Scientific Role of the James Webb Space Telescope in *"New Worlds, New Horizons"*

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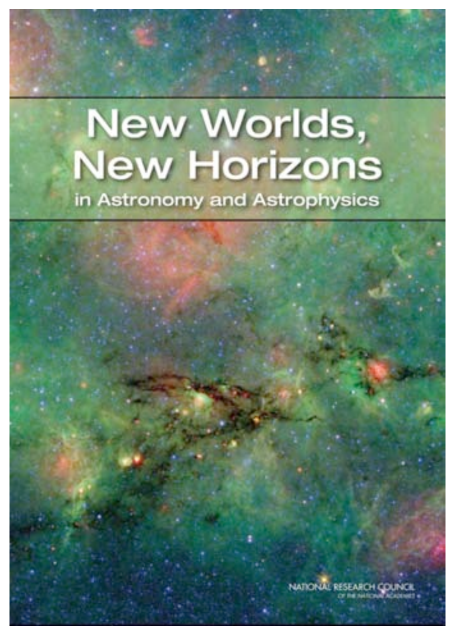
Abstract: The sixth decadal survey from the astronomy and astrophysics community, *New Worlds, New Horizons in Astronomy and Astrophysics*, identifies three science themes for the next decade: *Cosmic Dawn*, *New Worlds*, and *Physics of the Universe*. As is made clear in the survey, the James Webb Space Telescope (Webb) plays a critical scientific role in the two first themes, and a strong supporting role for the third theme. Many of the survey recommendations build on groundwork to be laid by Webb for the next decade of astronomical exploration.

Introduction

On 13 August 2010, the Space Studies Board released the sixth decadal survey from the astronomy and astrophysics community, "New Worlds, New Horizons in Astronomy and Astrophysics" (NWNH)[1]. NWNH identifies three science themes for the next decade: *Cosmic Dawn*: Searching for the First Stars, Galaxies, and Black Holes; *New Worlds*: Seeking Nearby, Habitable Planets; and *Physics of the Universe*: Understanding Scientific Principles.



Given its advanced stage of development, the James Webb Space Telescope (Webb) is assumed in the report to be part of the foundation on which advances in these areas will be built. The survey describes throughout how Webb will play a critical role for its first two science themes, and a strong supporting role for the third. The report does note the technological and fiscal challenges faced by the Webb program (NWNH 6-2).[*] As demonstrated in this white paper, however, the promise of Webb is integral to the science of the next decade. We highlight here the current status of Webb, and outline the specific links between Webb and the next decade's science.

James Webb Space Telescope

The James Webb Space Telescope (Webb) was the highest priority for large space missions in the 2001 decadal survey[2]. An infrared-optimized telescope, Webb is a successor to both the Hubble Space Telescope and the Spitzer Space Telescope. Webb's

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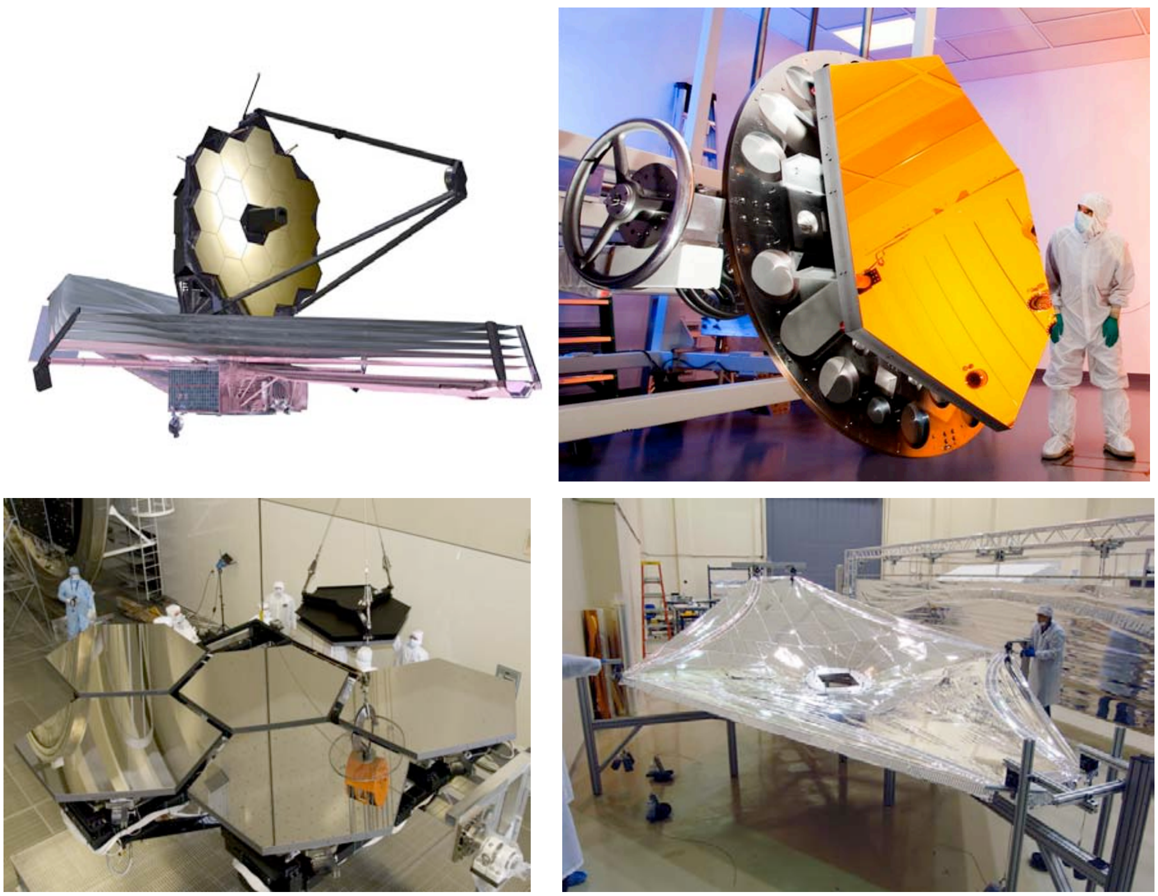
[*] We cite NWNH extensively; page numbers refer to the NWNH "Prepublication Copy" distributed on 13 August 2010.

6.5-m segmented mirror is more than twice the diameter of the Hubble mirror and seven times that of Spitzer, making Webb the largest space telescope in construction. Webb is due for launch in 2014, and will be operated for 5 years with enough fuel to allow an extension to ten years.

In April 2007, all ten of Webb's enabling technologies were ready for flight development. The project passed its Preliminary Design Review in March 2008; in April 2010, Webb passed its Critical Design Review (CDR), indicating approval to proceed with construction. Many of the most critical observatory components have advanced well beyond CDR status. For example, all the science instruments will be delivered in the summer of 2011, and the telescope optics are on a similar schedule. All of the components meet their performance requirements and will enable the revolutionary observations envisioned in NWNH.



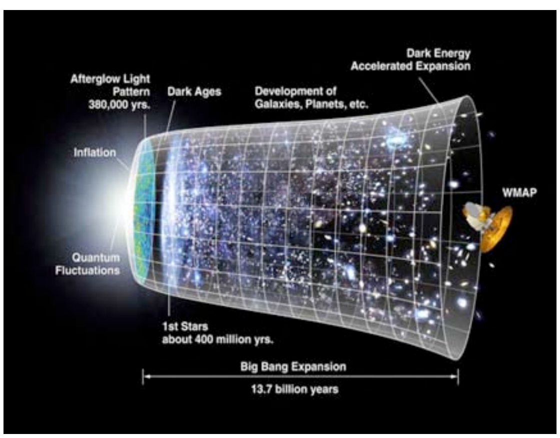
James Webb Space Telescope. *(upper left)* This artist's concept of the completed Webb shows its unusual design. *(upper right)* Each of Webb's eighteen mirror segments will be coated with a microscopically thin layer of gold to enhance the telescope's infrared capabilities. *(lower left)* Six mirror segments are prepped to move into the X-ray and Cryogenic Facility at NASA's Marshall Space Flight Center in Huntsville, Alabama, where they will experience temperatures dipping to -414°F to ensure they can withstand space's extreme cold. *(lower right)* The one-third scale sunshield membranes undergo final inspection.

Cosmic Dawn

"Astronomers are on the threshold of finding the root of our cosmic origins by revealing the very first objects to form in the history of the universe. This step will conclude a quest that is akin to that of an anthropologist in search of our most ancient human ancestors." NWNH, Page 7-5.

Webb plays a critical role for this science theme, often termed 'first light.' The "first stars" themselves are too faint to observe individually, but they should form protogalaxies - the collapsing clumps of gas that are the small building blocks of future galaxies like our Milky Way. Webb will provide unparalleled sensitivity to light emitted by the first galaxies and pinpoint the formation sites of the first stars (NWNH Page 7-5). Webb will also obtain spectra to determine the state of these early stellar populations and the relative abundances of the elements in them, both of which are key measurements to understand their formation and evolution. After Webb, the proposed next generation of giant ground-based optical/infrared telescopes would investigate these primitive objects in more detail (*i.e.*, measure their masses, more detailed chemical compositions, and ages).

Webb will be a crucial tool in tracing the trail from cosmic dawn to the light of today: how and why stellar birth rates grew, peaked when the universe was a few billion years old, and subsequently declined. Simulations suggest that the first galaxies were likely relatively small and that the giant galaxies observed today grew by successive mergers. Webb "will provide observations on the assembly of galaxies over cosmic time" through this merger sequence (NWNH Page 7-14). These observations will be complemented with ALMA: a "powerful synergy between [Webb] and ALMA applies not only to [the] first objects in the universe, but also to the generations of stars that followed them" (NWNH Page 7-5).



The cosmic timeline from inflation, to the first stars and galaxies of cosmic dawn, to the current universe. The change in the vertical width represents the change in the rate of the expansion of the universe, from exponential expansion during the epoch of inflation followed by long period of a slowing expansion during which the galaxies and large scale structures formed through the force of gravity, to a recent acceleration of the expansion over the last roughly billion years due to the mysterious dark energy. Credit: NASA Wilkinson Microwave Anisotropy Probe (WMAP) Science Team.

The "fossil record" of how our own Milky Way galaxy was assembled can be traced by studying galactic stellar populations with Webb (NWNH Page 7-14), along with LSST and adaptive optics capability on GSMT. Our understanding of star formation under a wide variety of physical conditions will benefit from surveys of the giant molecular clouds within which stars form. Complementary studies of the young stars spawned in these molecular regions will require infrared surveys with high angular resolution both in our galaxy and in the neighboring galaxies the Magellanic Clouds, using Webb in space and GSMT equipped with adaptive optics on the ground (NWNH 7-14).

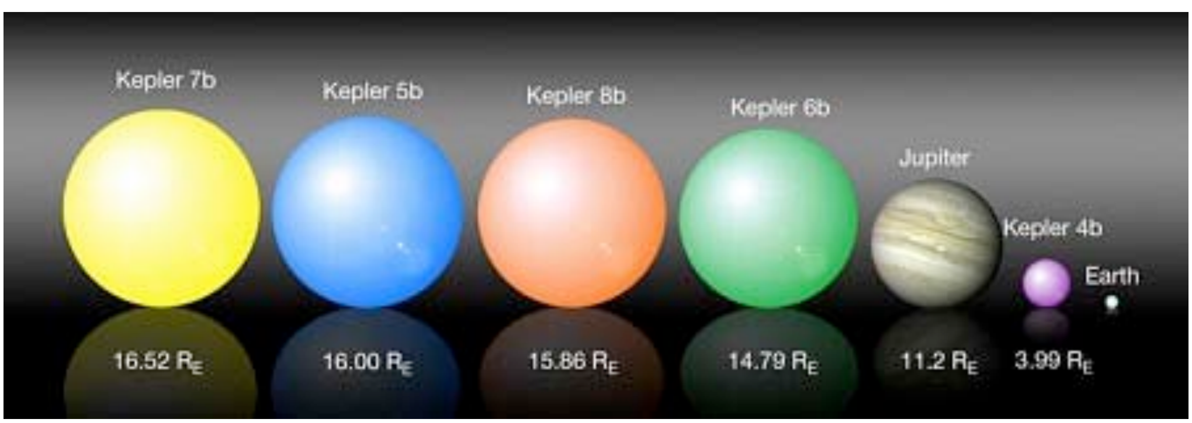
New Worlds

"Astronomers are now ready to embark on the next stage in the quest for life beyond the solar system—to search for nearby, habitable, rocky or terrestrial planets with liquid water and oxygen… The observational challenge is great, but armed with new technologies and advances in understanding of the architectures of nearby planetary systems, astronomers are poised to rise to it." NWNH, Page 1-3

The search for life around other stars is a multi-stage process. Webb will "take the first steps" along this path (NWNH Page 2-2), laying critical groundwork for the more complex and specialized instrumentation of a longer-term program. Webb, "with its superb mid-infrared capability, will also use imaging and spectroscopy transit techniques to study the atmospheres of exoplanets" (NWNH Page 7-9).

The currently operating Spitzer Space Telescope has already demonstrated the capability of seeing objects roughly twice the size of Earth around small stars. Webb's much larger collecting area will take the science to an entirely new level. Webb will be "a premier tool for studying planets orbiting stars that are smaller and cooler than the Sun" (NWNH Page 7-9). The goal is detecting water on an Earth-sized planet in the habitable zone around another star, and this goal is within the reach of Webb. "The era of study of … cousins of the Earth … is underway" (NWNH 2-4).

Knowledge of young circumstellar disks—from which planets eventually form—enriches and complements observations of mature exoplanets. Webb, along with ground-based adaptive-optics infrared telescopes, will provide spatially resolved multi-wavelength images and spectra of light scattered from these disks with spatial resolution comparable to that of ALMA (NWNH 7-8). The study of these nascent planetary systems will benefit greatly from the high spatial resolution of GSMT, fitted with high-contrast instrumentation so that the faint disks do not get lost in the glare of their parent stars; this would complement the wavelength coverage of Webb and ALMA (NWNH 7-15).



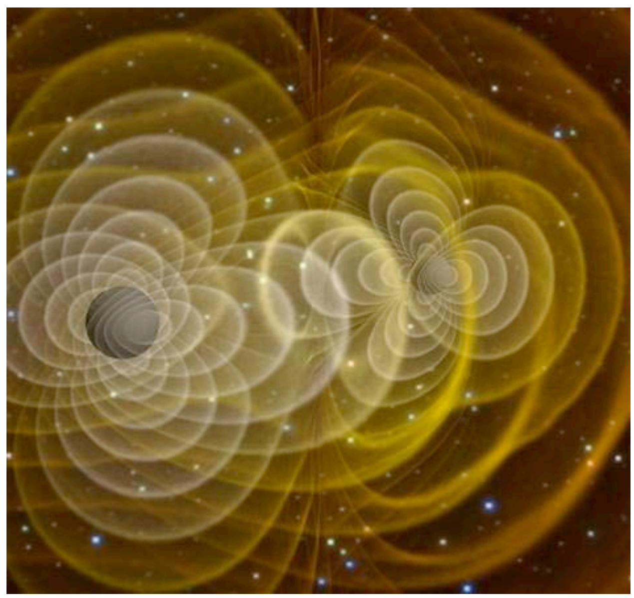
Five new exoplanets. The Kepler Mission announced the discovery of these planets, compared here with Jupiter and Earth, in early 2010. Credit: NASA Kepler Mission.

Physics of the Universe

"We can now say that there is a ubiquitous and ethereal substance called "dark energy" that is expanding the fabric of space between the galaxies at ever faster speeds and accounts for 75 percent of the mass-energy of the universe today. The effects are so tiny on the scale of an experiment on Earth that the only way forward is to use the universe at large as a giant laboratory." NWNH Page 7-10

One of the most remarkable advances in astrophysics throughout the past decade has been confirmation of cosmic acceleration, and the concomitant theory of dark energy as its explanation. Some doubt lingers, however, about whether there is something missing in our fundamental understanding of physics. "Comparing the expansion history of the universe with the history of the growth of structure will in principle enable us to test whether dark energy or modifications of general relativity are responsible for cosmic acceleration" (NWNH Page 2-27). Webb will excel in exploring the evolutionary pathway from "first light" to the galaxies of today (NWNH Pages 7-5 and 7-6), and thus may break the degeneracy between dark energy and fundamental physics. In particular, Webb's large aperture has the potential to vastly improve the calibration of the distance scale for the earliest supernovae that are the signposts of acceleration. In doing so, Webb will help refine our understanding of dark energy.

Another frequent focus of fundamental physics is the study of black holes, due to their extreme nature. Two of the major goals of the coming decade for these exciting and enigmatic objects are: first, to understand the cosmic evolution of black hole "ecosystems" (*i.e.*, the intense interplay between the black holes and their environments); and second, to figure out how these extremely powerful "engines" function. Black hole masses will be measured by Webb and ground-based optical and radio telescopes (NWNH 2-18).



Merging black holes. This simulated image of gravitational radiation from two merging black holes was created with NASA's Columbia supercomputer. A movie of this simulation can be found at http://www.nasa.gov/centers/goddard/mpg/146898main_viz_shiftingall_21.320x240.mpg. Credit: Chris Henze, NASA

Are the supermassive black holes we can now detect only the 'tip of the iceberg,' i.e., the most noticeable members of a vast but undetected population? Deep imaging surveys in the near-infrared and X-ray regimes, with follow-up spectroscopy by Webb and ground-based extremely-large telescopes, will detect and study the growth of the less massive objects through the capture of gas and accompanying emission of electromagnetic radiation (NWNH 2-14).

Summary

"New Worlds, New Horizons" lays out an engaging program for scientific exploration of the cosmos, and the James Webb Space Telescope plays an integral role in completing this program. The large aperture and targeted deep imaging capability of Webb scientifically complement NWNH's highest priority new facility WFIRST, a wide-field infrared survey telescope (NWNH 1-6). Webb furthermore exemplifies the international partnerships called out by NWNH (NWNH 3-4), with the European and Canadian space agencies contributing key components for the mission. The James Webb Space Telescope will continue in the tradition of Hubble and the other Great Observatories as a large-scale transformative scientific facility.

References

1. Space Studies Board, National Research Council, *New Worlds, New Horizons in Astronomy and Astrophysics*, National Academy Press, Washington, D.C., 2010.
2. Space Studies Board, National Research Council, *Astronomy and Astrophysics in the New Millennium*, National Academy Press, Washington, D.C., 2001.