Testimony of

Dr. Roger D. Blandford
Luke Blossom Professor in the School of Humanities and Sciences
Stanford University
and
Chair, Committee for a Decadal Survey of Astronomy and Astrophysics
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The National Academies

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Good morning. My name is Roger Blandford and I am the Luke Blossom Professor in the School of Humanities and Sciences at Stanford University. I chaired the 2010 National Research Council's Decadal Survey in Astronomy and Astrophysics, "New Worlds, New Horizons" (NWNH). The National Research Council (NRC) is the operating arm of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine of the National Academies, chartered by Congress in 1863 to advise the government on matters of science and technology.

I thank you for the opportunity to comment on James Webb Space Telescope (JWST) which was the highest priority recommendation in the 2001 decadal survey, Astronomy and Astrophysics in the New Millennium (AANM) and is a cornerstone of the scientific program advanced in NWNH. These comments are largely my own, although at times I will be referring to the findings of the 2001 and 2010 NRC Decadal Surveys.

Chairman Hall, Ranking Member Johnson, allow me to begin by thanking you and your colleagues for your support of this project, most recently through the House-Senate Conference, H.R. 2112 where the budget to complete the project under the NASA "replan" was restored and protection against further cost growth was instituted. I believe that this is a courageous recognition by you of the scientific importance and value of the telescope and an expression of confidence that NASA now has the management of this project under tight and realistic control.

JWST (formerly known as Next Generation Space Telescope) is a 6.5 meter diameter telescope. It is much larger than the Hubble Space Telescope (HST—2.4 meter diameter) and unlike HST, it will observe the universe from near the "second Lagrange Point", roughly four times as far away from the Earth as the moon but along the opposite direction to the sun. It will be protected from the sun by an elaborate sunshield. JWST is an engineering marvel and its 18 beryllium mirrors will be furled up within a rocket for launch and then deployed at its destination. This operation has to work perfectly as there will be no means of servicing it after launch.

The principal scientific goals of JWST are bold and exciting and a culmination of nearly fifty years of extraordinary discovery about the universe and our place in it. They are:

- to observe the very first stars, galaxies and black holes which formed at a time when the universe was about four percent of its present age
- to discover how stars and planets actually form today within our Galaxy
- to study planets orbiting nearby cool stars and assess their habitability

However, JWST will also operate as an astronomical observatory and many, and perhaps most, areas of astronomy will be transformed by JWST in much the same way as they have been revolutionized by HST.

JWST is specialized to observe in the infrared region of the spectrum. This is relevant because, although much light emitted by the most distant galaxies is in the optical and ultraviolet spectral bands, the wavelengths of this light are stretched roughly tenfold through the expansion of the universe into the infrared band, as we push out to greater distance and earlier times. There is a second reason why it is preferred to observe in the infrared and this is that the star-forming regions that will be intensively studied by JWST are filled with tiny grains of dust. These dust grains absorb and scatter optical and ultraviolet light but leave infrared radiation alone, enabling us to see deep inside them at these wavelengths. In addition, the light that is absorbed by dust will be re-emitted at infrared wavelengths and we can also observe the dust itself as a tell-tale tracer of star formation.

As well as being the natural successor of HST, JWST is the infrared successor of the much smaller (0.85 meter diameter) Spitzer Space Telescope, with over 50 times the light-gathering ability and 40 times the resolution as well as the Herschel telescope, led by the European Space Agency, which only observes at longer infrared wavelengths than JWST. Given this huge increase in performance over and complementarity to previous telescopes, JWST promises to be a scientific “game changer”.

One reason AANM chose JWST as its highest priority recommendation was its capacity to trace light from the first stars and galaxies during our “Cosmic Dawn” and to watch them grow up and change as the universe expanded. We now have a fairly precise “standard model” of cosmology, which allows us to predict the approximate date when the first stars and galaxies formed. This lies well within JWST’s reach and it will be able to observe the resulting “redshifted” optical and ultraviolet light. It will help explain just how the gas in the universe was converted from atomic to ionized form during the so-called “Epoch of reionization” which marked the end of our cosmic “dark age”. One of the many important discoveries that have been made in this area since the publication of AANM has been that massive black holes are rapidly grown in the nuclei of galaxies surprisingly soon after the formation of the first stars. We see these as the most distant “quasars” and JWST will help us understand how they formed and their impact on their surroundings.

A second reason for JWST’s recommendation in AANM was that it is expected to revolutionize our understanding of how stars and planets form in our Galaxy today. The scientific questions have become much more tightly framed largely through developing the capability to see deeper into the stellar nurseries and measuring stellar masses. The Atacama Large

Millimeter/submillimeter Array (ALMA), a ground-based telescope that was a top priority in the 1991 decadal survey, has just begun Early Science Operation at a site in Chile and is expected to complement JWST in this research.

A third major use for JWST has been largely developed over the past decade. The study of "New Worlds"—exoplanets orbiting other stars—has blossomed. Over seven hundred certified examples are now known, with many more suspected cases under investigation. The diversity of these planets and their host stars is remarkable. Understanding their nature and potential habitability was a major component of the NWNH prioritized science program. As an infrared telescope, JWST is especially well-suited to observe planets orbiting smaller and cooler stars than the sun, that emit mainly in the infrared band. A planet orbiting such a cool star at the right distance should be habitable and perhaps capable of supporting life. JWST has the capacity to see through the atmospheres of many of these planets and determine their composition so as to see if they have life-sustaining oxygen and water, for example. This technique, which was pioneered by Spitzer should work extremely well with JWST exploiting its superb performance in the middle range of the infrared spectrum. JWST also has the capability to observe planetary systems, including those like our solar system, in the process of formation. Here it will be able to observe the extensive disks of gas, stones and rocks, orbiting the host star, out of which planets are eventually assembled. The ability of JWST to tune into different wavelengths enables it to study both the hot regions close to the central star and the cooler parts that are further away.

So, the list of scientific attributes of JWST that justified top ranking in AANM a decade ago, not only remain relevant today but has actually grown. Indeed JWST as well as the ground-based telescope, ALMA, are cornerstones of the recommended new program from NWNH. In terms of the first stars and galaxies, ALMA is expected to detect the cold gas and the tiny grains of dust associated with the first large bursts of star formation. JWST, by contrast, should provide unparalleled sensitivity to the light emitted by the first galaxies and pinpoint the formation sites of the first stars. Furthermore, the highest-ranked, new large space project recommended by NMNH, the Wide Field InfraRed Space Telescope, WFIRST, is expected to complement the targeted infrared observation of JWST with a wide field investigation of dark energy and exoplanet studies. In addition, the highest ranked ground-based recommendation of NWNH, the Large Synoptic Survey Telescope will be the telescope that will find many of the most interesting galaxies and stars that will be followed up in detail by JWST. Likewise, the third-ranked large, ground-based project from NWNH, the Giant Segmented Mirror Telescope was recommended as a spectroscopic complement to JWST. In other words, JWST is central to the scientific program that was recommended by NWNH.

Decadal surveys have been a feature of American astronomy since the 1960s. They compel the astronomy community, through its representatives on the survey committee, to plan a realizable program for the coming decade and beyond. They invariably involve hard choices as the number of feasible missions and facilities greatly exceeds what can be afforded. The astronomy community respects and has always respected the outcome of these deliberations. It recognizes that the process represents the best way to advance the whole field under the constraint of finite resources. The community also acknowledges that the largest and most ambitious projects typically take more than a decade to bring to fruition and that this can lead to delays in realizing newer entries into the program. Space missions, in particular, can encounter unanticipated difficulties and costs can increase from those advertised when a project is first recommended. Although, the delay in the JWST launch was not appreciated at the time NWNH was written, it was acknowledged that there would be little new activity in space astronomy until JWST was launched, presumably in mid-decade. The American Astronomical Society (AAS) which reflects the views of the general astronomy and astrophysics community, continues to support JWST despite the strain its delay is placing on other potential space science missions. The American Physical Society has also endorsed the program. Importantly, JWST is an international collaboration and our European and Canadian partners have invested heavily in it and have been resolute in their support.

The most recent astronomy and astrophysics decadal survey (NWNH) broke new ground in many ways. It was the most inclusive survey to date through inviting white paper submissions from the astronomical community to help define the science program as well as the challenges in areas such as technology development, education, laboratory astrophysics, etc. – over 450 were received - and through requesting specific mission proposals – over 100 were reviewed. It exposed the freshly recommended projects to an independent cost, schedule and risk assessment and used the results to help define a program that conformed with agency-generated funding projections. The lessons learned from this exercise were shared with the leadership of the following two NRC decadal studies, in planetary science and heliophysics. Following its statement of task, NWNH adopted the performance, cost and schedule of JWST as supplied by NASA as part of its baseline set of programmatic and budgetary assumptions. The survey did not perform any independent study of JWST.

In view of the centrality of JWST in addressing the NWNH- recommended science program, the additional complement of space- and ground-based telescopes and facilities in the recommended program were definitely predicated upon the completion of JWST. I believe that, if JWST were not to be completed, then a very large part of the combined science program of AANM and NWNH would not be executable and there would be a consequent call to propose new infrared facilities to replace JWST. Indeed, if JWST were assumed not to exist at the time of white paper submissions to NWNH, then undoubtedly a similar infrared facility would have been proposed. Since the recommendations of the decadal survey were science-driven, the science priorities would not have changed without a JWST. However, I believe the recommended mission portfolio would have changed.

As I have outlined, JWST is confidently expected to achieve its science goals – explore cosmic dawn, examine stellar nurseries and probe exoplanets orbiting cool stars. However, as has been the case with HST, I expect that its ultimate scientific impact will be even greater including much “unscripted” discovery, Dramatic findings like the realizations that 96 percent of the universe is in an unseen “dark” form, that massive black holes reside at the centers of most galaxies and that most sun-like stars are also orbited by planets are still likely to be made. I believe that NASA should continue to support JWST because of the insight that it will provide into fundamental, longstanding questions of extraordinary scientific and popular appeal and its capacity for opening up discovery space. A considerable effort has gone into developing the NASA replan and, whereas any project can encounter unforeseen problems, JWST is now much better understood than it was a year ago and I am optimistic that it will be able to launch on its new schedule. Further grounds for confidence rest on the extraordinary success rate of recent space astrophysics missions. The performances of NASA's fleet of currently operating astrophysics missions - Chandra, Fermi, GALEX, HST, Kepler, RXTE and Swift – have all far exceeded scientific expectation. Similar remarks can be made about recently completed astrophysics missions and missions led by other countries with US partnership. Collectively, these voyages of discovery have maintained the long-held position of global scientific leadership for the US in this field.

In summary, launching and operating JWST would be scientifically transformational, internationally inspirational. It would also make a powerful statement that the United States still has the resolve to execute large, technically challenging and innovative scientific projects. No other country currently has this capability.

Thank you again for the opportunity to address you. I hope that my testimony will be helpful and I look forward to answering your questions.