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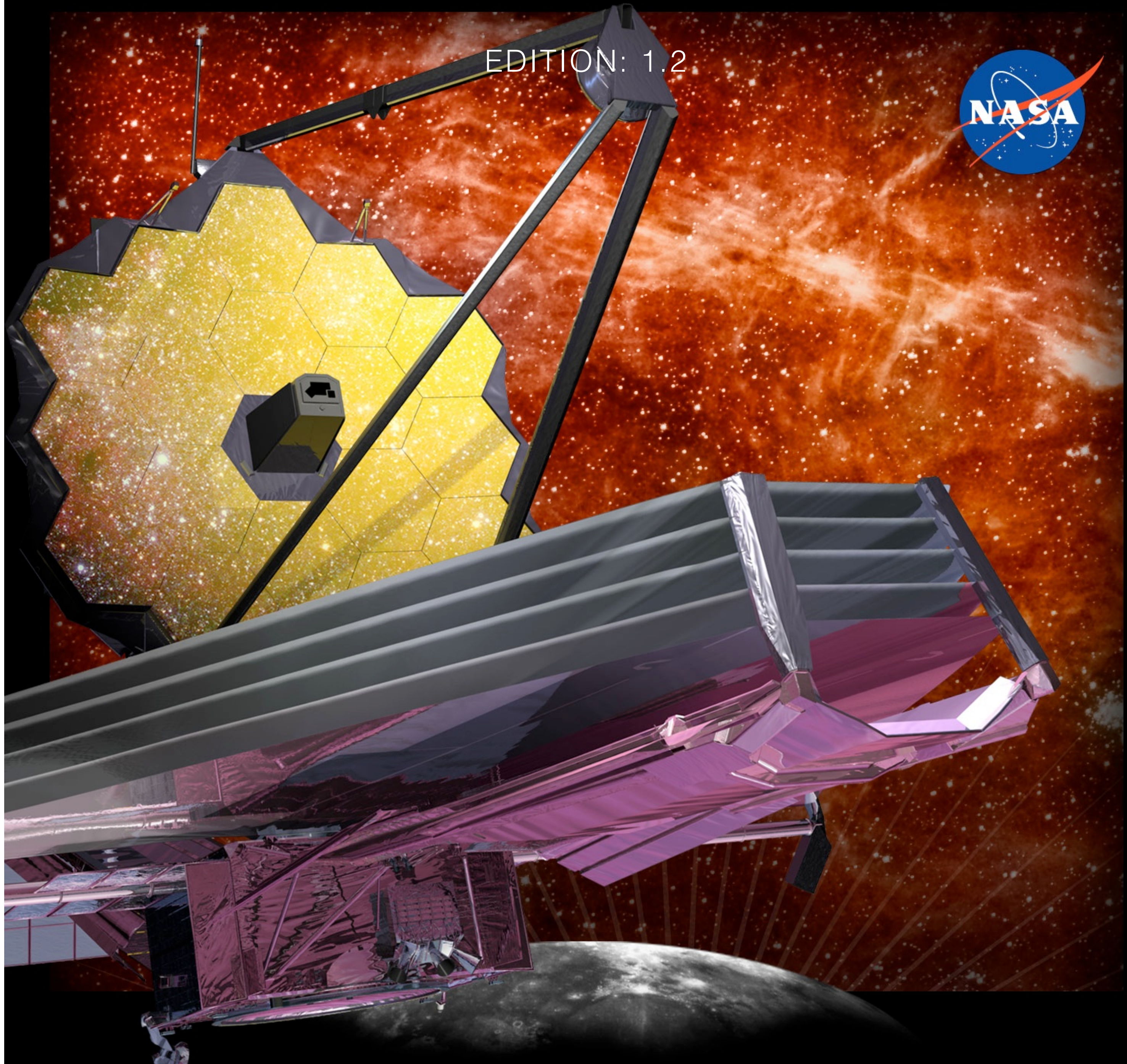


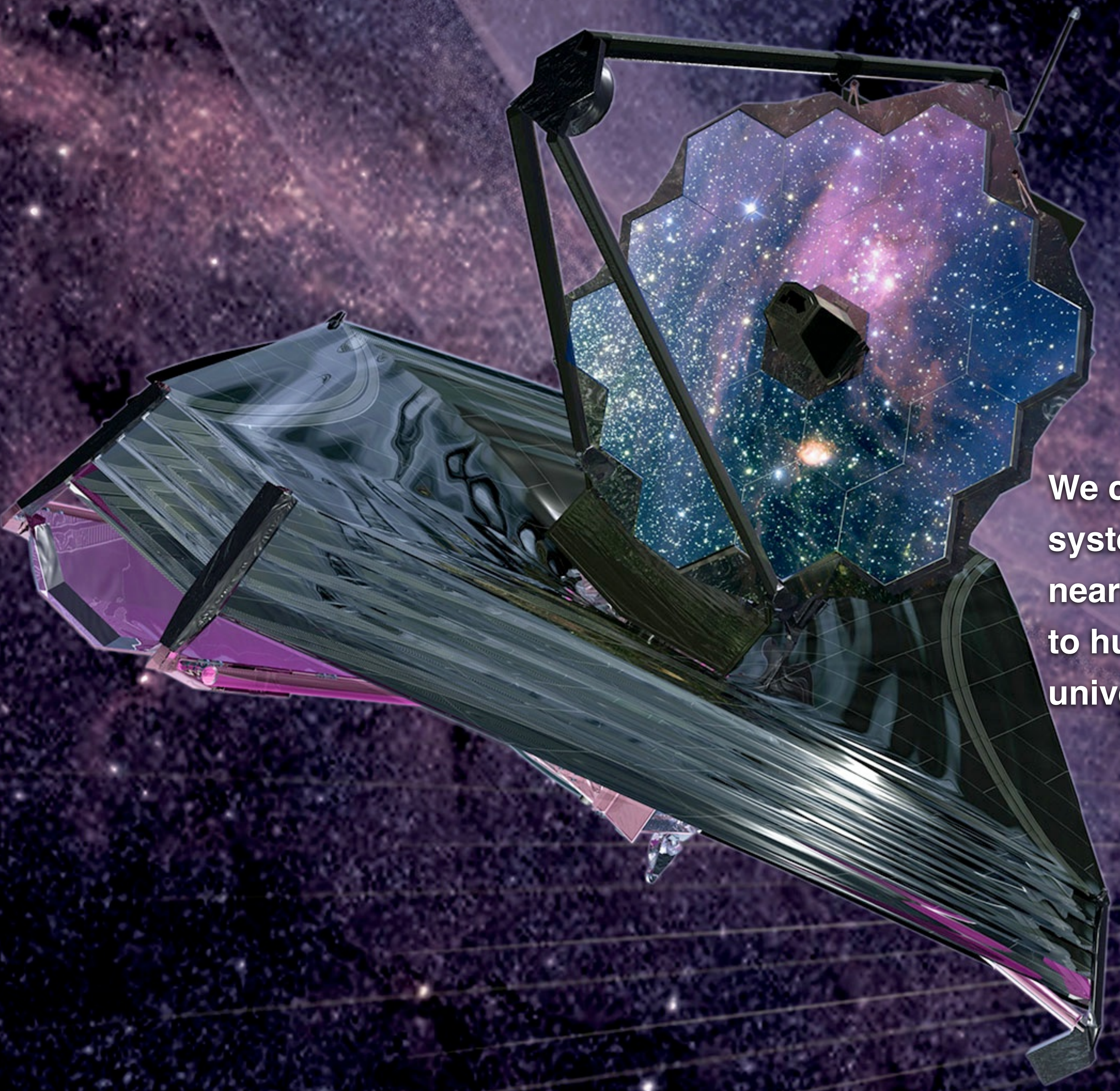
WebbTelescope.org

James Webb Space Telescope

Science Guide

CHAPTER 1

Introduction



We can see the beginning; the birth of stars, new solar systems, and evolving galaxies. A new telescope orbiting nearly a million miles from Earth, seeing in a light invisible to human eyes – gazing into the past, watching the universe come into being.

For best viewing

Viewing in portrait orientation removes several layout features.

HubbleSite & WebbTelescope

Produced by the Space Telescope Science Institute

Version: 1.2

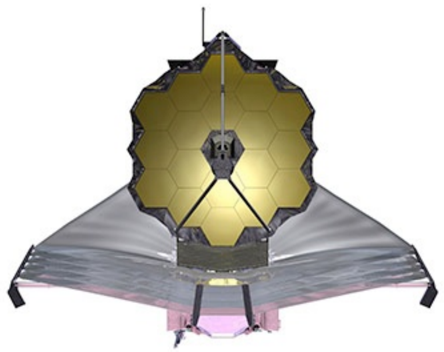
Release date: December, 2012

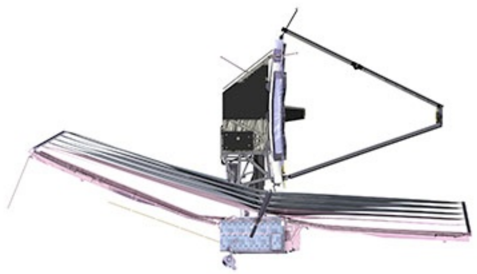
The James Webb Space Telescope is NASA's next orbiting observatory and the successor to the Hubble Space Telescope. A tennis court-sized telescope orbiting far beyond Earth's moon, Webb will detect infrared radiation and be capable of seeing in that wavelength as well as Hubble sees in visible light.

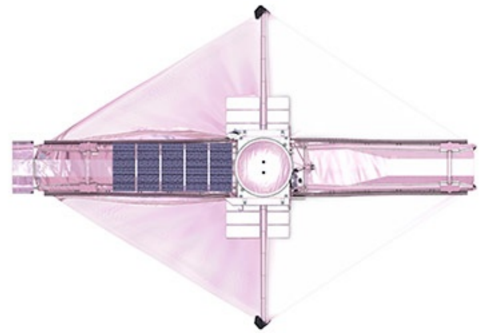
Infrared vision is vital to our understanding of the universe. The furthest objects we can detect are seen in infrared light, cooler objects that would otherwise be invisible emit infrared, and infrared light pierces clouds of dust, allowing us to see into their depths. Webb will unleash a torrent of new discoveries, opening the door to a part of the universe that has just begun to take shape under humanity's observations.

Right now, scientists and engineers from NASA, the European Space Agency, and the Canadian Space Agency are piecing Webb together, creating through cutting-edge technology an innovative observatory that not only withstands intense cold, but uses it to its advantage; an observatory that folds up inside a rocket for launch and unfurls like a butterfly opening its wings upon nearing its orbit. Later this decade, the Webb telescope will launch into space, sailing to the distant, isolated orbit where it will begin its quest. Supernovae and black holes, baby galaxies and planets' potential for supporting life – Webb will help reveal the answers to some of the biggest mysteries of astronomy.

The Webb Space Telescope embodies our most ambitious expression of pure human curiosity and intellectual innovation. Webb's mission is to understand cosmic evolution: how young structures become planets, stars, and galaxies.







SECTION 1

Sifting Through Cosmic Time

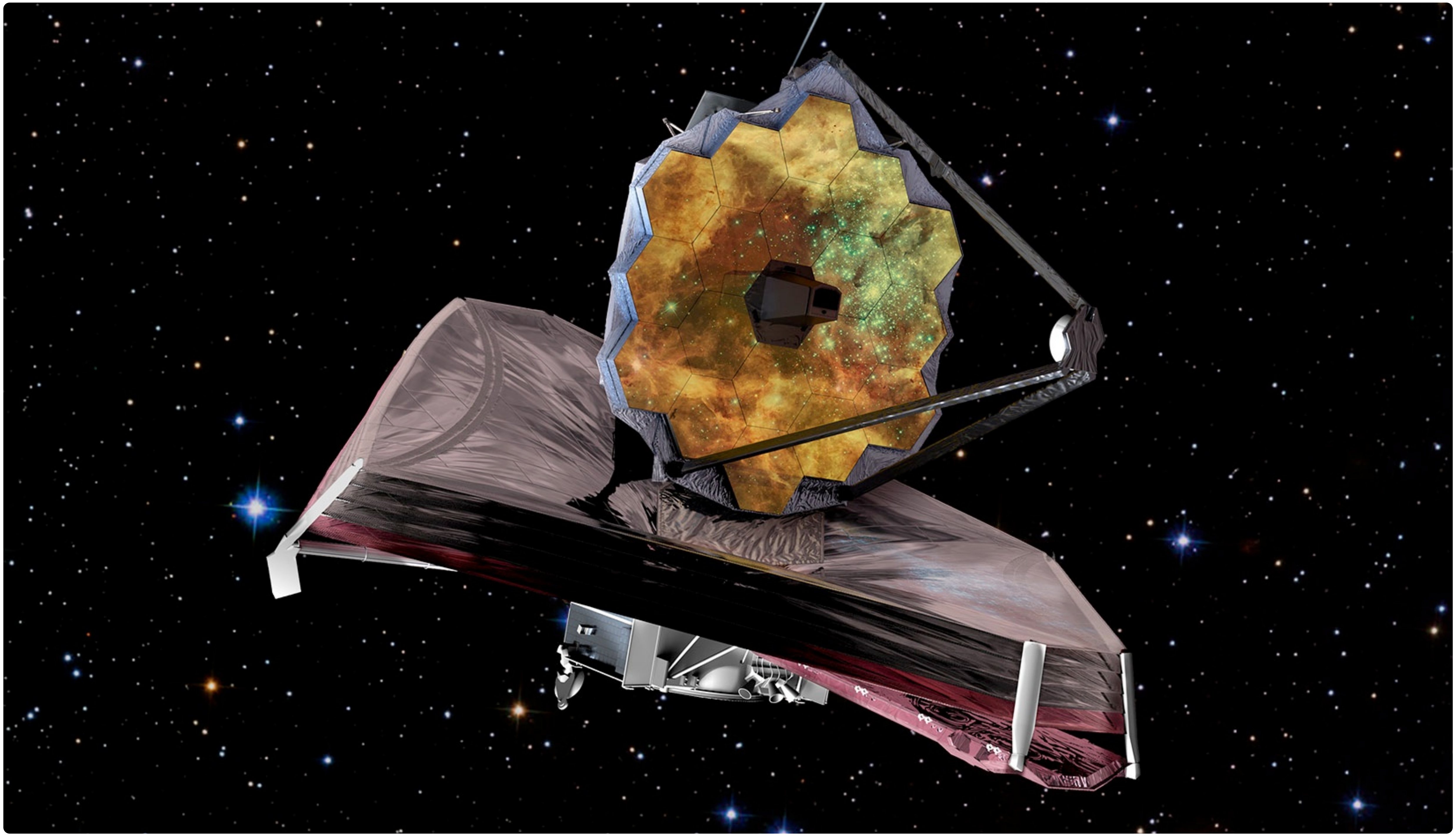


Figure 1.1 Webb Reflects the Cosmos (artist's impression)

The James Webb Space Telescope will be a cosmic time machine...

- Observing the first galaxies ...
- Tracking the evolution of galaxies ...
- Revealing the birth of stars and planets ...
- Characterizing other worlds with the potential for life.

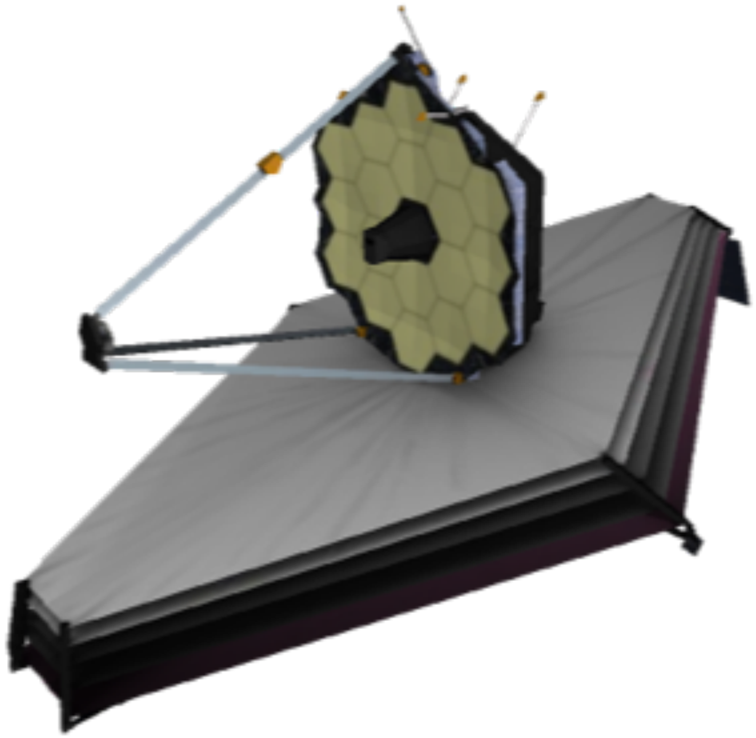
A Vision for the Future

Uncovering the Secrets of Our Cosmic Beginnings

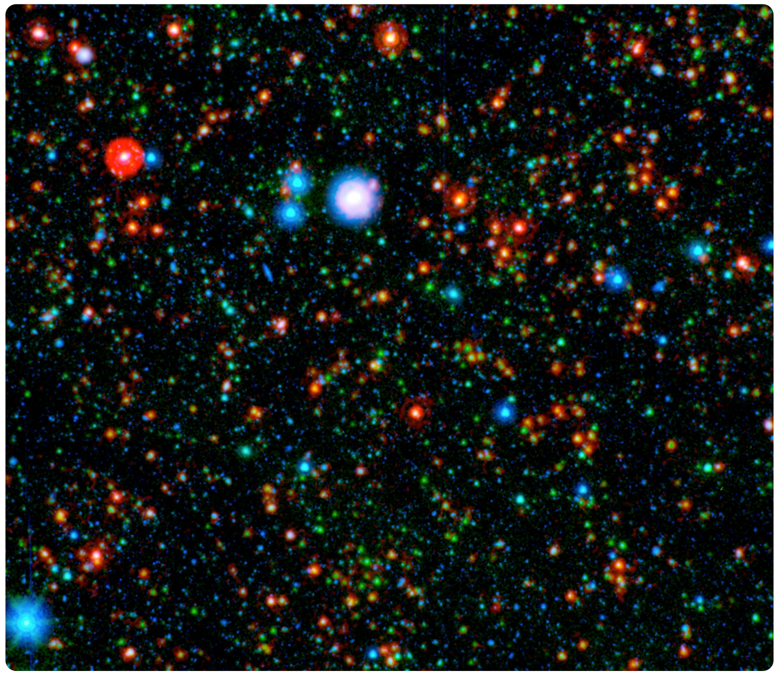
The Hubble Space Telescope's trailblazing discoveries clearly show us that we need to explore even more deeply into the universe. This is the promise of Hubble's successor, the James Webb Space Telescope. New mysteries await Webb's penetrating vision into the infrared universe, as well as answers to questions as old as human imagination: How did stars, galaxies and planets come into existence? Are we alone in the universe?

The Webb Space Telescope promises to carry us along on an even grander journey of exploration and discovery than was first begun by Hubble over two decades ago. If Hubble's history is any example, Webb's most important discoveries will provide insights into as yet unimagined celestial phenomena.

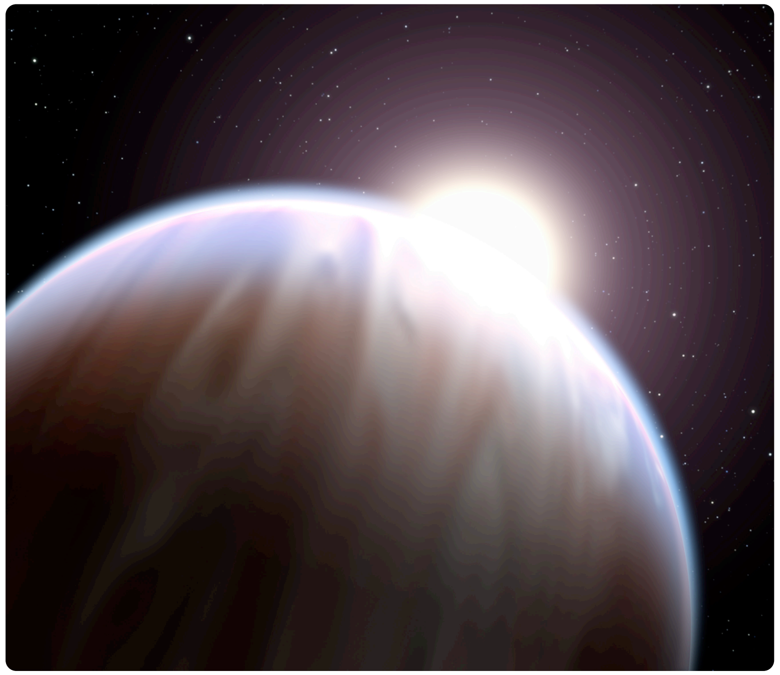
Interactive 1.1 **3D Model of JWST**



An "island universe" in the Coma Cluster



Ancient galaxy cluster still producing stars



Artist's view of an extrasolar planet

Cosmic Dawn

The evidence is compelling that the universe began 13.7 billion years ago as an expanding cauldron of phenomenal energies and exotic particles at the boundary of known physics. But how did the myriad stars and galaxies arise from this raw fury? Webb will at last show us what happened. It will see the very earliest galaxies, and perhaps even the first exploding stars.

Seeking New Worlds

Our pinwheel Milky Way Galaxy sparkles with the radiance of more than 100 billion stars. Our Sun and its planets have been residents of this galaxy for 4.5 billion years. But even our own planet and Sun have yet to give up the secrets of their origins. By looking deep into stellar nurseries elsewhere in the galaxy, we will at last understand the genesis of planets like Earth.

Seeking Living Planets

We live in cosmic isolation on a small world – the only bastion of life we know. With each new planetary discovery, however, chances of life among the stars grow ever stronger, though signs of it still elude us. Webb will have the resolution and sensitivity to scrutinize planets around nearby stars for the spectral fingerprint of water vapor. Webb might even measure the chemical by-products of life: an abundance of oxygen, carbon dioxide and methane in a world's atmosphere.

The Need for Infrared Vision

In 1994, just four years after the launch of the Hubble Space Telescope, astronomers began imagining what the next great space observatory would be. Though remarkable strides were being made by Hubble in unlocking the mysteries of the universe, a compelling science case for a new kind of telescope was emerging, one that would operate far from Earth, larger than any launched into space, and optimized to see in the infrared.

In astronomy, the infrared portion of the electromagnetic spectrum is prized for its wealth of scientific data. And, as the Hubble Space Telescope revolutionized optical astronomy, a next-generation observatory would do the same for the infrared, which holds the key to the very ancient, very distant universe.

As starlight travels billions of light-years across space it succumbs to the effects of the expansion of the universe. Over the course of their cosmic journey, as space itself expands, light waves become stretched, or shifted, to longer and redder wavelengths of energy. Eventually, visible light from the most distant stars becomes stretched to the point that it is now only detected in the infrared. So the earliest stars and the first galaxies fade from view, in part from extreme cosmic distances and in part because space itself continues its break-neck expansion begun by the Big Bang.

To extend their vision farther into space, astronomers will need the power to detect fainter objects and the capability to look farther down the spectrum into the shadowy realm of infrared light.

Interactive 1.2 Visible vs. Infrared: A Stellar Jet in Carina

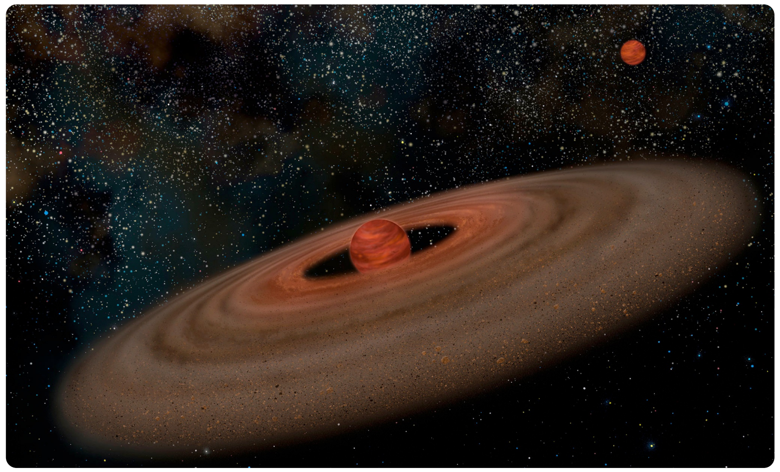
Hubble images demonstrate how observations taken in visible and in infrared light reveal dramatically different and complementary views of an object.

Interactive 1.3 Whirlpool Galaxy Seen in Different Wavelengths

At shorter wavelengths (visible light), the Whirlpool Galaxy's light comes mainly from stars. At longer wavelengths (infrared light), this starlight fades and we see the glow of interstellar dust.

With its longer wavelengths, infrared radiation passes much more readily through dense molecular clouds, which are impenetrable to visible light. These light-year–spanning collections of dust and gas are stellar nurseries, where new stars burst into life and planets coalesce from dusty debris rings.

Figure 1.2 Binary Brown Dwarf Stars (artist's concept)



The primary brown dwarf in this illustration is surrounded by a disk of material. Brown dwarfs are too small and cool to shine like stars but too massive and hot to be classified as planets.

Infrared light is also prized because it can reveal the otherwise invisible, cold, dark universe. Many enticing objects in space give off little or no visible light. Among these are failed stars known as brown dwarfs, forming stars and young planets, and the icy bodies in the outer suburbs of our solar system. These objects and many others shine brightly in the infrared, awaiting the Webb telescope to expand our vision and open up vast new portions of the cosmos to study.

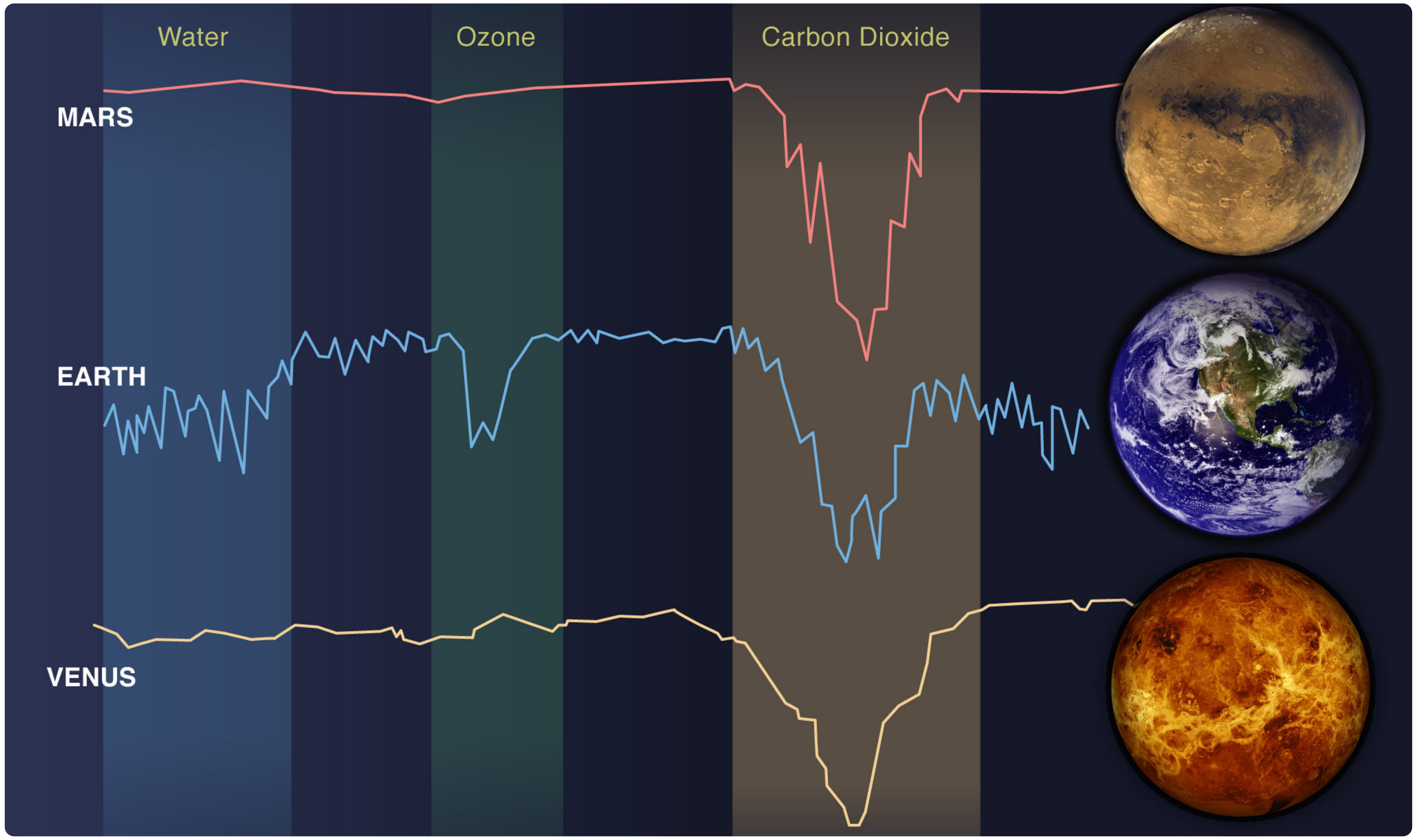
Webb will study the universe in two ways: by capturing images in infrared light, and through spectroscopy.

Spectroscopy is the breaking of light into its component colors for study and analysis. Just as a prism can be used to separate light into colors, a spectrograph spreads light into its various wavelengths, allowing them to be examined for details about the elements the object contains, its velocity, and its redshift.

The science case for infrared astronomy is clear and compelling, as strongly endorsed by the National Research Council in two successive decadal astronomy studies.

In 2001, the highest priority for large, space-based missions was the James Webb Space Telescope. In August 2010, the National Research Council again set their science priorities, and it was clear that the Webb telescope would be essential to pursue these compelling research areas. The three major science themes in the report were cosmic dawn, new worlds and the physics of the universe. The Webb telescope will play a leading scientific role in the first two priorities, while providing essential support for the third theme. In its most recent report, the 2010 Decadal Survey for Astronomy, the National Academy of Sciences (NAS) emphasizes the Webb telescope's pivotal role in the future of astronomy, both independently and in collaboration with other next-generation ground- and space-based observatories.

Figure 1.3 Spectroscopic Analysis of Three Planets



Spectroscopy can help us identify the composition of planets' atmospheres. By studying the dips and peaks in spectrographic lines, scientists can differentiate between planets whose atmospheres resemble those of Mars, Earth and Venus.

Unveiling the Cool, Dark Cosmos

The 18th-century British astronomer Sir Frederick William Herschel was the first to discover that there were types of light that cannot be seen. His experiments revealed energies beyond the red portion of the visible spectrum called infrared light, which human bodies are equipped to perceive as heat. When we warm our hands over a fire, for instance, we are experiencing infrared radiation.

Scientists didn't begin unlocking the secrets of the infrared universe, however, until a century later. In the 1960s, research into this new realm began modestly, as infrared detectors were first floated high into Earth's atmosphere by balloon-borne instruments and were later installed on high-flying aircraft. These initial experiments yielded indistinct but tantalizing images, revealing for the first time an entire universe previously hidden from view.

To advance our understanding, however, infrared astronomy would also need to undergo a series of evolutionary advances. So the quest began to find more ideal observing platforms and to spur new innovations in infrared detectors.

Mountaintop observatories addressed the principal need for a better and more stable window on the universe.

1800
Sir Frederick William Herschel (1738–1822) discovers infrared rays in the spectrum.

Early 1920s
Seth Nicholson (far right) and Edison Pettit (second from left) measure infrared wavelengths and temperatures on the Moon, planets, sunspots, and stars.

1967
Project Hi Star surveys the cosmos at wavelengths of 4, 10, and 20 microns. Cooled infrared telescopes on rockets can observe the sky for several minutes.

1974
The Kuiper Airborne Observatory (KAO) begins research operations.

1983
The Infrared Astronomical Satellite (IRAS) is launched.

1995
The European Space Agency launches the Infrared Space Observatory (ISO).

Astronomers prized these locales for their high and dry conditions, which are essential for near- and mid-infrared astronomy. But even the thin mountain air poses challenges that limited the potential for infrared astronomy. The atmosphere itself, even in the coldest of conditions, emits an infrared glow that blocks part of the infrared light. If astronomers were to have a pristine view of the universe in the infrared, they would have to travel beyond the confines of Earth's atmosphere.

This new high-flying approach began when the first space-based infrared telescope was launched into orbit in the 1980s. NASA's pioneering Infrared Astronomical Satellite (IRAS) mapped the entire sky and found it ablaze with infrared sources; this led to the Spitzer Space Telescope, a larger and more sophisticated instrument and one of NASA's Great Observatories. Spitzer, along with Hubble, paved the way for envisioning and perfecting the technology for Webb, which combines the best aspects of both Great Observatories. Webb has the resolution of Hubble and the infrared wavelength coverage of Spitzer, yet with much higher sensitivity.

1997
Two-Micron All-Sky Survey (2MASS) begins operations.

1997
Near Infrared Camera and Multi-Object Spectrometer (NICMOS) is installed on the Hubble Space Telescope during Servicing Mission 2.

2003
The Spitzer Space Telescope is launched.

2009
Wide Field Camera 3 is installed on the Hubble Space Telescope during Servicing Mission 4.

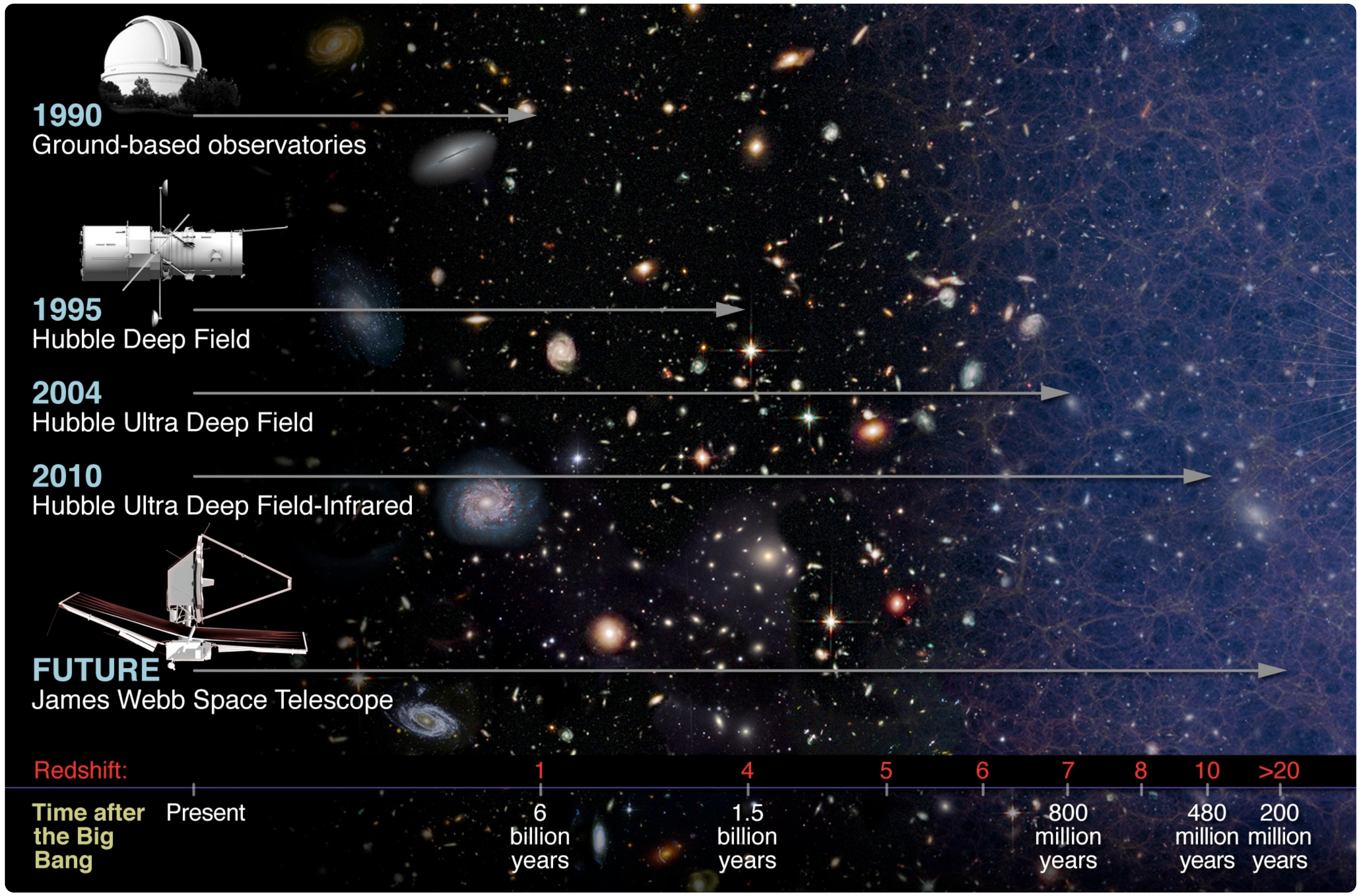
2010
Stratospheric Observatory For Infrared Astronomy (SOFIA) conducts first-light infrared observations of Jupiter.

Future
The James Webb Space Telescope will be launched.

The Giant Space Mirror

Figure 1.4 Inspecting Uncoated Webb Primary Mirror Segments

Figure 1.5 Observatory Comparison: Probing the Early Universe



Webb will have seven times the collecting area of the Hubble Space Telescope and 50 times the area of the Spitzer Space Telescope's mirror.

The next phase of infrared astronomy would do more than simply build on these remarkable pioneering instruments. The Webb telescope would be in every way a superior instrument, utilizing both innovations in optical and mechanical engineering to create the largest mirror ever launched into space. The size of Webb's primary mirror is unprecedented for a space telescope and is essential to bring infrared astronomy to a new level of exploration. For all wavelengths, a larger mirror means greater sensitivity and the ability to see fine detail. For an infrared telescope, this is especially important because of a fundamental property of light: the longer the wavelength, the lower the resolution.

To achieve this size, Webb follows a proven technology path now used on the largest telescopes on Earth – build large by building in segments. Pioneered on the 32.8-foot (10-meter) Keck telescopes in Hawaii, this technology is enabling Webb's mirror to surpass all previous space telescopes in size and power. Comprising 18 hexagonal segments, each 4.27 feet (1.3 meters) across, Webb's mirror segments will achieve the same performance as a single 6.5-meter mirror.

CHAPTER 2

Science Overview

Webb's exploration of the universe begins where the most powerful modern observatories reach their limits.

Science mission goals:

- **Search for the earliest stars and galaxies**
- **Map the evolution of galaxies**
- **Study star and planet formation in the universe today**
- **Search for the potential for life in the universe**

Key Science Questions for Webb

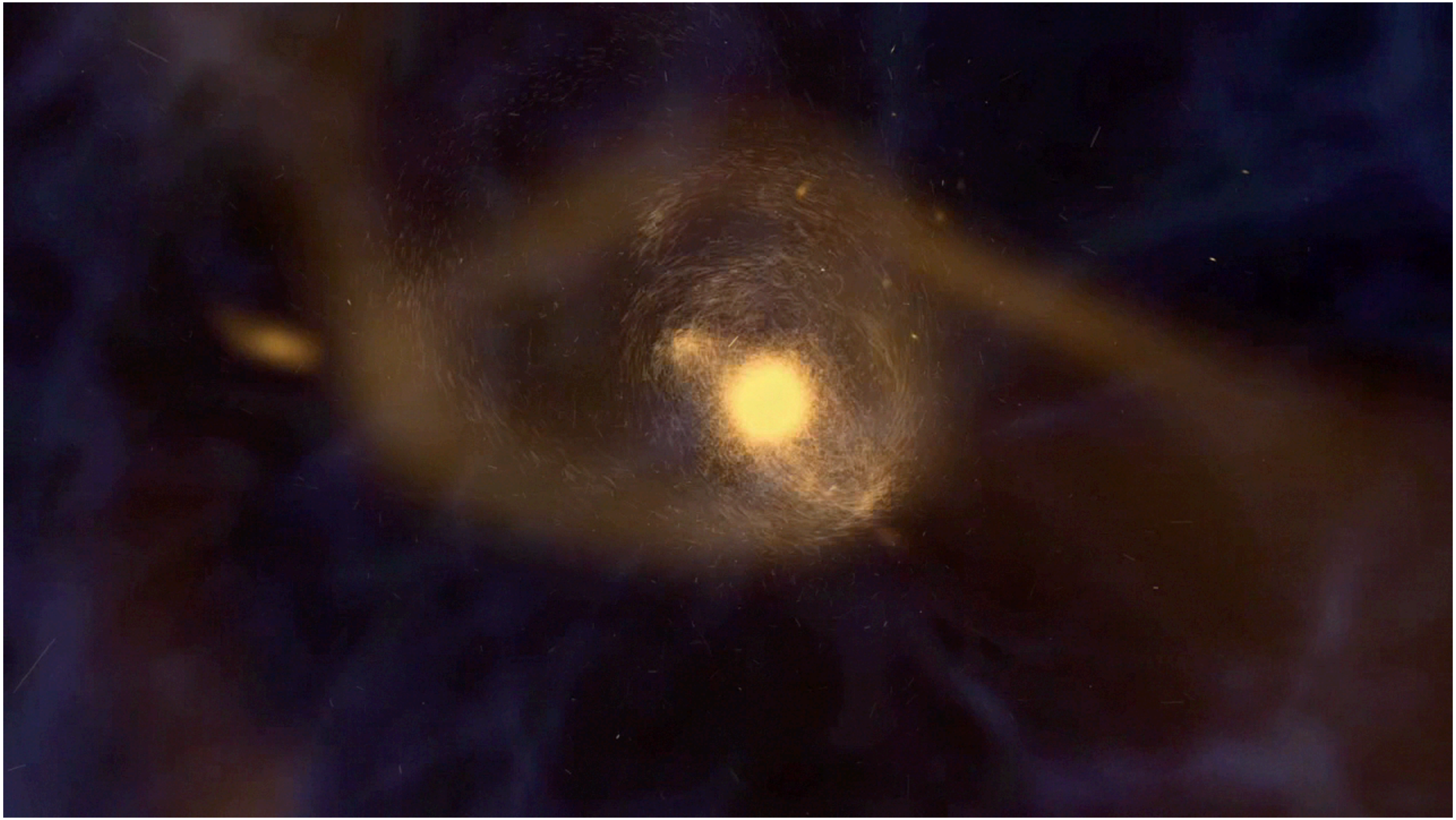
- When do stars begin to truly bond together into objects we call galaxies?
- What was the role of stars and galaxies in reionizing the universe?
- What are the processes that drove galaxy formation?
- What is the relationship between black holes and galaxy formation?
- How did early stars form?
- What was the nature of the first supernovae that exploded in the early universe?

The James Webb Space Telescope will bring us ever closer to the point when the first supermassive stars burst into life. From these ancient cosmic origins, Webb will chart the growth of galaxies from amorphous masses of perhaps millions of stars to the giant spiral shapes, home to the hundreds of billions of stars we see today.

It will reveal the chaotic and turbulent regions in which gravity has bound enough material to ignite fusion, creating new stars, and study the swirling disks around those young stars that give rise to new planets.

It will use its sophisticated instruments to sample the light from planets around distant stars, looking for traces of water and the chemistry of life.

Dark Ages to First Light



Movie 2.1 **Simulation of the Formation of the First Mini-Galaxies in the Universe**

Cosmic dawn, or the epoch of first light, is the transformative period in the history of the universe marked by the appearance of the first stars and galaxies.

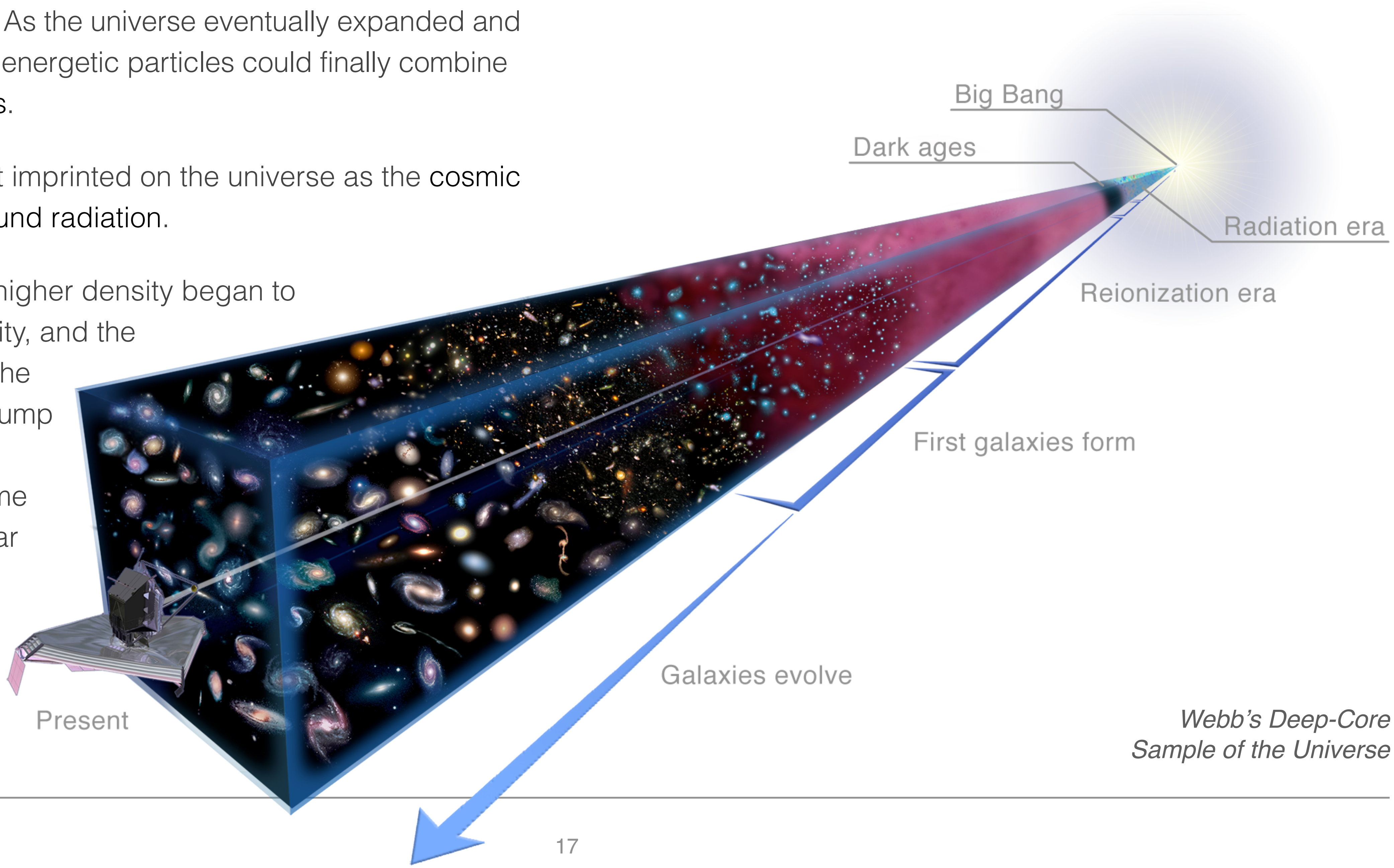
Prior to this, the universe was devoid of discrete sources of light, suffused with an obscuring fog of primordial hydrogen and helium gas cooked up in the first moments of the Big Bang.

For its first 380,000 years, the universe was a seething mass of subatomic particles. As the universe eventually expanded and cooled, these highly energetic particles could finally combine to form neutral atoms.

We see that moment imprinted on the universe as the cosmic microwave background radiation.

Over time, areas of higher density began to collapse under gravity, and the neutral hydrogen in the universe began to clump together. Eventually, these regions became so dense that nuclear furnaces were born.

As these first stars emerged, their light and radiation slammed into the surrounding sea of hydrogen gas, breaking apart the neutral atoms and scattering their individual protons and electrons. At first, these areas were like small bubbles or islands of ionized gas surrounding bright energy sources. The neutral hydrogen in the universe, however, still dominated, preventing light from traveling freely through space.



Webb's Deep-Core Sample of the Universe

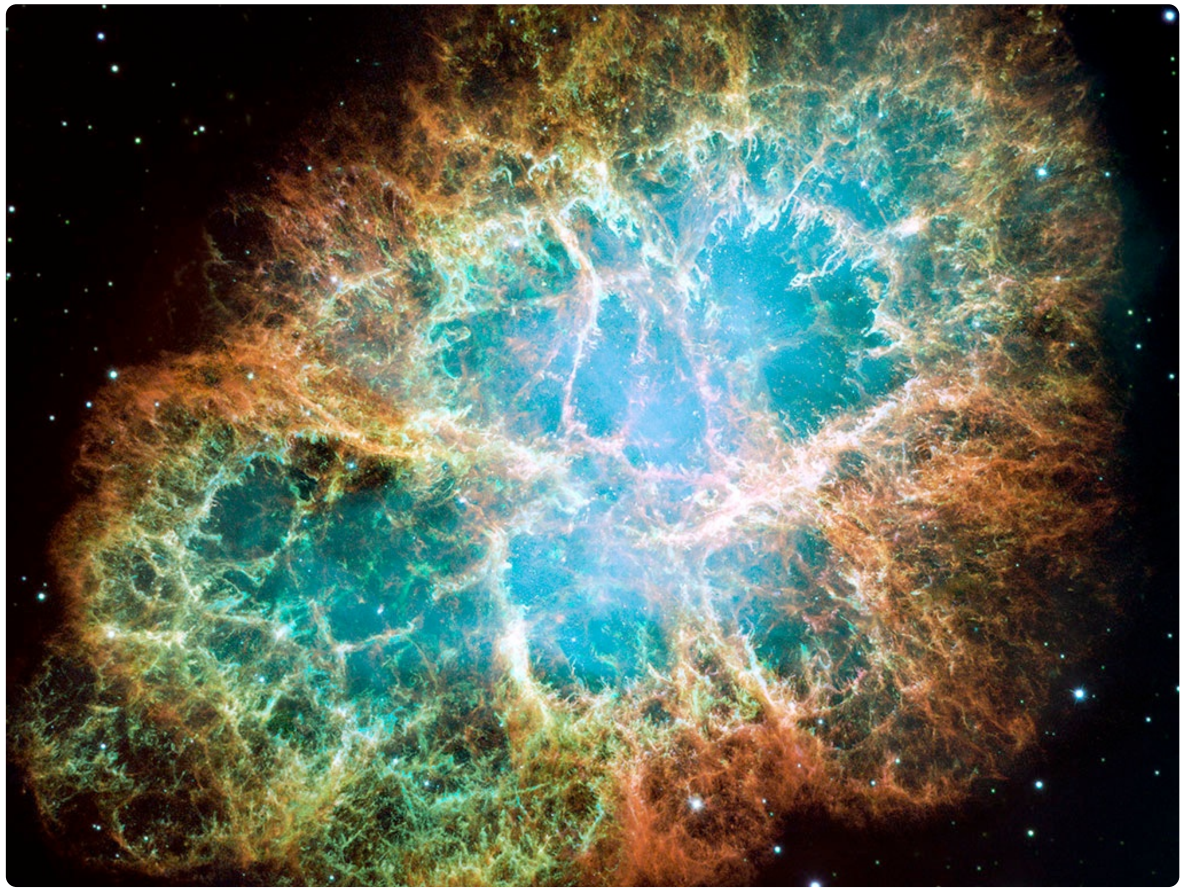
These cosmic bubbles eventually grew, fueled by an as yet unknown balance of hot, massive stars and powerful jets of energy streaming from incredibly dense and voracious black holes. As these primordial beacons punched ever larger holes into the neutral universe, the islands of light eventually began to overlap, enabling ionizing radiation to travel farther and farther. Once the majority of the universe was reionized, within 1 billion years after the Big Bang, light across much of the electromagnetic spectrum could travel unimpeded through the cosmos, eventually revealing the universe as we see it today.

These first stars were unlike the stars we observe in the universe today. They were incredibly large – up to 300 times more massive than our Sun – and many millions of times brighter. They shone for only a few million years before detonating as supernovae.

These supernova explosions significantly altered the chemical makeup of the cosmos. Carbon, oxygen and iron were first forged in stellar cores and then scattered into space. Other heavier elements were shocked into existence by the incredible fury of the supernovae themselves. These new elements were then taken up in the next generation of stars and eventually formed planets, asteroids, comets, and even life.

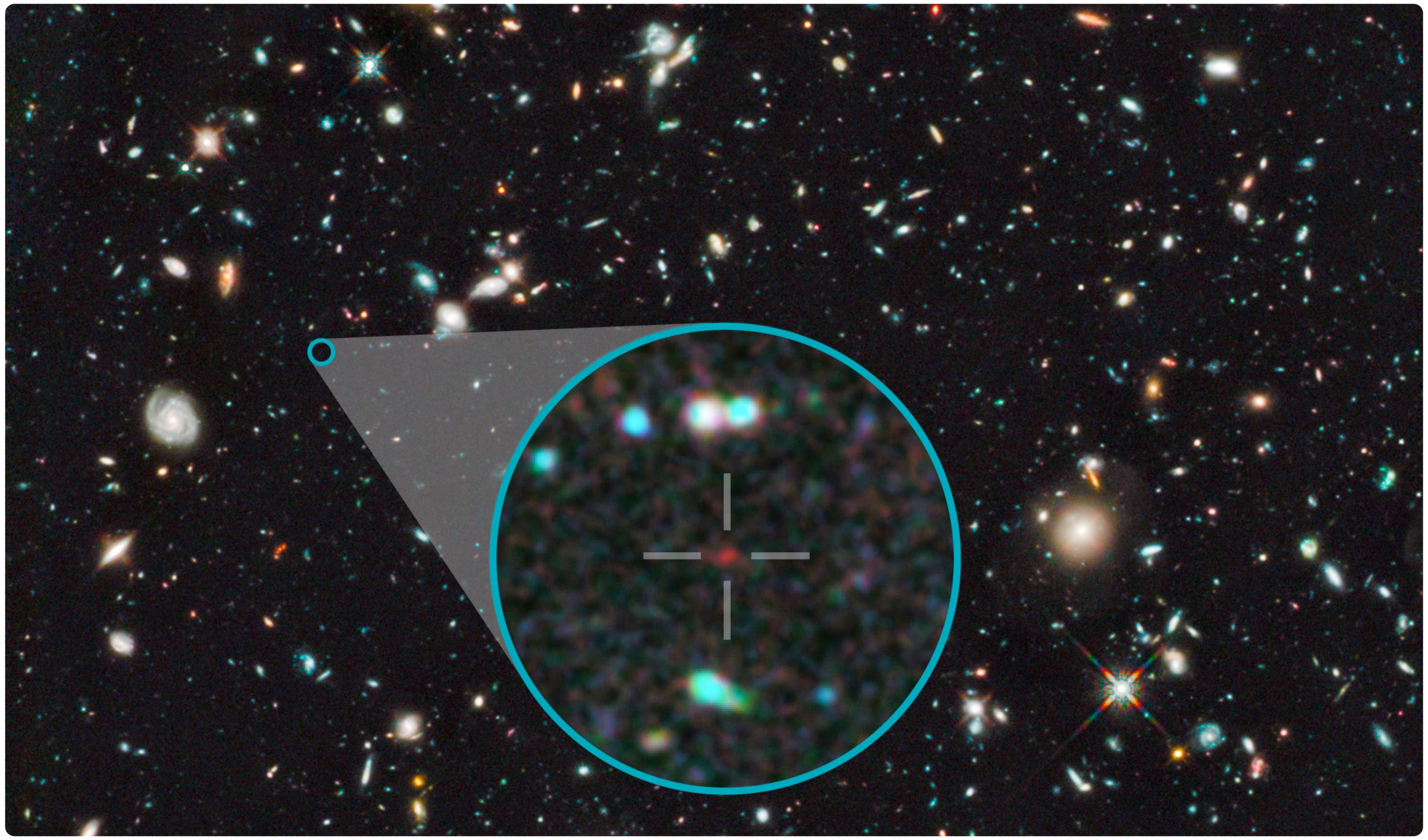
Modern telescopes now struggle to penetrate the cosmic dark ages. The most distant galaxies are seen already in their adolescent stages of development.

Gallery 2.1 Supernova Remnants



The Crab Nebula is a six-light-year-wide expanding supernova remnant, all that remains of a tremendous stellar explosion. Observers in China and Japan recorded the supernova nearly 1,000 years ago, in 1054.

Figure 2.1 The Most Distant Galaxy Candidate Ever Seen in Universe



The farthest and possibly one of the very earliest galaxies ever seen in the universe appears as a faint red blob in this ultra-deep–field infrared exposure taken with the Hubble Space Telescope. Based on its color, astronomers believe the object existed when the universe was only 0.5 billion years old.

To go even further back and find the sought-after first stars and galaxies, the Webb telescope will probe deeper than ever before into the near- and mid-infrared. This is the portion of the spectrum that contains the remnant light from these earliest objects.

After Webb has identified these nascent objects, it will begin to tell us more about what they are like. It will take that faint light and spread it out to look for the spectral signals that hold the clues to the chemical makeup of these objects, revealing how they are both moving and evolving. Recent glimpses using rare cosmic alignments known as gravitational lenses have enabled astronomers to study extremely distant galaxies. Webb will look for clues in the spectral signatures of the most distant galaxies to study the motions of stars and gas, helping astronomers build a complete picture of the infancy of galaxies.

Interactive 2.1 Galaxy Ages in the Hubble Ultra Deep Field

Peel back the layers of time in the HUDF to reveal galaxies at different stages of evolution.

SECTION 2

The Cosmic Web

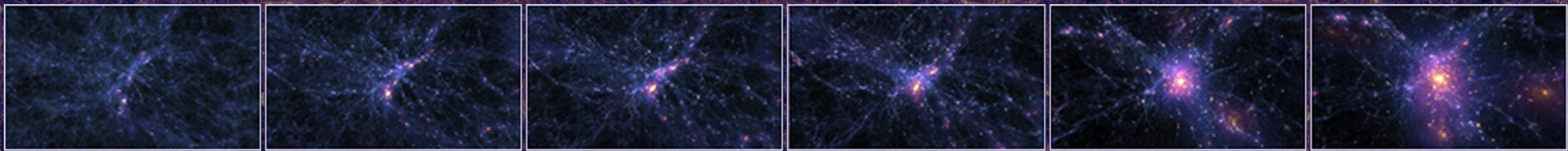
Movie 2.2 Gas and Dust Condenses to Form Galaxies and the “Cosmic Web” (simulation)

The first protogalaxies formed when the universe was just a few hundred million years old.

They formed along great filaments of dark matter that provided the scaffolding for galaxy construction.

Where dark matter filaments intersected, hydrogen collected to form the first compact blue star clusters.

The sequence below illustrates the collection of matter (white) and dark matter (purple) over time into galactic masses to create what is known as the "cosmic web."



SECTION 3

Building Blocks

Movie 2.3 **Simulation of Two Galaxies Undergoing a Two-Billion-Year-Long Collision**

Galaxies are the building blocks of the universe. They trace the distribution of normal matter and enigmatic cold dark matter. They also drive the process of star formation and recycle stellar material into the next generation of stars and planets.

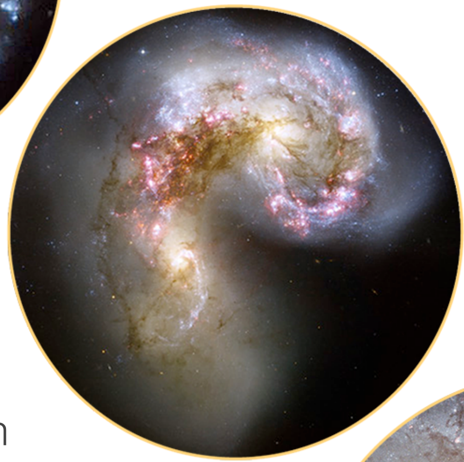
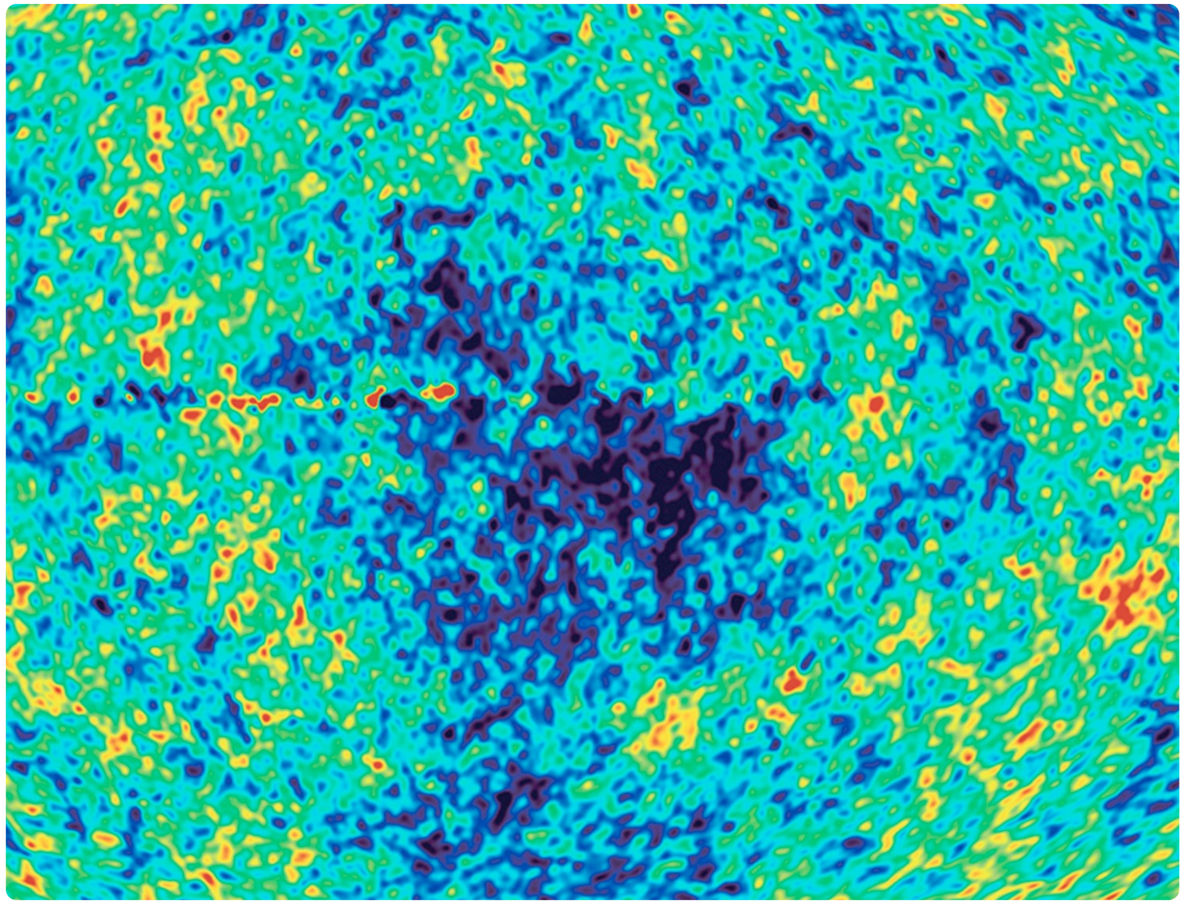


Figure 2.2 Cosmic Microwave Background Radiation



This image reveals 13.7-billion-year-old temperature fluctuations (shown as color differences) that correspond to the seeds of matter that grew to become today's galaxies.

Images of the cosmic microwave background radiation show that there was structure to the universe even before there were stars and galaxies. Though we can see these faint primordial ripples and the large clusters of galaxies today, much in the theories about the transition from one to the other still needs to be refined.

The large scale structure of the cosmic web suggests that primordial gas formed a vast web, built on a scaffold of dark matter. This web of matter should now correspond – on the grandest scales – to the distribution and clumping of galaxies in the universe today. Favored models suggest that clusters of stars, clouds of dust and gas and small galaxies combined over time through a process known as hierarchical merging. This process, in which smaller clumps of dark matter and stars came together over time, formed the

menagerie of galaxies and galaxy clusters that dominate space today.

Astronomers believe that the complex interaction of stars, galaxies and dark matter produced present-day galaxies. The first generation of stars not only seeded later galaxies with elements heavier than hydrogen, the resulting shockwaves from supernovae may have set up a cascading series of starbursts that fueled further galactic evolution.

This process continues today, even close to home. The Magellanic Clouds are being drawn into the Milky Way, and our nearest large galactic neighbor, the Andromeda Galaxy, continues its course for a head-on collision with the Milky Way, some 4 billion years from now.

The process of galactic evolution remains as a grand challenge in astronomy and many questions remain. How and when did the Hubble sequence form? What are the roles of star formation and black holes in galaxy formation? What processes created the divergent shapes of galaxies, from elliptical- to spiral-shaped?

To answer these questions, the Webb telescope will look at groups of stars and other galactic precursors to understand their growth and evolution. The Webb telescope will use both its imaging and spectroscopic capabilities to study early galactic shapes, motion and evolution. The Webb telescope also will enable astronomers to learn about the types of stars in these early galaxies, which would have been strikingly different from the stars we see in the universe today.

Andromeda will collide with our galaxy in about 4 billion years. The two will merge to form a single galaxy in about 6 billion years.

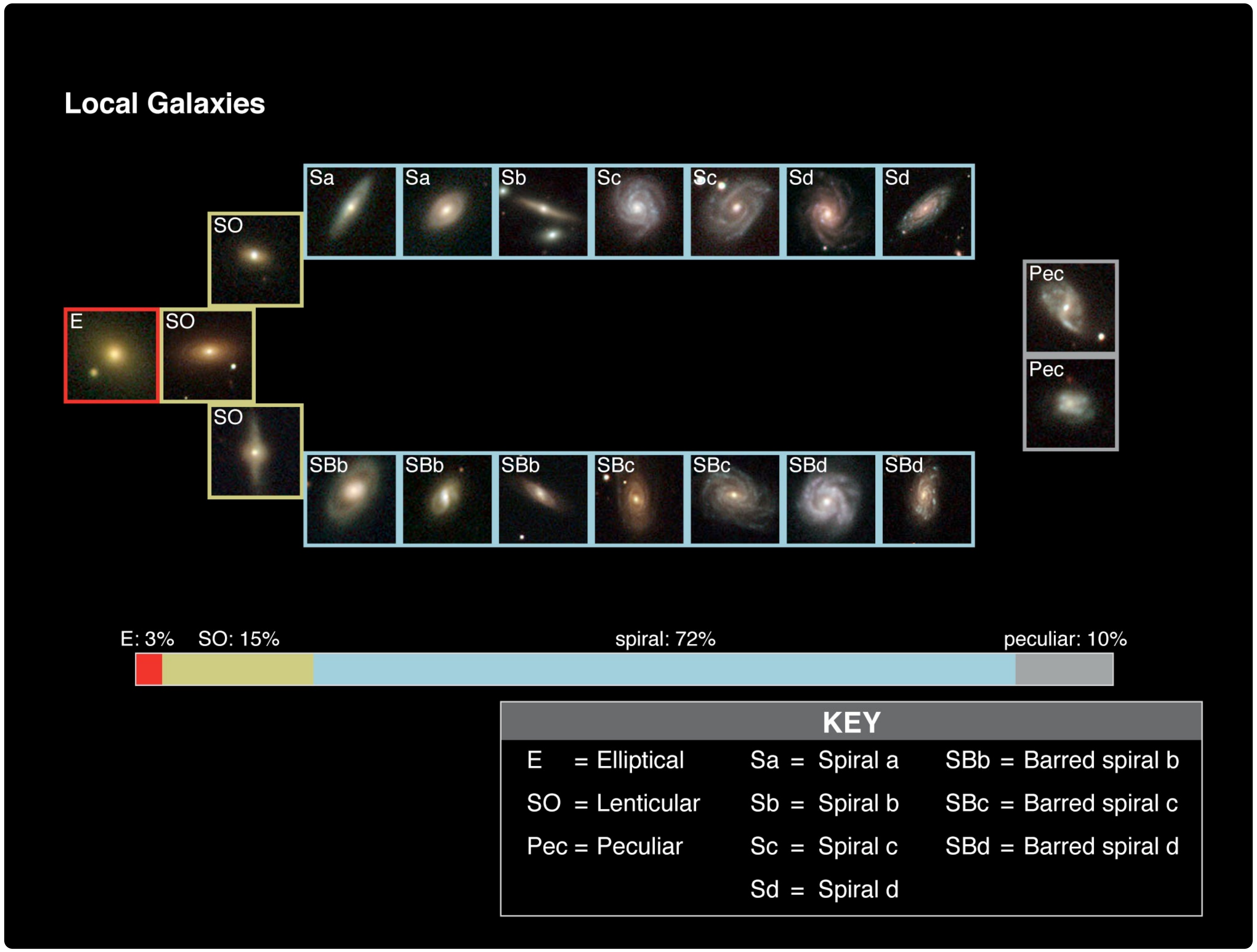
Hubble Sequence

With more powerful modern telescopes able to image galaxies at much greater distances, and further back in time, astronomers have been constructing a new Hubble sequence, or galaxy classification scheme, for populations of galaxies that existed when the universe was much younger, and find it to be remarkably different.

The Hubble sequence diagrams (right) shows how many more peculiar-shaped galaxies (Pec) are seen among distant galaxies (6 billion years ago), as opposed to local galaxies.

Collisions and mergers between galaxies give rise to enormous new galaxies and, although it was commonly believed that galaxy mergers decreased significantly 8 billion years ago, newer results also suggest that mergers were still occurring frequently after that time – up to as recently as 4 billion years ago.

Gallery 2.2 Hubble Sequence: A Guide to Galaxy Types



Three percent of galaxies are elliptical (E), 15 percent lenticular (S0), 72 percent spiral (Sa to Sd or SBb to SBd), and 10 percent peculiar (Pec) among local (younger) galaxies.

New Stars, New Worlds

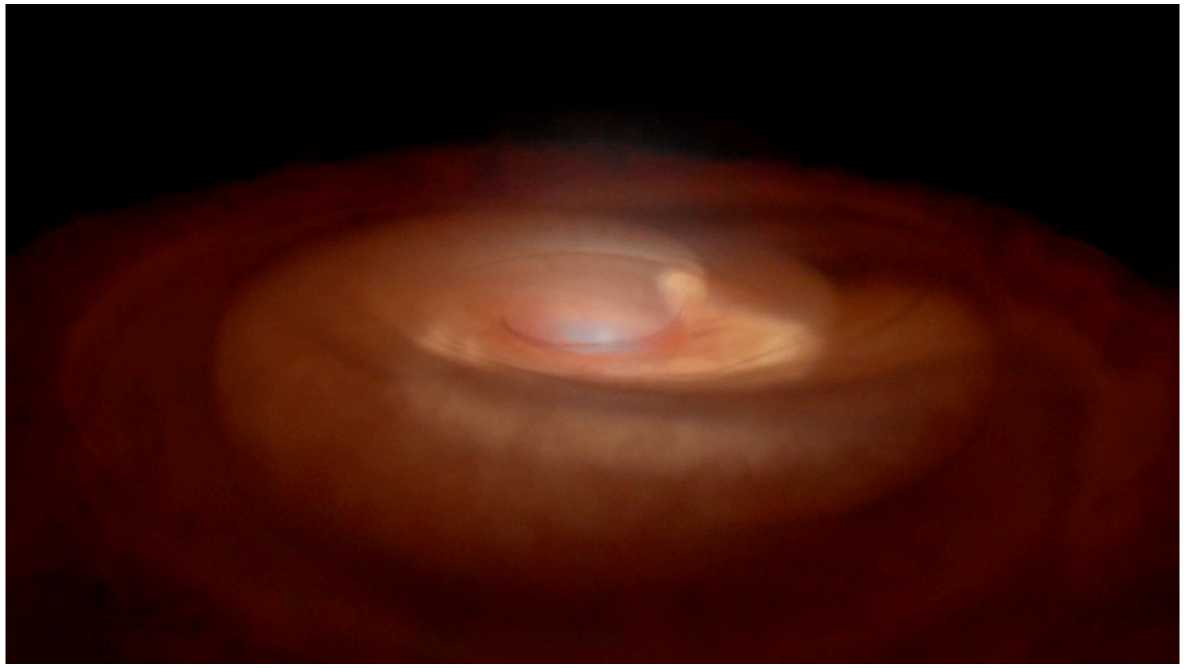
Figure 2.3 **The Orion Nebula, A Star-Forming Nursery**

The Orion Nebula, located approximately 1,350 light-years from Earth, is a massive cloud of dust and gas. Visible with the naked eye as a faint smudge in the constellation Orion the Hunter, this giant molecular cloud hides perhaps hundreds of protoplanetary disks, areas that are in the process of forming stars and planets. The James Webb Space Telescope, with its infrared capabilities, will be able to probe deeply into this and other star-forming regions to study the conditions that lead to new solar systems.

Interactive 2.2 Protoplanetary Disks in the Orion Nebula

Get a closer look at young planetary systems in the making – disks of gas and dust, which will one day give rise to solar new systems.

Movie 2.4 Solar System Formation



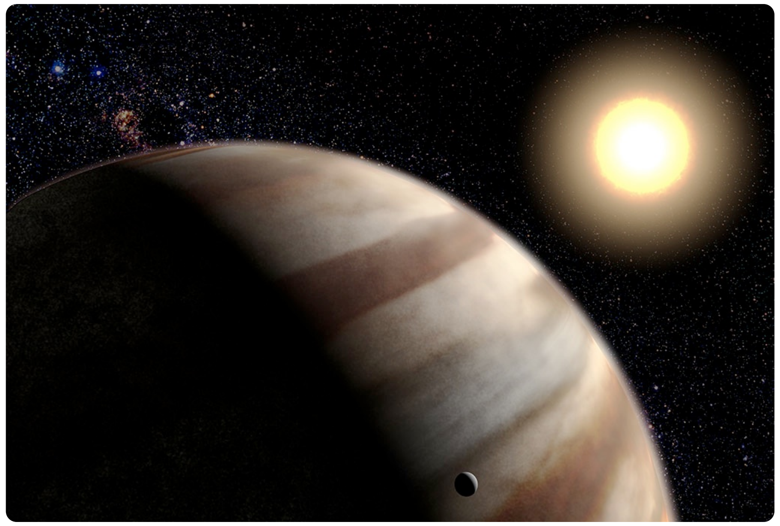
The protoplanetary disk around a young, isolated star evolves over 16,000 years. Bright, dense spiral arms of gas and dust gradually develop and then collapse into denser clumps that could form planets.

Scientists know that stars form in clouds of dust and gas in which pockets of higher density collapse under gravity. Eventually enough matter collects at high enough density and temperature to ignite nuclear fusion and a new star is born. Around this nascent star, additional material spins down to form a swirling disk filled with ice, rocks and left-over gas that escaped the initial formation of the star. As bits of material collide and combine, small planetesimals gradually grow, sweeping up the remaining debris in their orbits to become true planets.

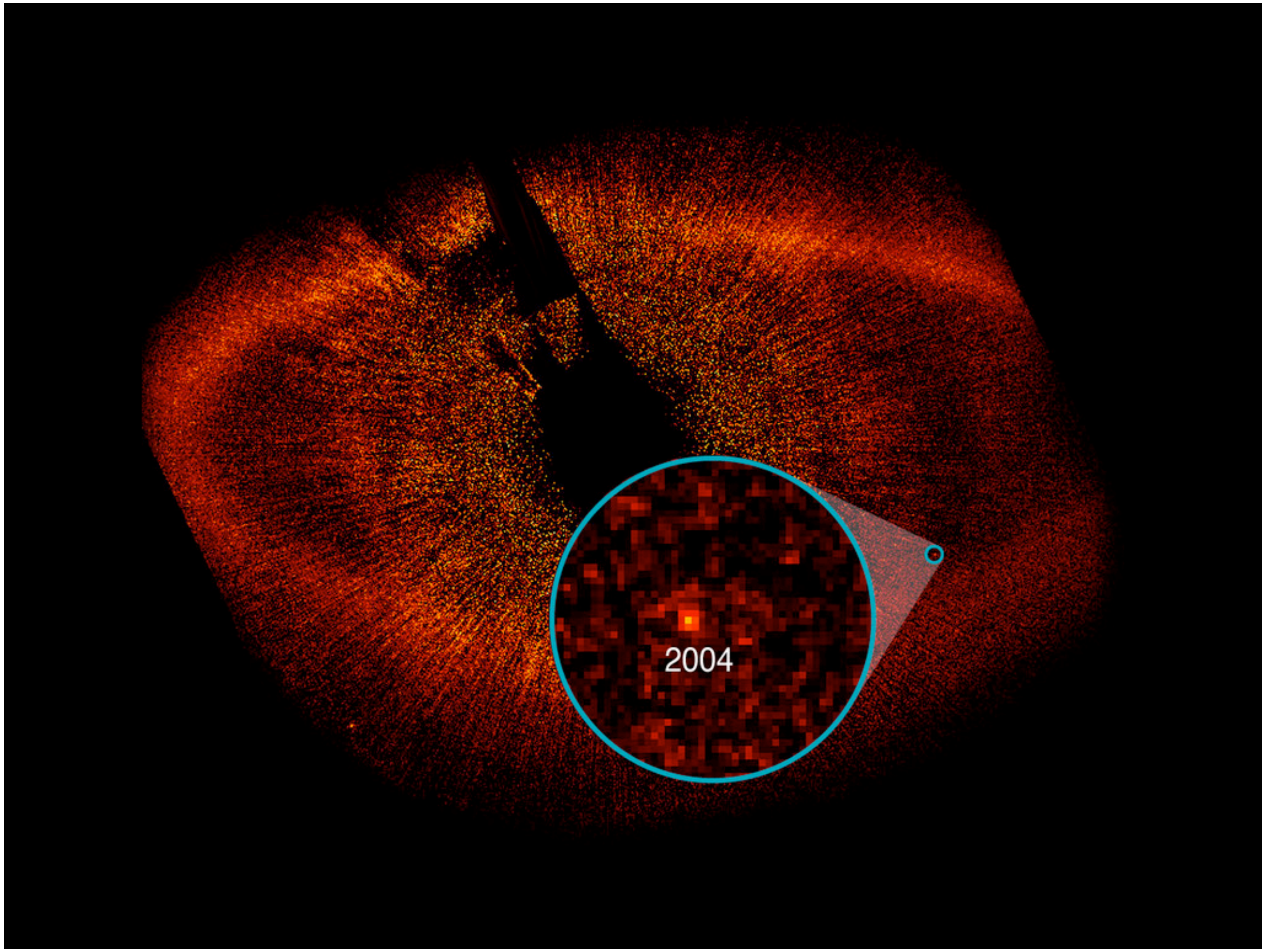
This is the basic model of star and planet formation, but the specifics are still very much a mystery.

One element of this mystery is how planets settle down into their final orbits. We now know that a large fraction of stars have gas-giant planets like Jupiter. Some of the first planets ever discovered were massive Jupiter-like worlds that were in orbits blisteringly close to their host stars. These exotic "hot Jupiters" were at odds with how we believed our own solar system formed. This surprising discovery suggests that planets don't stay put, and some force rearranges planets like balls on a

Figure 2.4 Hot Jupiter (artist's concept)



Interactive 2.3 Hubble Observations of Planet Fomalhaut b



Astronomers blocked light from the star Fomalhaut, in the center of this image, in order to see the much dimmer planet as it passes near the dust ring around the star. Images taken years apart show the planet moving along its expected orbit.

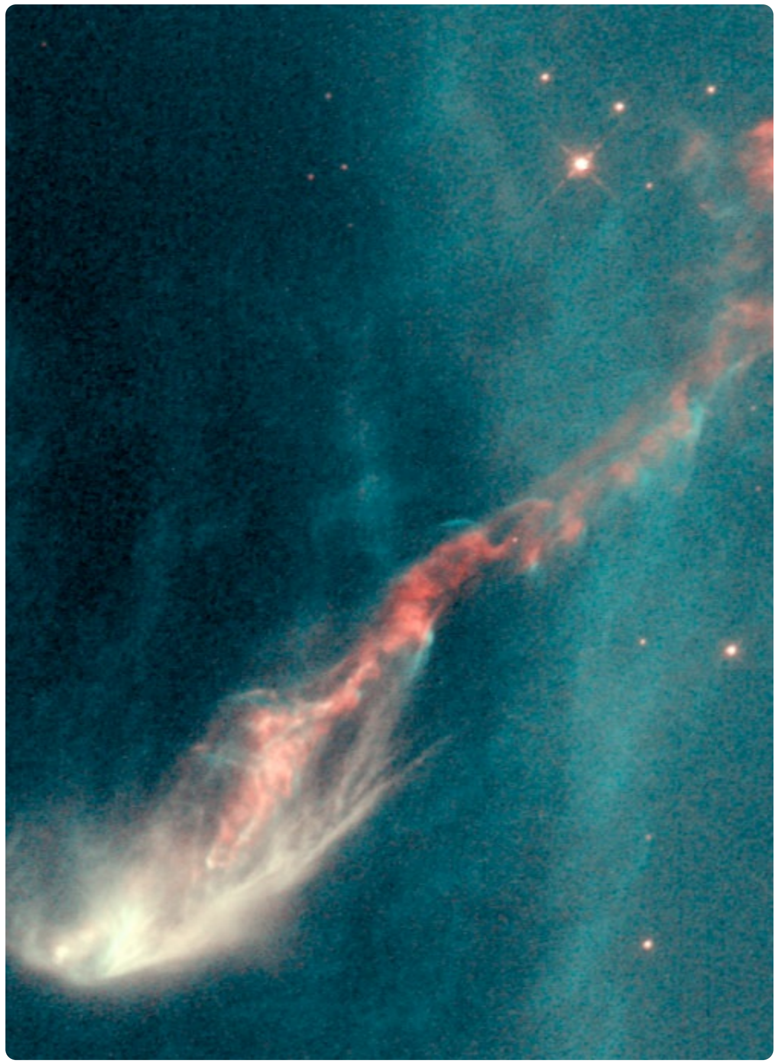
billiard table. Being able to observe solar systems with Webb – as they form and evolve – will help solve the mystery of the roaming planets.

Another mission for Webb to unravel is the complex and dynamic push-and-pull that goes into forming a new star. Throughout the formation of a solar system, there is a constant battle between gravity pulling material together and rising heat and radiation pushing it away. How stars form amid these conflicting forces has been a subject of debate.

A leading theory is that part of the heat generated by gravitational contraction is released by jets of energy ejected from the poles of the newly forming star, enabling it to strike just the right balance, gaining mass and sustaining fusion.

The Webb telescope will be able to observe these young stars and their jets and protoplanetary disks, revealing the distribution and migration of material around a forming star and imaging gaps in the dust and gas in the swirling disk surrounding it. These gaps form from the gravitational effects of growing planets and reveal the inner workings of an infant solar system. Webb's fine-grained spectroscopy will reveal the structure and motion of the disk, uncovering the missing links between a planetary system and the primordial material from which it arose.

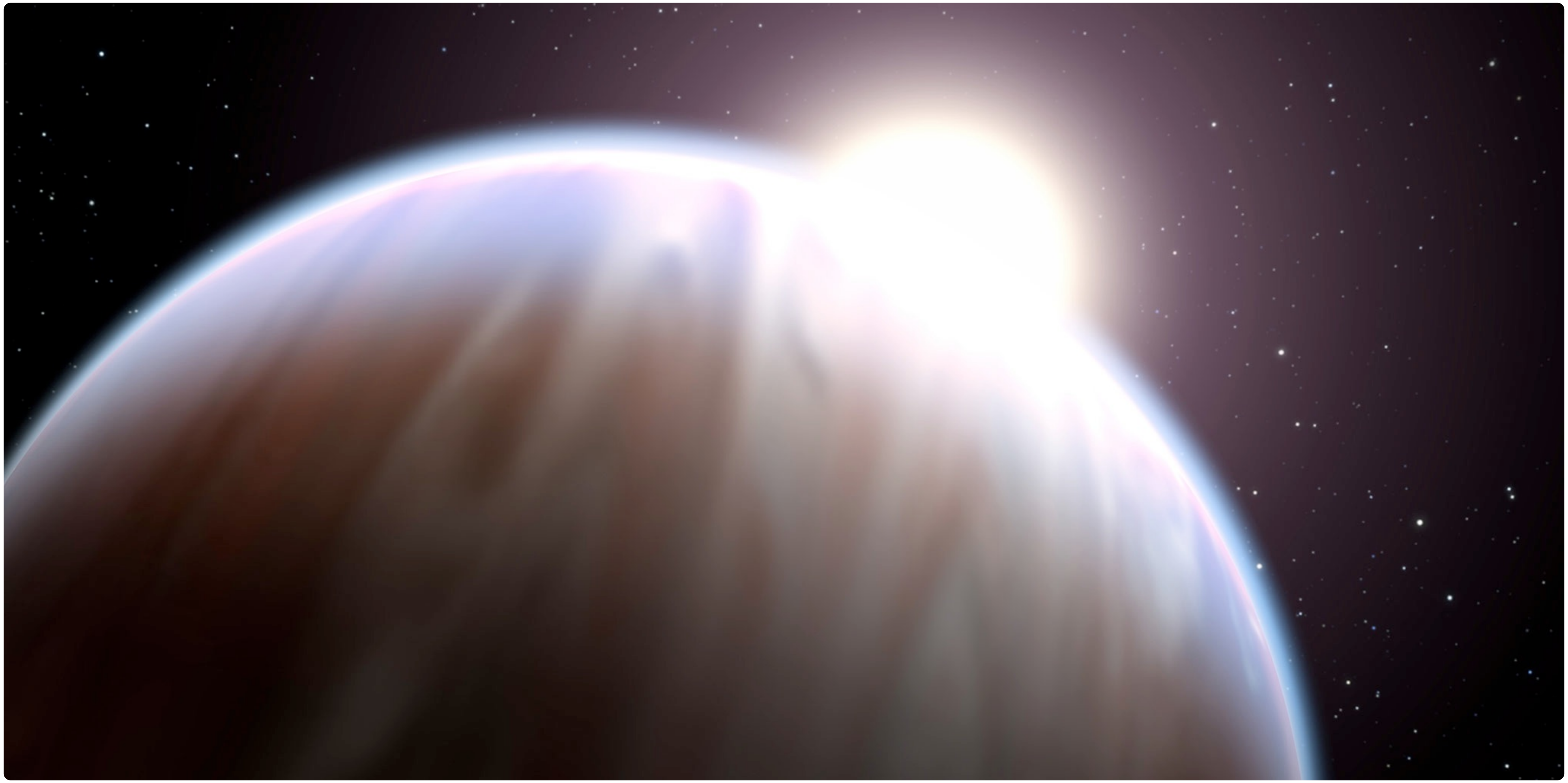
Gallery 2.3 Narrow Jets Erupt During Stellar Formation



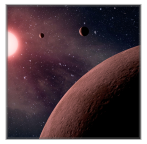
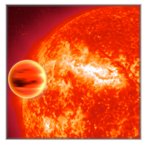
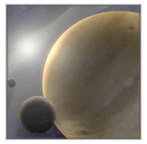
Stellar jet Herbig-Haro (HH) 47 shoots off at supersonic speeds in opposite directions through space.

SECTION 5

Living Planets



Methane and water vapor were detected in the atmosphere of extrasolar planet HD 189733b (artist’s concept).

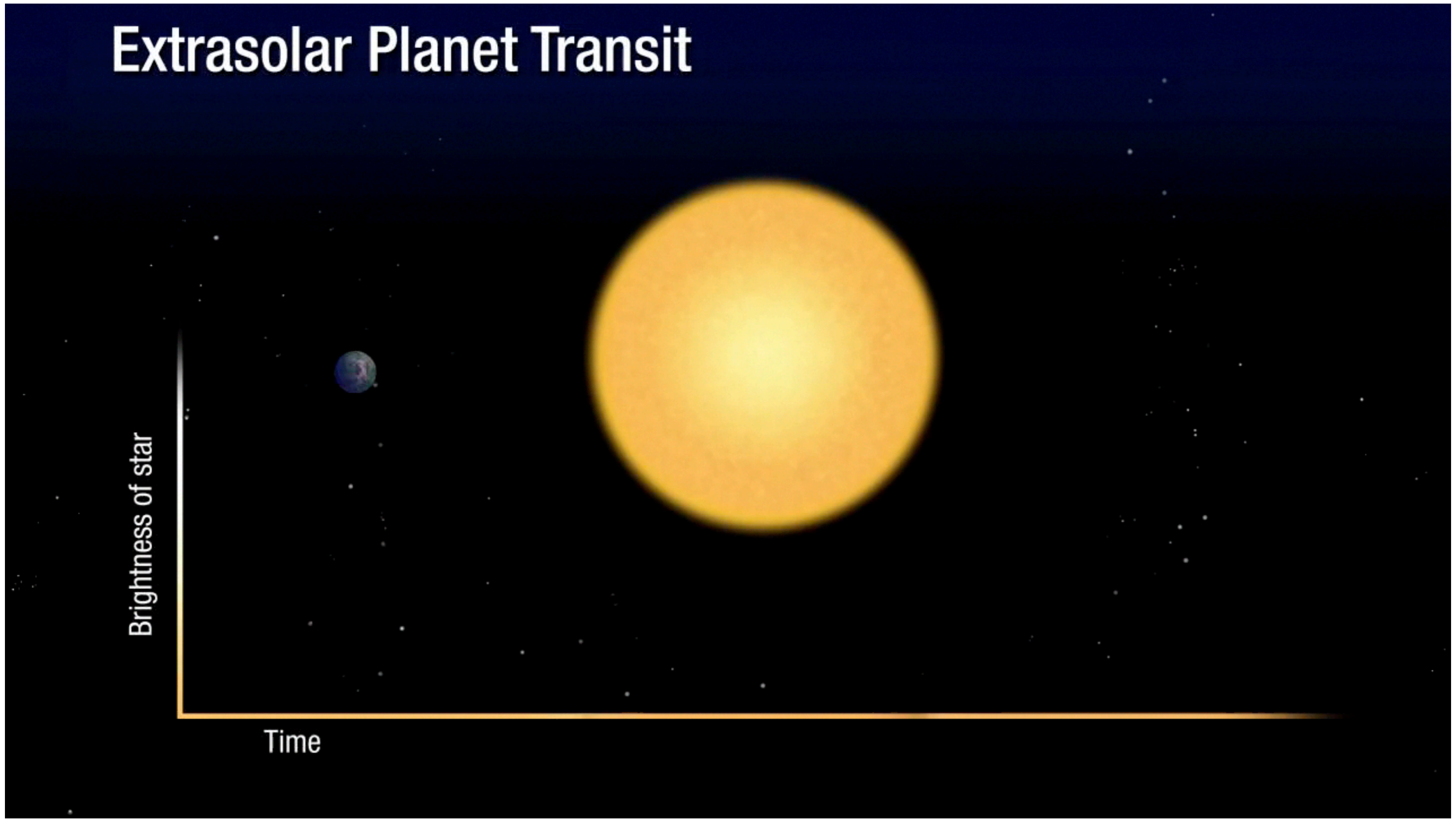
   

A decade ago, scientists assumed that planetary systems filled the Milky Way, but only a handful of potential planetary systems had been identified. Recently, more than 500 planets have been detected around stars other than the Sun. These exoplanets are found in a variety of environments. Some are hotter than Jupiter with orbits smaller than Mercury's. Others are Neptune-like worlds orbiting far from their host star. Though harder to detect, data now support the discovery of large, rocky planets, often referred to as super-Earths.

The science of detecting exoplanets has advanced considerably during the past decade. The first planets ever detected were found by studying the faint motion of stars. Gravity from orbiting planets, particularly massive planets with very small orbits, tugs on the star, imparting a faint, but perceptible wobble to the star. This is detectable on Earth by a subtle shift in the star's wavelength. This wobble technique provided the first conclusive evidence that other stars contain planets.

Another technique studies the amount of light emitted by a star. As a planet passes in front of, or transits, its star, there is a slight drop in the amount of light detected on Earth. This technique is extremely useful in determining the size and length of the planet's orbit. It also reveals the relative size of the planet.

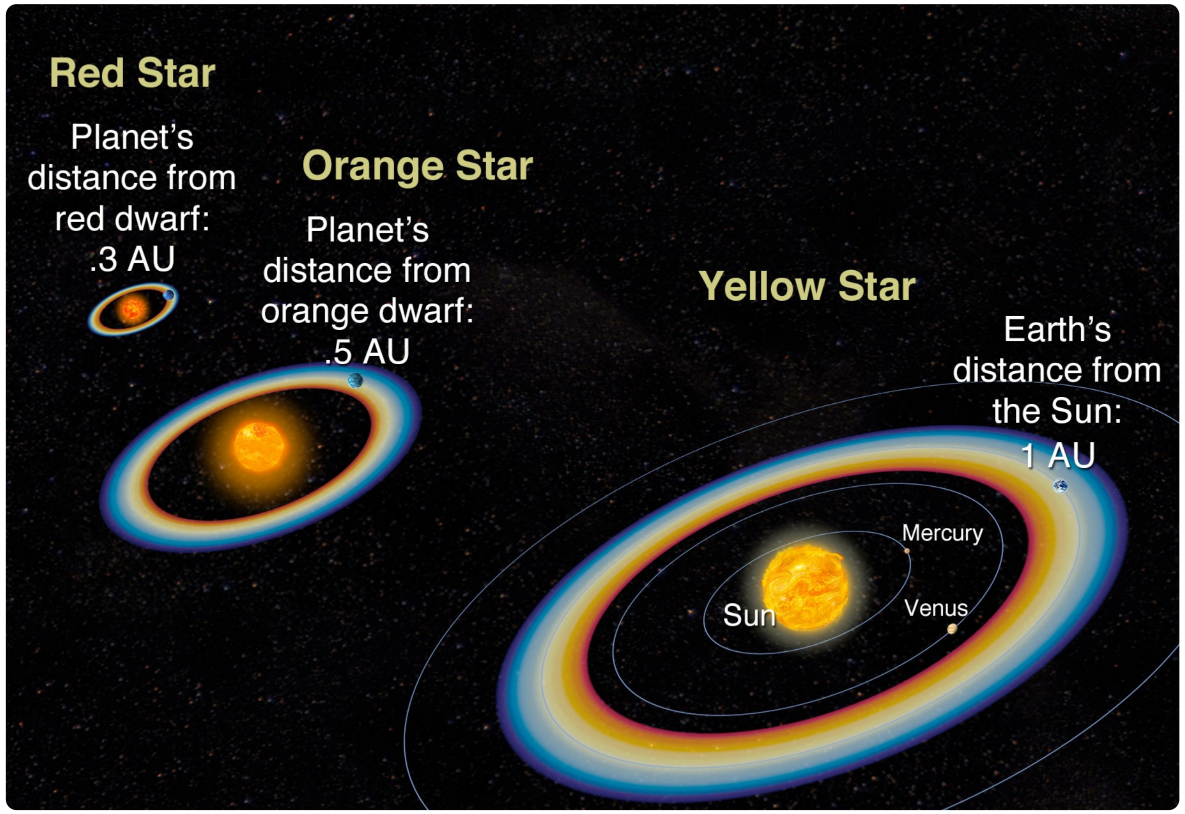
Movie 2.5 Animation of an Extrasolar Planet Transit



Planets that pass in front of their parent stars from our viewpoint will cause the star to dim slightly as they block some of the light. Astronomers monitor stars for these telltale changes in brightness.

This technique also can reveal the chemical make-up of a planet's atmosphere. By carefully observing the planet as its edge transits in front of the star, it's possible to tease out the light passing through the planet's atmosphere. By subtracting the signal known to come from the star, the spectroscopic fingerprint of the planet's atmosphere can be found. Both the Hubble and Spitzer space telescopes have managed this feat with hot Jupiters. The James Webb Space Telescope should be able to study the smaller, rocky super-Earths.

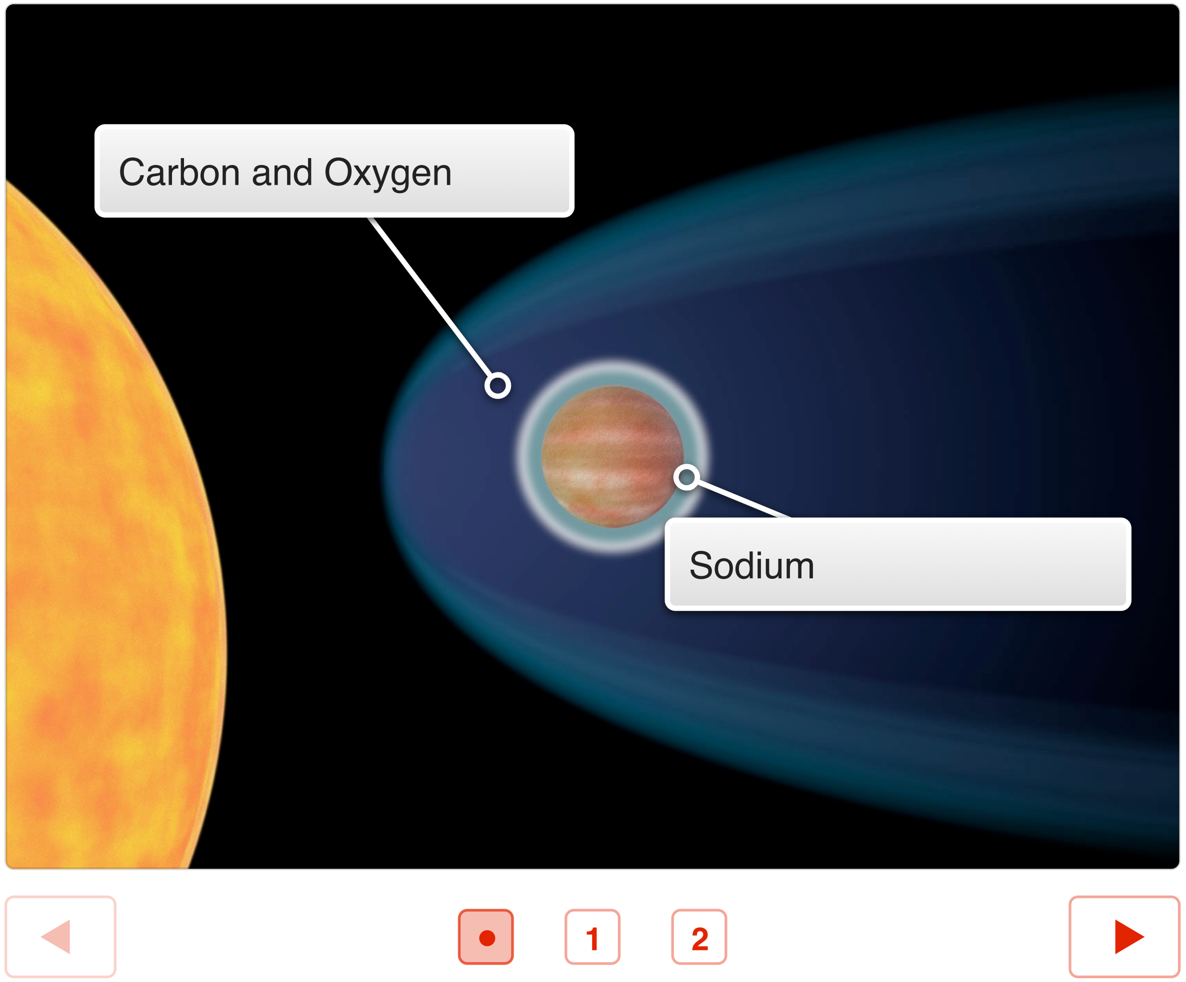
Figure 2.5 Habitable Zone Models by Stellar Type



Depending on stellar mass and luminosity, planets on which liquid water could exist on the surface will be at different distances from their parent star.

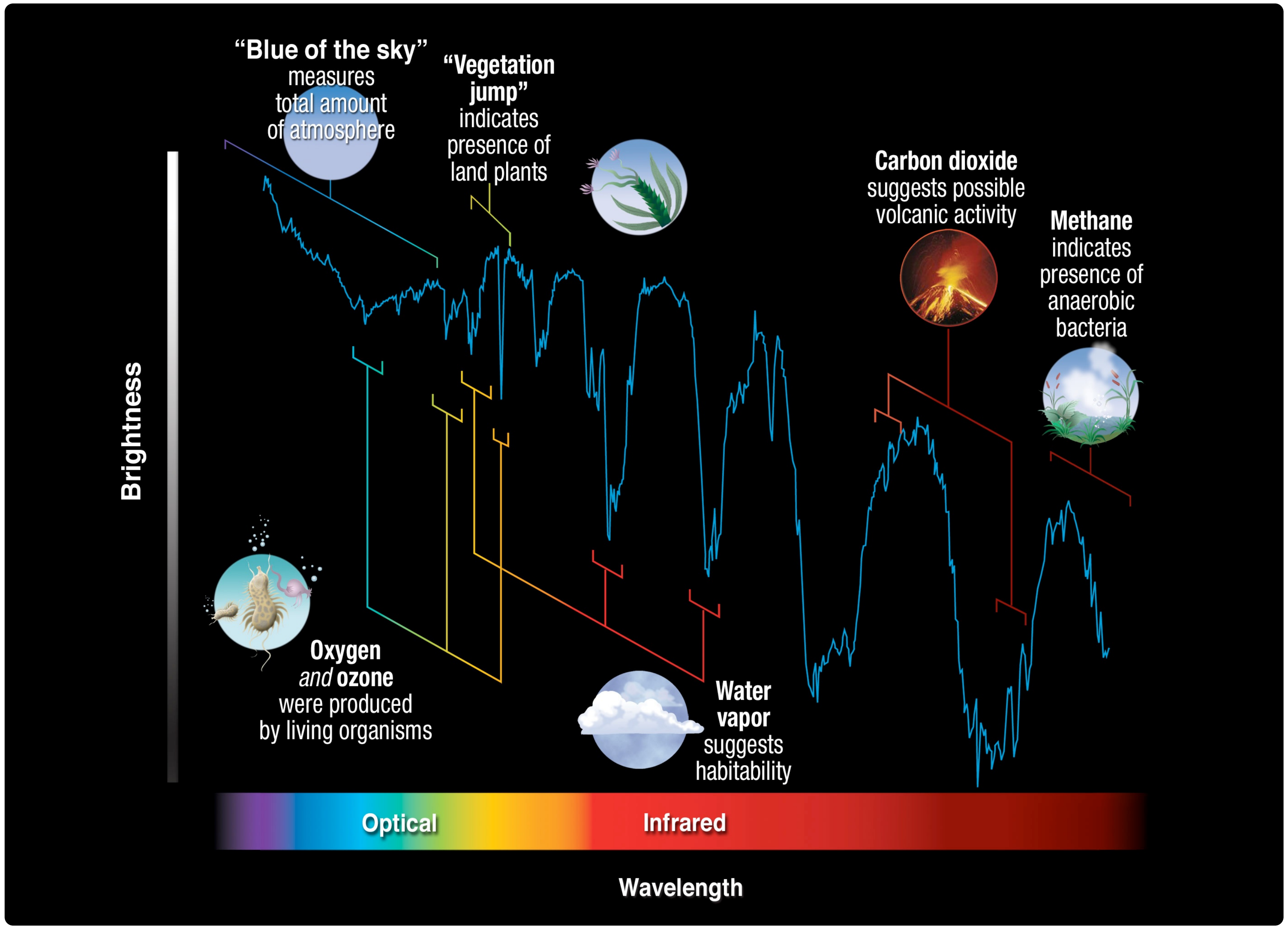
Interactive 2.4 Hubble Measures the Atmospheric Structure of an Extrasolar Planet

Light passing through the atmosphere around a planet is scattered and acquires a signature from the atmosphere.



Webb's infrared vision should be able to distinguish the heat signature of a planet from its host star. This could reveal the presence of carbon dioxide deep in the planet's atmosphere. Webb's spectroscopic instruments should also be able to detect carbon dioxide during a transit. More intriguing, it should also be able to detect the signature for water.

Figure 2.6 **Earth's Spectrum**



Numerous spacecraft have looked back to the Earth and measured sunlight reflected off our planet. The resulting spectrum shows peaks and valleys at different visible and infrared wavelengths, which are caused by the absorption of light by the chemical composition of the atmosphere. Life on Earth depends on the presence of water, so if we are looking for an Earth-like planet, one of the signatures we would hope to find would be water vapor. In addition, plants and photosynthetic bacteria release oxygen, and anaerobic bacteria releases methane.

One important mission for Webb will be to characterize planets around nearby stars that may reside in the "habitable zone," where water oceans might exist.

Regardless of the chemistry of a planet, one important mission for Webb will be to detect planets around nearby stars that may reside in the all-important "habitable zone." All stars, from the relatively common red dwarfs to their behemoth brothers known as red giants, have an area surrounding them where the temperature is just right to enable liquid water to exist on the surface. Not too hot that it evaporates nor too cold that it becomes encased in a shell of ice.

Since liquid water was a prerequisite for life on Earth, it is assumed that it would offer the best hope for finding life on another world. An extended survey with Webb should be able to study a super-Earth around a nearby red-dwarf star, revealing more about an exoplanet than we have ever learned about any exoplanet. The hope is that Webb will be able to identify an atmosphere that could support life.

CHAPTER 3

The Space Telescope

The James Webb Space Telescope is the largest and most complex observatory ever sent into space.

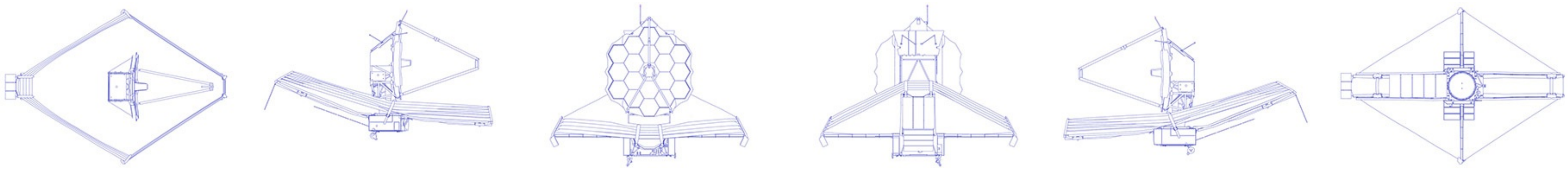
Primary Telescope Stats

- Mission duration: 5 years required; 10 years goal
- Total payload mass: 13,640 pounds (6500 kilograms)
- Diameter of primary mirror: 21.3 feet (6.5 meters)
- Collecting area of mirror: 269 square feet (25 square meters)
- Mass of primary mirror: 1551 pounds (705 kilograms)
- Number of primary mirror segments: 18
- Optical resolution: Approximately 0.1 arcseconds
- Wavelength coverage: 0.6–28 microns
- Size of sunshield: 69.5 by 46.5 feet (21.2 by 14.2 meters)
- Sunshield material: Five layers of silicon-coated Kapton
- Orbit: 930,000 miles (1.5 million kilometers) from Earth
- Operating temperature: Below –370° Fahrenheit (50 Kelvin)

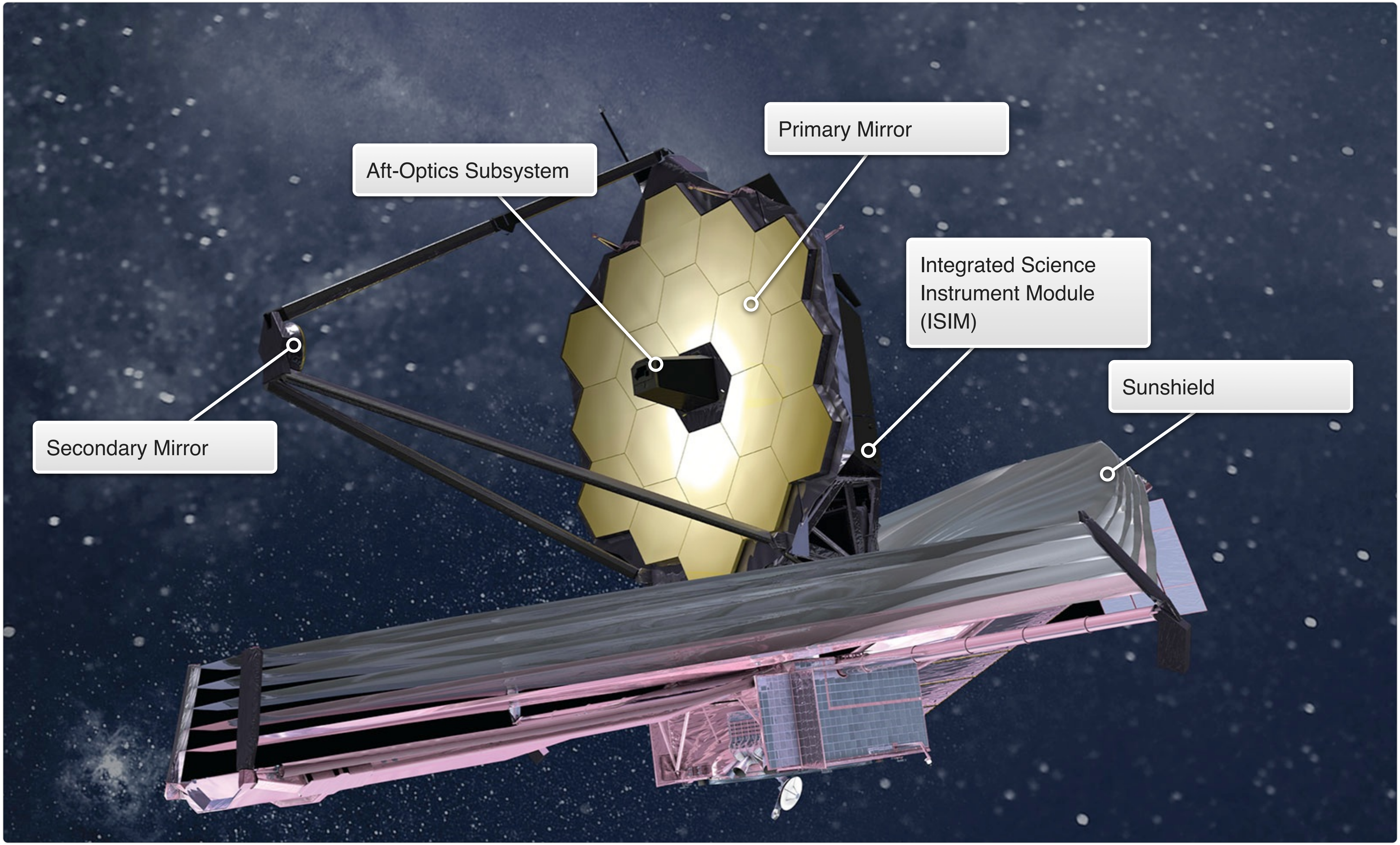
Through the Looking Glass

With a mirror towering more than two stories high, Webb will be the largest observatory ever sent into space. For all its size and mass (tipping the scales at six tons), the Webb telescope must fit in the limited cargo space of an Ariane 5 rocket, the workhorse of launch vehicles provided by the European Space Agency, a partner in Webb's development. To fit into its cozy travel compartment, the telescope will transform in an astronomical equivalent of origami until it is compact enough to nestle inside the rocket's shroud – its solar panel and mirror tower retracted, its primary mirror, sunshield, secondary mirror, communications antennae and momentum flap folded neatly for deployment en route to its ultimate destination.

The Webb telescope will function as a single observatory, but it is actually made up of three distinct elements: the Integrated Science Instrument Model (ISIM), which houses the telescope's powerful instruments; the Optical Telescope Element, which collects and focuses the faint infrared light from deep space; and the Spacecraft Element. The Spacecraft Element contains the sunshield and the Spacecraft Bus, which holds major subsystems like communications, electrical power, command and data handling, propulsion, thermal control and attitude control.



Interactive 3.1 **Webb Telescope's Design: Cold Side**



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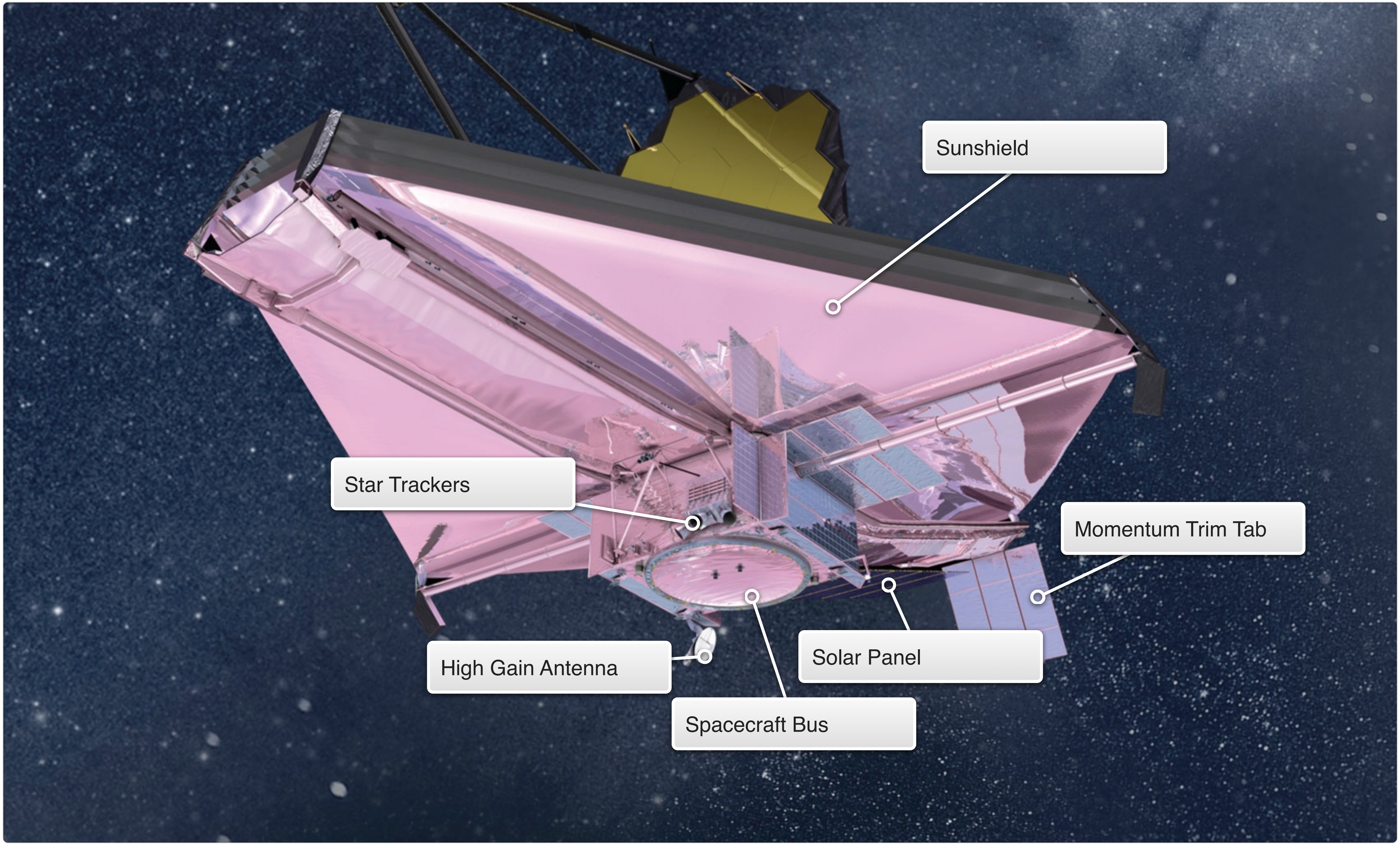
Interactive 3.2 **Webb Telescope's Design: Hot Side**



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SECTION 1

Sunshield and Cryogenics

Figure 3.1 A Full-scale JWST Sunshield Membrane

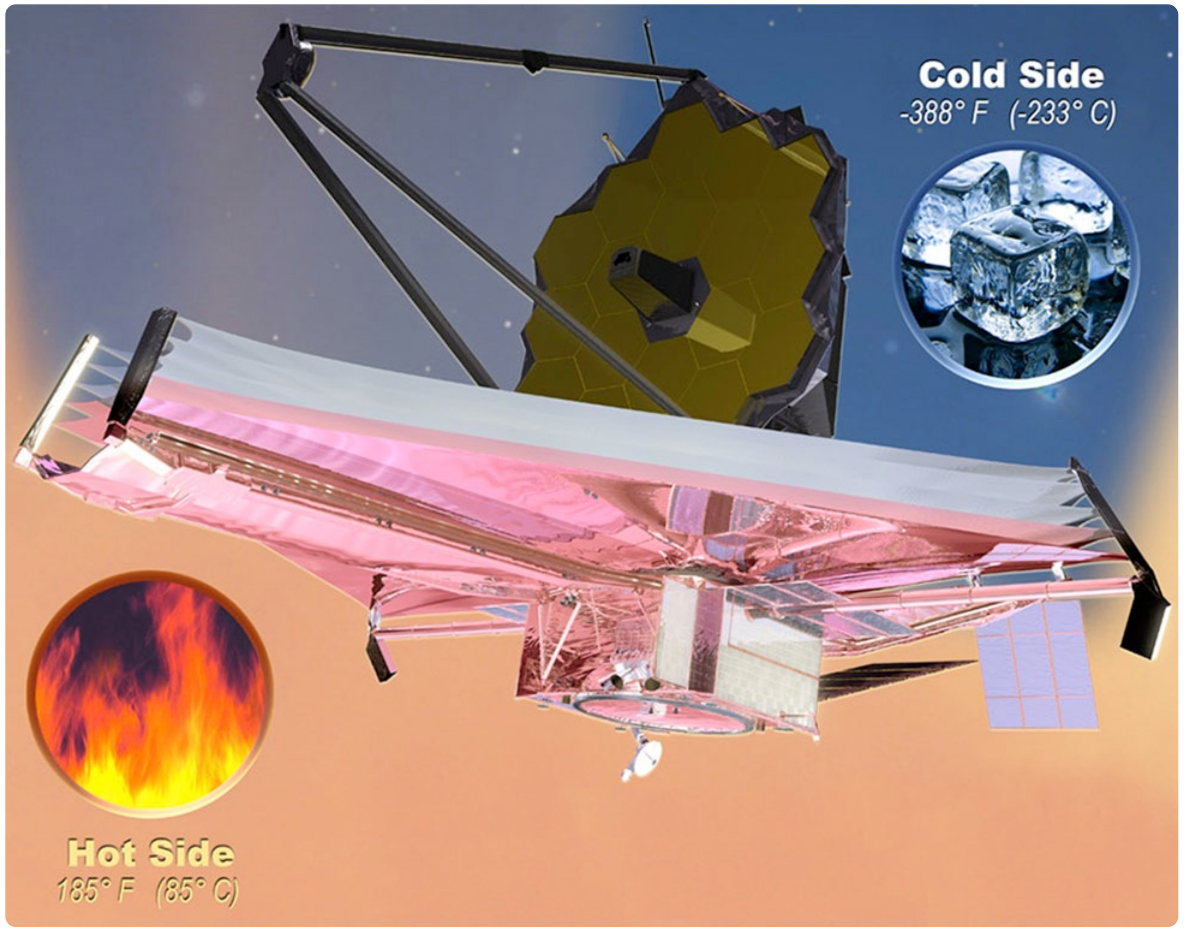
Chilling Out

Heat is the eternal enemy of infrared-detecting technology. It's easy to drown faint infrared signals from the distant universe in the infrared radiation emitted by a telescope's own equipment. For an infrared telescope to function effectively, it has to be kept extremely cold – in Webb's case, almost unbelievably cold.

Webb was designed to be as cold as possible without relying on extensive cryogenics like its infrared forerunner, the Spitzer Space Telescope. Webb's visually striking sunshield, which appears like the prow of a ship behind the telescope mirror, will provide this cold environment.

The multilayer sunshield forms a protective barrier from the most significant heat sources in space. For Webb, those heat sources are the Sun, Earth, Moon and the telescope itself. All objects, even a telescope located deep in space, emit infrared light, and any of these sources could easily swamp Webb's highly sensitive infrared cameras. Webb's sunshield divides the telescope into two sides – a hot side that contains the systems that keep Webb running and can reach temperatures near boiling (185 degrees Fahrenheit, or 85 Celsius), and a cold side where the instruments and mirrors reside that reaches a brutal -388 degrees Fahrenheit, or -233 Celsius).

Figure 3.2 Webb's Division of Labor

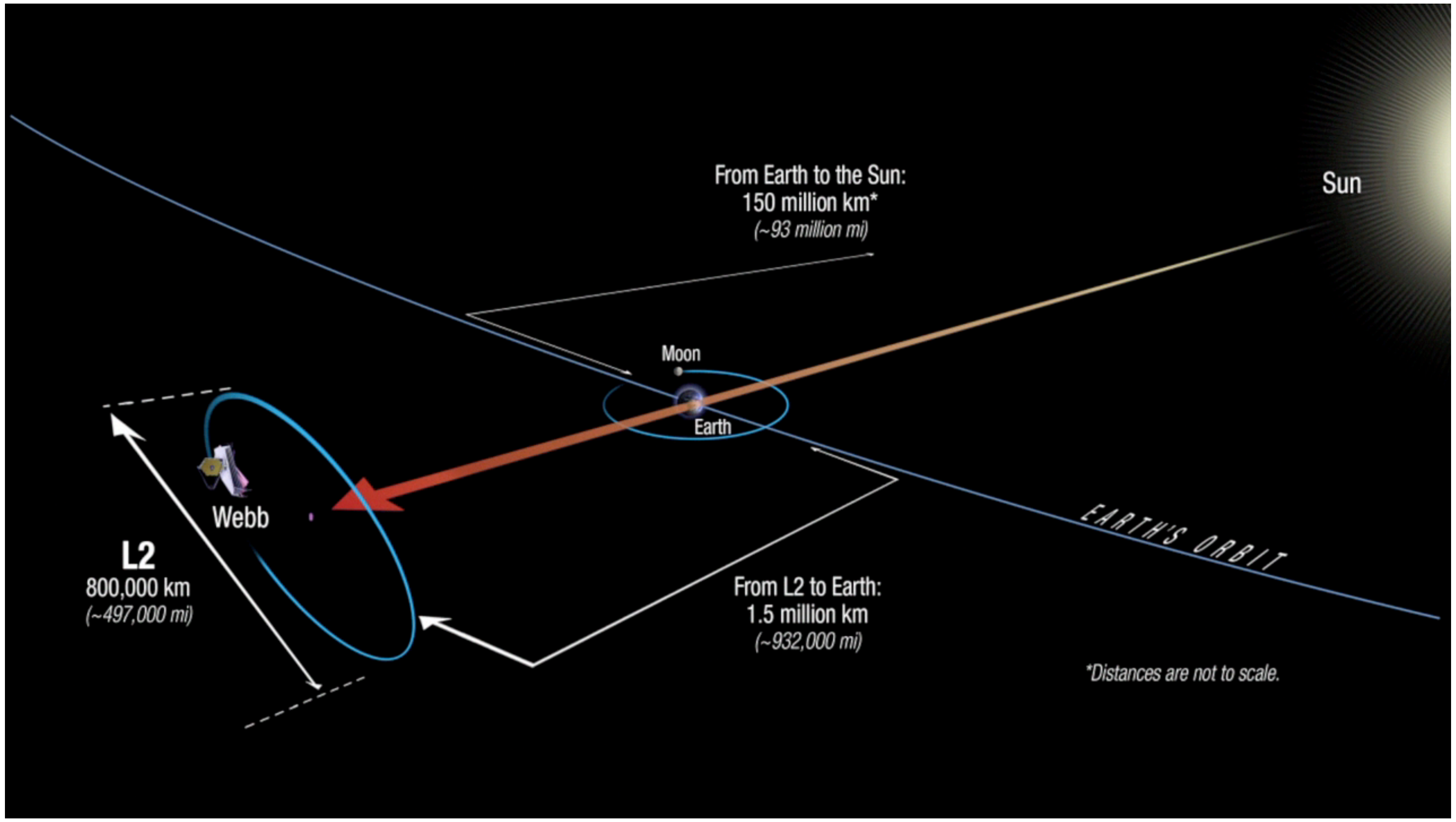


Webb is designed to deal with the extreme temperatures of space. The sunshield separates Webb's hot side, containing its solar panel, computer and navigational jets, from its cold side, which holds the mirrors and science instruments.

But Webb still needs a location that allows its sunshield to constantly wall off the Sun, Earth and Moon. Fortunately, gravity offers an elegant solution. The Earth, Moon and Sun exert gravitational tugs on each other, creating a few special neighborhoods in the solar system where the respective forces balance neatly. One of these, the Earth/ Sun Lagrange Point 2, or L2, will enable Webb to orbit at a comparatively stable location in space while keeping the telescope optics and instruments safely behind the spacecraft's sunshield. The Sun, Earth and Moon will always remain in the same direction, away from the telescope on the far side of the sunshield. From this vantage point, Webb will survey much of the universe as it travels around the Sun in lock-step with the Earth, changing its view in step with the changing seasons.

At this distant orbit, 930,000 miles (1.5 million km) from Earth, Webb will be outside of Earth's protective magnetic field, making it a constant target for

Movie 3.1 Webb's Field of Observation



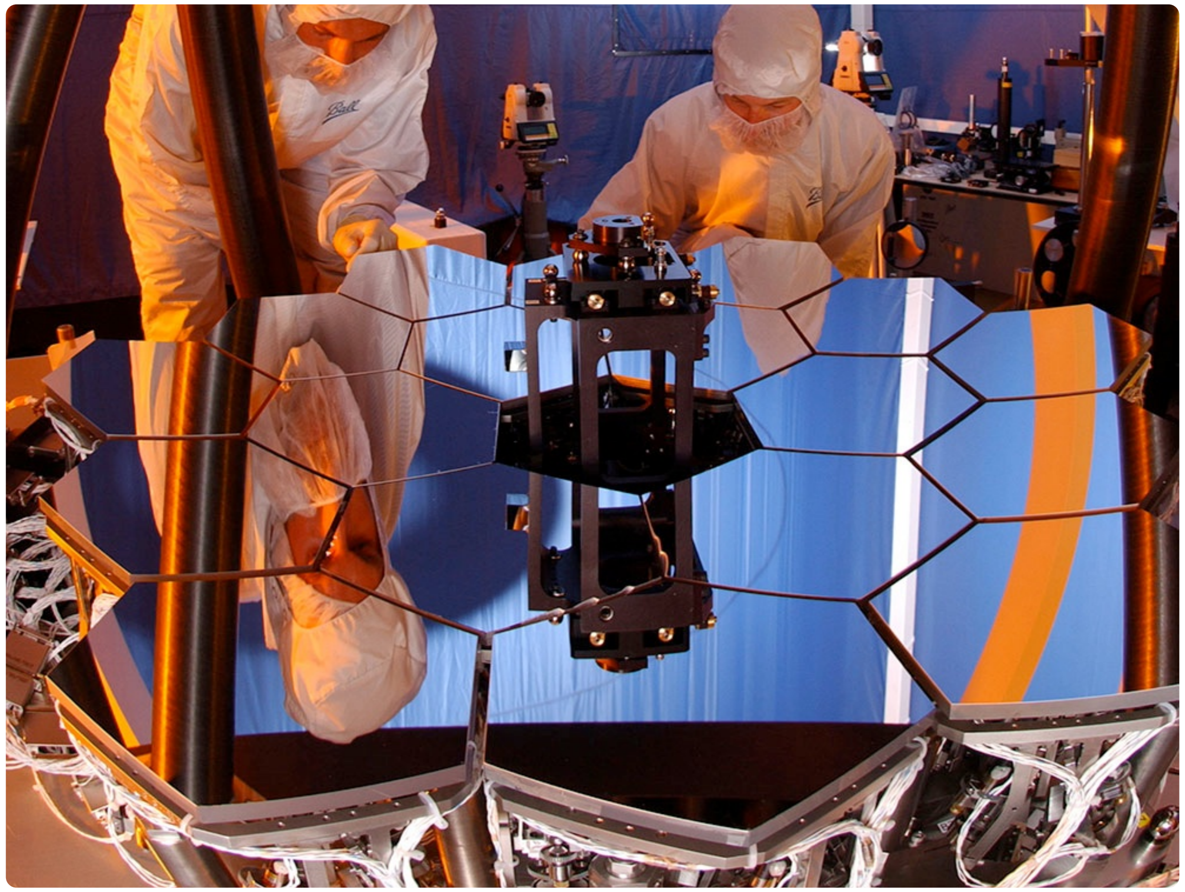
The Webb telescope will follow the Earth around the Sun, orbiting around L2 once every 198 days. The region of sky that Webb may look within is fixed with respect to the Sun-Webb line (i.e., rotates once per year) and is defined by the need to keep Webb's mirror always in the cold shadow behind the sunshield.

potentially damaging high-energy cosmic rays. Cosmic rays can interfere with the telescope's signals or even build up electrical charges that can create the equivalent of small lightning strikes on the telescope. Such sparks can hurt sensitive equipment or damage the telescope's materials. Webb has been engineered to take this into account, with extra shielding for detectors and conduction areas in the sunshield to prevent voltage from accumulating.

Taken collectively, the sunshield, the telescope's design and its orbit will achieve temperatures that previously required a heavy and fleeting supply of coolant. By engineering an inherently colder spacecraft, scientists will extend the lifetime of the telescope and its program of frontier science.

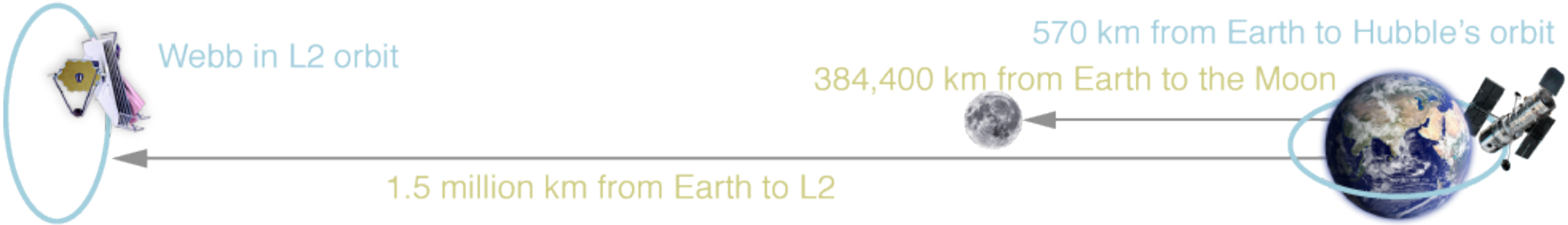
Because Webb will be in such a distant orbit, servicing missions similar to those on the Hubble Space Telescope are impossible. To compensate, Webb will have a special subsystem that will correct for any errors in the optics of the telescope. This system, known as a wavefront sensing and control subsystem, is similar to the sophisticated adaptive optics technologies used on ground-based telescopes. But as adaptive optics take out the twinkling of starlight, Webb's system will ensure that the entire telescope has a crisp and clear vision.

Figure 3.3 Scaled Telescope Testbed



Ball Aerospace has engineered a 1/6-scale telescope testbed which is traceable to the flight telescope so that wavefront sensing and control can be developed and demonstrated in a high-fidelity environment.

Webb will be located far beyond the Moon at Lagrange Point 2 (L2), a semi-stable location in space.



Not to scale

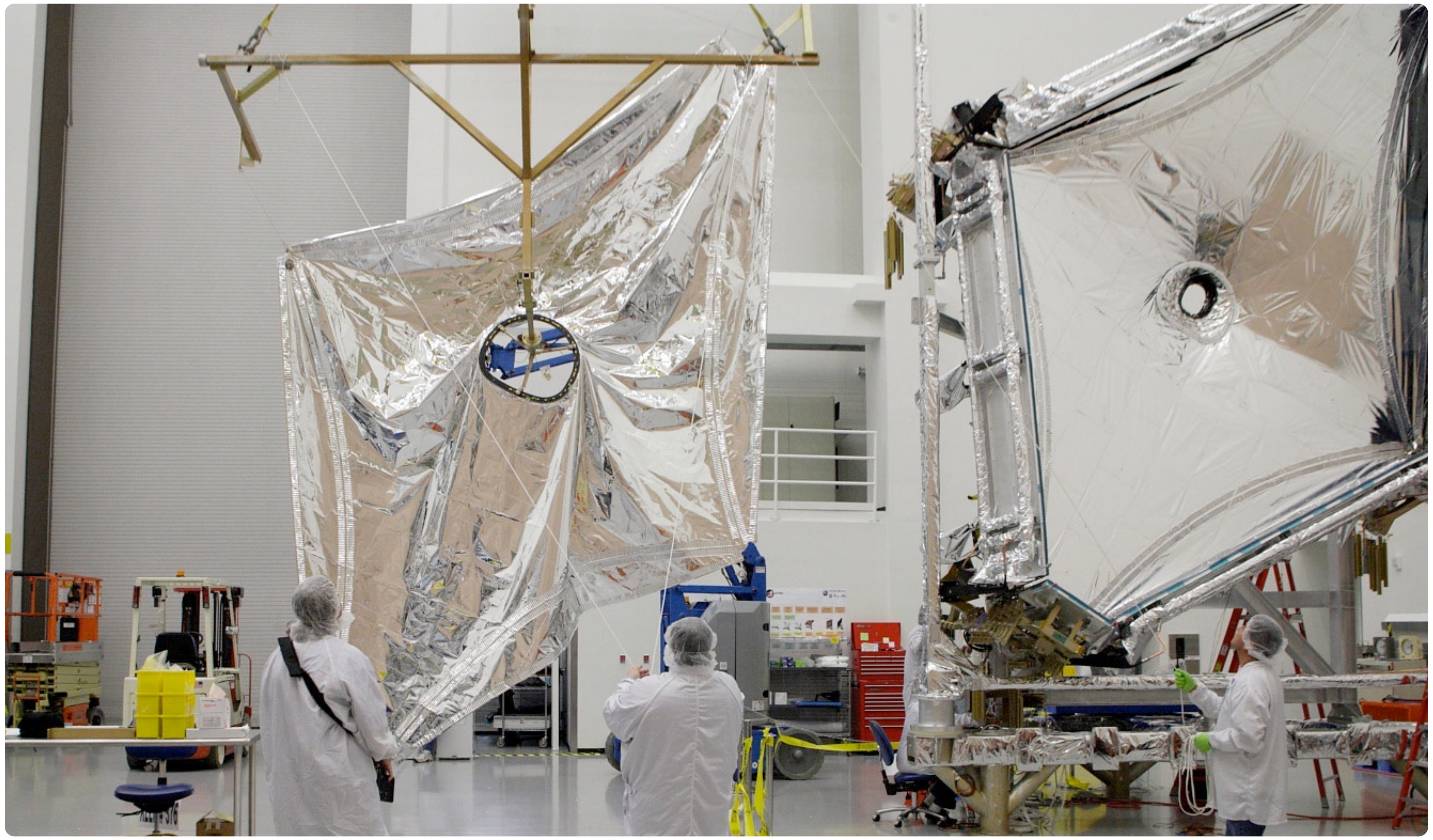
The Sunshield

The sunshield is Webb's most distinctive feature. It is the first and most important line of defense against the light and heat from the Sun and Earth. Its main function is to separate Webb's warm, Sun-facing side from its cold, science side. Not long after launch, the sunshield will slowly unfurl, stretched taut by cables attached to motors.

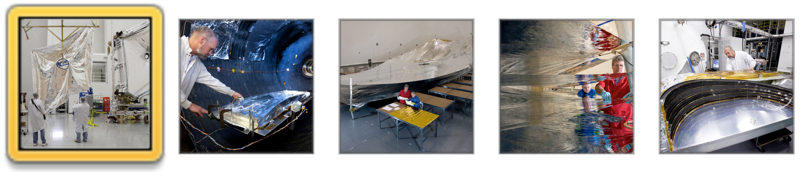
Like body armor, the sunshield will be made up of multiple layers, each adding a level of strength and protection.

Webb's sunshield consists of five layers of a heat-resistant material called Kapton that is coated in silicon. Each layer, less than a millimeter thick, is durable enough to withstand the rigors of space. Collectively, all five layers will offer a safe and insulating source of shade for the telescope. Part of the sunshield's strength comes from its supporting ribs, which give it stability without becoming brittle. This is vital for the integrity of this sunshield because it allows for small holes to form – debris

Gallery 3.1 Building the Sunshield

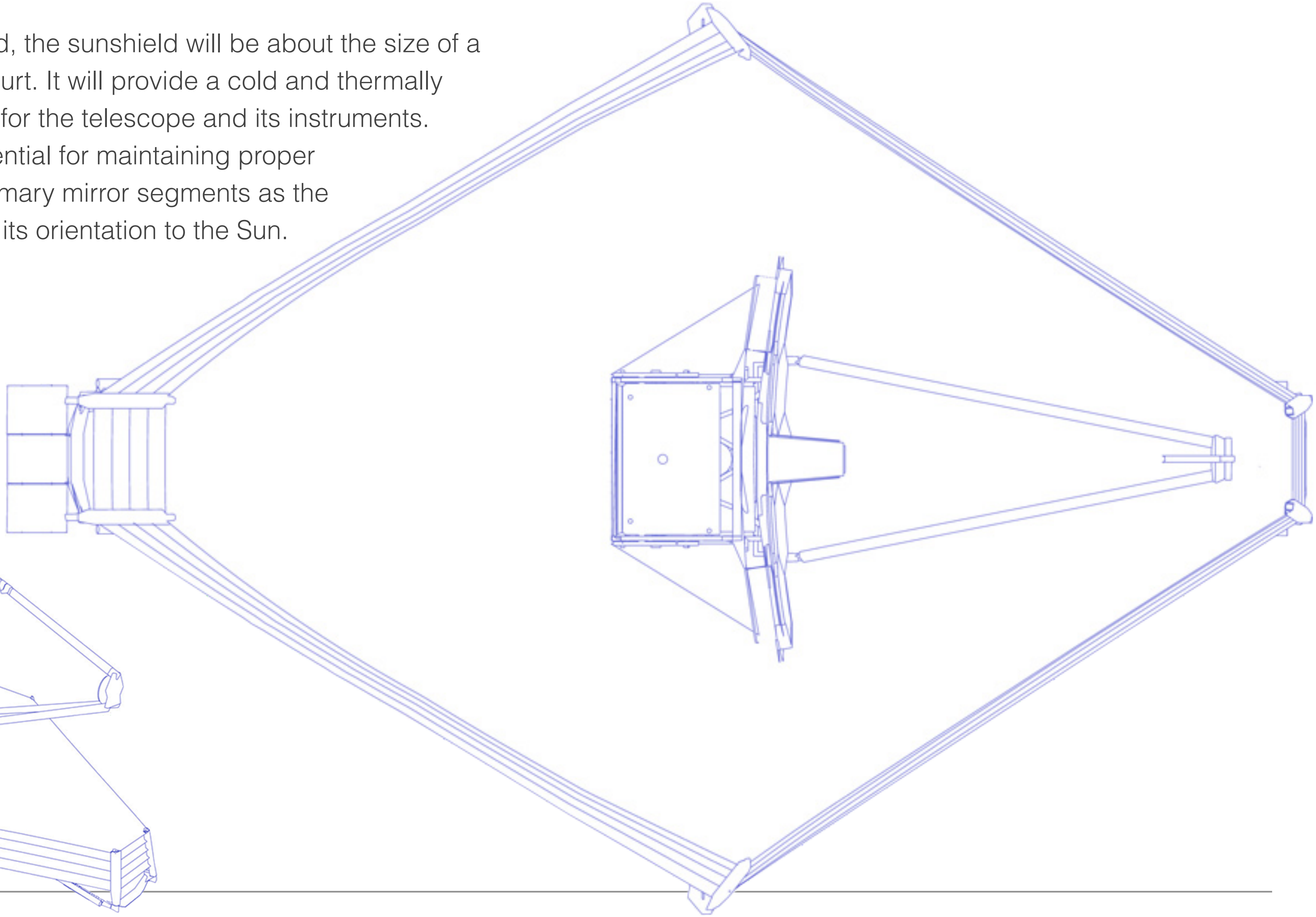


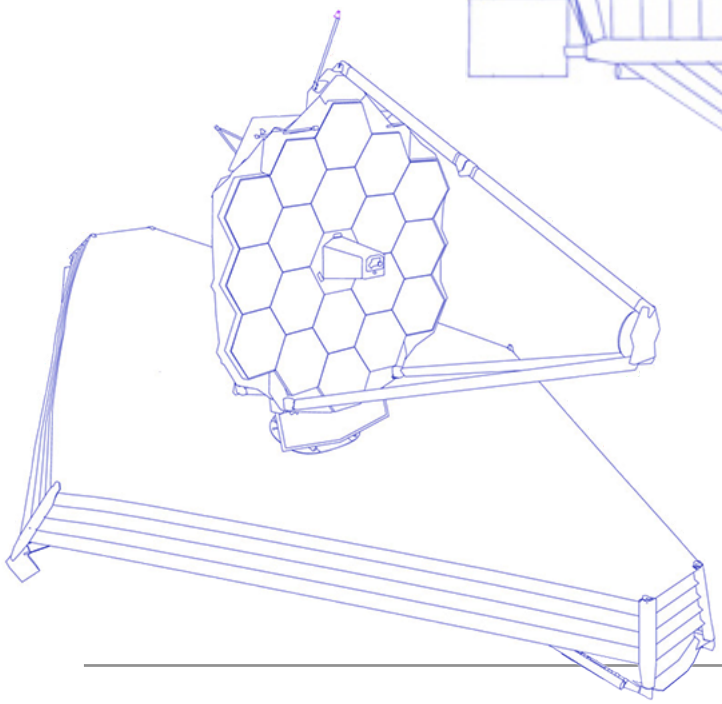
A layer is installed on a 1/3-scale model of the Webb Telescope's sunshield by engineers at Northrop Grumman.



and micrometeorites are a constant concern of all space missions – without causing additional damage. The multilayer design also means that any one hole doesn't compromise the effectiveness of the shield.

When fully deployed, the sunshield will be about the size of a regulation tennis court. It will provide a cold and thermally stable environment for the telescope and its instruments. This stability is essential for maintaining proper alignment of the primary mirror segments as the telescope changes its orientation to the Sun.





SECTION 2

Mirrors

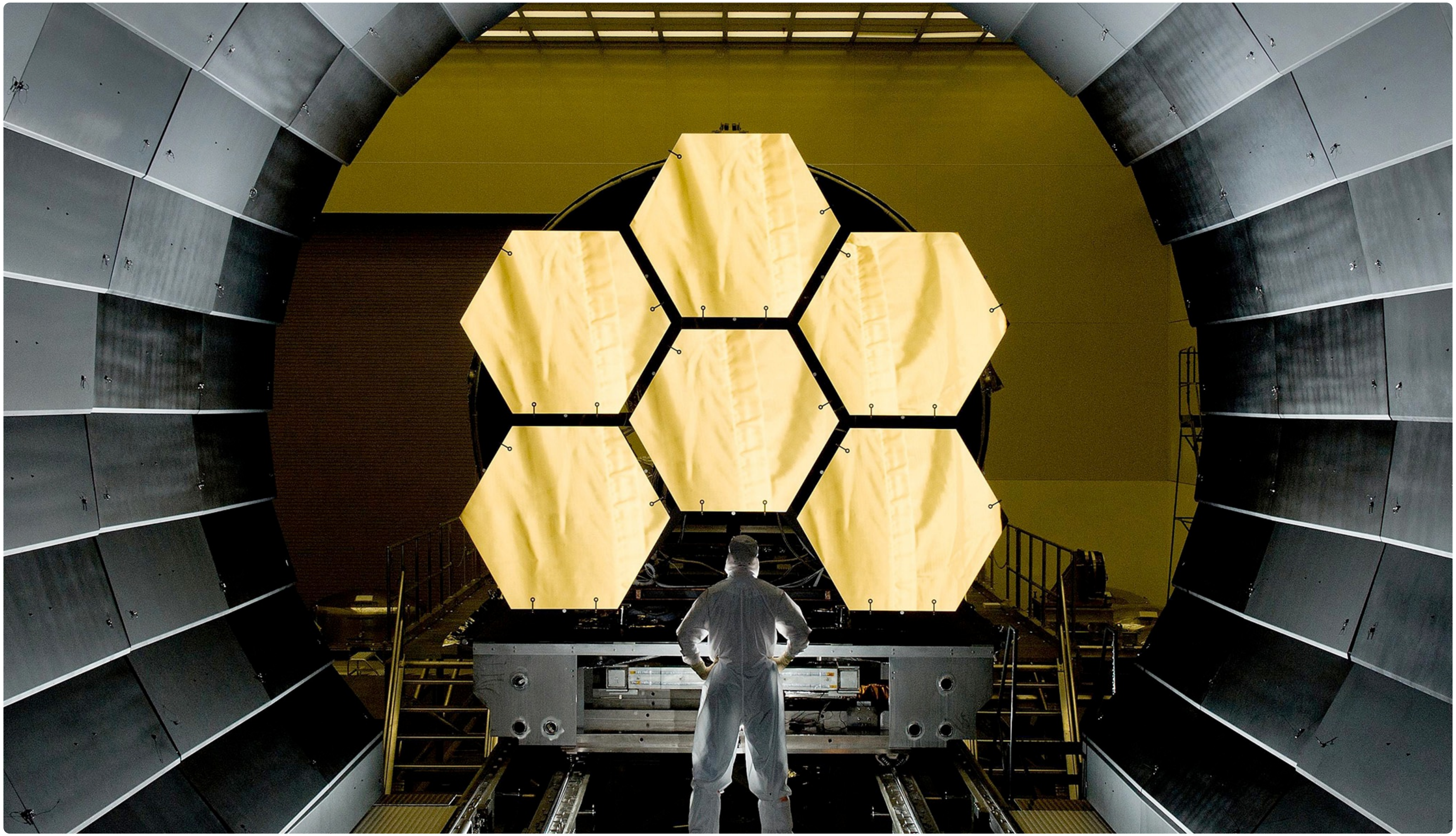


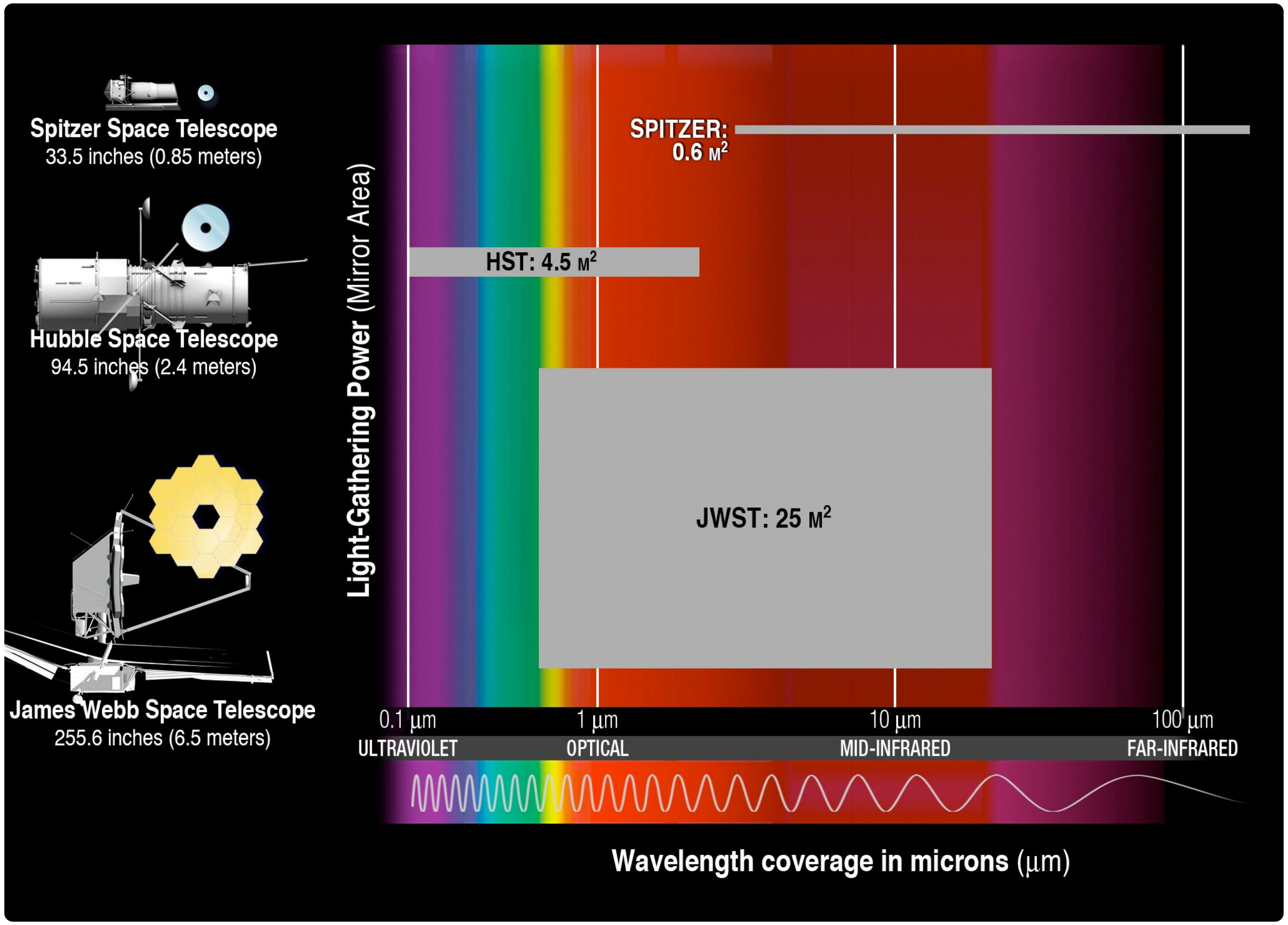
Figure 3.4 **Six Completed Segments of Webb's Primary Mirror**

The eye of the Webb observatory is an entire system collectively referred to as the Optical Telescope Element, or OTE. The OTE gathers the infrared light from distant objects and directs it to the science instruments. This portion of the spacecraft contains all of Webb's optics, including the Fine Steering Mirror (FSM) and the structural pieces that hold everything together.

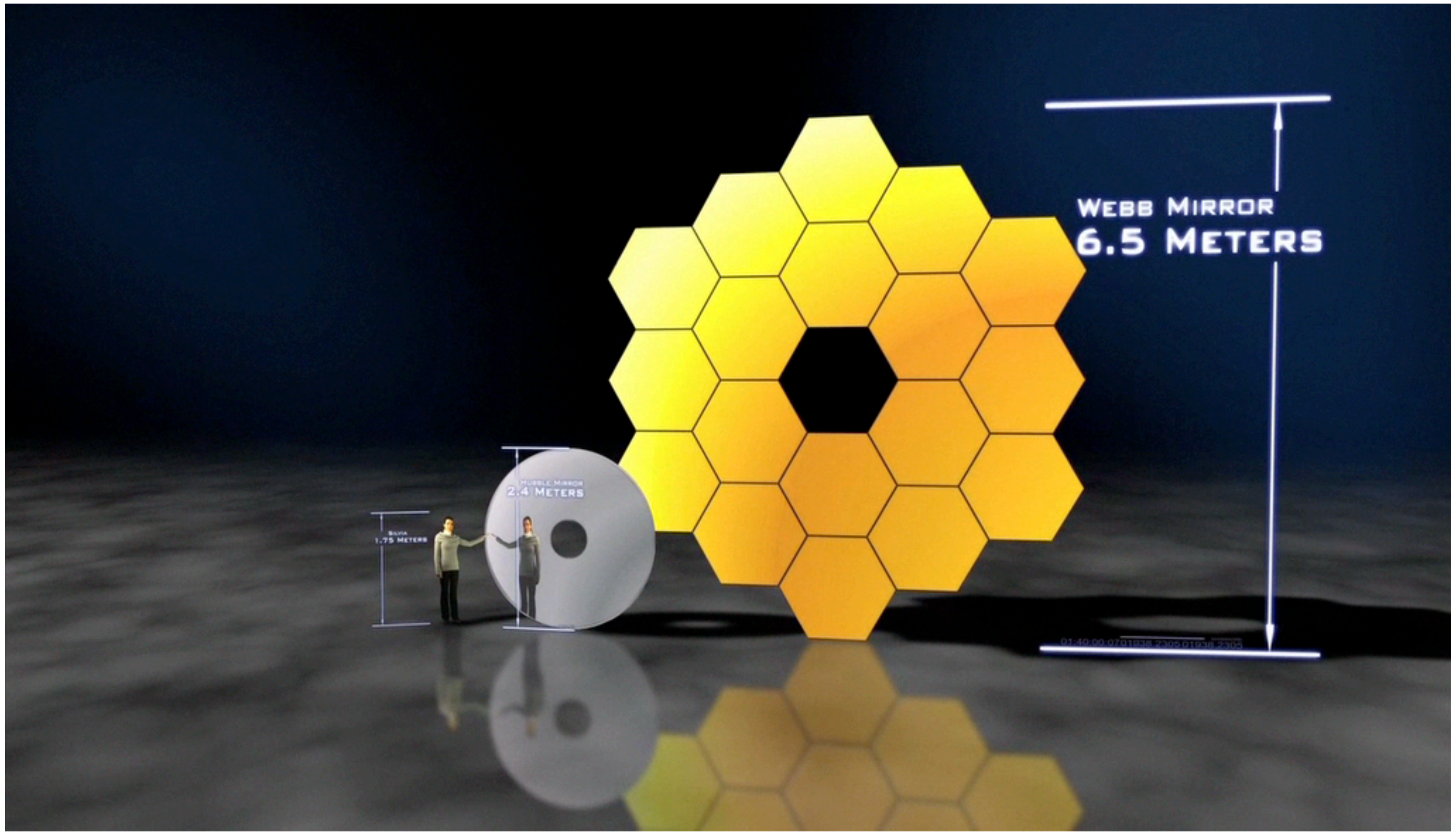
The most important part of Webb's design is its giant mirror. Mirror size is vital for all telescopes, but particularly for infrared telescopes. Infrared light, being longer than visible light, requires a proportionally larger mirror to produce the same quality image we would achieve in visible light.

The infrared precursor of Webb is the relatively compact Spitzer Space Telescope, which has a 2.7-foot (0.8-meter) mirror. The Webb telescope's primary mirror is 21.3 feet (6.5 meters) across, with about seven times the collecting area of the Hubble Space Telescope and 50 times the area of Spitzer's mirror. Webb's resolution will be three times more powerful than Hubble's in the infrared and eight times more powerful than Spitzer's. Its size will allow it to see in the infrared as clearly as Hubble sees in visible light. This is particularly important for science, enabling Webb to probe much farther and much more clearly into the early universe than Hubble was designed to achieve.

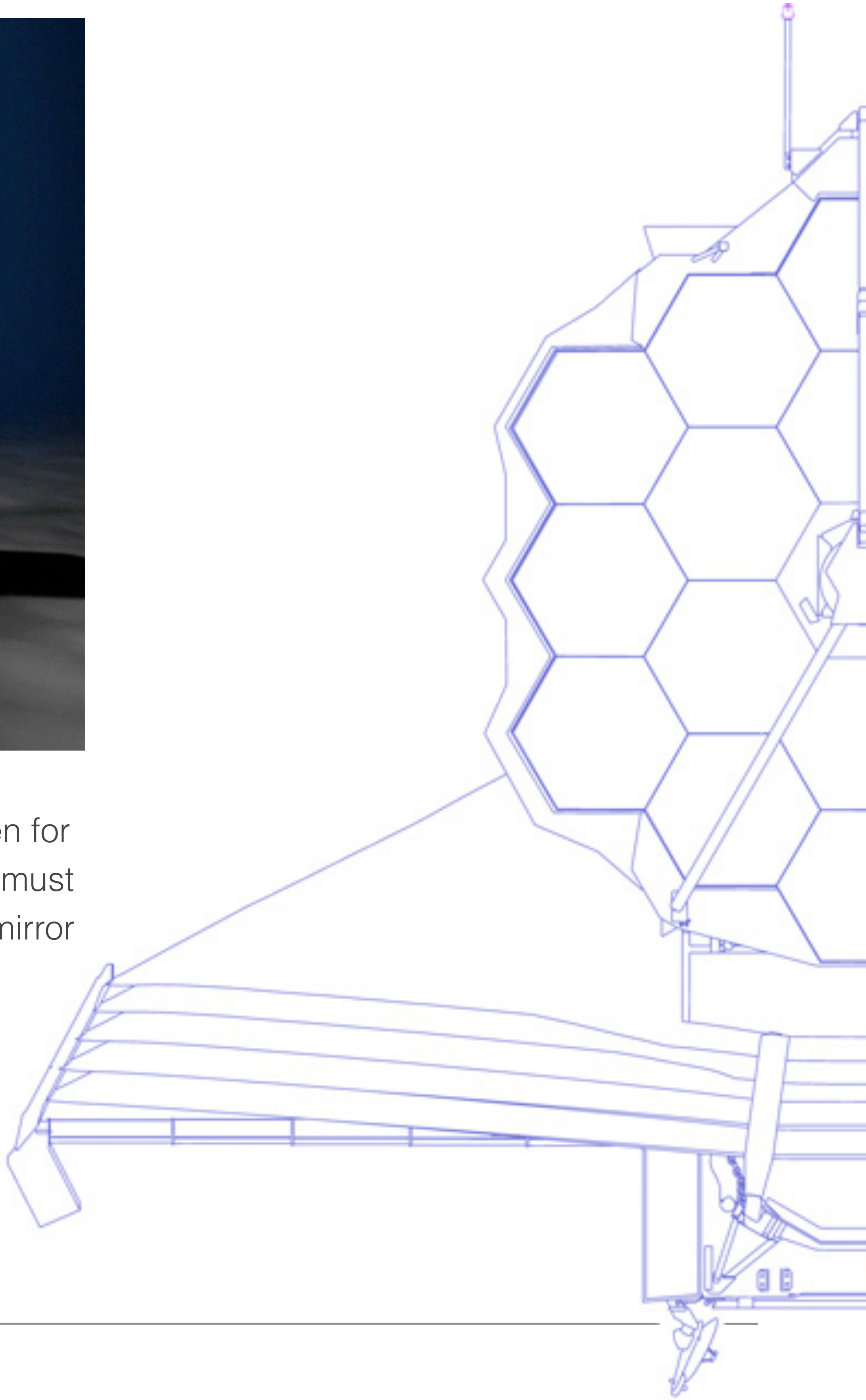
Figure 3.5 Comparison of Observatory Primary Mirror Size and Wavelength Coverage

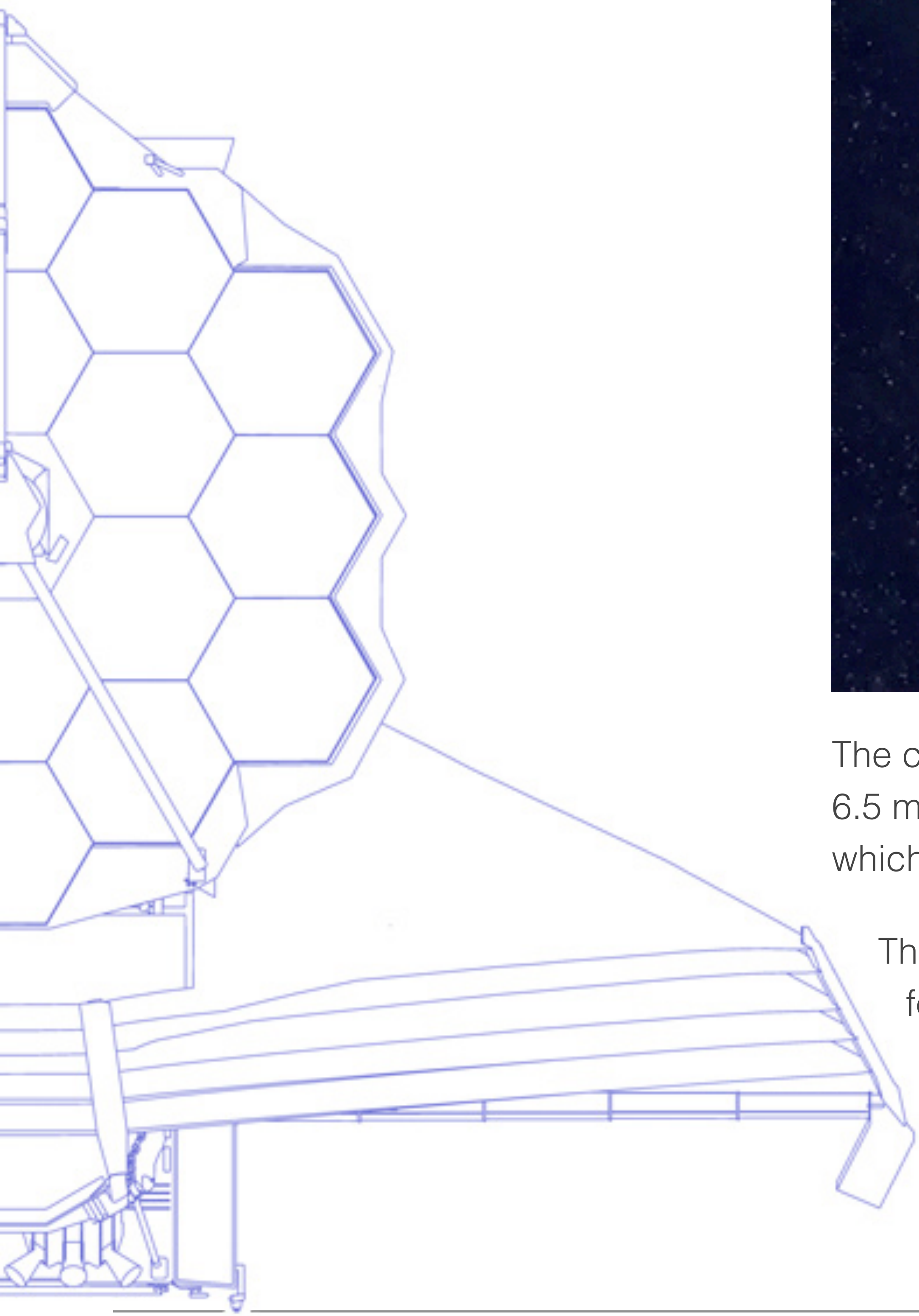


Movie 3.2 **Space Telescope Mirror Comparison**

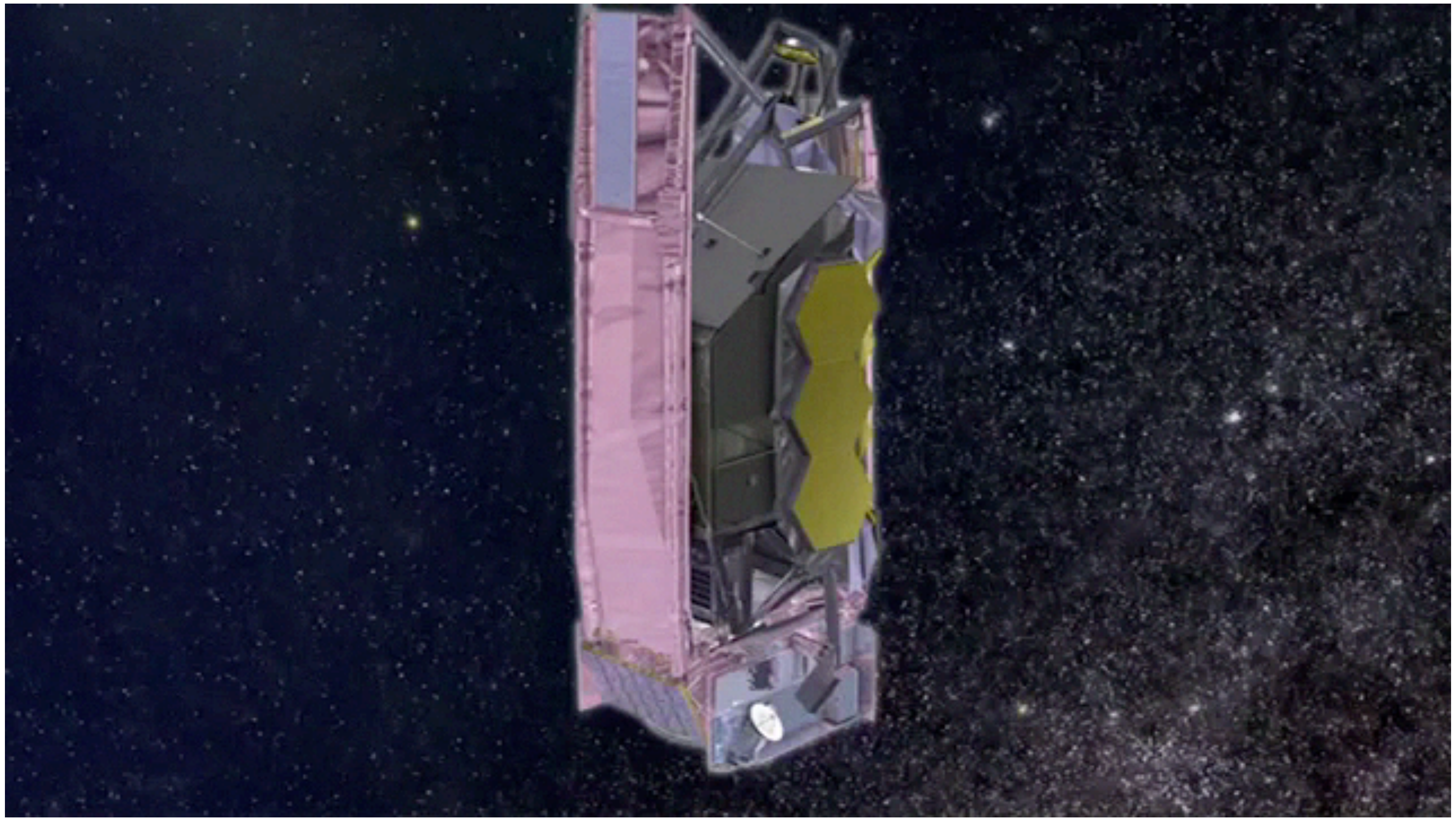


A mirror this size, however, presents a number of technological challenges, even for ground-based observatories. Large mirrors are difficult to cast. Once cast they must be coated with a reflective finish, requiring a vacuum chamber larger than the mirror itself. Transporting a large mirror is also extremely difficult; launching one into space would be nearly impossible. That is why engineers decided that Webb would have a primary mirror made up of many segments. Webb's smaller segments could be more easily made, efficiently coated and safely transported. Webb's segments, however, are not identical. To give Webb clear vision across the entire mirror surface, the 18 segments are divided into three groups of six, each group having a slightly different shape or optical prescription.





Movie 3.3 Sunshield and Mirror Deployment Sequence



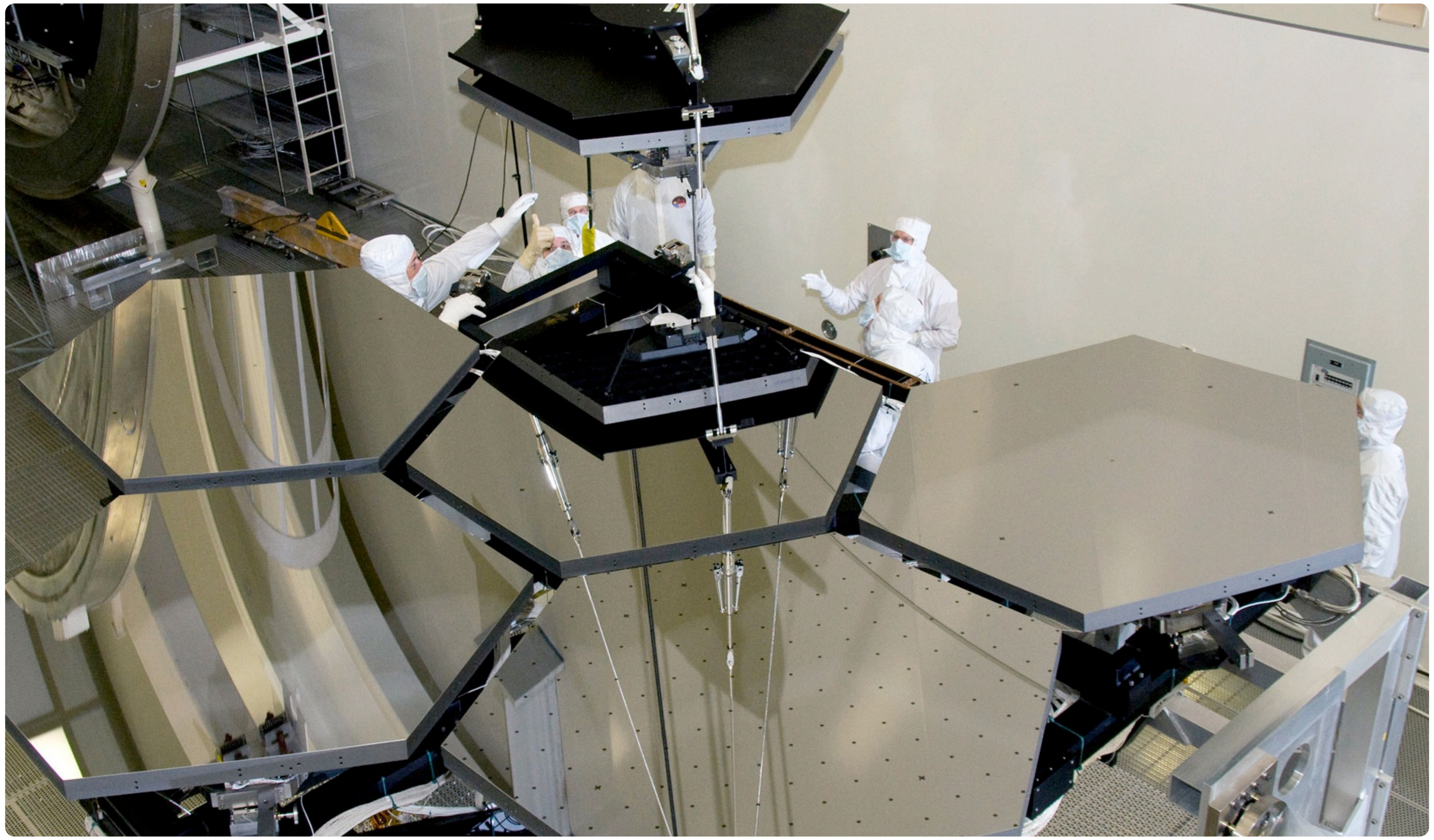
The commanding size of Webb's mirror, however, poses one additional challenge. At 6.5 meters across, the Webb mirror overflows even the widest launch vehicles, which are only 5 meters across.

This is where Webb's segmented mirror design has another advantage. It can fold. Much like the leaves of a table that can be folded down when you're not expecting guests, the two sides of the Webb telescope are able to fold in to make the entire mirror more compact – small enough to fit into the payload bay of the Ariane 5 rocket that will carry it into deep space.

Reflecting On Metal

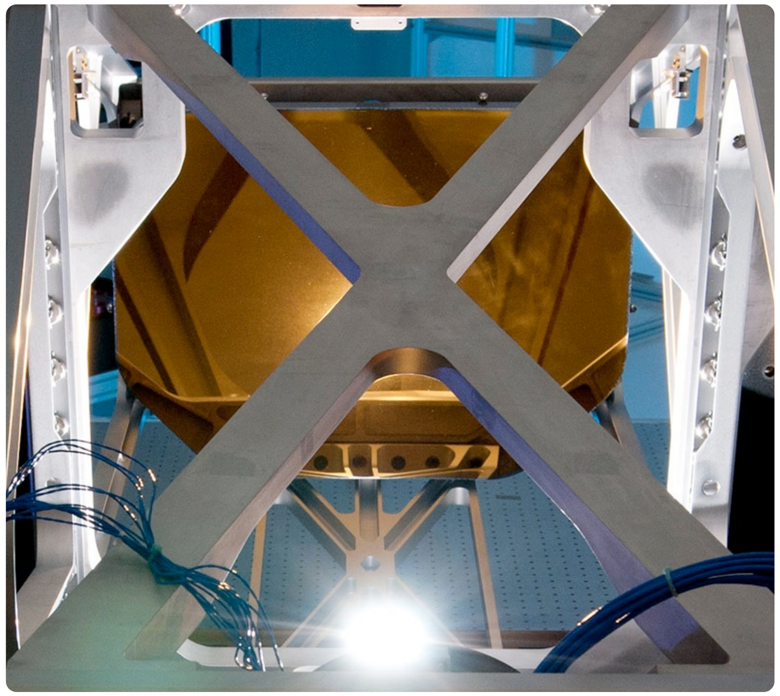
Even the most durable glass would find the ride into orbit risky and the frigid temperatures of deep space unmanageable. A better option was found for Webb's mirror segments: the element beryllium. Among metals, beryllium is lightweight, which is a good thing when traveling into space.

Gallery 3.2 Building the Primary Mirror



Six of Webb's primary mirror segments are prepared to move to the X-ray and Cryogenic Facility at Marshall Space Flight Center.

Gallery 3.3 Secondary and Tertiary Mirrors

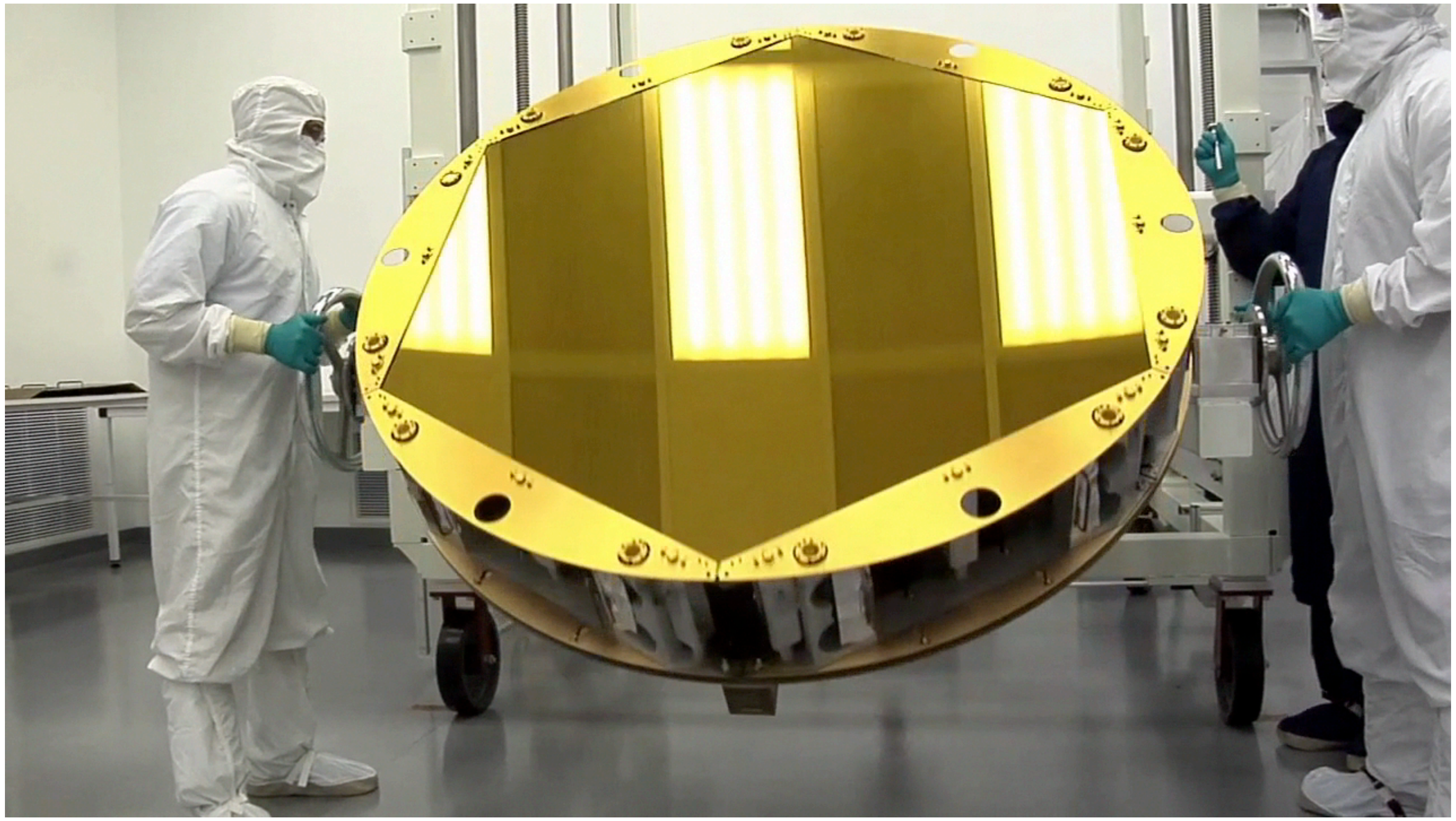


Webb's tertiary mirror is nestled into the Aft Optics bench, which also holds Webb's fine-steering mirror.

This metal also resists warping from extremely cold temperatures, essential for operating in space. Since beryllium is not particularly reflective in the infrared, however, a fine layer of gold – about 3 grams – is applied to each segment. This gold coating is not an aesthetic choice; it’s an engineering requirement for Webb because gold reflects red and infrared light especially well. Gold makes the mirror 98 percent reflective to infrared light where ordinary aluminum mirrors are only 85 percent reflective to visible light.

To give the mirrors their coating, gold is heated to more than 2,500 degrees Fahrenheit. The resulting gold vapor is deposited on the beryllium mirrors. Several coatings are applied to achieve the desired thickness, a mere 120 nanometers (about one millionth of an inch), or 200 times thinner than a human hair. Enhancing this precision, Webb will be able to reshape the surface of the mirror segments, even when the telescope is in orbit. Each segment is supported by six adjustable posts, allowing the mirrors to tilt, twist and shift to face the correct direction and position. A pressure pad located behind each segment will precisely pull and push each segment as needed to adjust the shape and focus of the mirror on the fly.

Movie 3.4 **Behind the Webb: The Golden Touch**



Engineering Systems

Figure 3.6 **The Integrated Science Instrument Module (ISIM)**

More than a telescope, Webb also is a complex spacecraft, requiring power, guidance, communications and propulsion systems worthy of any deep-space mission. Housed in the section of Webb called the Spacecraft Bus are Webb's six major subsystems, its infrastructure. The bus provides the necessary support functions for operating the observatory.

The Electrical Power Subsystem converts sunlight shining on the solar array panels into the power needed to operate the other subsystems of the spacecraft as well as the science instruments.

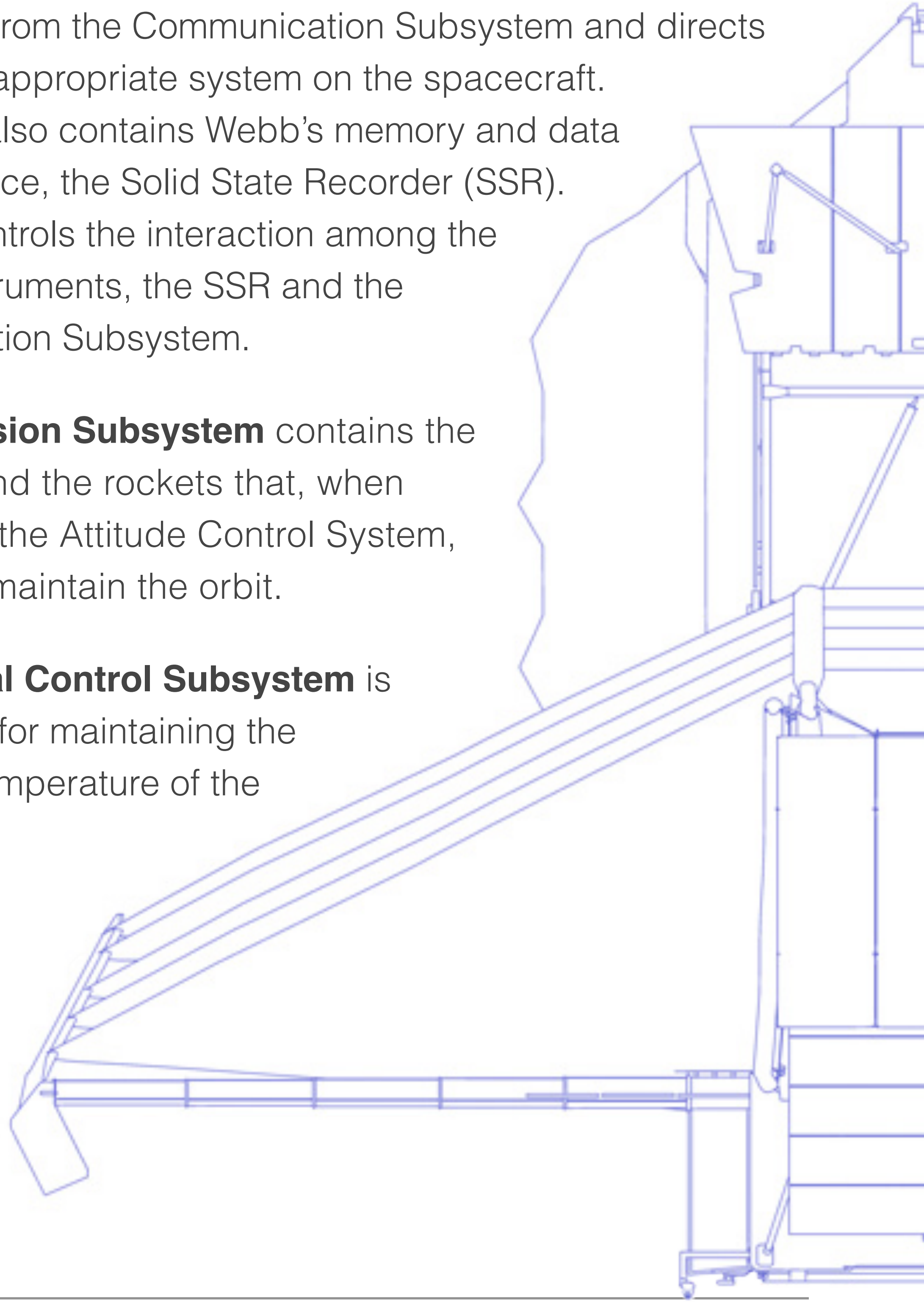
The Attitude Control Subsystem senses Webb's orientation, maintains a stable orbit, and provides the coarse pointing of the observatory to the area on the sky that the telescope will observe.

The Communication Subsystem sends data to and receives commands through the Deep Space Network, operated by NASA's Jet Propulsion Laboratory in Pasadena, California.

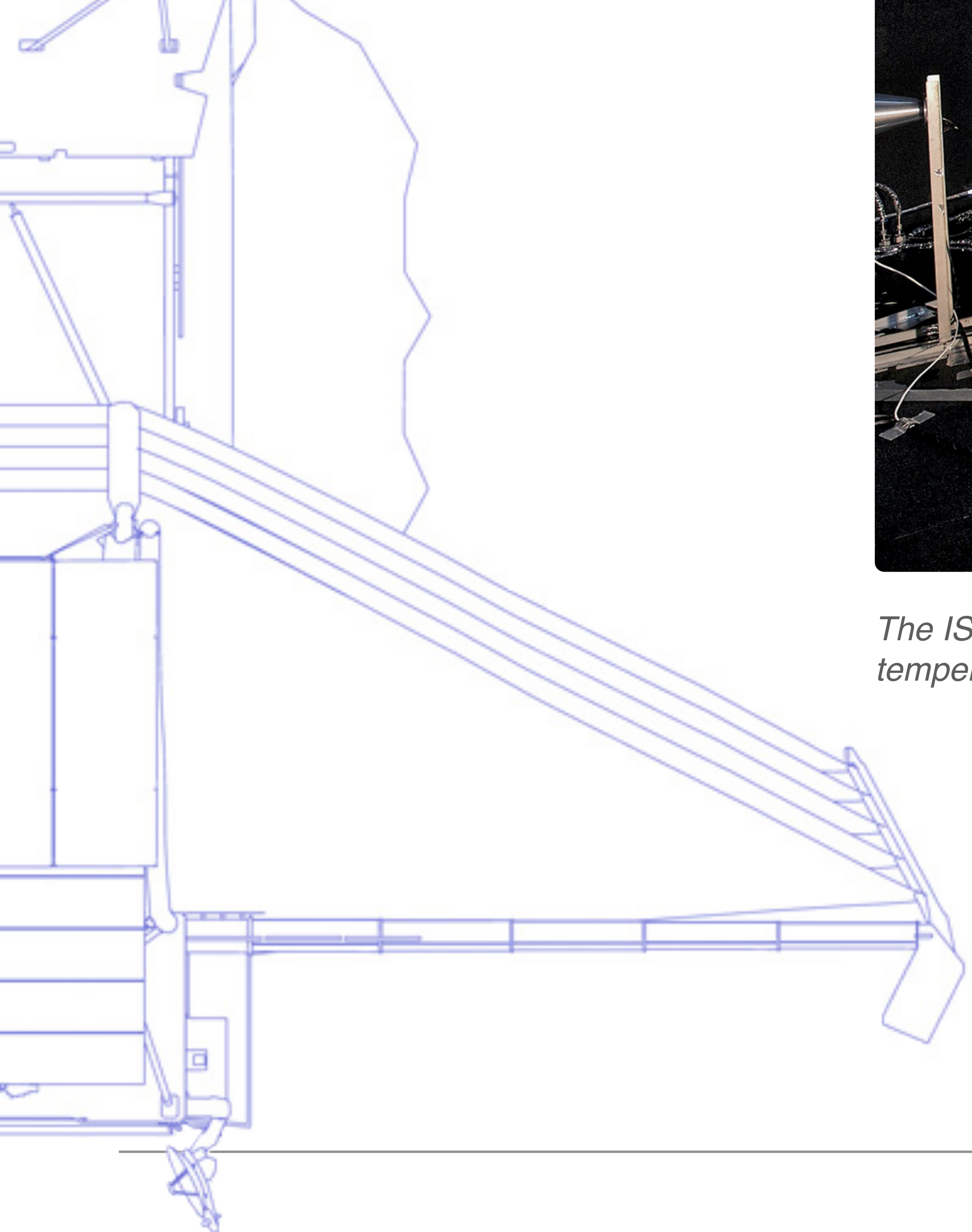
The Command and Data Handling (C&DH) Subsystem is the brain of the spacecraft. The system has a computer and the Command Telemetry Processor (CTP), which takes in the commands from the Communication Subsystem and directs them to the appropriate system on the spacecraft. The C&DH also contains Webb's memory and data storage device, the Solid State Recorder (SSR). The CTP controls the interaction among the science instruments, the SSR and the Communication Subsystem.

The Propulsion Subsystem contains the fuel tanks and the rockets that, when directed by the Attitude Control System, are fired to maintain the orbit.

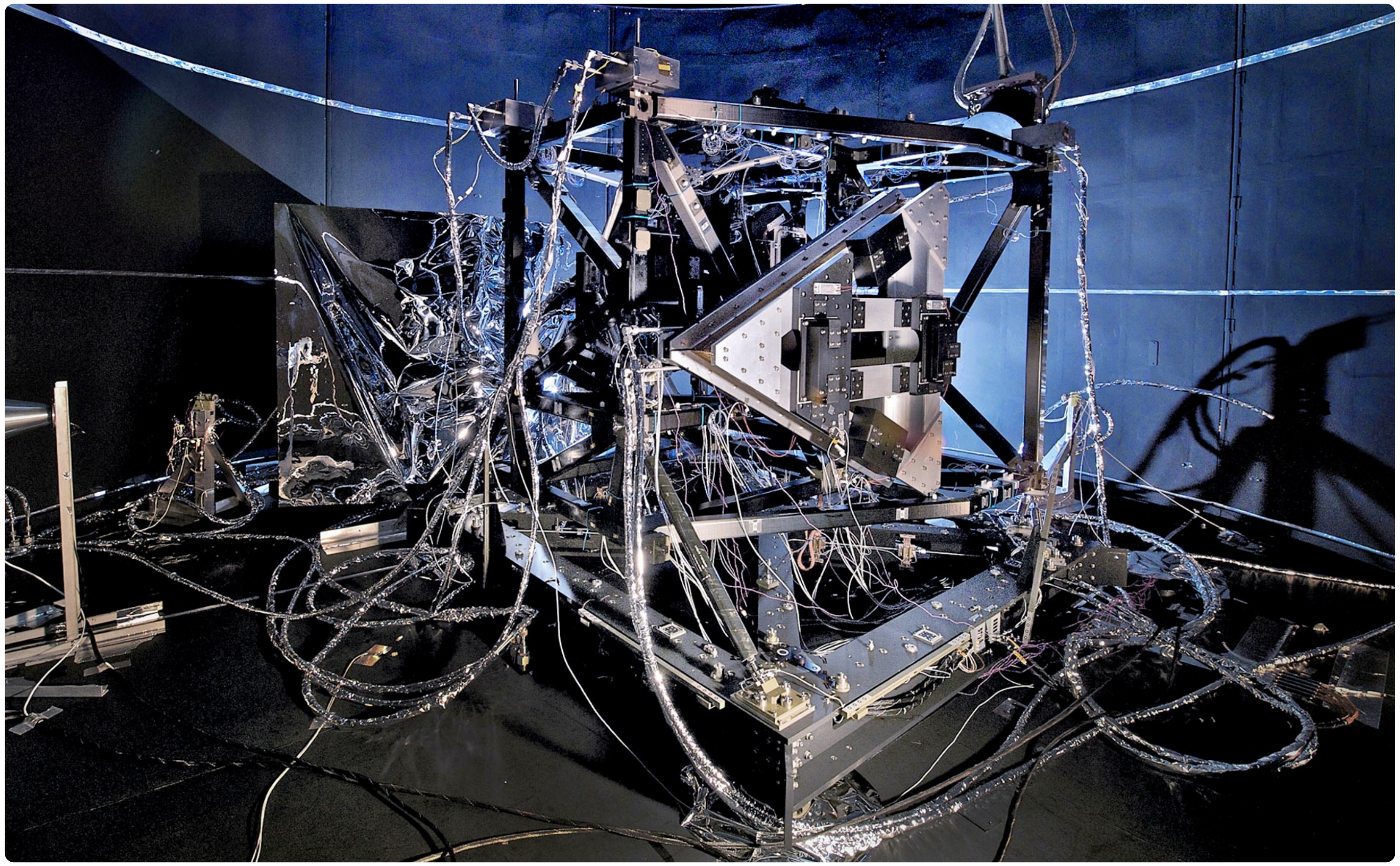
The Thermal Control Subsystem is responsible for maintaining the operating temperature of the spacecraft.



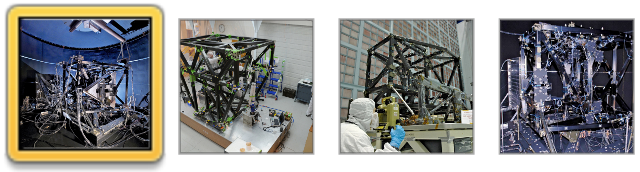
The Integrated Science Instrument Module is the heart of Webb. It houses the four main Webb instruments that perform the telescope's science operations, and the subsystems needed to operate them.



Gallery 3.4 Building and Testing the Integrated Science Instrument Module (ISIM)



The ISIM, with the NIRSpec Mass Simulator attached to its side, is lowered to sub-Pluto temperatures during cryogenic testing.



Instruments

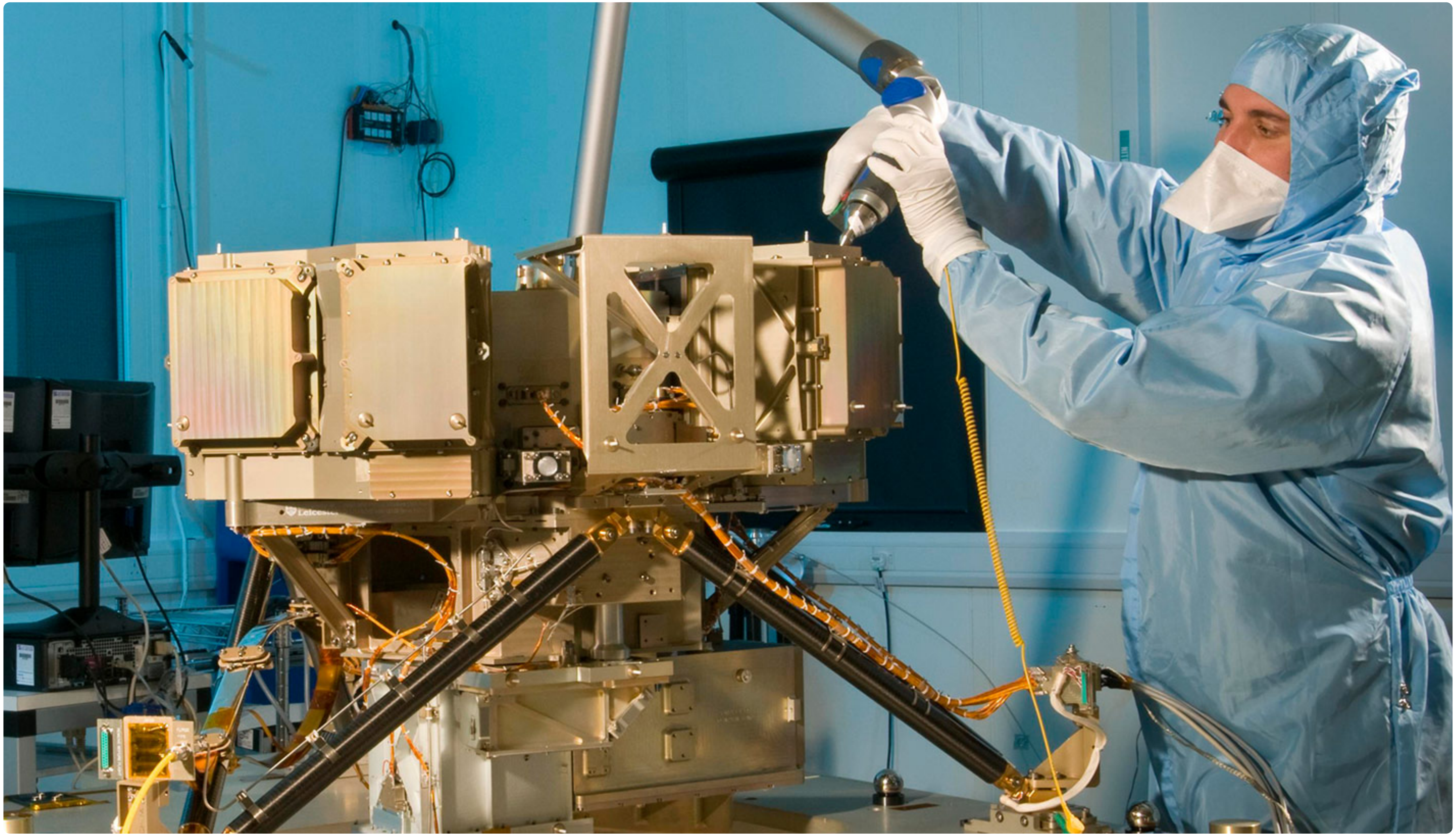
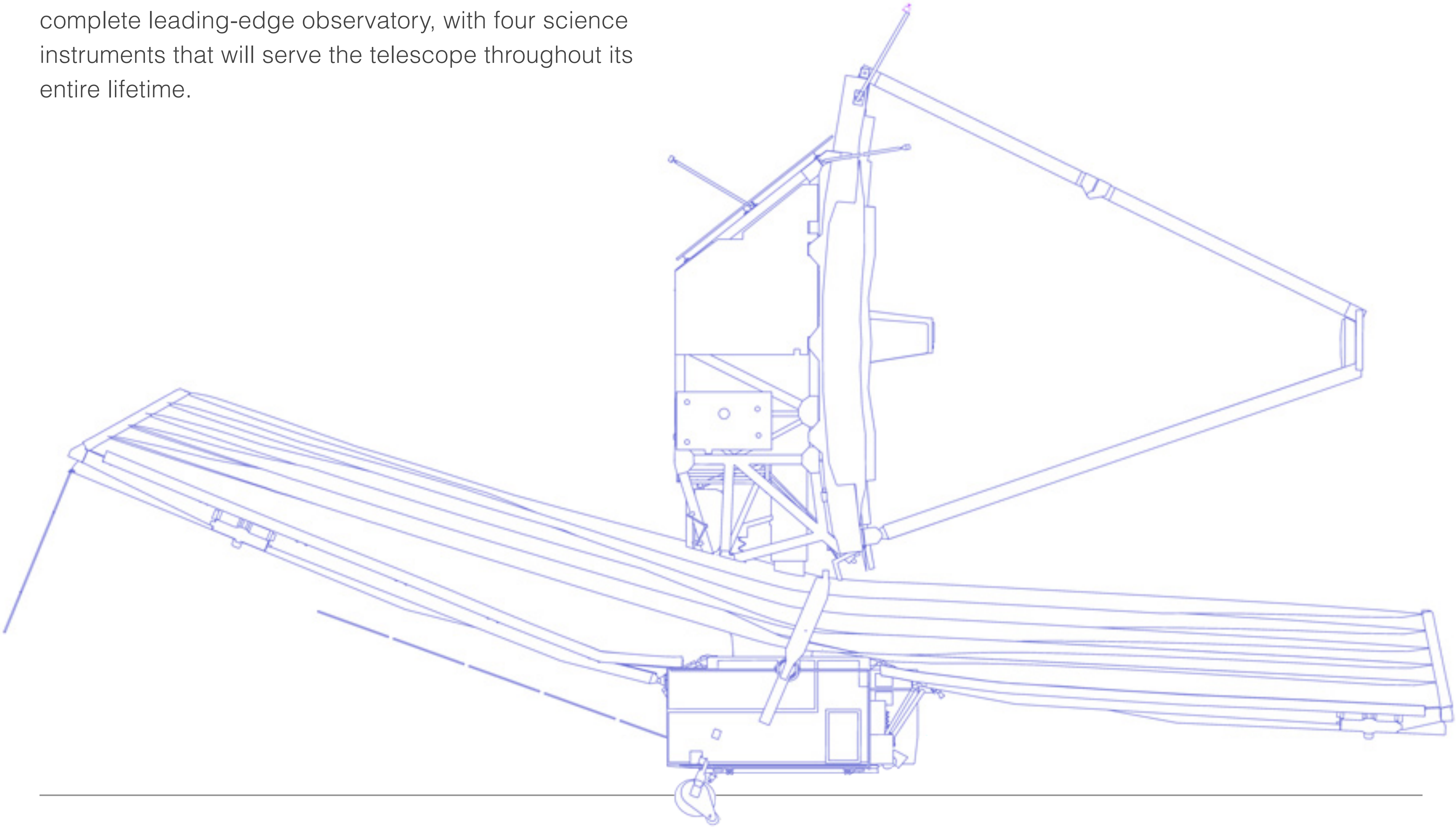


Figure 3.7 **Mid-Infrared Instrument (MIRI)**

Much of Webb's power and sensitivity come from its primary mirror, but it's the instruments that turn that faint light into breathtaking images and groundbreaking science. While Hubble was designed to be upgraded through periodic servicing missions, Webb's distant orbit means it must be a complete leading-edge observatory, with four science instruments that will serve the telescope throughout its entire lifetime.



Near-Infrared Camera

The Near-Infrared Camera, or NIRCam, is an imager with a large field of view and high angular resolution that looks at near-infrared wavelengths. The camera module provides wide-field, broadband imagery, promising to continue the breathtaking astrophotography that made Hubble such a universally admired science instrument. It will detect light from the earliest stars and galaxies in the process of formation. It will also study the population of stars in nearby galaxies, as well as young stars in the Milky Way and objects in the Kuiper Belt, part of the cold outer reaches of our own solar system. This science instrument also functions as the telescope's wavefront sensor, monitoring image quality and measuring when and how the vision of the telescope needs to be corrected. NIRCam is being built by the University of Arizona.

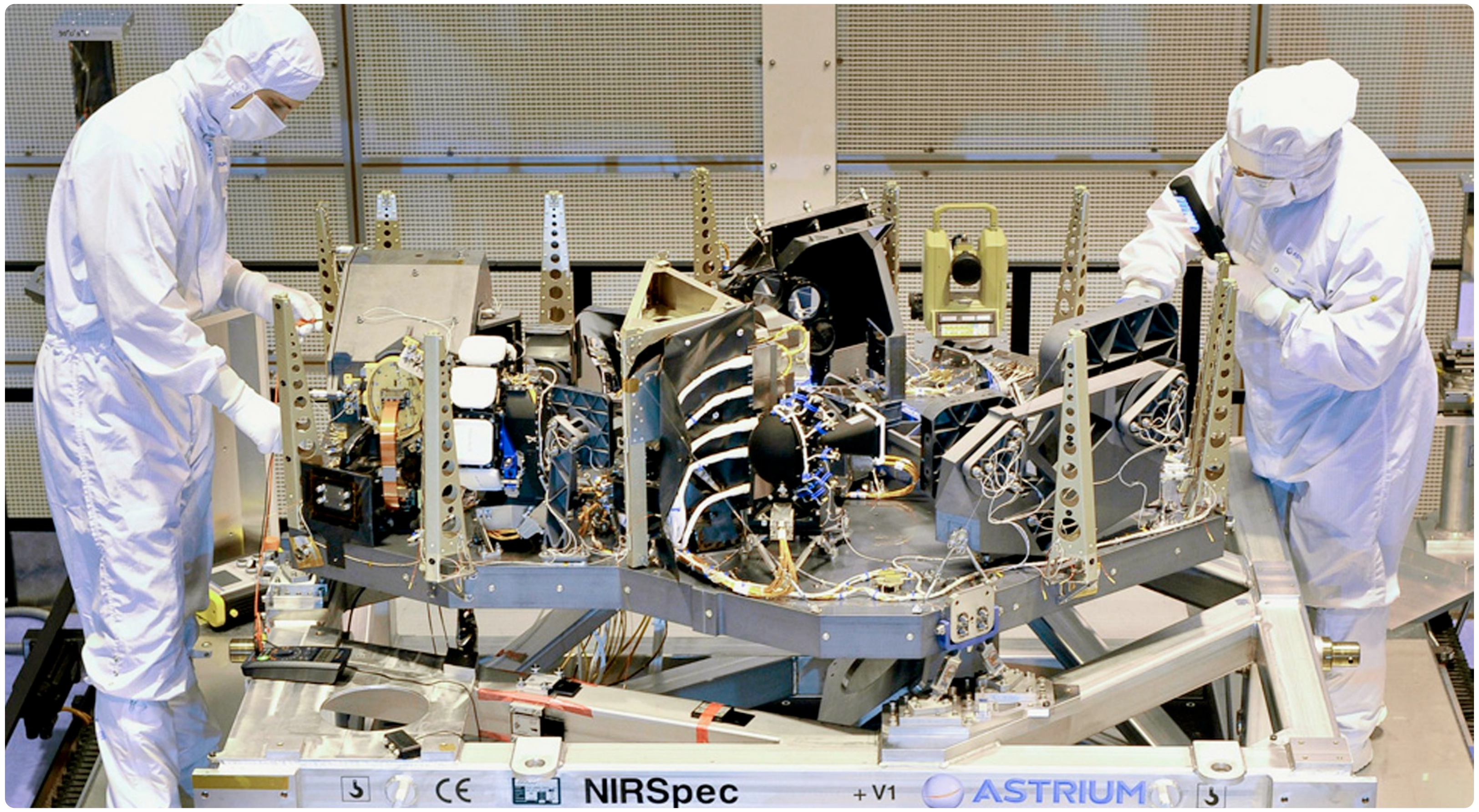
Gallery 3.5 The Near-Infrared Camera (NIRCam)

A test piece of the Near-Infrared Camera optical bench is prepared for stress testing.

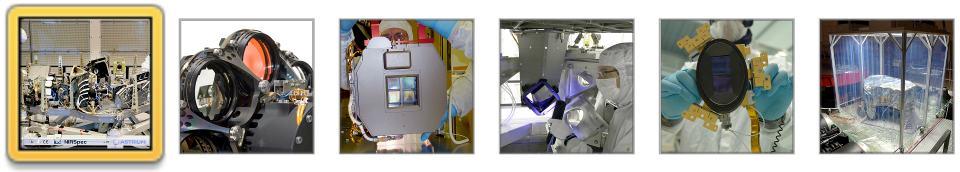
Near-Infrared Spectrograph

The Near-Infrared Spectrograph, or NIRSpec, is a multi-object, near-infrared spectrograph. This instrument spreads light into its component colors, or in the case of infrared, into its various wavelengths. This instrument allows scientists to simultaneously observe more than 100 objects in a 9-square-arcminute field of view. The innovative technology behind this feat is a system of 248,000 microshutters all arranged on a wafer about the size of a postage stamp. Each microshutter is a tiny cell that measures a microscopic 100 by 200 microns across, or about the width of three to six human hairs. They block out surrounding light sources to isolate a specific object, much the same way that the human eye does when it squints to see fine details. The microshutters are arranged in a waffle-like grid and have lids that open and close when a magnetic field is applied. Each cell can be controlled individually, allowing it to view or block specific portions of the sky and study many objects simultaneously.

Gallery 3.6 The Near-Infrared Spectrograph (NIRSpec)



Engineers work on NIRSpec, the instrument that will be used to analyze the light from cosmic objects.

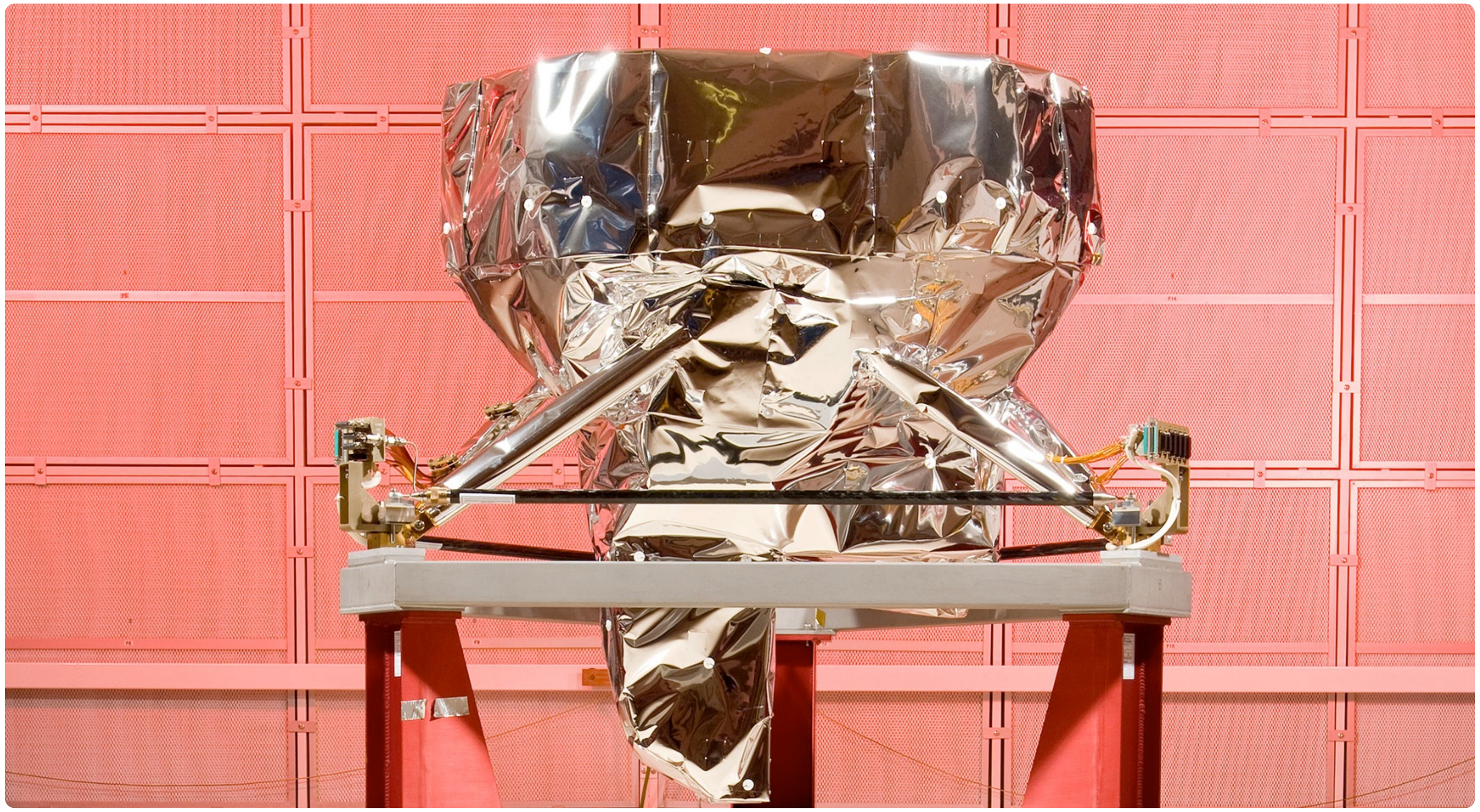


NIRSpec is being built by the European Space Agency and will study, among other things, star formation and the chemical composition of young, distant galaxies.

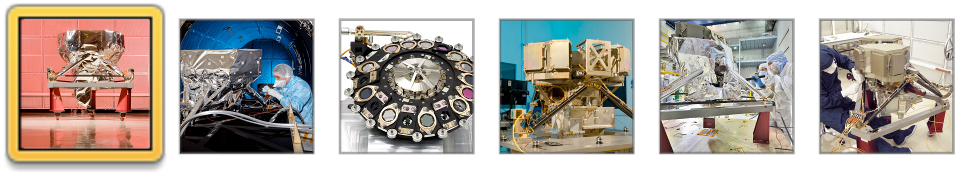
Mid-Infrared Instrument

The Mid-Infrared Instrument, or MIRI, will function as both an imager and a spectrograph. The other half of this instrument, the spectrograph module, will enable medium-resolution spectroscopy over a smaller field of view than the imager. By examining mid-infrared wavelengths, MIRI will study distant stellar populations, the physics of newly forming stars, and the sizes of faintly visible comets as well as objects in the Kuiper Belt. MIRI, developed by a consortium of 10 European institutions and NASA's Jet Propulsion Laboratory, was delivered to Goddard Space Flight Center in spring 2012.

Gallery 3.7 The Mid-Infrared Instrument (MIRI)



MIRI is both a camera and a spectrograph, capable of taking pictures and analyzing light.



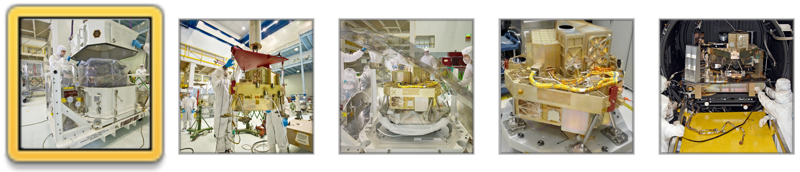
Fine Guidance Sensor/Near-Infrared Imager Slitless Spectrograph

The Fine Guidance Sensor (FGS) allows Webb to point precisely, so that it can obtain high-quality images.

The Near Infrared Imager and Slitless Spectrograph part of the FGS/NIRISS will achieve the following science objectives: first-light detection, exoplanet detection and characterization, and exoplanet transit spectroscopy. It has a wavelength range of 0.7 to 5.0 microns, and is a specialized instrument with three main modes, each of which addresses a separate wavelength range. FGS/NIRISS, developed by the Canadian Space Agency, was delivered to Goddard Space Flight Center in summer 2012.

Gallery 3.8 The Fine Guidance Sensor/Near Infrared Imager Slitless Spectrograph (FGS/NIRISS)

Technicians at NASA carefully remove half of the FGS shipping case after its arrival at Goddard Space Flight Center.



A Space Odyssey

Figure 3.8 **An Ariane 5 Ready for Launch** *©2010 ESA, CNES and Arianespace/Photo Optique Vidéo CSG*

Ariane 5 Fast Facts

- Typical length: 50.5 m
- Typical liftoff mass: 780 tons
- Payload capacity: 10 metric tons to geostationary transfer orbit (GTO) and over 20 metric tons into low-Earth orbit (LEO)
- Launch: Kourou, French Guiana

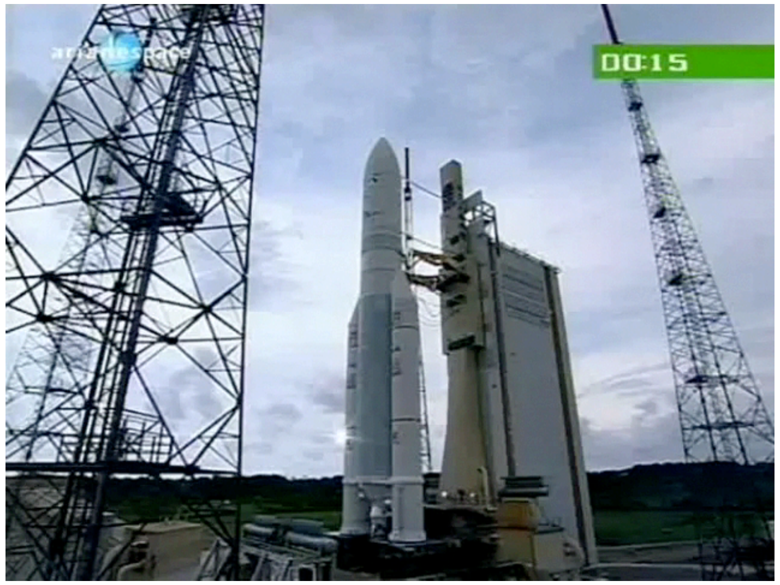
Webb's mirrors and sunshield will fold to fit inside the Ariane 5 rocket. They will deploy as they near their orbit.

The Webb Space Telescope is a venture that crosses borders and oceans. The Canadian Space Agency built Webb's Fine Guidance Sensor and Near-Infrared Slitless Spectrograph. The European Space Agency (ESA) helped to build the Mid-Infrared Instrument and the Near-Infrared Spectrograph. Both ESA and CSA will supply engineers and scientists to help in Webb operations after launch. And ESA has the critical task of providing the rocket that will take Webb into orbit.

Going the Distance

The Ariane 5 rocket will carry the Webb Space Telescope from the surface of the Earth to its new home 932,000 miles from Earth, more than three times the distance of the Moon from Earth. In comparison, the Hubble Space Telescope is in near-Earth orbit, approximately 350 miles above the ground.

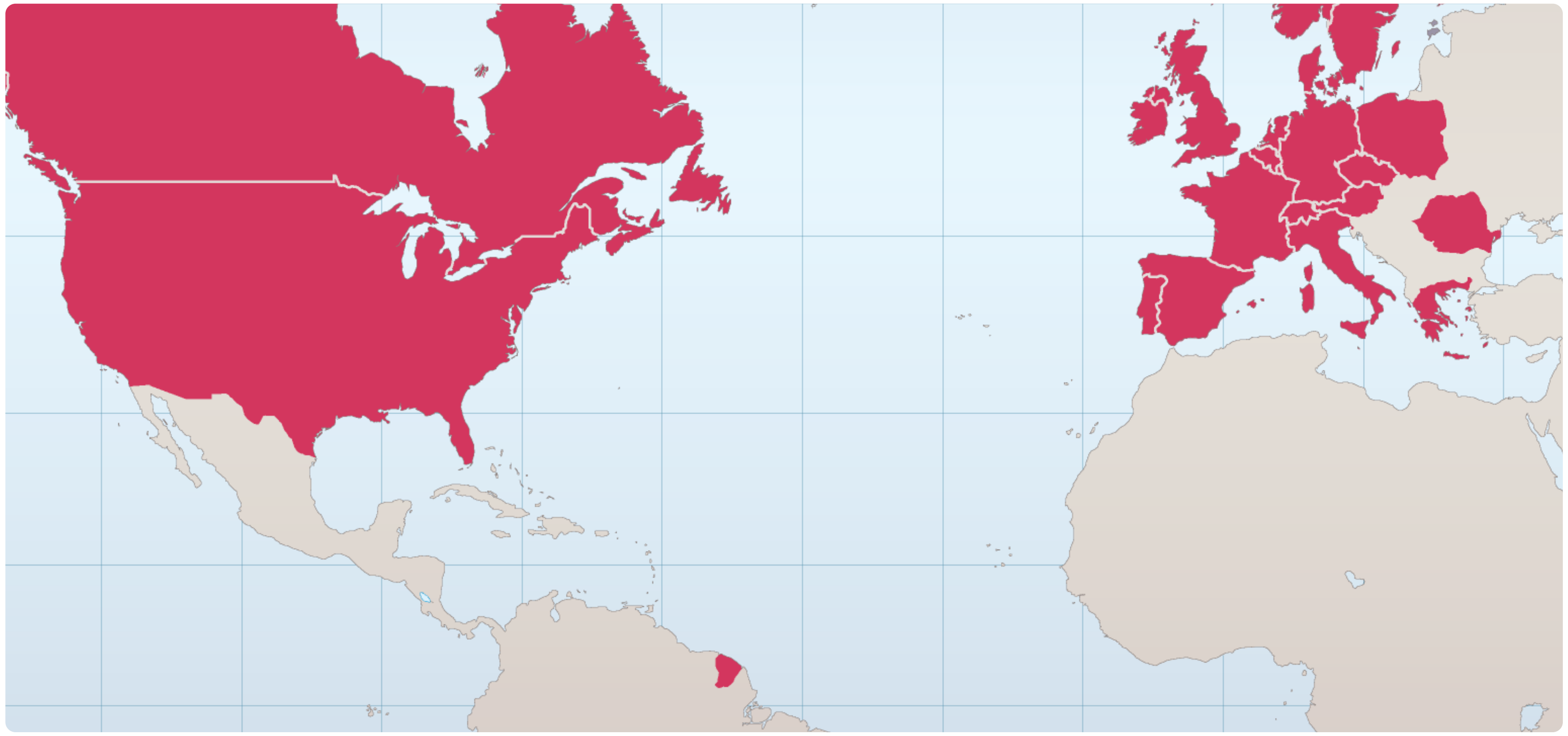
Movie 3.5 Previous Launch of an Ariane 5 Rocket



An Ariane 5 rocket, flight V192, lifts off from Europe's Spaceport in French Guiana, 2009

The Webb telescope will be launched from the Arianespace's ELA-3 launch complex near Kourou, French Guiana, located in South America. Being near Earth's equator, this launch site will take advantage of the rotation of the Earth, imparting an extra boost to the rocket, helping to send it into orbit and on to its ultimate destination.

Figure 3.9 Countries involved in Webb's development



Countries highlighted in red on this map are participating in Webb's creation, their contributions covering everything from design to launch.

Worldwide Involvement

Dozens of contractors and subcontractors throughout the US and around the world are contributing to the Webb Space Telescope. Here are some of the key participants.

NASA Centers:

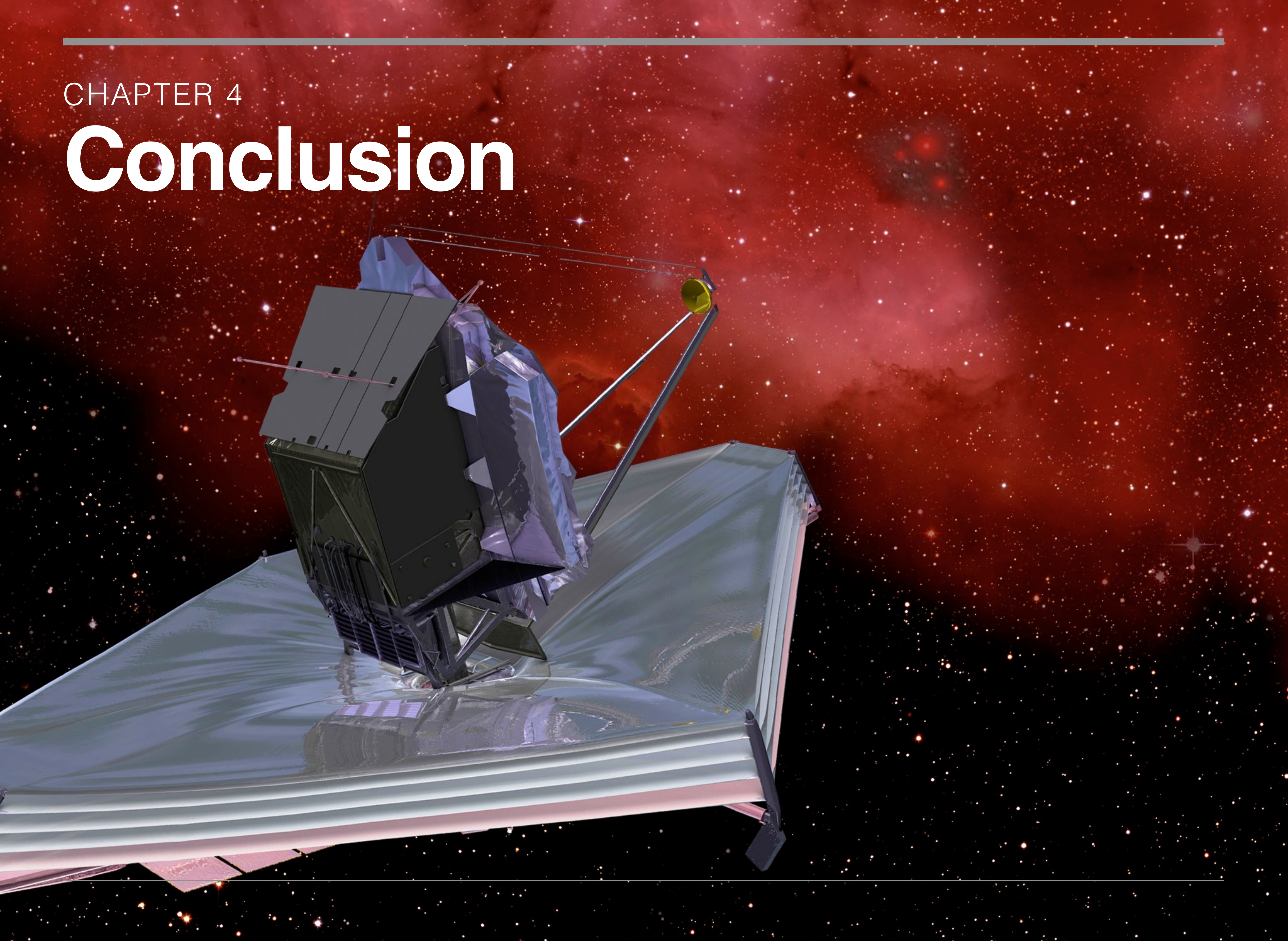
- Goddard Space Flight Center:
  Webb lead, oversees development, construction and testing
- Marshall Space Flight Center:
  Mirror testing
- Johnson Space Center:
  Observatory testing

Major Contractors:

- Northrop Grumman Aerospace Systems:
  Prime contractor
- Ball Aerospace:
  Constructing the primary mirror
- ATK:
  Providing sunshield material
- European Space Agency:
  Responsible for NIRSpec and MIRI
- EADS-Astrium:
  Working on NIRSpec
- European Consortium:
  Contributing to MIRI
- Jet Propulsion Laboratory:
  Contributing to MIRI
- Lockheed Advanced Technology:
  Working on NIRCam
- Canadian Space Agency:
  Constructing the FGS guider and NIRISS
- ComDev:
  Working on FGS

CHAPTER 4

Conclusion



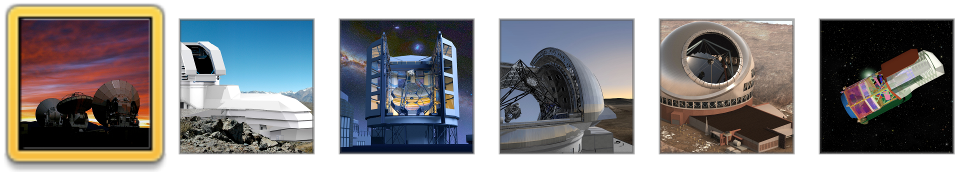
Built on the heritage of the Hubble (optical) and Spitzer (infrared) Space Telescopes, Webb is the cornerstone of the National Academy of Science's 2010 decadal survey.

Other telescopes were recommended with the assumption that Webb will be up and operating and working in symbiosis with them.

The James Webb Space Telescope will push the boundaries of our vision and uncover new details about the hidden universe. Its innovative design, colossal size and incredible resolution will open up a new version of the universe to us – the invisible infrared universe. But as unique as Webb is, it won't be working alone.

Gallery 4.1 Webb's Partnering Observatories

Atacama Large Millimeter/submillimeter Array (ALMA) test facility



Synergy Between Future Facilities

Intriguingly, Webb will have a special impact when working in synergy with other next-generation ground- and space-based observatories. During the past several decades, a number of major discoveries have been made when two or more observatories worked in concert to study the same object. The Hubble Space Telescope has often been used in collaboration with telescopes such as the Keck Observatory in Hawaii and the Very Large Array (VLA) in New Mexico. These

Figure 4.1 **Synergy Between Observatories**

	JWST	GSMT	WFIRST	ALMA	LSST
Cosmic Dawn Can we see the first stars and galaxies in the universe?	●	●	●	●	
New Worlds How do stars and planets like our own form?	●		●	●	
Physics of the Universe What are the laws that govern our universe?		●	●		●

These telescopes' different areas of expertise will allow astronomers to obtain a comprehensive view of the universe.

ground-based telescopes added additional wavelength coverage to research and also utilized their greater resolution to expand the science impact of Hubble.

It is anticipated that Webb will undertake similar collaborations with other leading-edge instruments. These next-generation observatories, which will become operational during Webb's lifespan, will add their unique capabilities to address the major science questions highlighted in the National Research Council's most recent Decadal Survey.

The Atacama Large Millimeter/submillimeter Array (ALMA) will study the cold, dark regions of the universe that shine brightly in the millimeter portion of the spectrum, such as protoplanetary disks. This will complement Webb's studies in the infrared of these same areas.

In addition, a Giant Segmented Mirror Telescope (GSMT) will be able to achieve higher resolution spectroscopy of very faint and distant objects, helping to unravel the shape and motion of very early galaxies.

Along with the Large Synoptic Survey Telescope (LSST) and the Wide-Field Infrared Survey Telescope (WFIRST), Webb will use techniques such as gravitational lensing, the property of light to bend around massive objects, to expand our understanding of dark energy and to better map the distribution of dark matter. It will also be able to find very distant supernovae that Webb will be able to follow.

What We Don't Know

In its quest to detect the oldest stars and the most distant galaxies, the Webb Telescope will serve as a cosmic time machine, taking astronomers and the public back to when the first sources of light in the universe burst into existence, setting the stage for all of cosmic evolution.

These questions are clearly within the reach of Webb, but what are most intriguing are the questions we can't yet foresee and the discoveries that will once again reshape our understanding of space and our place in the universe.

When the Hubble Space Telescope was launched, it too had specific, pressing science topics to explore. Yet some of Hubble's most significant discoveries – such as the mysterious, unexplained "dark energy" driving the universe's expansion faster and faster – have been a surprise, arising from areas that astronomers never expected.

We can only wonder at the possibilities Webb poses, the astronomy-changing shocks and marvels it may have in store for us, once it takes to the stars.

The Legend Behind the Name

The Webb Telescope was named after the second NASA administrator James Edwin Webb. During his service from 1961–1968 he oversaw great progress in the space program. Webb strengthened the space science program and was responsible for over 75 launches. He also helped pave the way to future NASA successes, such as the historic Apollo lunar landing, which took place shortly after his retirement from NASA in 1968.

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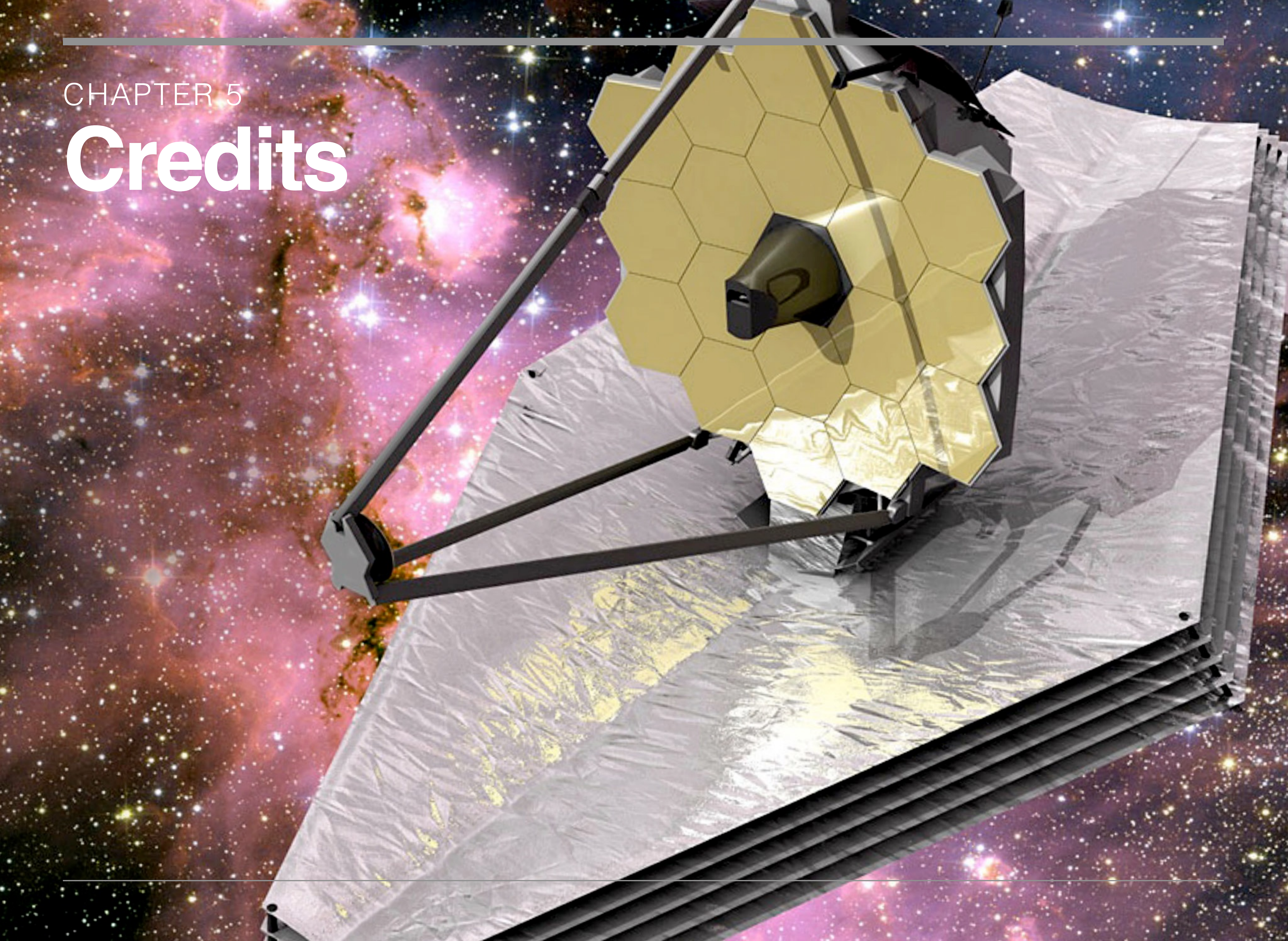
Figure 4.2 **James Webb (1906–1992)**

CHAPTER 5

Credits



Contributors

Produced by the Space Telescope Science Institute (STScI)

Production team: *Chuck Blue, Tony Darnell, Tiffany Davis, Christine Godfrey, Nelly Ivanova, Ann Jenkins, Stephanie Smith, Ray Villard, Tracy Vogel, Donna Weaver*

Science advisors: *Alberto Conti, Jason Kalirai, Massimo Stiavelli, Frank Summers*

Many thanks to our colleagues at STScI and NASA's GSFC, including Alberto Conti, Bonnie Eisenhamer, Stratis Kakadelis, Mike McClare, Ray Villard and Ann Feild

Figure 5.1 The SASP Webb eBook Team

STScI summer student, Nelly Ivanova (center), with her 2012 SASP mentors for the JWST eBook project, Tiffany Davis and Alberto Conti.

Space Astronomy Summer Program Internship: Webb eBook Project

The Space Telescope Science Institute, home to the scientific operations center for the Hubble Space Telescope and the future James Webb Space Telescope, brings highly motivated college students with a strong interest in space astronomy to Baltimore, Md., each summer for the Space Astronomy Summer Program (SASP).

Students work individually with STScI researchers and staff on projects that include data reduction and interpretation, software development, scientific writing, and preparing data for public releases. The program's goals are to expose advanced undergraduates to forefront research in astrophysics and the workings of a space-based observatory; provide opportunities for growth, achievement, and personal development; and help students develop and maintain contacts among colleagues and peers.

The Webb eBook Project is heavily indebted to Nelly Zhivkova Ivanova, who was selected from over 300 applicants to participate in the 2012 SASP. Nelly is currently completing her combined bachelor's/master's degree in Journalism and Science Communication at Sofia University in Bulgaria. During her academic career, Nelly has interned at national newspapers, movie production studios, youth astronomy conferences, and has traveled much of Europe to pursue her interest in journalism. She has received numerous national and international awards for her academic knowledge of astronomy, physics and math, as well as her creative abilities in literature. She desires to someday have a profession that combines her two passions – astronomy and journalism.

Credits

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- *Webb model credit: Northrop Grumman Corporation, NASA, and G. Bacon (STScI)*

Opening Movie

Credit: NASA/Goddard Space Flight Center

Chapter 1: Introduction

PAGE 1

Webb-Milky Way Illustration
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Artist Concepts of Webb
Credit: NASA

Section 1: Sifting Through Cosmic Time

PAGE 4

Figure 1.1
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Interactive 1.1
Credit: NASA, and Northrop Grumman Corporation

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Spiral Galaxy NGC 4911 in the Coma Cluster
Credit: NASA, ESA and the Hubble Heritage Team (STScI/AURA)

Ancient Galaxy Cluster Still Producing Stars
Credit: NASA/JPL-Caltech/K. Tran (Texas A&M Univ.)

Artist's View of Extrasolar Planet HD 189733b
Credit: NASA, ESA, and G. Bacon (STScI)

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Interactive 1.2
Credit: NASA, ESA, and Hubble SM4 ERO Team

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Interactive 1.3

- *Visible image credit: NASA, ESA, S. Beckwith (STScI), and The Hubble Heritage Team (STScI/AURA)*
- *Near-infrared image credit: 2 Micron All-Sky Survey (2MASS) project, UMass/IPAC-Caltech*
- *Mid-infrared image credit: NASA/JPL-Caltech/R. Kennicutt (Univ. of Arizona)*

Figure 1.2
Artwork credit: Gemini Observatory, courtesy of L. Cook
Science credit: NASA, ESA, and K. Todorov and K. Luman (Penn State University)

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Figure 1.3
Diagram credit: NASA and STScI
Science credit: NASA, ESA

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Timeline:

- *1800 image credit: Lemuel Francis Abbott*
- *Early 1920s image credit: Larry Webster, Mount Wilson Observatory*
- *1967 image credit: Hi Star*
- *1974 image credit: NASA*
- *1983 image credit: Infrared Processing and Analysis Center, Caltech/JPL*
- *1995 image credit: ESA/ISD VisuLab*

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Timeline:

- *1997 (1) image credit: Photo by Rae Stiening*
- *1997 (2) image credit: NASA*
- *2003 image credit: NASA/JPL-Caltech/R. Hurt (SSC)*
- *2009 image credit: NASA*
- *2010 image credit: DLR/DSI*
- *JWST ("Future") image credit: NASA*

Section 2: The Giant Space Mirror

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Figure 1.3
Credit: NASA/MSFC/David Higginbotham/Emmett Given

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Figure 1.4
Illustration credit: NASA, ESA, A. Field and C. Godfrey (STScI)
Science Credit: NASA, ESA, G. Illingworth (University of California, Santa Cruz), R. Bouwens (University of California, Santa Cruz, and Leiden University), and the HUDF09 Team

Chapter 2: Science Overview

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Webb Science Illustration
Artwork credit: NASA, and A. Feild (STScI)
Disk credit: ESO/L. Calçada
Galaxies credit: NASA, ESA, S. Beckwith (STScI) and the HUDF Team

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Disk Illustration
Credit: ESO/L. Calçada

Section 1: Dark Ages to First Light

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Movie 2.1
Credit: NASA/Goddard Space Flight Center and the Advanced Visualization Laboratory at the National Center for Supercomputing and B. O'Shea, M. Norman

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Webb's Deep-Core Sample of the Universe
Credit: NASA, ESA, and A. Feild (STScI)

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Gallery 2.1

- *A Giant Hubble Mosaic of the Crab Nebula*
  Credit: NASA, ESA, J. Hester and A. Loll (Arizona State University)
- *Cassiopeia A: Colorful, Shredded Remains of Old Supernova*
  Credit: NASA and The Hubble Heritage Team (STScI/AURA)
- *Gaseous Streamers from Nebula N44C Flutter in Stellar Breeze*
  Credit: NASA and The Hubble Heritage Team (STScI/AURA)
- *Celestial Fireworks: Sheets of Debris From a Stellar Explosion (N 49, DEM L 190)*
  Credit: NASA and The Hubble Heritage Team (STScI/AURA)
- *Supernova Remnant N 63A Menagerie*
  Credit: NASA, ESA, HEIC, and The Hubble Heritage Team (STScI/AURA)
- *Close-Up Visible Light Image of Kepler's Supernova Remnant*
  Credit: NASA, ESA, The Hubble Heritage Team (STScI/AURA)

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Figure 2.1
Credit: NASA, ESA, G. Illingworth (University of California, Santa Cruz), R. Bouwens (University of California, Santa Cruz, and Leiden University), and the HUDF09 Team

Interactive 2.1
HUDF image credit: NASA, ESA, S. Beckwith (STScI) and the HUDF Team
Galaxy separation credit: NASA and F. Summers (STScI)

Section 2: The Cosmic Web

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Movie 2.2 and video stills
Credit: NASA/Goddard Space Flight Center and the Advanced Visualization Laboratory at the National Center for Supercomputing Applications

Background image
Credit: The Millennium Simulation Project, Max-Planck-Institute for Astrophysics, Springel et al. (Virgo Consortium), 2005

Section 3: Building Blocks

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Movie 2.3
Credit: NASA/Goddard Space Flight Center and the Advanced Visualization Laboratory at the National Center for Supercomputing Applications, B. Robertson, L. Hernquist

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Figure 2.2
Credit: NASA/WMAP Science Team

String of galaxies

- *HUDF WFC3/IR*
  Credit: NASA, ESA, G. Illingworth and R. Bouwens (University of California, Santa Cruz), and the HUDF09 Team
- *Elliptical Galaxy NGC 1132 - Hubble*
  Credit: NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration
- *Hubble Interacting Galaxy NGC 6050*
  Credit: NASA, ESA, the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration, and K. Noll (STScI)

- *The Antennae Galaxies/NGC 4038-4039*
  Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)-ESA/Hubble Collaboration
- *Spiral Galaxy M74*
  Credit: NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration
- *Barred Spiral Galaxy NGC 1300*
  Credit: NASA, ESA, and The Hubble Heritage Team (STScI/AURA)

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Andromeda Galaxy
Credit: Bill Schoening, Vanessa Harvey/REU program/NOAO/AURA/NSF

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Gallery 2.2
Credit: NASA, ESA, Sloan Digital Sky Survey, R. Delgado-Serrano and F. Hammer (Observatoire de Paris)

Section 4: New Stars, New Worlds

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Figure 2.3
Credit: NASA,ESA, M. Robberto (Space Telescope Science Institute/ESA) and the Hubble Space Telescope Orion Treasury Project Team

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Interactive 2.2
Credit: NASA,ESA, M. Robberto (Space Telescope Science Institute/ESA) and the Hubble Space Telescope Orion Treasury Project Team and L. Ricci (ESO)

Movie 2.4
Credit: NASA/Goddard Space Flight Center and the National Center for Supercomputing Applications

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Figure 2.4
Illustration credit: NASA and G. Bacon (STScI/AVL)
Science credit: NASA, D. Charbonneau (Caltech & CfA), T. Brown (NCAR), R. Noyes (CfA) and R. Gilliland (STScI)

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Gallery 2.3
- *Three-Trillion-Mile-Long Jet From a Wobbly Star (HH 47)*
  Credit: J. Morse/STScI, and NASA
- *Cosmic Skyrocket*
  Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)
- *Mystic Mountain Jet Detail*
  Credit: NASA, ESA, and M. Livio and the Hubble 20th Anniversary Team (STScI)
- *Reddish Jet of Gas Emanates From Forming Star HH-30*
  Credit: C. Burrows (STScI & ESA), the WFPC 2 Investigation Definition Team, and NASA

Section 4: Living Planets

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Extrasolar Planets
- *Artist's View of Extrasolar Planet HD 189733b*
  Credit: NASA, ESA, and G. Bacon (STScI)
- *Planetary System in the Cygnus constellation*
  Credit: NASA/JPL-Caltech
- *Transiting exoplanet HD 189733b*
  Credit: ESA - C. Carreau
- *Giant Planet*
  Credit: NASA/JPL-Caltech/T. Pyle (SSC)

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Movie 2.5
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Figure 2.5
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Interactive 2.4
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Figure 2.6
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Chemical Soups Around Cool Stars
Credit: NASA/JPL-Caltech/T. Pyle (SSC)

Chapter 3: The Space Telescope

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Webb Telescope Illustration: Front View
Artwork credit: NASA and A. Feild (STScI)
Model credit: Northrop Grumman Corporation, NASA and G. Bacon (STScI)

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Line drawings of Webb
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Interactive 3.1
Credit: NASA

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Interactive 3.2
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Section 1: Sunshield and Cryogenics

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Figure 3.1
Credit: Northrop Grumman Aerospace Systems

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Figure 3.2
Credit: Northrop Grumman

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Movie 3.1
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Figure 3.3
Credit: NASA

Lagrange Point 2
Credit: NASA, ESA, Goddard Space Flight Center and C. Godfrey (STScI)

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Gallery 3.1

- *1/3-scale sunshield*
  Credit: Nexolve
- *Sunshield test article*
  Credit: Northrop Grumman Aerospace Systems
- *Full-scale sunshield pathfinder*
  Credit: Northrop Grumman Aerospace Systems
- *Full-scale sunshield pathfinder, close-up*
  Credit: Northrop Grumman Aerospace Systems
- *Sunshield test article, center portion*
  Credit: Northrop Grumman Aerospace Systems

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Line drawings of Webb
Credit: Northrop Grumman Corporation

Section 2: Mirrors

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Figure 3.4
Credit: NASA/MSFC/David Higginbotham

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Figure 3.5
Credit: STScI

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Movie 3.2
Credit: NASA/Goddard Space Flight Center

Line drawing of Webb
Credit: Northrop Grumman Corporation

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Movie 3.3
Credit: NASA/Goddard Space Flight Center

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Gallery 3.2

- *Uncoated primary mirror segments prepared for testing at Marshall Space Flight Center*
  Credit: NASA/MSFC/Emmett Givens
- *Engineering Design Unit primary mirror segment with gold coating*
  Credit: Drew Noel
- *Engineering Design Unit primary mirror segment being inspected on arrival at Goddard Space Flight Center*
  Credit: NASA/Chris Gunn
- *Primary mirror segments ready for cryogenic testing at Marshall Space Flight Center*
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- *Tertiary mirror in the Aft Optics Bench*
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Credit: NASA and M. Estacion (STScI)

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Credit: NASA/GSFC/Chris Gunn

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Line drawing of Webb
Credit: Northrop Grumman Corporation

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Figure 3.7
Credit: Stephen Kill, STFC

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Line drawing of Webb
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- *MIRI being inspected upon delivery at Goddard Space Flight Center*
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Credit: Arianespace, ESA and NASA

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Figure 4.1
Credit: NASA and C. Godfrey (STScI)

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Figure 4.2
Credit: NASA

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Webb Telescope Illustration from Above
Artwork credit: NASA and A. Feild (STScI)
Model credit: Northrop Grumman, NASA and G. Bacon (STScI)

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Figure 5.1
Credit: STScI

Adaptive optics

A technique that compensates for atmospheric turbulence by quickly adjusting the light path in the optics. This removes seeing effects and enables the telescope to achieve much better resolution, closer to its theoretical resolving power.

Related Glossary Terms

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Chapter 3 - Sunshield and Cryogenics

Arcminute

One arc minute is 1/60 of a degree of arc. The angular diameter of the full moon or the Sun as seen from Earth is about 30 arc minutes.

Related Glossary Terms

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Chapter 3 - Instruments

Atom

The smallest unit of matter that possesses chemical properties. All atoms have the same basic structure: a nucleus containing positively charged protons with an equal number of negatively charged electrons orbiting around it. In addition to protons, most nuclei contain neutral neutrons whose mass is similar to that of protons. Each atom corresponds to a unique chemical element determined by the number of protons in its nucleus.

Related Glossary Terms

Electrons, Neutral atoms, Protons, Subatomic particles

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Big Bang

A broadly accepted theory for the origin and evolution of our universe. The theory says that the observable universe started roughly 13.7 billion years ago from an extremely dense and incredibly hot initial state.

Related Glossary Terms

Reionizing

Index Find Term

Chapter 2 - Dark Ages to First Light

Cosmic microwave background radiation

Radiative energy filling the universe that is believed to be the radiation remaining from the Big Bang. It is sometimes called the “primal glow.” This radiation is strongest in the microwave part of the spectrum but has also been detected at radio and infrared wavelengths. The intensity of the cosmic microwave background from every part of the sky is almost exactly the same.

Related Glossary Terms

Big Bang, Electromagnetic spectrum

Index Find Term

Chapter 2 - Dark Ages to First Light

Cosmic rays

High-energy atomic particles that travel through space at speeds close to the speed of light; also known as cosmic-ray particles.

Related Glossary Terms

Drag related terms here

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Chapter 3 - Sunshield and Cryogenics

Electromagnetic spectrum

The entire range of wavelengths of electromagnetic radiation, including radio waves, microwaves, infrared light, visible light, ultraviolet light, X-rays, and gamma rays.

Related Glossary Terms

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Chapter 1 - Sifting Through Cosmic Time

Electrons

Negatively charged elementary particles that typically reside outside the nucleus of an atom but are bound to it by electromagnetic forces. An electron's mass is tiny: 1,836 electrons equals the mass of one proton.

Related Glossary Terms

Atom, Subatomic particles

Index Find Term

Chapter 2 - Dark Ages to First Light

Galaxies

Collections of stars, gas, and dust bound together by gravity. The smallest galaxies may contain only a few hundred thousand stars, while the largest galaxies have thousands of billions of stars. The Milky Way galaxy contains our solar system. Galaxies are classified or grouped by their shape. Round or oval galaxies are elliptical galaxies and those showing a pinwheel structure are spiral galaxies. All others are called irregular because they do not resemble elliptical or spiral galaxies.

Related Glossary Terms

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Chapter 1 - Sifting Through Cosmic Time

Heavier elements

Hydrogen and helium are the two simplest and dominant elements in the universe. More complex elements, like carbon, gold, nitrogen and oxygen, were created from hydrogen and helium by nuclear fusion and fission. Astronomers call all the elements more massive than these, "heavy elements."

Related Glossary Terms

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Find Term

Chapter 2 - Dark Ages to First Light

Infrared

The part of the electromagnetic spectrum that has slightly lower energy than visible light, but is not visible to the human eye. Just as there are low-pitched sounds that cannot be heard, there is low-energy light that cannot be seen. Infrared light can be detected as the heat from warm-blooded animals.

Related Glossary Terms

Drag related terms here

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Chapter 1 - Introduction

Magellanic Clouds

The Magellanic Clouds are two dwarf irregular galaxies. Known as the Large Magellanic Cloud (LMC) and the Small Magellanic Cloud (SMC), the galaxies are in the Local Group, a small cluster of more than 30 galaxies, which includes the Andromeda and Milky Way galaxies. The closer LMC is 168,000 light-years from Earth. Both galaxies can be observed with the naked eye in the southern night sky.

Related Glossary Terms

Galaxies

Index Find Term

Chapter 2 - Building Blocks

Microwaves

Electromagnetic waves in the region between infrared and radio wavelengths. Microwave wavelengths fall between one millimeter and one meter.

Related Glossary Terms

Cosmic microwave background radiation, Electromagnetic spectrum, Wavelengths

Index Find Term

Neutral atoms

Atoms that have no excess positive or negative charge.

Related Glossary Terms

Atom, Subatomic particles

Index Find Term

Chapter 2 - Dark Ages to First Light

Nuclear fusion

A nuclear process whereby several small nuclei are combined to make a larger one whose mass is slightly smaller than the sum of the small ones. The difference in mass is converted to energy by Einstein's famous equivalence, "Energy = Mass times the Speed of Light squared." Nuclear fusion appears to be the source of the energy of the Sun and of stars.

Related Glossary Terms

Atom

Index Find Term

Chapter 2 - New Stars, New Worlds

Protons

Positively charged elementary particles that reside in the nucleus of every atom.

Related Glossary Terms

Atom, Subatomic particles

Index Find Term

Chapter 2 - Dark Ages to First Light

Quasar

The brightest type of active galactic nucleus, believed to be powered by a supermassive black hole. The word “quasar” is derived from quasi-stellar radio source, because this type of object was first identified as a kind of radio source. Quasars also are called quasi-stellar objects (QSOs). Thousands of quasars have been observed, all at extreme distances from our galaxy.

Related Glossary Terms

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Reionizing

An epoch in the early universe during which the low-density hydrogen gas between galaxies became ionized. Ionization occurred when ultraviolet radiation from the first stars and quasars heated the diffuse material until its electrons were liberated.

Related Glossary Terms

Atom, Big Bang, Electrons, Galaxies, Protons, Quasar

Index Find Term

Chapter 2 - Science Overview

Resolution

A measure of the smallest separation at which a telescope can observe two neighboring objects as two separate objects.

Related Glossary Terms

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Chapter 1 - Sifting Through Cosmic Time

Shockwaves

High-pressure waves that travel at supersonic speeds. Shock waves are usually produced by an explosion.

Related Glossary Terms

Supernovae

Index Find Term

Chapter 2 - Building Blocks

Spectroscopic

The ability to spread electromagnetic radiation into its component frequencies and wavelengths for detailed study. A spectrograph is similar to a prism, which spreads white light into a continuous rainbow.

Related Glossary Terms

Electromagnetic spectrum, Wavelengths

Index Find Term

Chapter 2 - Building Blocks

Subatomic particles

Particles that make up atoms such as protons, electrons and neutrons

Related Glossary Terms

Electrons, Protons

Index Find Term

Chapter 2 - Dark Ages to First Light

Supernovae

The explosive death of massive stars whose energy output causes their expanding gases to glow brightly for weeks or months. A supernova remnant is the glowing, expanding gaseous remains of a supernova explosion.

Related Glossary Terms

Drag related terms here

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Chapter 2 - Dark Ages to First Light

Wavelengths

Light is measured by its wavelength (in nanometers) or frequency (in Hertz). One wavelength equals the distance between two successive wave crests or troughs. Radio waves can have lengths of several feet; the wavelengths of X-rays are roughly the size of atoms.

Related Glossary Terms

Drag related terms here

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Chapter 1 - Sifting Through Cosmic Time