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Statement of

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Chairman Palazzo, Ranking Member Edwards, and Members of the Subcommittee, I am pleased to have the opportunity to appear before you to discuss the scientific mission of the James Webb Space Telescope (Webb).

I've been a telescope builder all my life. Since I was about eight years old, I've wanted to know, "how did we get here?" When I was a kid, nobody really knew. So I became a telescope builder. And now, quite a few years later, I am a Nobel Prize winner. Despite our progress profound questions remain, which is the reason I think Webb is the most important project I could be working on. That's why I'm here.

Webb will be the premier observatory of the next decade. To understand Webb's scientific mission, we need to review in broad brushstrokes our current picture of the Universe. And that picture has been painted almost entirely by the space astronomy program initiated here at NASA, thanks in no small part to longstanding Congressional support, and the powerful curiosity of the American public about the Universe in which we live.

First Light

We know today that the universe is nearly 13.8 billion years old. For the first 400 thousand years after the Big Bang, the Universe was hot, but it had no distinct objects in it. There were no stars, and there were no galaxies. The universe was a hot soup of fundamental particles, such as free protons and electrons. And light could not travel very far through that hot soup.

At around the 400 thousand year mark, the hot soup had cooled enough so that electrons and protons and helium nuclei could pair up to form hydrogen and helium atoms, in a process called "Recombination." As the electrons were now bound to atomic nuclei, light could travel freely without being stopped by frequent scattering off the free electrons.

The Universe went from being opaque to transparent at this point. The 'afterglow' of this era of recombination is what we can see as the Cosmic Microwave Background, and it is still the brightest radiation in the universe. Our NASA team won the Nobel Prize in 2006 for building and using a satellite called COBE (the Cosmic Background Explorer) to investigate this Cosmic Microwave Background. I was the head scientist for the COBE, and I led the team that proposed it when I was just a few months out of graduate school.

After recombination came the first stars. The emergence of the first stars probably came when the Universe was a few hundred million years old. We think that these first stars were 30 to 300 times as massive as our Sun and millions of times as bright, burning for only a few million years before exploding as supernovae. But we've never seen them; even the Hubble can't see them, and Webb is the only telescope currently planned that could do the job.

The emergence of these first stars marks the end of the "Dark Ages" in cosmic history. Understanding these first sources is critical, since they greatly influenced the formation of later objects such as galaxies. And we would like to know our own history: how did we get here from the early universe?

So why do we need an infrared telescope to see that first light? Imagine light leaving the first stars nearly 13.4 billion years ago and traveling through space and time to reach our telescopes. We're essentially seeing these objects as they were when the light first left them 13.4 billion years ago. But because the universe has been expanding, the light that was emitted by these first stars and galaxies as visible or ultraviolet light actually got shifted to redder wavelengths by the time it reached us. The Hubble has probably seen a few traces of galaxies almost that far back in time. But to really see and understand that light, and the galaxies that came even before those, we need a large telescope mirror and science instruments that see in the infrared: we need Webb!

The Assembly of Galaxies

Today we know from pictures taken with the Hubble that galaxies existed less than one billion years after the Big Bang, relatively soon after the emergence of the first stars. While most of these early galaxies were smaller and more irregular than present-day galaxies, some were very similar to those seen nearby today.

Our computer models tell us that galaxies began to grow when dark matter clumped together under the force of its own gravity. Dark matter is an invisible form of matter whose total mass in the universe is roughly five times that of "normal" matter (that is, the stuff made of "atoms"). It can be thought of as the scaffolding of the universe. In fact, we wouldn't be here (the galaxies wouldn't have formed) without dark matter. The visible ordinary matter we see then collected inside this scaffolding in the form of stars and galaxies.

This build-up of large systems was accompanied by the formation of luminous stars from gas and dust. We believe that the interaction of stars and galaxies with the invisible dark matter produced the present-day galaxies.

This process of galaxy assembly is still occurring today - we see many examples of galaxies colliding and merging to form new galaxies. In our own local neighborhood of space, the Andromeda galaxy is headed toward the Milky Way for a future head-on collision – just a few billion years from now.

Despite all the work done to date, we still have many questions about the assembly of galaxies. How exactly were galaxies formed? How did we end up with the large variety of galaxies we see today? What is the nature of the relationship between black holes and the galaxies that host them? How did the black holes originally form, and how did they grow so large? These are some of the fundamental questions about galaxies that Webb will tackle. Because Webb will be a facility that can see not only the earliest galaxies to form, but also nearby, older galaxies, it is the first space observatory that can witness the complete life history of galaxies in the universe.

The Birth of Stars and Protoplanetary Systems

Although stars have been the main topic of astronomy for thousands of years, we have begun to understand them in detail only in recent times through the advent of powerful telescopes and computers.

A hundred years ago, scientists did not know that stars are powered by nuclear fusion, and 60 years ago they did not know that stars are continually forming in the Universe. We still do not know the details of how clouds of gas and dust collapse to form stars, or why most stars form in groups.

To unravel the birth and early evolution of stars we need to be able to peer into the hearts of dense and dusty cloud cores where star formation occurs. These regions cannot be observed at visible light wavelengths, as the dust makes such regions opaque, and they must therefore be observed at infrared wavelengths. Webb will allow us to do that.

We also do not understand exactly how planetary systems start to form around young stars, but we do know that a large number of stars like our Sun have planets. The number of confirmed planets and candidate planets is now in the thousands. The continual discovery of new and unusual planetary systems has made us re-think our ideas and theories about how planets are formed. We realize that to get a better understanding of how planets form, we need to have more observations of planets around young stars, and more observations of leftover debris around stars, which can come together and form planets.

Planets & Origins of Life

The first planet outside our solar system was discovered in 1992. Since then, we have come to the realization that planets are in fact quite common. Most of the confirmed planets discovered so far are large gas giants like Jupiter, although that is because larger planets are more easily detected with current techniques. Thanks to NASA's Kepler mission we now know that small planets (down to Earth-size and even smaller) are much more common than large ones, even though they're hard to find. One essential objective of Webb is to observe planets orbiting in the habitable zone of their star, where it is possible for liquid water and perhaps even life to exist. (For this category of measurement, we need to know where and when to look in advance; Webb is not designed for searches, but rather for detailed observations of the most interesting targets.) We calculate that Webb could even detect the presence of water on a planet somewhat larger than Earth orbiting a star somewhat smaller than the Sun, and tell us whether such a planet could have an ocean. Although Webb was originally conceived for very different purposes, we are very pleased that it will have this capability too.

To trace the origins of the Earth and life in the Universe, we need to study planet formation and evolution, including the material around stars where planets form. A key issue is to understand how the building blocks of planets are assembled. We do not know if all planets in a planetary system form in place or travel inwards or outwards after forming elsewhere. We also do not know how planets reach their ultimate orbits, or how large planets affect the smaller ones in solar systems like our own. Simulations already show that the early Solar System may not have been stable and the giant planets may have migrated significantly, causing a rain of asteroids and comets that left craters on the Earth for hundreds of millions of years.

The dwarf planets and icy bodies in the outer reaches of our Solar System are evidence of conditions when our Solar System was very young. We can directly compare those conditions to the objects and dust observed around other stars. The sensitive instruments on Webb will be able to obtain infrared images of giant planets and planetary systems and characterize their ages and masses and atmospheric constituents by measuring their spectra. Webb will also be able to measure spectra of the dusty disks around other stars to determine the constituents of such disks that give rise to planetary systems.

In addition to studying planets outside our solar system, we want to learn more about our own home. Studying the chemical and physical history of the small and large bodies that came together to form the Earth may help us discover how life developed on Earth. We are especially curious about how and when the water in the oceans was delivered to Earth – was it part of the original formation, or did it arrive later from comets, for instance? Webb will be powerful enough to identify and characterize comets and other icy bodies in the outermost reaches of our solar system, which might contain clues to our origins on Earth. Importantly, Webb can also be used to study the outer planets and their moons in our Solar System and thereby provide complementary data to NASA missions that have (or will) travel to these bodies to study them.

The Successor to Hubble

Webb often gets called the replacement for Hubble, but we prefer to call it a successor. After all, JWST is the scientific successor to Hubble; its science goals were motivated by results from Hubble. Hubble's science pushed us to look to longer wavelengths to "go beyond" what Hubble has already done.

An infrared telescope needs to be cooled to a low temperature, so it does not emit too much of its own infrared light. To make it cold we need to put it in deep space, where it can be shielded from the heat and light of both the Earth and the Sun. It also needs to be shielded from the infrared energy produced by its own spacecraft. So Webb will have a tennis-court sized sun shield that will unfold in space.

One of Webb's four instruments also requires a refrigerator that uses gaseous helium to keep its detectors at a temperature of about 6 Kelvin (negative 449 degrees Fahrenheit), so it can sense the reddest light that Webb is designed to observe. This capability is key to detecting the first galaxies to form after the Big Bang and all of the aforementioned science goals.

Webb's primary mirror will be composed of 18 hexagonal units made of beryllium – a material light enough that you could pick up one of those units yourself – but which can be machined and polished until it has essentially perfect curvature. If you were to stretch this material the length of the United States, the difference between the peaks and valleys would be about 3 inches. These mirrors are finished and will be installed onto the telescope backplane support structure later this year at the Goddard Space Flight Center.

International Cooperation

Webb is an excellent example of what can be done by international partnerships to solve very difficult engineering challenges. The United States is leading a very capable partnership that includes the European and Canadian Space Agencies. The Canadian Space Agency has spent more on its portion of the Webb telescope (the Fine Guidance Sensor and Near-InfraRed Imager and Slitless Spectrograph) than on any other space science project; in return their aerospace industry has been busy and Canadian scientists are guaranteed access to observing time. The European contribution is much larger: they led the development of two of the four flight instruments, and they are providing the Ariane 5 rocket, a launch vehicle that meets Webb's mission requirements and has an excellent record of over 60 successful launches in a row. In return, European scientists are also guaranteed access to Webb observing time.

Each scientific project is different, but scientific discoveries know no boundaries. International cooperation has been very successful for NASA.

Synergy with other projects

Webb was designed to do what could never be done with other equipment, on the ground or in space. It measures infrared light, which is largely blocked by the Earth's atmosphere, and which is strongly emitted by the Hubble and by warm ground-based telescopes.

But just as the Hubble discoveries were followed up by larger ground-based observatories like the twin Keck telescopes in Hawaii, Webb discoveries will be followed up by the next generation of even larger ground-based telescopes like the Thirty Meter Telescope and the Giant Magellan Telescope, now in planning and initial construction. These huge telescopes, offer the capability of very high spectral resolution (number of colors that can be distinguished in the incoming light) and will provide important follow-up data that will complement the data we get from Webb.

Also, just as great sky surveys showed us the most interesting places to look with Hubble, new sky surveys with better detectors at newly accessible wavelengths will find targets for Webb. The Large Synoptic Survey Telescope, planned for first light in 2019, will locate transient objects, things that change or flash, and these new targets will be of prime interest for Webb. The Kepler observatory has already given us a long list of exoplanet systems, and some will be chosen for detailed Webb observations.

The TESS (Transient Exoplanet Survey Satellite), to be launched in 2017, will find closer and brighter exoplanet targets for follow-up by Webb. The WFIRST (Wide Field InfraRed Survey Telescope) recommended by the 2010 Decadal Survey of the National Academy of Sciences would scan much of the sky at infrared wavelengths, revealing new targets and possibly new kinds of rare targets, for Webb to see. Indeed, the entire 2010 Decadal Survey of the National Academy was built around Webb capabilities.

Operating at much longer wavelengths with totally different technologies, radio telescope arrays like ALMA (Atacama Large Millimeter/submillimeter Array) offer dramatic views of the universe as well. ALMA has already revealed an image of a disk of material orbiting a star that may be making planets as we speak. Piecing together the information from a wide range of observatories is part of the cosmic jigsaw puzzle astronomers must tackle to get good answers to tough questions.

The United States possesses an excellent industrial infrastructure to undertake Webb. When we needed beryllium mirrors fabricated to amazing accuracy, U.S. companies had the know-how. When we needed infrared detectors with astonishing sensitivity, U.S. companies had the know-how. When we needed to unfold a telescope much larger than the rocket, U.S. companies had the know-how. Many of these companies are the best in the world at what they do.

STEM education

America's leadership in large-scale science and technology projects depends crucially on the talent and inspiration of our citizens to take on challenges of every sort, from organizational to scientific and technical. NASA's projects inspire the public with their beautiful pictures, their stunning discoveries, and their ability to make the nearly-impossible dreams come true. Children come into science wanting to know what we are made of, how we got here, what is the history of the universe, and where we are going. These are not simple questions, and there are no final answers, but the quest inspires children to learn and adults to continue to learn. People come to the United States from around the world to pursue their dreams, and NASA is one of the reasons.

NASA's Hubble Space Telescope is a prime example of our contributions to education. Nearly every science classroom in the country has posters and teaching materials from Hubble. Every astronomy textbook is illustrated with Hubble pictures. Math teachers use examples from NASA projects to show why children need to know how to measure and calculate. We expect the James Webb Space Telescope will provide similar inspiration for students and teachers around the country.

Summary

We are an exceptional country for even dreaming up something like Webb, and we are close to seeing this dream realized. Well over 1,000 engineers and scientists in the United States, plus our partners in Canada and Europe, have worked to make this possible. Over 10,000 professional astronomers will use the telescope, as they have used the Hubble Space Telescope, to make amazing discoveries, and rewrite our textbooks again.

In 2018, Webb will unfold in space, a million miles from Earth, over a two-week period to begin its planned 5-year primary mission. I am confident that the telescope will work -- and that its scientific payoff will be immense. By bringing home powerful new views of deep space, Webb will change the way we understand the Universe, its history, and our place in it. I am sure you will be proud of the role you will play in making possible the pictures and discoveries that Webb will bring us. Thank you for listening, and I would be happy to answer any questions you have.