope, n. a device for viewing distant objects either through optical magnification or through digital rendering of images compiled from detected data

transit, v. to pass in front of

transmit, v. to send or convey from one place to another

universe, n. the entirety of everything in space

wavelength, n. the distance from crest to crest of a wave

zodiac, n. an imaginary band in astrological observation that centers on twelve constellations that feature prominently in astrological mythology and appear in the night sky in a repeating annual pattern

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