# James Webb Space Telescope

## Frequently Asked Questions for Scientists and Engineers

25 November 2008

# JWST and its Science Programs

## 1. What is JWST?

JWST is the James Webb Space Telescope, a facility-class space observatory operating in the visible, near and mid infrared. JWST's 6.6-meter diameter primary mirror has a 25-square-meter collecting area formed from eighteen hexagonal segments, and will be diffraction limited at 2 microns. The telescope will be an infrared-optimized general-observer facility with four science instruments: a near-IR camera (0.6-5 microns) from the University of Arizona; a near-IR spectrograph (1-5 microns) from the European Space Agency (ESA); a tunable-filter imager (1.5-5 microns) from the Canadian Space Agency (CSA); and a mid-IR camera/spectrograph (5-28.5 microns) provided jointly by the Jet Propulsion Laboratory and ESA. In addition, CSA is providing the Fine Guidance Sensor. JWST is projected to launch in 2013 on an Ariane 5 ECA rocket to an orbit around the second Sun-Earth Lagrange point.

## 2. How can I get more information about JWST?

For more information, see the Project website (http://www.jwst.nasa.gov). A detailed description of the science and implementation for JWST has been published (Gardner et al. 2006, Space Science Reviews, 123, 485; available without subscription at http://www.springerlink.com/content/h2374012xk30qpw5/). We send out a JWST email newsletter several times a year (sign up at: http://jwst.gsfc.nasa.gov/scientists.html) and hold JWST Town Hall meetings at the winter meetings of the American Astronomical Society.

## 3. How about a JWST talk?

If your institution would like to have a colloquium talk about JWST, or if you would like a talk about JWST at a conference you are organizing, please contact the JWST science team at: contactswg@jwst.nasa.gov. We are also available for public talks.

## 4. Who was James E. Webb?

JWST is named after James E. Webb (1906 – 1992), NASA's second administrator. Webb is best known for leading Apollo, a series of lunar exploration programs that landed the first humans on the Moon. However, he also initiated a vigorous space science program that was responsible for more than 75 launches during his tenure, including America's first interplanetary explorers. For more information, see: http://jwst.gsfc.nasa.gov/whois.html, or Webb's official NASA biography at: http://www.hq.nasa.gov/office/pao/History/Biographies/webb.html.

## 5. What science will JWST accomplish?

Topics in four areas of modern astronomy are being used to craft the engineering design of JWST: First Light and Reionization; The Birth of Galaxies; The Birth of Stars and Protoplanetary Systems; and Planetary Systems and the Origin of Life. In addition, JWST's instrument suite will have wide applicability across a broad range of scientific issues. For a detailed description of JWST science see Gardner et al. 2006, SSRv, 123, 485.)

# JWST Observations

## 6. What advantages will JWST provide over Hubble, Spitzer, and other existing telescopes?

JWST possesses a combination of large aperture, diffraction-limited image quality, and infrared sensitivity over a broad wavelength range hitherto not available from ground- or space-based facilities. Its capabilities will let us understand the full population of galaxies at redshifts from 6 to 10 (for example to determine why we are finding early galaxies that are brighter and older than some theoretical predictions) and to detect the first galaxies to form as early as redshift 15. JWST is also needed to explore the assembly of galaxies and their nuclear black holes and how they are inter-related through processes such as feedback. It will trace the earliest stages of stellar evolution, penetrating the dense cold cloud cores where stars are born. It will obtain spectra to reveal the conditions in protoplanetary disks and to search for biologically important molecules, and will map the evolution of planetary systems by imaging debris disks and by studying exoplanets directly through both imaging and by observing transits.

**7. What advantages will JWST provide over a future 30-meter telescope on the ground?**

JWST is designed to make observations that are not possible from the ground, regardless of ground-based telescope aperture. The Astronomy and Astrophysics Advisory Committee, which evaluates ground- and space-based programs by NASA, NSF, and the Department of Energy, commissioned an extensive report on the complementary natures of JWST and a 30-meter ground-based telescope (available at http://www.nsf.gov/mps/ast/aaac/reports/gsmt-jwst_synergy_combined.pdf). Between 1 and 2.5 microns, JWST's strengths are complementary to those of the next-generation 30-meter aperture telescopes. Beyond about 2.5 microns, where ground-based sensitivity is severely limited by thermal emission from the atmosphere, JWST's advantage in sensitivity will be immense, and JWST wavelength coverage extends to 28.5 microns.

**8. What are the policies and plans for observing with JWST?**

The policies for JWST guest observers will be very similar to those of the other Great Observatories, with more than 85% of the observing time available to those submitting observing proposals from the astronomical community. The current expectation is that general-observer (GO) programs will start in the first year of the mission with a cycle 1 call for proposal nominally being issued nine months before launch. We expect that cycle 1 will include a mix of small, medium and large GO programs. Guaranteed time observers will complete their programs in the first three years of the mission. No specific decision has been taken regarding Legacy, Treasury or Key programs but it is expected that the community will have the opportunity to comment on these ideas through a User Committee and that any initiative will be properly advertised and open to the astronomical community. NASA is planning for all JWST data to be public after one year, similar to HST, and that E/PO efforts will also be similar to those for HST. The astronomical community, including amateur astronomers and the public, will be able to request data from the JWST archive.

**9. What is JWST's lifetime?**

JWST will have a mission lifetime of not less than 5-1/2 years after launch, with the goal of having a lifetime greater than 10 years. The lifetime is limited by the amount of fuel used for maintaining the orbit, and by the testing and redundancy that ensures that everything on the spacecraft will work (mission assurance). JWST will carry fuel for a 10-year lifetime (with margin); the project will do mission assurance testing to guarantee 5 years of scientific operations starting at the end of the commissioning period 6 months after launch.

## JWST's Budget

**10. How much does JWST cost?**

The total life-cycle cost to NASA for the JWST mission is ~$5B in real-year dollars. In addition, there are European and Canadian contributions.

**11. Will JWST's budget and schedule remain stable?**

The JWST project has maintained the same budget and schedule since 2005.

**12. How does JWST plan to finish on time and within budget?**

For this large complex space project, much new technology was needed. To mitigate risk and minimize overall costs, the JWST Project adopted the strategy of developing all required technology early. Studies show that increased investment in Phase A/B results lower risk of overrun at completion. All critical Project technologies reached Technical Readiness Level 6 (TRL-6) as determined by a Technology Non-Advocate Review (T-NAR) in early 2007. This achievement was well in advance of the Spring 2008

Project-wide NAR and transition to Phase C/D (the time at which TRL-6 is required), and fully half a decade prior to a 2013 launch. For TRL-6, a technology must be demonstrated to provide the needed performance in a flight-like environment; such demonstrations typically include thermal-vacuum testing, vibration testing, or life-cycle testing, for example. We continue to progress on all of these fronts.

### 13. What else is JWST doing to finish on time and within budget?

The Project is minimizing costs and mitigating risk with a "tiered integration and testing program" like other complex space missions. By testing at individual instrument level, integrated-instruments level, instrument-package/optics level, and finally at full observatory level, anomalies can be caught earlier in mission development, when mitigation strategies are simpler and costs are lower. Substantial hardware is already in fabrication (e.g., the near-infrared camera, mid-infrared instrument, and fine guidance sensor have passed their Critical Design Reviews and are building engineering test units; the mirror segments are well along). In other words, the JWST project is much more front-loaded with technology-development costs than space missions that use more conventional technologies: ~49% of the total project cost will be spent in Phase A/B. The price tag for these strategies comes early in the project, as the community saw in 2005-2006. The benefits will come later, when the Project budget profile begins to ramp down after FY08.

### 14. Can NASA save money by scaling JWST down to a 4-m?

No. Blanks for the eighteen primary mirror segments for JWST's 6.6-m mirror have already been manufactured and are in various stages of polishing. Changing to a smaller diameter mirror now would require a major mission redesign with a concomitant delay, yielding a large net cost increase. Even simply removing several mirror segments from the current design would create problems with stray light in the optics and the balance of mass in the spacecraft.

### 15. Who paid for the full-scale JWST model?

The full-scale model was built and is supported entirely with Northrop Grumman Space Technology internal funds.

## JWST's Instruments

### 16. What are the capabilities of NIRCam?

The Near-Infrared Camera (NIRCam) provides filter imaging in the 0.6 to 5.0 micron range. With a dichroic splitting the light at 2.4 microns, NIRCam provides simultaneous imaging of a 2.2 by 4.4 arcmin$^2$ field of view in two filters. The short wavelength channel contains eight 2048 by 2048 pixel detectors with 32 milliarcsec pixels, and the long wavelength channel contains two 2048 by 2048 pixel HgCdTe detectors with 65 milliarcsec pixels. NIRCam contains 7 broad-band filters, 12 medium-band filters, and several narrow-band filters. It contains the weak lenses and other hardware that will be used for wavefront sensing for the telescope. NIRCam contains a coronagraphic capability. NIRCam broad-band imaging will reach 11.4 nJy (AB=28.8) point-source detection at 2.0 microns, 10 sigma in 10,000 seconds. For more details see: http://ircamera.as.arizona.edu/nircam/.

### 17. What are the capabilities of NIRSpec?

The Near-Infrared Spectrograph (NIRSpec) uses a MEMS micro-shutter array to provide simultaneous spectroscopy of more than 100 sources over a field of view large than 3 by 3 arcmin$^2$. In addition to the multi-object capability, it includes fixed slits and an integral field unit (IFU) for imaging spectroscopy. Six grating will yield resolving powers of R ~ 1000 and R ~ 3000 in three spectral bands over 1.0 to 5.0 microns. A single prism will yield R ~ 100 over 0.6 to 5 microns. The shutters in the microshutter array project to 203 by 463 milliarcsec on the sky on a 267 by 528 milliarcsec pitch. The mosaic of 4 subunits produces a final array of 730 (spectral) by 342 (spatial) shutters. The IFU consists of 30 slices, each 100 milliarcsec, over a field of view of 3 by 3 arcsec. The NIRSpec detector array consists of two 2048 by 2048 pixel arrays sensitive over 0.6 to 5.0 microns. The NIRSpec prism sensitivity is 132 nJy (AB=26.1) in the continuum at 3.0 microns. The R ~ 1000 line sensitivity is $1.64 \times 10^{-18}$ erg $s^{-1}$ $cm^{-2}$ at 2.0 microns. These are 10 sigma in 10,000 seconds.

### 18. What are the capabilities of TFI?

The Tunable Filter Imager (TFI) uses a Fabry-Perot etalon to provide narrow-band near-IR imaging over a field of view of 2.2 by 2.2 arcmin with a spectral resolution of R ~ 100. The wavelength coverage is 1.6 to 4.9 micron with a gap between 2.6 and 3.1 micron. The TFI detector is a single 2048 by 2048 pixel detector array with 65 milliarcsec pixels. The TFI includes a coronagraphic capability. TFI imaging will reach 126 nJy (AB=26.1) point source sensitivity at 3.5 microns, 10 sigma in 10,000 seconds.

### 19. What are the capabilities of MIRI?

The Mid-Infrared Instrument (MIRI) provides imaging and spectroscopy over the wavelength range 5 to 28.5 micron. The imaging module provides broad-band imaging, coronagraphy and low-resolution slit spectroscopy. It has a 1024 by 1024 pixel detector array with 110 milliarcsec pixels. The coronagraphy is done with quarter-phase coronagraphs at 10.65, 11.4 and 15.5 microns, and a Lyot stop optimized for 23 microns. The low-resolution slit operates over 5 to 10 microns with R ~ 100). MIRI uses an image slicer and dichroics to provide imaging spectroscopy over four simultaneous concentric fields of view ranging from 3 to 7 arcsec on a side. The spectral resolution ranges from R ~ 2400 to 3600. MIRI spectroscopy uses two 1024 by 1024 Si:As arrays with plate scales between 200 to 470 milliarcsec. MIRI imaging sensitivity is 700 nJy (AB=24.3) at 10.0 microns and 8.7 μJy (AB=21.6) at 21.0 microns. MIRI spectroscopic line sensitivity is $1.0 \times 10^{-17}$ erg $s^{-1}$ $cm^{-2}$ at 9.2 microns and $5.6 \times 10^{-17}$ erg $s^{-1}$ $cm^{-2}$ at 22.5 microns. These are 10 sigma in 10,000 seconds.

## JWST's Technology

### 20. Is the technology ready for JWST?

All the basic technologies necessary for the mission were demonstrated in early 2007. At that time an independent review board confirmed that they were at Technology Readiness Level 6 (TRL-6), a year prior to the Project transition to Phase C/D when TRL-6 is required. For TRL-6, a technology must be demonstrated to provide the needed performance in a flight-like environment; such demonstrations typically include thermal-vacuum testing, vibration testing, or life-cycle testing, for example. Substantial progress on the remaining secondary items has also occurred since (e.g., microshutter production, crycooler power requirements). Flight detector arrays and microshutter arrays have been selected and are in test. All the technologies required for the mission are therefore developed to the necessary level.

### 21. What is the current status of ISIM?

(*Status as of November 2008*) The Integrated Science Instrument Module (ISIM) project's current priority is preparing for its Critical Design Review (CDR) in March 2009. All 4 science instruments plus the guider have been through their own CDRs already. The flight science instruments begin to arrive for integration into the ISIM in early 2010. The ISIM technical status is nominal with only normal development issues in-work. The MIRI flight detectors and the NIRCam short-wave flight detectors are in hand. Long-wave detectors for NIRCam, NIRSpec, and FGS are in fabrication with no significant issues.

### 22. What is the current status of the telescope?

(*Status as of November 2008*) There are 18 flight JWST primary mirror segments plus 3 spares including the pathfinder Engineering Demonstration Unit (EDU). The segment blanks were all machined out of beryllium and lightweighted. Most of the segments are currently in the coarse or fine polishing phase. Upon completion of the initial polishing, the segments are built up into a primary mirror segment assembly (PMSA), with the attachment of the mirror actuators onto the back. The PMSAs are cryogenically tested at the X-ray Calibration Facility (XRCF) that was built at Marshall Space Flight

Center to test and calibrate Chandra. Currently, the EDU is undergoing thermal vacuum testing in the XRCF and the first flight mirror will arrive there soon.

**23. What is the performance of the JWST detectors?**

The HgCdTe detectors for JWST's three short wavelength instruments were under development early in the Project's history. The 2.5-micron cutoff detectors for the short wavelength arm of NIRCam have always met the performance requirements while some tailoring of Teledyne's processes was required to meet the dark current requirement for the 5-micron cutoff detectors. The recent issues hindering completion of the flight detector fabrication have not been the result of poor performance of the detectors but rather several production problems such as one which caused a number of dead pixels around the edges of an array. All of these problems have now been solved.

The MIRI detectors build on the heritage from the Infrared Array Camera (IRAC) on Spitzer, but with significant performance enhancements such as the 1024 by 1024 format and modifications in the detector prescription for better performance in the 5 to 10 micron range. Excellent detector arrays have been produced at Raytheon Vision Systems (RVS) that have been shown to support the instrument requirements for sensitivity. They are being built into the flight focal plane modules by RVS and JPL, after which they will be characterized at JPL prior to delivery. Engineering grade focal plane modules are already performing well in the verification model MIRI instrument testing at Rutherford Appleton Laboratories.

**24. Will this complex spacecraft really work?**

JWST requires several new technologies, but these have been validated by testing and external review fully six years prior to launch. The program has a three-year integration and test (I&T) plan. The Project has purposely phased the contingency funding to ensure it fully covers this I&T phase, where most of the risk is, and to help resolve any problems that crop up during I&T. The deployments involved in JWST are being provided by Northrop Grumman Space Technology (NGST), the world's leader in satellite deployments. NGST has built satellites with more difficult and complex deployments, including 640 deployments with more than 2000 elements, with no mission failures. The Project follows NASA standard management requirements in which passage through each development stage is gated by independent expert review. The Project is managed by Goddard Space Flight Center whose mission success record exceeds that of any civil space sector organization (government or private).

**25. Will the thermal design really work?**

The JWST thermal concept is rooted in the experience with Spitzer. The performance of that mission demonstrates the accuracy of the thermal models that were used to predict its operating temperature through the same kind of radiative cooling being used with JWST. The Spitzer outer shell – which is analogous to the cold part of JWST – is running at exactly the temperature (35 K) predicted by its thermal models. An extensive program of iterative testing and modeling with full-size components – "pathfinders" will verify the JWST models. Pathfinders of increasing fidelity are constructed, along with tests of smaller assemblies (electrical harness, multi-layer insulation, radiator coatings). The pathfinders are compared with detailed thermal models so that scientists and engineers can be confident that the "bootstrapping" process results in a good physical understanding of the hardware. This understanding is verified by thermal vacuum testing. Because no single thermal-vacuum test can simulate realistic operational conditions for a fully integrated JWST observatory, a series of tests will verify performance of individual assemblies (instrument module, sunshield, spacecraft bus). These are followed by a comprehensive thermal test that involves the complete telescope and instrument module. Temperature data gathered during these tests are used to fine-tune thermal models to make them more representative of flight hardware. Independent thermal models are developed by NASA and the prime contractor team to mitigate risk. Finally, the Project uses external reviewers with relevant experience to assess the JWST thermal design and testing approach.

**26. Will astronauts be able to service JWST like they did HST?**

Unlike HST, which orbits roughly 350 miles above the surface of Earth and is therefore accessible by the Space Shuttle, JWST will orbit the second Lagrange point (L2), which is roughly 1,000,000 miles from Earth. There is currently no servicing capability that can be used for missions orbiting L2, and therefore the JWST mission baseline design does not rely upon a servicing option. However, the JWST Project has studied and is considering the possibility of adding a fixture to enable attachment of a future servicing vehicle to the observatory. They have also studied whether there are any types of servicing activities that might be feasible, and identified the top-level requirements that would need to be met by a future servicing capability in order to service JWST, e.g., contamination control considerations to avoid damage to exposed JWST optical surfaces.

**27. What is JWST doing to ensure that its gyros last the full mission?**

The gyroscopes on HST and Chandra are mechanical devices dependent on bearings for their function, and they face problems typical of such designs. JWST has adopted a different gyroscope technology. The "Hemispherical Resonator Gyroscope" (HRG) uses a quartz hemisphere vibrating at its resonant frequency to sense the inertial rate. The hemisphere is made to resonate in a vacuum, and the hemisphere's rate of motion is sensed by the interaction between the hemisphere and separate sensing electrodes on the HRG housing. The result is an extremely reliable package with no flexible leads and no bearings. The internal HRG operating environment is a vacuum, thus once the gyroscope is in space any housing leaks would actually improve performance. Stress analyses of HRGs show this design has a "mean time before failure" of 10 million hours. As of June 2006, this type of device had accumulated more than 7 million hours of continuous operation in space without a failure. This new technology eliminates the bearing wear-out failure mode, leaving only random failure and radiation susceptibility of the electronics (which all such devices share, and which can be mitigated by screening and shielding).

**28. How big is the JWST mirror?**

The JWST primary mirror is made of 18 segments and stretches 6.6 meters from tip to tip. Its area of slightly more than 25 square meters and its diffraction-limited resolution are approximately equivalent to a 6.0 meter conventional round mirror. At 2 microns, the FWHM of the image will be about 70 milli-arcsec.

The 18 hexagonal segments are arranged in a large hexagon, with the central segment removed to allow the light to reach the instruments. Each segment is 1.32 m, measured flat to flat. Beginning with a geometric area of 1.50 $m^2$; after cryogenic shrinking and edge removal, the average projected segment area is 1.46 $m^2$. With obscuration by the secondary mirror support system of no more than 0.86 $m^2$, the total polished area equals 25.37 $m^2$, and vignetting by the pupil stops is minimized so that it meets the >25 $m^2$ requirement for the total unobscured collecting area for the telescope. The outer diameter, measured along the mirror, point to point on the larger hexagon, but flat to flat on the individual segments, is 5 times the 1.32 m segment size, or 6.6 m (see figure). The minimum diameter from inside point to inside point is 5.50 m. The maximum diameter from outside point to outside point is 6.64 m. The average distance between the segments is about 7 mm, a distance that is adjustable on-orbit. The 25 $m^2$ is equivalent to a filled circle of diameter 5.64 m. The telescope has an effective f/# of 20 and an effective focal length of 131.4 m, corresponding to an effective diameter of 6.57 m. The secondary mirror is circular, 0.74 m in diameter and has a convex aspheric prescription. There are three different primary mirror segment prescriptions, with 6 flight segments and 1 spare segment of each prescription. The telescope is a three-mirror anastigmat, so it has primary, secondary and tertiary mirrors, a fine steering mirror, and each instrument has one or more pick-off mirrors.

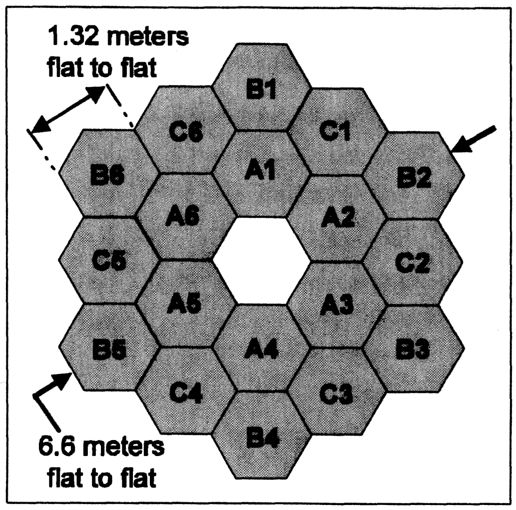


Figure 1: The JWST primary mirror consists of 18 hexagonal segments with three different prescriptions.

**29. How does the collecting area of JWST compare to HST?**

HST has a 2.4 m diameter round primary mirror. For ACS and STIS, the central obscuration by the secondary is 0.33r, where r is the 1.2 m radius. WFPC2 had a larger internal obscuration, which was oversized to ensure alignment, ranging between 0.39r and 0.43r. Using the 0.33r obscuration, the area of HST's mirror is $\pi\,(1.2^2)\,(1\text{-}0.33^2) = 4.0\ m^2$. Therefore, the ratio between the 25.0 $m^2$ JWST mirror and the HST mirror is 6.25.

## JWST's Integration and Testing

**30. How is JWST being tested?**

JWST will be tested incrementally during its construction, starting with individual mirrors and instruments (including cameras and spectrometers) and building up to the full observatory. JWST's mirrors and the telescope structure are first each tested individually, including optical testing of the mirrors and alignment testing of the structure inside a cold thermal-vacuum chamber. The mirrors are then installed on the telescope structure in a clean room at Goddard Space Flight Center (GSFC). In parallel to the telescope assembly and alignment, the instruments are being built and tested, again first individually, and then as part of an integrated instrument assembly. The integrated instrument assembly will be tested in a thermal-vacuum chamber at GSFC using an optical simulator of the telescope. This testing makes sure the instruments are properly aligned relative to each other and also provides an independent check of the individual tests. After both the telescope and the integrated instrument module are successfully assembled, the integrated instrument module will be installed onto the telescope, and the combined system will be sent to Johnson Space Flight Center (JSC) where it will be optically tested in one of the JSC chambers. The process includes testing the 18 primary mirror segments acting as a single primary mirror, and testing the end-to-end system. The final system test will assure that the combined telescope and instruments are focused and aligned properly, and that the alignment, once in space, will be within the range of the actively controlled optics. In general, the individual optical tests of instruments and mirrors are the most accurate. The final system tests provide a cost-effective check that no major problem has occurred during assembly. In addition, independent optical checks of earlier tests will be made as the full system is assembled, providing confidence that there are no major problems.

**31. Why is JWST being tested this way?**

The most expensive tests of a large space telescope are the final system tests. The Hubble Space Telescope did not have a final system test – which could have caught the problem in the fabrication of the Hubble primary mirror – because it was deemed too complex and expensive. Unlike Hubble, JWST is not easily serviceable; thus JWST must be done right. The challenge has been to design a test strategy that assures success but is also affordable. The JWST test plan emphasizes incremental testing, accompanied by independent checks at each level of assembly to minimize the uncertainties left for the final system test. The plan does include a final system test, and this test makes use of the JWST active optics. This final test will assure that JWST can be aligned on-orbit, making the test cost effective yet retaining adequate redundancy and accuracy to detect any problems.

**32. Why is this testing strategy optimal for JWST?**

JWST must operate at very cold temperatures so that its mirrors' and instruments' self-generated heat will not swamp its sensitive infrared sensors. At the same time, JWST is being designed to have optical performance that is significantly more challenging than that required by the Spitzer telescope. Lessons learned from Spitzer, as well as COBE, WMAP, and other cryogenic and comparable optical telescopes, led the JWST team to design a test flow that is optimized for the cold performance. This approach uses testing at incremental levels of assembly, in order to minimize the chance the telescope will have to be disassembled to fix problems late in the development (when it would be time-consuming and expensive). The lessons also led to a final test configuration in which minimal hardware is inside of the helium shroud used to cool the telescope. Also, the test configuration – with the primary mirror "cup up" – eliminates the need for a large, heavy tower and permits easier transportation of the telescope in and out of the chamber (via a large side door).

**33. Why is this testing strategy cost-effective?**

The overall JWST Project testing strategy will test all individual components as early as possible in the project schedule after they have been manufactured, so that time is available to fix or replace them if needed without costly schedule impacts. More complex systems, such as science instruments and operational systems, will get tested later in the Project schedule: early enough that fixes can be implemented if needed without major schedule impacts, but late enough in the project that necessary design effort and analyses have adequate time to complete. All critical JWST components and systems will be independently verified at the lowest possible level of assembly. In this approach, subtle manufacturing errors or system performance flaws have the best chance of surfacing early and unambiguously, which will minimize the risk of large and costly schedule impacts later in the project.

**34. What lessons has JWST learned from past missions?**

Many lessons were learned from building optical, UV and X-ray missions like HST and Chandra, including a key aspect of the JWST strategy: early independent tests of key optical parameters, with the highest performance tests performed at the lowest levels of assembly. The strategy also includes a full-up system test of the final assembly to catch significant errors anywhere in the optical chain. The lessons learned from earlier cryogenic telescopes have directly led to a most robust cold-testing strategy, including early testing, a "cup-up" design, keeping as much of the testing hardware as possible external to the helium shroud, and designing the testing equipment to be relatively accessible during the test period.

## JWST and NASA Programmatic Issues

**35. Wouldn't it be better to fly a number of smaller missions instead of one big mission?**

Science goals and their associated measurement requirements ultimately define mission sizes. For some science questions the appropriate mission size is large, for others smaller missions will suffice. The 2000 decadal survey defined a number of scientific challenges some of which required technically ambitious missions. JWST was the top-ranked priority in the 2000 Decadal Survey. It addresses science that cannot be done by any other means. The balance between big and small missions is the result of prioritization in the Decadal Survey and NASA's implementation strategy. Historical publication and citation rates of the Great Observatories, as well as flagship Solar System missions like Cassini and Galileo, show that they are extremely productive facilities, enabling thousands of scientists to do forefront research with state-of-the-art instrumentation.

**36. Will JWST be reviewed in the Decadal Survey?**

The formal answer to this question is "No" as the guidelines for the survey remove from reprioritization those missions in development. "In development" means in phase C, having passed PDR and been confirmed, which happened to JWST in 2008. However, JWST will be a major component of the NASA program in the next decade, and we expect that the Decadal Survey report will discuss JWST and its role in astronomy. How the community plans to use JWST might also be discussed.

**37. How does the astronomical community provide feedback on JWST?**

Community input to JWST comes through several paths. The Science Working Group provides regular input to the NASA Headquarters Program Scientist and the Goddard Space Flight Center Project office. The SWG includes the NASA Project scientists, the principal investigators of each science instrument team and interdisciplinary scientists who are expert in the broad range of science encompassed by the mission. Their contact information can be found at: http://www.jwst.nasa.gov/workinggroup.html. The NASA Astrophysics Subcommittee, (http://science.hq.nasa.gov/strategy/NAC_sci_subcom/astrophysics.html) also represents the broad astrophysics community, and provides input on the astrophysics portfolio including JWST to the NASA Advisory Council. For certain key questions, NASA convenes special "blue ribbon" panels, such as the Science Assessment Team in 2005. Finally, as the operations phase of the JWST mission approaches, the Space Telescope Science Institute will convene a Users's Committee to advise on operations aspects.

**38. What will be the successor to JWST?**

NASA expects to follow the priorities recommended by the Decadal Survey for future missions.