The James Webb Space Telescope

RESEARCH ARTICLE

TABLE OF CONTENTS

1. Introduction

The James Webb Space Telescope (JWST), also known as Webb, is a powerful space observatory designed to observe infrared light. It builds upon and expands the discoveries made by the Hubble Space Telescope. With its ability to detect longer wavelengths and its significantly enhanced sensitivity, Webb can observe farther into the past to detect the earliest galaxies formed in the universe and can look through dust clouds where new stars and planetary systems are currently taking shape

2. Mission Objectives

The James Webb Space Telescope is a giant leap forward in our quest to understand the universe and our origins. Webb is examining every phase of cosmic history: from the first luminous glows after the Big Bang to the formation of galaxies, stars, and planets to the evolution of our own solar system. Webb's infrared-detecting technology reveals the hidden universe to our eyes: stars shrouded in clouds of dust, water in the atmospheres of other worlds, and the first light from some of the earliest galaxies ever formed.

2.1 Early Universe

Webb is a powerful time machine with infrared vision that is peering back over 13.5 billion years to see the first stars and galaxies forming out of the darkness of the early universe.

Understanding the Early Universe.

> After the Big Bang, the universe was a hot, opaque "soup" of particles (i.e. protons, neutrons, and electrons). About 300,000 years later, during the era of recombination, protons and electrons combined to form neutral atoms, making the universe transparent and allowing light to travel freely for the first time. However, the universe remained dark until the first stars ignited, ending the cosmic dark ages. These first stars were massive and short-lived, producing intense ultraviolet light that ionized hydrogen atoms in a period called the epoch of reionization (up to about 1 billion years after the Big Bang).

JWST's Role

JWST will conduct ultra-deep infrared surveys to detect the faintest, most distant galaxies. It will perform spectroscopy to analyse the composition and properties of these early objects.

By studying the epoch of reionization, JWST will help answer fundamental questions like when and how reionization occurred, what the first galaxies were like, and what sources caused reionization.

Significance

Observing the first light sources helps us understand how the universe evolved from a simple particle soup to the complex cosmic structures we see today.

https://science.nasa.gov/wp-content/uploads/2023/06/webb-flickr-52210366419-b1d32fcb3f-4k-jpg.webp?resize=1960,2000 (Attached image)

2.2 Galaxies Over Time

Webb's unprecedented infrared sensitivity is helping astronomers to compare the faintest, earliest galaxies to today's grand spirals and ellipticals, helping us to understand how galaxies assemble over billions of years.

Types and Evolution of Galaxies

- Spiral galaxies, like our Milky Way and NGC 3344, formed over billions of years through processes including galaxy collisions.
- Elliptical galaxies are generally formed by the collision and merging of similarly sized galaxies.

Role of Dark Matter

Dark matter, an unseen type of matter that constitutes roughly five times the mass of ordinary matter, serves as the cosmic framework. Galaxies develop as normal matter accumulates within concentrations of dark matter. These dark matter structures expand hierarchically, with smaller clumps merging to form larger ones, directing the process of galaxy formation.

How do Galaxies form Today?

- Galaxy assembly continues, with many ongoing mergers and collisions.
- For example, the Andromeda galaxy is predicted to collide with the Milky Way billions of years from now.

JWST's Role

- JWST observes galaxies from the distant past to compare with nearby galaxies, helping to trace galaxy growth and evolution.
- Its advanced instruments allow detailed study of early stars, chemical element formation, and galaxy mergers.
- Spectroscopic surveys of thousands of galaxies will deepen understanding of how galaxies formed, evolved, and built-up heavier elements over time.

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2.3 Star Lifecycle

Webb can penetrate and observe massive clouds of dust that block visible-light telescopes like Hubble, revealing regions where stars and planetary systems are forming.

The Hidden Stars Within Dusty Nebulae

https://science.nasa.gov/wp-content/uploads/2023/06/mystic-mountains-jpeg.webp

The iconic "Pillars of Creation" in the Eagle Nebula, as seen in visible light by the Hubble Space Telescope, are towering columns of gas and dust where new stars are being born. However, many of these newborn stars remain hidden from view because their visible light is blocked by thick dust clouds.

When observed in infrared light, more structure within the dust is revealed, and stars previously invisible emerge. Even Hubble's near-infrared images can unveil hidden stars, but a telescope optimized for infrared—like the James Webb Space Telescope (JWST)—can see even deeper into these cosmic nurseries.

Why Infrared Matters

Infrared telescopes can "see through" dust that blocks visible light. This is similar to how an infrared camera can detect the warmth of a person's arm hidden inside a plastic bag, even though the arm is invisible to the naked eye. In astronomy, this ability allows scientists to observe the heat (infrared light) emitted by stars and planets forming within dense clouds.

Revealing the Birthplaces of Stars and Planets

- **Nebulae like the Eagle and Carina are stellar nurseries, where clouds of gas and dust collapse to form new stars.**
- **In visible light, these regions appear as opaque clouds, but in infrared, the hidden stars and intricate structures become visible.**

JWST's Role

To study the birth and evolution of stars and planets, astronomers must look into the dense, dusty cores of nebulae—regions opaque to visible light but transparent in infrared. Infrared telescopes like JWST can:

- Observe star formation hidden within dust clouds.

- Image disks of material around young stars, revealing early planetary systems.
- Detect organic molecules crucial for life.

2.4 Other Worlds

Webb is telling us more about the atmospheres of extrasolar planets, and perhaps will even find the building blocks of life elsewhere in the universe. In addition to other planetary systems, Webb is also studying objects within our own Solar System.

Exoplanet Discoveries and Methods

- The first discovered exoplanet orbited a pulsar, an unexpected host star type. Since then, thousands of exoplanets have been found around various types of stars, with efforts increasingly focusing on smaller, Earth-like planets.
- JWST studies exoplanets primarily through infrared observations, which are ideal because many atmospheric molecules have strong spectral features in the infrared.
- Key techniques include:
  - Transit method: Detecting dips in starlight as planets pass in front of their stars.
  - Spectroscopy: Analysing starlight filtered through a planet's atmosphere to identify chemical signatures like water, methane, and sodium.
  - Coronagraphy: Blocking starlight to directly image faint exoplanets near bright stars.
- JWST has achieved the first direct image of an exoplanet (e.g., a Saturn-mass planet around star TWA 7), opening new frontiers for atmospheric characterization.

Scientific Goals for Exoplanets

- Understand how planets form and evolve, including their building blocks and orbital dynamics, and search for planets in the habitable zone where liquid water and life might exist.
- Characterize atmospheres to detect potential biosignatures and study planetary systems' chemical and physical histories.

Solar System Studies

- JWST complements other NASA missions by providing high-sensitivity infrared observations of planets, moons, asteroids, comets, and Kuiper Belt objects.
- JWST will monitor seasonal weather on giant planets and study small bodies' mineralogy inaccessible to Earth-based telescopes.

3. Technical Design and Engineering

The Observatory is the space-based portion of the James Webb Space Telescope system. It is comprised of the Optical Telescope Element (OTE), the Integrated Science Instrument Module (ISIM), the sunshield, and the spacecraft bus.

Optical Telescope Element OTE

The OTE is the eye of the Observatory. It consists of the mirrors and the backplane. The OTE gathers the light coming from space and provides it to the science instruments located in the ISIM. The backplane is like the “spine” of Webb. It supports the mirrors.

The Optical Telescope Element OTE includes:

- Mirrors: Webb is known for its iconic hexagonally segmented golden primary mirror but there are 3 other mirrors in Webb's optics that all function together to bring light to Webb's instruments
    - Diameter: 6.5 meters (21 feet), made of 18 gold-coated beryllium hexagonal segments.
    - Collecting Area: 25.4 m^2, over six times larger than Hubble’s mirror

      https://science.nasa.gov/wp-content/uploads/2023/09/5890960025-42fefef802-b.jpg {Attached image)

  - Backplane: The backplane is actually part of what we call the "telescope structure" and includes: the backplane; the secondary mirror support structure; the main backplane support fixture (BSF); and the deployable tower structure that lifted the telescope off of the spacecraft. The three arms at the top come together into a ring where the round secondary mirror resides.

ISIM and Instruments

The Integrated Science Instrument Module ISIM contains Webb’s cameras and instruments. It integrates four major instruments and numerous subsystems into one payload.

- The Integrated Science Instrument Module contains these instruments:

Instrument	Function	Key Features

NIR Cam (Near-Infrared Camera)	Imaging and spectroscopy (0.6–5 μm)	Aligns mirrors, blocks bright objects, studies early galaxies and exoplanets
NIR Spec (Near-Infrared Spectrograph)	Multi-object spectroscopy (0.6–5 μm)	Uses micro shutter arrays to observe up to 100 objects simultaneously, analyzes composition and motion
MIRI (Mid-Infrared Instrument)	Imaging and spectroscopy (5–28 μm)	Probes colder objects, studies star and planet formation, and uses an advanced cryocooler
FGS/NIRISS (Fine Guidance Sensor/Near-Infrared Imager and Slitless Spectrograph)	Precision pointing, imaging, spectroscopy	Enables high-precision observations, studies exoplanet atmospheres

Sunshield

The sunshield separates the observatory into a warm sun-facing side (spacecraft bus) and a cold anti-sun side (OTE and ISIM). The sunshield keeps the heat of the Sun, Earth, and spacecraft bus electronics away from the OTE and ISIM so that these pieces of the Observatory can be kept very cold (The operating temperature has to be kept under 50 K or - 370 F).

- Size: 22 x 12 meters (about the size of a tennis court).
- Layers: Five layers of Kapton E with aluminium and doped-silicon coatings.
- Function: Reduces temperature from ~85°C on the hot side to ~–233°C on the cold side, enabling infrared observations.

Spacecraft Bus

The spacecraft bus provides the support functions for the operation of the Observatory. The bus houses the six major subsystems needed to operate the spacecraft: the Electrical Power Subsystem, the Attitude Control Subsystem, the

Communication Subsystem, the Command and Data Handling Subsystem, the Propulsion Subsystem, and the Thermal Control Subsystem.

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Webb's Launch and Beyond

Launch Date: Webb was launched on December 25, 2021 in French Guiana.

Vehicle: The James Webb Space Telescope was launched on an Ariane 5 rocket. The launch vehicle and launch site were part of the European Space Agency's contribution to the mission.

Location: Webb was launched from Arianespace's ELA-3 launch complex at Europe's Spaceport located near Kourou, French Guiana.

Components

The Launch Segment has 3 primary components:

1. Launch Vehicle: an Ariane 5 with the cryogenic upper stage provided in the single launch configuration, with a long payload fairing providing a maximum 4.57-meter static diameter and useable length of 16.19 meters.
2. Payload Adapter: comprised of the Cone 3936 plus the ACU 2624 lower cylinder and clamp-band, which provided the separating mechanical and electrical interface between the Webb Observatory and the Launch Vehicle.
3. Launch campaign preparation and launch campaign. The launch campaign preparation and launch campaign were the mutual responsibility of NASA, ESA, Northrop Grumman, and Arianespace.

Webb's Orbit

Unlike Hubble, which orbits Earth at only a few hundred miles up, Webb orbits the Sun almost a million miles from Earth at a location known as L2.

A Solar Orbit: The James Webb Space Telescope actually orbits the Sun, 1.5 million kilometres (1 million miles) away from the Earth at what is called the second Lagrange point or L2.

Getting There: It took roughly 30 days for Webb to reach the start of its orbit at L2, but it took only 3 days to get as far away as the Moon’s orbit, which is about a quarter of the way there.

Webb at L2: Webb orbits around L2; it does not sit precisely at L2. Roughly to scale; it is actually similar in size to the Moon's orbit around the Earth! This orbit (which takes Webb about 6 months to complete once) keeps the telescope out of the shadows of both the Earth and the Moon. Unlike Hubble, which goes in and out of Earth shadow every 90 minutes, Webb has an unimpeded view that allows science operations 24/7.

What is L2?

Joseph-Louis Lagrange was an 18th-century mathematician who found the solution to what is called the “three-body problem.” That is, is there any stable configuration in which three bodies could orbit each other, yet stay in the same position relative to each other? As it turns out, there are five solutions to this problem - and they are called the five Lagrange points, after their discoverer. At Lagrange points, the gravitational pull of two large masses precisely equals the centripetal force required for a small object to move with them.

Keeping Webb Cool

Webb primarily observes infrared light, which can sometimes be felt as heat. Because the telescope observes the very faint infrared signals of very distant objects, it needs to be shielded from any bright, hot sources. This also includes the satellite itself! The sunshield serves to separate the sensitive mirrors and instruments from not only the Sun and Earth/Moon, but also the spacecraft bus.

The telescope itself operates at about 225 degrees below zero Celsius (minus 370 Fahrenheit). The temperature difference between the hot and cold sides of the telescope is huge - you could almost boil water on the hot side, and freeze nitrogen on the cold side!

To have the sunshield be effective protection (it gives the telescope the equivalent of SPF one million sunscreen) against the light and heat of the Sun/Earth/Moon, these bodies all have to be located in the same direction.

This is why the telescope is out at the second Lagrange point.

Webb's Deployment

Webb's fully deployed operational configuration is far too large to fit into any available rocket so it was designed to fold into a compact launch configuration that fit inside the Ariane 5.

Folding For Launch

Webb's design was not only driven by the science requirements for the mission, but also by the need to be able to fold it tightly for launch and successfully deploy it in space while in flight to its final destination orbiting L2(Lagrange point 2)

Unfolding Webb

Webb's First 6 Months

The Ariane 5 launch vehicle provided thrust for roughly 26 minutes after liftoff from French Guiana. Moments after the upper (second) stage engine cut-off, Webb separated from the upper stage and began flying on its own in its fully stowed state**.**

- **First day**: On the first day, Webb’s solar panels and high-gain antenna were deployed automatically. Ariane’s precise launch sent Webb directly to L2, requiring only a small trajectory correction maneuver, which conserved fuel and extended the telescope’s operational life.
- **First week:** In the first week, after a second trajectory correction, major deployments began with the fore and aft sunshield pallets. The spacecraft bus and telescope were separated by extending a 2-meter telescoping tower, allowing further sunshield deployment. The sunshield membranes were then unpinned and pulled out by extending the midbooms on the port and starboard sides, followed by tensioning the membranes. Meanwhile, radiators and other components were also deployed.
- **Second Week:** Mirror/Telescope Deployment: During the second week after launch, deployment of the telescope structures by unfolding and latching the secondary mirror tripod and rotating and latching the two primary mirror wings is done. This brought Webb into its fully deployed operational configuration**.**
- **First Month:** During the first month, the telescope and instruments cooled gradually in the sunshield’s shade, with controlled heating to prevent ice formation on mirrors and detectors. All primary and secondary mirror segments were unlocked and tested for movement. Near month’s end, the final mid-course maneuver placed Webb into its optimal orbit around L2, and scientific instruments were powered up. The following five months focused on optics alignment and instrument calibration.
- **Second to Fourth months:** Using the Fine Guidance Sensor, Webb locked onto a bright star and collected data mainly with NIRCam, though initial images were distorted due to unaligned primary mirror segments. Over several months, each segment was individually adjusted and aligned with the secondary mirror, achieving a fully aligned telescope. The cooldown phase ended as the cryocooler reached its lowest temperature, enabling MIRI to begin collecting quality data.
- **Fifth and Sixth months:** Calibration and commissioning completion involved carefully tuning all scientific instruments across their various modes while observing representative targets. Webb also demonstrated tracking of moving objects such as asteroids, comets, moons, and planets within our solar

system. Additionally, “Early Release Observations” were conducted to showcase the observatory’s capabilities immediately after commissioning concluded.
- **After six months:** “Science operations!” Webb began its science mission and started to conduct routine science operations

5. Engineering Challenges and Solutions

The James Webb Space Telescope (JWST) faced multiple challenges and limitations spanning technical, programmatic, and operational domains:

- **System Complexity**: JWST's design involved numerous simultaneous first-of-a-kind challenges, including a large segmented primary mirror operating at cryogenic temperatures (~50 K). This complexity led to many design iterations, extensive modelling, and architecture updates, increasing cost and schedule risks. The need to maintain extreme stability and operate at very low temperatures introduced material property challenges such as thermal contraction and damping issues.
- **Thermal Management and Orbit:** To achieve the necessary cold environment for infrared observations, JWST cannot operate in low Earth orbit because of Earth's heat. Instead, it orbits the Sun-Earth L2 point about 1.5 million km away, which is thermally stable but poses challenges for communication, navigation, and orientation. The spacecraft's orientation is highly constrained to keep its instruments shielded from sunlight, complicating pointing and station-keeping maneuvers.
- **Verification and Testing:** The telescope's size and complexity made ground testing difficult. Verification required extensive modelling and specialized facilities to simulate the cryogenic environment and the space conditions. The early integration and testing phases were challenging due to the limited modularity and the need to validate complex subsystems working together.
- **Programmatic Constraints**: JWST experienced significant cost overruns and schedule delays, partly due to funding uncertainties and the complexity of managing such a large, unprecedented mission. The mission's high cost led to controversy within the scientific community, as it consumed a significant portion of NASA's astrophysics budget, thereby affecting funding for other projects.
- **Navigation and Station-Keeping**: The telescope's orbit around L2 is dynamically unstable, requiring regular station-keeping maneuvers to maintain position. Solar radiation pressure is a significant non-gravitational perturbation that must be precisely modelled and countered to keep the telescope stable and properly oriented.
- **Data Challenges:** The vast amount of data and the novel discoveries from JWST have sometimes challenged existing astrophysical models, requiring new calibration and interpretation approaches.

6. Key Achievements and Scientific Discoveries

1. The universe evolved significantly faster than we previously thought.

Webb, designed to study the universe's first billion years, unexpectedly revealed bright, massive galaxies forming within 300 million years after the Big Bang, including supermassive black holes and an infant Milky Way-like galaxy at 600 million years. It observed galaxies that ceased star formation within a billion years and others evolving rapidly into modern spirals by 1.5 billion years. This rapid early growth challenges previous expectations and reshapes our understanding of the cosmic dawn and galaxy formation.

2. Deep space is scattered with enigmatic "Little Red Dots."

Webb has revealed a new type of galaxy: a distant population of mysteriously compact, bright, red galaxies dubbed Little Red Dots. What makes Little Red Dots so bright and so red? Are they lit up by dense groupings of unusually bright stars or by gas spiralling into a supermassive black hole, or both? And whatever happened to them? Little Red Dots seem to have appeared in the universe around 600 million years after the Big Bang (13.2 billion years ago), and rapidly declined in number less than a billion years later.

3. Pulsating stars and a triply lensed supernova are further evidence that the "Hubble Tension" is real.

The universe's expansion rate, known as the Hubble constant, shows conflicting values depending on measurement methods—a problem called the Hubble Tension. Webb's data confirms these discrepancies are not due to measurement errors by accurately distinguishing stars in crowded fields and analysing a gravitationally lensed supernova appearing at multiple times and locations. Webb continues to refine expansion measurements using diverse objects and methods to resolve this cosmic puzzle.

4. Webb has found surprisingly rich and varied atmospheres on gas giants orbiting distant stars.

While Hubble first detected gases in a gas giant exoplanet's atmosphere, Webb has advanced this by identifying a variety of chemicals like hydrogen sulphide and ammonia for the first time outside our solar system. Webb also studies exotic climates, detecting silica "snow" on WASP-17 b and temperature and cloud differences on WASP-39 b

5. A rocky planet 40 light-years from Earth may have an atmosphere fed by gas bubbling up from its lava-covered surface.

Detecting and analysing thin atmospheres around small rocky planets is difficult, but Webb's sensitive infrared measurements enable it. So far, Webb has ruled out significant atmospheres on several rocky exoplanets and found possible signs of carbon monoxide or carbon dioxide on the lava world 55 Cancri e. These findings pave the way for NASA's future Habitable Worlds Observatory, aimed at directly imaging and searching for life on Earth-like planets around Sun-like stars.

6. Webb exposes the skeletal structure of nearby spiral galaxies in mesmerizing detail.

Galaxies are cosmic cities of stars, planets, dust, gas, dark matter, and black holes, but Webb's infrared vision reveals their structure and star-environment interactions in unprecedented detail. It shows dust filaments tracing spiral arms, old star clusters in cores, newborn stars in glowing cocoons, and hot young stars creating cavities, while illustrating how stellar winds and explosions reshape galaxies.

7. It can be hard to tell the difference between a brown dwarf and a rogue planet.

Brown dwarfs form like stars but can't fuse hydrogen, while rogue planets form like planets but drift freely after ejection. Webb has found hundreds of brown-dwarf-like objects, some so small they blur the line between gas giants and brown dwarfs. After three years of observations, we now understand there's a continuum from planets to brown dwarfs to stars, though formation details remain uncertain.

8. Some planets might be able to survive the death of their star.

When a star like our Sun dies, it swells up to form a red giant large enough to engulf nearby planets. It then sheds its outer layers, leaving behind a super-hot core known as a white dwarf. Is there a safe distance that planets can survive this process? Webb might have found some planets orbiting white dwarfs. If these candidates are confirmed, it would mean that it is possible for planets to survive the death of their star, remaining in orbit around the slowly cooling stellar ember.

9. Saturn's water supply is fed by a giant fountain of vapor spewing from Enceladus.

Saturn's moon Enceladus, an icy ocean world, emits a massive water vapor plume from its south pole, first detected by Cassini and now revealed by Webb to span over 6,000 miles—about 20 times the moon's size. This plume forms a donut-shaped cloud around Saturn, feeding water into the planet's rings and atmosphere. Webb's observations provide new insights into Enceladus's water system and its potential for hosting life, enhancing our understanding of the Saturnian system and the solar system's evolution.

10. Webb can size up asteroids that may be headed for Earth.

In 2024, astronomers discovered an asteroid that, based on preliminary calculations, had a chance of hitting Earth. Such potentially hazardous asteroids become an immediate focus of attention, and Webb was uniquely able to measure the object, which turned out to be the size of a 15-story building. While this particular asteroid is no longer considered a threat to Earth, the study demonstrated Webb's ability to assess the hazard.

Webb also provided support for NASA's Double Asteroid Redirection Test (DART) mission, which deliberately smashed into the Didymo's binary asteroid system, showing that a planned impact could deflect an asteroid on a collision course with Earth. Both Webb and Hubble observed the impact, serving witness to the resulting spray of material that was ejected. Webb's spectroscopic observations of the system confirmed that the composition of the asteroids is probably typical of those that could threaten Earth.

7. International Collaboration

- **NASA:** Lead agency, overall mission management.
- **ESA (European Space Agency):** Provided the launch vehicle (Ariane 5) and key instruments.
- **CSA (Canadian Space Agency):** Supplied the Fine Guidance Sensor and NIRISS instrument.

8. Comparison with the Hubble Space Telescope

Feature	Hubble Space Telescope	James Webb Space Telescope
Mirror Diameter	2.4 meters	6.5 meters
Wavelength Range	UV, Visible, Near-IR	Near-IR, Mid-IR (0.6–28 μm)
Orbit	560 km above Earth	1.5 million km (L2)
Main Focus	Visible/UV astronomy	Infrared astronomy
Launch Year	1990	2021

9. Data and Impact

- **Data Volume:** JWST has generated nearly 550 terabytes of scientific data in its first three years.
- **Global Access:** Thousands of astronomers worldwide use JWST's data, fostering international collaboration and open science.
- **Inspirational Value:** JWST's discoveries and images have captivated the public and inspired new generations of scientists and engineers.

10. Conclusion

The James Webb Space Telescope stands as a triumph of human ingenuity and international cooperation. Its unprecedented sensitivity, technical innovations, and scientific reach are reshaping our understanding of the universe—from the first stars and galaxies to the potential for life on distant worlds. JWST will continue to be at the forefront of astronomical discovery for years to come.

In just three years of operations, Webb has brought the distant universe into focus, revealing unexpectedly bright and numerous galaxies. It has unveiled new stars in their dusty cocoons, remains of exploded stars, and skeletons of entire galaxies. It has studied weather on gas giants and hunted for atmospheres on rocky planets. And it has provided new insights into the residents of our own solar system.

Citations

- Lessons learned from systems engineering on the James Webb Space Telescope, Michael Menzel, Keith Parrish, Lee Feinberg, Paul Geithner, Julie Van Campen, Michael McElwain, Sandra Irish

- James Webb Space Telescope Navigation Optimization Challenges James B. Logan (1, *), Ashok K. Verma (1), Sarah M. Cavanaugh (1), Andrew I. Yu (2)

- Science with the James Webb Space Telescope. Published online by Cambridge University Press:

- James Webb Space Telescope - https://science.nasa.gov/mission/webb/

- NASA Technical Reports Server (2023), "The Design, Verification and Performance of the James Webb Space Telescope"

- Proceedings of the International Astronomical Union (2006), "Science with the James Webb Space Telescope"