SUBCOMMITTEE ON SPACE AND AERONAUTICS
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

HEARING CHARTER

Unfolding the Universe: Initial Science Results from the James Webb Space Telescope

November 16, 2022
10:30 a.m.
Hybrid: 2318 Rayburn House Office Building and Remotely on Zoom

PURPOSE

The purpose of the hearing is to receive testimony on the initial science, scientific findings and discoveries of National Aeronautics and Space Administration's James Webb Space Telescope, as well as plans for future scientific investigations.

WITNESSES

- **Dr. Mark Clampin,** Astrophysics Division Director, National Aeronautics and Space Administration (NASA)
- **Dr. Steven L. Finkelstein,** Professor of Astronomy, University of Texas at Austin
- **Dr. Natalie Batalha,** Professor of Astronomy and Astrophysics and Director of Astrobiology, University of California, Santa Cruz

OVERARCHING QUESTIONS

- *What are the initial scientific results from the data obtained by the James Webb Space Telescope (JWST)?*
- *What have scientists learned so far from the initial observations, and how has the telescope contributed to our better understanding of the universe?*
- *What new questions in the field of astronomy and astrophysics have been raised by the data obtained by JWST so far?*
- *What are the plans for future scientific investigations with JWST?*

BACKGROUND

NASA, along with its international partners, the European Space Agency (ESA) and the Canadian Space Agency (CSA), launched the James Webb Space Telescope (JWST or Webb) on December 25, 2021, on board an Ariane 5 rocket to its destination at the second Lagrange point, or L2,[1] nearly one million miles away from Earth. After more than 20 years of design, development, and testing, one month of an incredibly complex on-orbit deployment that included 344 potential single-point failures, and six months of commissioning activities, JWST is now conducting science operations as the largest and most powerful telescope humans have ever sent to space.

JWST is a large, infrared, space-based telescope managed within the Astrophysics Division of NASA's Science Mission Directorate. The telescope is intended to be a complement and scientific successor to the Hubble Space Telescope and the Spitzer Space Telescope, two of NASA's Great Observatories.[2] JWST's unprecedented improvements in sensitivity and resolution allow astronomers to see the Universe in greater detail and at further distances. NASA formally authorized the start of project formulation for the Next Generation Space Telescope (NGST), as the mission was then named, in 1999. In 2000, the NGST was recommended as the top-priority major initiative of the decadal survey in astronomy and astrophysics and envisioned as an 8-meter-class infrared space telescope "designed to detect light from the first stars and to trace the evolution of galaxies from their formation to the present" that "will revolutionize understanding of how stars planets form in our galaxy today."[3] Those themes have carried through as the scientific thrusts of the JWST mission today.

The Committee on Science, Space, and Technology held multiple oversight hearings during the development of the James Webb Space Telescope, including in 2011, 2015, and 2018. Today's hearing is the Committee's first hearing on the early science and scientific results of the telescope's observations.

<u>Infrared Astronomy</u>

JWST is optimized to observe infrared light. The human eye detects visible, or optical, light, while infrared light has a longer wavelength and lies just beyond the red end of the optical portion of the electromagnetic spectrum, as shown in Figure 1. Infrared light is used in astronomy to study cooler objects, such as young stars that have not yet begun burning hydrogen or planets forming in disks around stars. Astronomers also observe in the infrared range to see through dust—which usually blocks optical light—within nebula or star-forming clouds. The light from the first stars and galaxies in the Universe is originally emitted as optical or ultraviolet light, but it arrives to Earth in the form of infrared light because it is stretched to a longer wavelength by traveling great distances across an expanding universe. Astronomers refer to this stretching effect as "redshift."

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[1] Lagrange Points are five positions where the gravitational forces of two large objects—such as the Earth and the Sun—equals the centripetal force required for a small object—such as a spacecraft—to orbit in place relative to the two larger objects. In the Earth-Sun system, L2, or the second Lagrange Point, is directly opposite the Earth from the Sun, one million miles from Earth.
[2] The Great Observatories are a series of space-based telescopes launched over the course of two decades and comprised of the Hubble Space Telescope, Compton Gamma-Ray Observatory, Chandra X-Ray Observatory, and Spitzer Space Telescope.
[3] National Research Council. *Astronomy and Astrophysics in the New Millennium.* Washington, DC: The National Academies Press, 2001. Available at: https://doi.org/10.17226/9839.

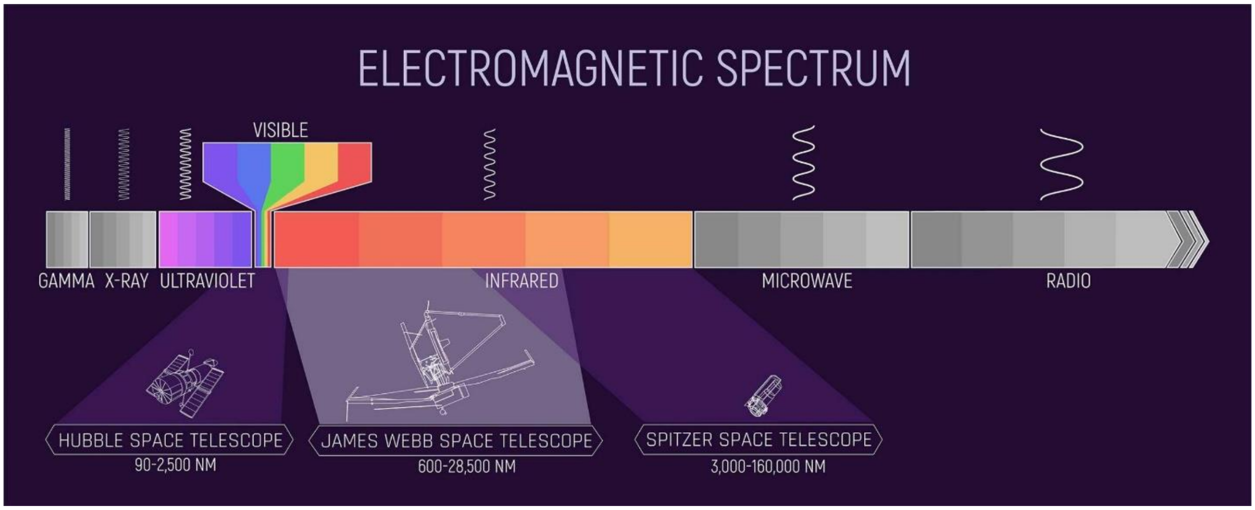

Figure 1: JWST observes infrared light, which is just beyond the red end of the visible portion of the electromagnetic spectrum. Credit: NASA and J. Olmstead (STScI).

Astronomers subdivide the infrared spectrum into three categories, defined by wavelength: near-infrared, mid-infrared, and far-infrared. JWST observes in near- and mid-infrared wavelengths. Near-infrared light has the shortest wavelength, closest to the red end of the optical portion of the electromagnetic spectrum; cooler stars are brightest in the near-infrared, and dust is typically transparent. In the mid-infrared range, astronomers can see and study the dust itself when it is warmed up by starlight, and planetary bodies, including planets, asteroids, and comets. As shown in Figure 1,[4] NASA's Hubble telescope observes in the ultraviolet, visible, and near-infrared ranges, while the Spitzer Space telescope, decommissioned in 2020 after a sixteen-year mission, observed in the mid- and far-infrared.

Science of the JWST Mission

As a large flagship mission, JWST is expected to address a wide range of scientific questions across astronomy and astrophysics. The mission's key science objectives are divided into four science themes:[5,6]

- **The End of the Dark Ages: First Light and Reionization**: According to theory and observations, right after the Big Bang, in a period astronomers call the Dark Ages, the early Universe was hot, dark, and made up of uncombined protons, electrons, and neutrons. After up to a few hundred million years, atoms and then molecules formed and eventually formed the first stars and galaxies, the first light sources. As those stars and galaxies formed and evolved, all of the hydrogen in between galaxies went from being neutral to ionized (having charge) by approximately one billion years after the Big Bang, and that hydrogen remains ionized today. Within the first light and reionization theme,

[4] Available at: https://webbtelescope.org/contents/media/images/4188-Image.
[5] Gardner, J.P., Mather, J.C., Clampin, M. *et al.*, "The James Webb Space Telescope," 2006, *Space Sci Rev* **123**, 485–606. Available at: https://doi.org/10.1007/s11214-006-8315-7.
[6] Space Telescope Science Institute, "JWST's Science Focus." Available at: https://www.stsci.edu/jwst/about-jwst/science-themes.

JWST's key science objective is to find and understand these very first stars and galaxies and the ionization history of the early universe.

- **The Assembly of Galaxies**: Models and observations show that small galaxies were the first to form, and, over a process that continues today, become larger through interactions and with one another. Black holes at the centers of galaxies, star formation, and the explosions or collisions of stars all are theorized to play a role in this process of galaxy assembly. Within the assembly of galaxies theme, JWST's key science objective is to observe galaxies across cosmic time, from the earliest era (Reionization) to present to better understand how they evolve and how their compositions change over time.
- **The Birth of Stars and Protoplanetary Systems**: Large clouds of gas and dust, into which it is difficult to see, form dozens or hundreds of stars at a time as the gas and dust gravitationally condenses and eventually ignites nuclear fusion. Most stars are found in pairs, called binaries, or in larger multi-star systems. Planets generally form in the material leftover from star formation, which forms disks around young stars, called protoplanetary disks. For the birth of stars and protoplanetary systems theme, JWST's key science objective is to study, in detail, the complex process that form individual stars and eventual planetary systems and the distinct phases of those processes.
- **Planetary Systems and the Origins of Life**: Searches using both ground-based and space-based telescopes have identified thousands of planets that orbit stars other than our Sun—exoplanets—and have shown that most stars have at least one planet. Many stars have planetary systems that look very different from our own Solar System, such as having Jupiter-sized exoplanets closer to the star than Mercury is to the Sun. The physical characteristics of different exoplanets and planetary systems—such as planet size, number and arrangement of planets—as well as their chemical compositions may reflect how they formed and evolved and the means through which life can form. For this theme on planetary systems and the origins of life, JWST's key science objective is to characterize planets and planetary bodies in our own Solar System and in systems around other stars, which includes investigating the potential for the origins of life.

JWST Observatory and Scientific Instruments

The primary mirror of JWST is 6.5 meters across at its widest point and comprises 18 hexagonal, gold-coated segments. The primary mirror initially collects light, which is then focused onto a secondary mirror and then directed into the scientific instruments. A five-layer sunshield, approximately the size of a tennis court, prevents heat and light from external sources—such as the Sun and other planets as well as the telescope's own spacecraft hardware—from reaching the telescope optics and scientific instruments. With the sunshield in place, the telescope mirrors and scientific instruments operate at a temperature of 37 Kelvin (-395°F), which is necessary to observe in the infrared.

The observatory has four scientific instruments:

- **Near-Infrared Camera (NIRCam)** takes images in near-infrared wavelengths, and it is equipped with multiple coronagraphs, which can block the light from a very bright object, like a star, to allow imaging of a nearby faint object, like a companion brown dwarf or distantly orbiting planet. NIRCam will be used to study early galaxies, young stars in our own Milky Way, and the small, icy bodies in the Kuiper Belt of our own Solar System.

- **Near-Infrared Spectrograph (NIRSpec)** disperses near-infrared light into individual wavelengths of light to create a spectrum, onto which atoms and molecules imprint unique features that can reveal detailed characteristics about an astronomical object, such as temperature, rotation speed, and chemical composition. The NIRSpec microshutter array,[7] has approximately 250,000 individual microshutters, or tiny windows that open and close individually to allow the instrument to collect spectra simultaneously from up to 100 different objects. NIRSpec will characterize very faint, distant objects, like the first galaxies to form after the Big Bang, as well as the atmospheres of exoplanets.
- **Mid-Infrared Instrument (MIRI)** is both a camera and a spectrograph for mid-infrared observations. MIRI will be able to take wide images of large, resolved objects, like nebulae and star-forming regions in the Milky Way. To observe in the mid-infrared, MIRI needs to be further cooled to 7 K (-441°F), which is accomplished by a cryocooler, which acts essentially as a refrigerator.[8] Spectroscopy with MIRI will enable further detailed study of star formation in distant galaxies and exoplanet atmospheres.
- **Fine Guidance Sensor/Near-Infrared Imager and Slitless Spectrograph (FGS/NIRISS)** is a single instrument module comprising a coupled pair of instruments. The FGS is optimized for extreme accuracy and stability to ensure JWST is pointing precisely for all of its scientific observations. NIRISS collects near-infrared imagery and spectroscopy that complements JWST's other near-infrared instruments. NIRISS being directly coupled with FGS enables unique observations that rely on extremely high stability, such as imagery of fine detail or distinct spectra of objects very close together. NIRISS will observe exoplanet atmospheres as well as galaxies, including early galaxies whose appearances on the sky are enlarged but also warped by a phenomenon called gravitational lensing.[9]

Initial Science Observations

On July 12, 2022, NASA released the first scientific images from JWST after a six-month process of testing and commissioning the instruments to ensure they operate and perform as designed. At that point, the mission commenced full scientific operations of the telescope. JWST observing time is allocated by specific science investigations, and potential observers submit proposals to define observations needed for science investigations. Observing programs are typically allocated over approximately one-year cycles designated by number (Cycle 1, Cycle 2, *et cetera*). General Observer (GO) programs are the largest category of scientific observations, and are programs openly solicited from the scientific community and selected through peer review. Guaranteed Time Observations (GTO) programs are defined by the instrument and telescope science teams and associated interdisciplinary scientists. A Director's Discretionary

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[7] Microshutters are a new technology that was developed for JWST. The 250,000 microshutters on the NIRSpec array are each 100 micrometers (μm) long by 200 μm wide. NASA, "Webb Innovations: Microshutters." Available at: https://www.jwst.nasa.gov/content/about/innovations/microshutters.html.

[8] NASA, "Webb Innovations: Cryocooler." Available at: https://webb.nasa.gov/content/about/innovations/cryocooler.html.

[9] Gravitational lensing occurs when a distant object—such as an early galaxy—is blocked behind a large, nearby object—such as a massive galaxy or cluster of galaxies—as viewed from Earth. The light from the distant object can be bent by the gravity around the massive object and produce a magnified, but distorted image of the distant object.

Time allocation is used to conduct time-critical observations that cannot be performed through a GO or other proposal cycle. In addition, a small allocation is reserved for ongoing calibration programs that support all of the science programs and instruments.