Quest

Volume 5 Article 1

2021

The James Webb Space Telescope and Scientific Progress

Robert Astle
Collin College, rastle1@collin.edu

Recommended Citation
Astle, Robert (2021) "The James Webb Space Telescope and Scientific Progress," *Quest*: Vol. 5 , Article 1.
Available at: https://digitalcommons.collin.edu/quest/vol5/iss1/1

Independent Research Paper

Research in progress for PHYS 2425: University Physics I

Faculty Mentor: Raji Kannampuzha, Ph.D.

The following paper represents research work done by students in University Physics 2425, the first half of a two-semester introductory course in physics. It is a calculus-based physics course, intended primarily for physics, chemistry, math, and engineering majors. Students are introduced to the concept of academic research by learning to ask research-focused questions and then use the library resources to pursue outside research to find answers. For this assignment, students are asked to investigate a physical science, biological science, or technology problem or topic of their choice by searching the academic literature and then writing a research paper. They are asked to include at least one professional journal article in the references, and the provided rubric contains the same requirements of any professional science journal. In addition, students are required to complete two peer reviews of the paper draft. This helps them see other student work and get constructive criticism from their peers before they submit the final paper.

In the following paper, Robert Astle investigates the James Webb Space Telescope (JWST), the largest infrared observatory ever sent into space. This paper discusses the superior technical capabilities of JWST and compares it to the predecessor, the Hubble Space Telescope. The author explores the potential discoveries of JWST, including the formation of galaxies, the evolution of the universe, and dark matter—all of which could significantly contribute to the advancement of physics.

The James Webb Space Telescope and Scientific Progress

Robert Astle

The study of physics strives to use quantitative and mathematical relationships to describe the behavior of matter and energy. The ultimate end goal of this process is to obtain an accurate description of the behavior of nature's most elementary constituents. During the twentieth century, physicists made remarkable progress toward this goal, both with the theories they developed and the experiments they devised to test them. In recent decades, however, a growing insufficiency in our observational capability has contributed to a pervasive stagnation problem by leaving the scientific community with few phenomena that current theories cannot explain. At the same time, the pressure to publish papers and develop new theories remains.

Many of the most well-funded experiments have not yielded as much valuable insight as hoped, leaving the most cutting-edge theories to remain untested and unproven. For example, in an article for *Scientific American*, Hossenfelder (2019) presents serious criticisms of proposals for a new particle collider while drawing attention to other, more productive methods of observation. She states, "A larger particle collider is presently extremely costly as compared with other planned but unfunded large-scale experiments into the foundations of physics, such as telescopes, satellite missions, gravitational–wave interferometers or high-precision measurements." Hossenfelder (2019) further argues that these newer or less-utilized forms of experimentation have greater promise in helping to solve the problems that the study of physics currently faces. This is a valuable point because science intrinsically relies on the observation of nature, the absence of which inevitably leaves scientists with an incomplete picture of the natural world.

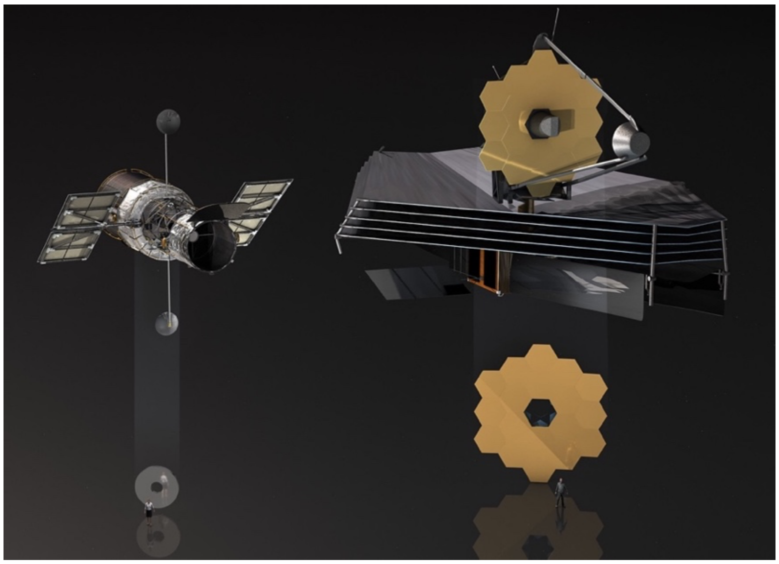
The James Webb Space Telescope (JWST) is a revolutionary new orbital observatory that NASA is currently developing in Redondo Beach, California, in partnership with Northrop Grumman, the European Space Agency (ESA), and the Canadian Space Agency. It is scheduled to launch in 2021 aboard an Ariane 5 rocket provided by ESA. Thirty years after the launch of Hubble, JWST represents the next logical step in both technological advancement and scientific achievement because of its improved sensitivity to infrared light and ability to detect new light sources (Seery, 2004). This paper investigates how JWST can contribute to the advancement of physics by breaking through the present state of stagnation and moving into the next era of discovery.

Description

This inquiry collected information from the official website for JWST, as well as articles from peer-reviewed scientific journals that discuss topics related to the telescope. These publications provide important insight into JWST's capabilities and what kinds of phenomena it can potentially observe. To determine whether this telescope can significantly contribute to the advancement of science, researchers need an understanding of what the telescope may discover. JWST has many technical features, capabilities, and scientific goals that are relevant to this investigation, including its innovative light-deflecting surface, advantageous location in space, and its ability to detect light sources too faint or obscured for any other telescope (Seery, 2004). The device's most notable component is its unfolding mirror, which deflects light from distant objects into the telescope's photographic sensors. The reflective material spans 6.6 meters in contrast to the 2.4 meters of the Hubble Space Telescope’s mirror, giving it a light-collecting area about seven times greater than that of Hubble and enabling it to detect smaller and fainter light sources. JWST reaches this size while maintaining a weight of 11,000 pounds, compared to Hubble's 24,000 pounds (Seery, 2004). An illustration from NASA's JWST website, seen in Figure 1, demonstrates the significant size difference.

Figure 1

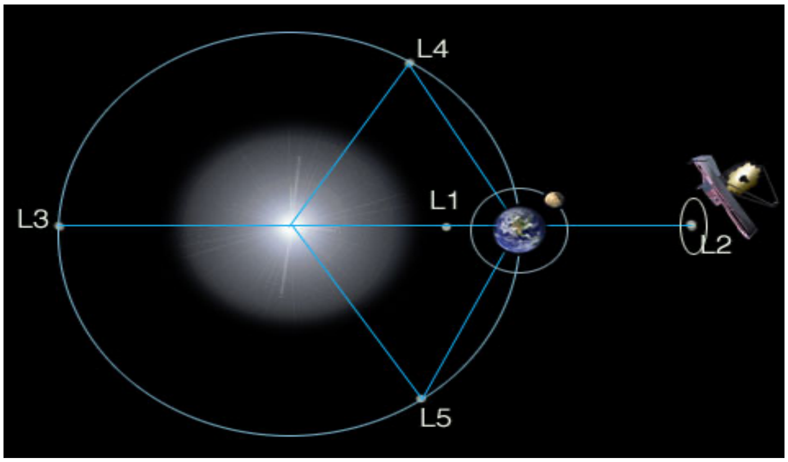
Illustration comparing the size of the Hubble Space Telescope (left) to the JWST (right), including a comparison of their primary mirrors, shown below (Webb vs Hubble Telescope, *n.d.*).



An extendable sunshield, which expands to a width of 21.2 meters, protects the telescope's sensitive mirrors and instruments from incoming light from the earth, moon, and sun, allowing them to operate at a temperature of -387°F (*The sunshield*, n.d.). This low temperature prevents interference from infrared light, which is a product of heat. JWST performs its mission in orbit of the sun at the Sun-Earth system's L2 Lagrange point. This unique location is 940,000 miles from Earth in the direction opposite to the sun. Here, the force of the earth's and sun's gravity work together to keep the spacecraft in the same position relative to both objects. This means that as Earth moves around the sun, the spacecraft always follows it so that it maintains the same proximity to the earth (Seery, 2004). Because Earth is always between the telescope and the sun, it shields the telescope from some of the sun's light, helping it to maintain a low temperature. The diagram in Figure 2 illustrates where the telescope will be in relation to Earth and the sun.

Figure 2

A diagram of the Sun-Earth system, illustrating the locations of all 5 Lagrange points. JWST will be positioned at the L2 Lagrange point (Webb Orbit*, n.d.*).



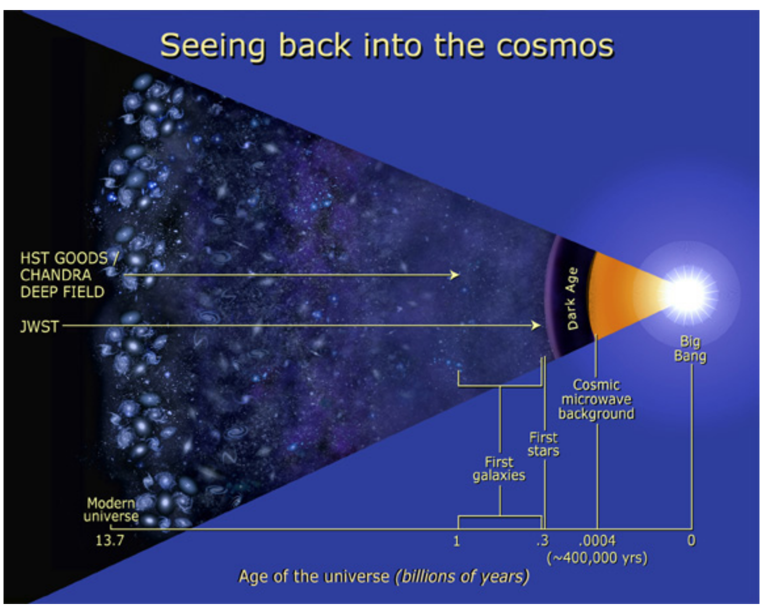
JWST's ability to see into the near-infrared and mid-infrared wavelengths sets it apart from its predecessors more than any of its other features. This capability, combined with the increased size of its primary mirror, provides a thousand times more sensitivity to infrared light than Hubble. Increased sensitivity allows it to discover objects that are invisible to present-day telescopes and achieve more impactful discoveries than any existing observation tools. Additionally, with a total of 64 million pixels, its photographic array is almost 500 times the size of the one inside the Spitzer Space Telescope (Seery, 2004). It also has 16 times the number of pixels in the Wide-field Infrared Survey Explorer ("WISE," 2017). A higher resolution enables JWST to examine distant objects in much greater detail. These advanced capabilities allow it to perform several unique objectives, including its goals to observe the first galaxies, verify the universe's geometric properties, and provide deeper insight into the development of the Milky Way Galaxy (Seery, 2004).

Discussion

Among the many facets of JWST's mission, its goal to study objects from the universe's distant past has the greatest potential to impact humanity's scientific understanding. Because of its high image resolution and sensitivity in the infrared wavelengths, information from this telescope will enable physicists to examine objects from the earliest phases of the universe's development, an era that has hitherto remained invisible. Because these objects are so much farther away than younger ones, the light emitted from them has traveled through space for so long that the expansion of the universe has stretched it into the infrared range, rendering it undetectable by visible-light telescopes. This distance is also the reason we can still see these objects as though they were in the very beginning of their lives, as shown in Figure 3.

Figure 3

A timeline of the universe's development. JWST will capture infrared light from the first stars, which likely appeared about 13.4 billion years ago (Webb vs Hubble, *n.d.*).



The light they emitted at that time has spent 13.5 billion years travelling through space and is only now reaching the solar system. While the Hubble Space Telescope can produce images of galaxies as old as 700 million years, JWST is able to analyze the very beginning of their lives, as well as the first stars to inhabit them. It will provide information about the universe from when it was much smaller than it is today and stars and galaxies first began to appear (Seery, 2004). The investigation of the universe's first stars is important because of their crucial role in developing the objects and galaxies that currently populate the universe. Furthermore, the remnants of the earliest stars may still be present in the universe. When some of the earliest stars exploded as supernovae, what remained of them may have coalesced into black holes. As these black holes attracted matter from the space around them, they eventually formed “mini-quasars.” These objects ultimately became the supermassive black holes that now reside within the cores of the largest galaxies (*First light*, n.d.).

Because JWST makes it possible to observe the first stages of a galaxy’s life, it will enable physicists to better understand the processes that assemble these structures and determine their chemical and morphological characteristics. Therefore, it is useful to consider the various galactic phenomena that JWST could examine and what they would reveal about the galaxies in which they took place. Data gathered from galaxies at the beginning of their life cycle will reveal many factors that determine their physical features. These include the relationship of a galaxy’s environment, mass, and age with its rate of star formation and what types of stars are most likely to form within it. Not only is JWST able to facilitate such important discoveries, but no other telescope currently exists that allows researchers to fully determine the relationships between stars of various ages or to reach a complete understanding of how stars developed in the distant past (Gardner et al., 2006, p. 514). Furthermore, for most known relationships among the properties of galaxies, we still have little understanding of the physical processes that govern them. These include the notably consistent relationships between galactic characteristics such as luminosity, mass, momentum, and material composition (Gardner et al., 2006, p. 516). Likewise, this lack of understanding is because no precise measurements are available about these relationships and other factors that might affect them. With sufficient infrared sensitivity to observe galaxies during the time that these processes unfolded, JWST will provide such measurements. Only this information will provide an accurate picture of galaxies during every stage of the universe's life or enable us to make sense of the earliest natural phenomena (Gardner et al., 2006, p. 511).

In addition to a better understanding of the universe's evolution, it is plausible that observations of the early universe will shed light on one of the most elusive mysteries in the study of physics: dark matter. Ever since its existence was first hypothesized, dark matter has remained an unavoidably perplexing issue. Several theories attempt to explain what sort of substance it is. One theory suggests that dark matter consists of weakly-interacting massive particles, or WIMPs. Some have hypothesized that WIMPs behave like antiparticles in such a way that, at high concentrations, they will collide with each other, annihilating themselves and releasing energy (Illie et al., 2012, p. 2164). The energy released from such WIMP annihilations could have provided the heat necessary to power the first stars, which are called "supermassive dark stars (SMDSs)" (Illie et al., 2012, p. 2164). This thermal energy from antimatter annihilation would cause these early stars to obtain a size and brightness that ordinary, fusion-powered stars could not achieve. If JWST can detect stars in the early universe with these characteristics, it would further support the existence of WIMPs. Understanding the behavior of dark matter would contribute information critical to fully grasp how the universe operates.

Due to its high image resolution and sensitivity in the infrared wavelengths, JWST will provide accurate data about what took place in the universe as early as 300 million years into its existence. At that time, the universe's contents were radically different from what they are in the present day. The prospect of observing the universe during this phase of its development offers an unprecedented opportunity to accelerate the advancement of science because this exploration will uncover objects unlike any that are present in the universe today. This capability will provide new insights into how these objects, and the phenomena associated with them, have shaped the universe into what we currently observe.

The discovery of previously unknown phenomena will present the world with entirely new questions to ask and problems to solve. Throughout the history of physics, solving difficult mathematical problems has consistently been the key to revolutionary discoveries (Hossenfelder, 2018). Therefore, there can only be progress in physics when more advanced observations uncover new mathematical problems for physicists to solve. Aside from the possible detection of supermassive dark stars, if the next generation of telescopes were to discover some unexpected behavior in the process of star formation, like the interaction of gravity and light or the effects of the universe's rapid initial expansion, current theories would have to adapt to account for this new information. JWST will be capable of discoveries that will bring the world's physicists closer to a comprehensive understanding of the natural world's basic behavior. The results could forever change the way people understand the universe they inhabit.

In addition to paving the way for great technological innovation, scientific breakthroughs have the effect of inspiring new generations of explorers to examine and seek to understand the natural world. In a time when we lack the ability to rigorously test most of the latest attempts to unify our scientific understanding of the universe, JWST and other similar observatories have the potential to initiate a new era of discovery. It is, therefore, of great importance that these kinds of projects receive continued support from the general public. Future generations will undoubtedly reflect on these undertakings and remember the kind of eager curiosity that elevates human life to its greatest potential.

Conclusion

In response to the growing problem of insufficient observational input in the study of physics, compared to the abundance of theoretical innovation, new methods of observation are necessary. To that end, this study's primary objective was to determine whether the James Webb Space Telescope and similar space observatories could provide the data necessary to test and refine our most cutting-edge theories. This examination of relevant scientific literature found that several kinds of natural phenomena could provide important insight into the processes that shape the universe. These include the emergence of the first stars and galaxies, the evolution of galactic structures over their lifetimes, and the possible effects of dark matter in the early universe. It also identified observations that will be necessary to measure them, such as photographic and spectrographic surveys of high-redshift light sources. JWST has unprecedented infrared sensitivity and the potential to observe cosmic events that took place farther back in time than any telescope before it. It will thus be able to perform these crucial observations, expanding the horizon of humanity’s observational capability to the point that many groundbreaking discoveries will be possible. There can be little doubt that JWST will significantly contribute to the progress of science.

References

First light & reionization. (n.d.). *James Webb Space Telescope - NASA*. Retrieved January 25, 2021, from https://jwst.nasa.gov/ content/science/firstLight.html

Gardner, J. P., Mather, J. C., Clampin, M., Doyon, R., Greenhouse, M. A., Hammel, H. B., Hutchings, J. B., Jakobsen, P., Lilly, S. J., Long, K. S., Lunine, J. I., Mccaughrean, M. J., Mountain, M., Nella, J., Rieke, G. H., Rieke, M. J., Rix, H., Smith, E. P., Sonneborn, G., . . . & Wright, G.S. (2006). The James Webb Space Telescope. *Space Science Reviews, 123*(4), 485–606. https://doi.org/10.1007/ s11214-006-8315-7

Hossenfelder, S. (2018, Nov. 19). *The present phase of stagnation in the foundations of physics is not normal*. Backreaction. http://backreaction.blogspot.com/2018/11/ the-present-phase-of-stagnation-in.html

Hossenfelder, S. (2019, July 23). *Which should come first in physics: Theory or experiment? Glad you asked*. Scientific American. blogs.scientificamerican.com/ observations/ which-should-come-first-in-physics-theory-or-experiment-glad-you-asked/

Ilie, C., Freese, K., Valluri, M., Iliev, I. T., & Shapiro, P. R. (2012). Observing supermassive dark stars with James Webb Space Telescope. *Monthly Notices of the Royal Astronomical Society, 422*(3), 2164-2186. https://doi.org/10.1111/ j.1365-2966.2012.20760.x

Seery, B. D. (2004). James Webb Space Telescope (JWST). *AccessScience*. https://doi.org/10.1036/1097-8542.YB040500

The sunshield. (n.d.). *James Webb Space Telescope - NASA*. Retrieved January 25, 2021, from https://jwst.nasa.gov/content/observatory/sunshield.html

Webb orbit. (n.d.). *James Webb Space Telescope - NASA.* Retrieved January 25, 2021, from https://jwst.nasa.gov/content/about/orbit.html

Webb vs Hubble Telescope. (n.d.). *James Webb Space Telescope - NASA*. Retrieved January 25, 2021, from https://jwst.nasa.gov/content/about/comparisonWebbVsHubble.html

WISE spacecraft and instruments. (2017, August 3). *NASA*. https://www.nasa.gov/mission_pages/WISE/spacecraft/index.html