AstroTalk: Behind the news headlines of November 2017

Richard de Grijs (何锐思)
(Kavli Institute for Astronomy and Astrophysics, Peking University)

Preparations for James Webb Space Telescope operations offer tantalizing prospects of major breakthroughs

The vault-like, 12 meter-diameter, 40-ton door of Chamber A at NASA's Johnson Space Center in Houston, Texas (USA), was unsealed on 18 November, signaling the end of cryogenic testing for the *James Webb Space Telescope*, *JWST* for short.

The historic chamber's massive door opening brings to a close about 100 days of testing for the *JWST*, a significant milestone in the telescope's journey to the launch pad. The cryogenic vacuum test began when the chamber was sealed shut earlier this year, on 10 July. Scientists and engineers at Johnson Space Center put the *JWST*'s optical telescope and integrated science instrument module ('OTIS') through a series of tests designed to ensure the telescope functioned as expected in an extremely cold, airless environment similar to that of space.

> "*After 15 years of planning, chamber refurbishment, hundreds of hours of risk-reduction testing, the dedication of more than 100 individuals through more than 90 days of testing, and surviving Hurricane Harvey, the OTIS cryogenic test has been an outstanding success*," said Bill Ochs, *JWST* project manager at NASA's Goddard Space Flight Center in Greenbelt, Maryland (USA). "*The completion of the test is one of the most significant steps in the march to launching Webb*."

These tests included an important alignment check of the *JWST*'s 18 primary mirror segments, to make sure all of the gold-plated, hexagonal segments acted like a single, monolithic mirror. This was the first time the telescope's optics and its instruments were tested together, although the instruments had previously undergone cryogenic testing in a smaller chamber at Goddard Space Flight Center.

The *JWST* telescope team persisted with the testing even when Hurricane Harvey slammed into the coast of Texas on 25 August as a category-4 hurricane before stalling over eastern Texas and weakening to a tropical storm, where it dropped as much as 127 cm of rain in and around Houston. Many *JWST* telescope team members at Johnson Space Center endured the historic storm, working tirelessly through overnight shifts to make sure the cryogenic testing was not interrupted.

> "*The individuals and organizations that have led us to this most significant milestone represent the very best of the best. Their knowledge, dedication, and execution to successfully complete the testing as planned, even while enduring Hurricane Harvey, cannot be overstated*," said Mark Voyton, *JWST* optical telescope element and integrated science instrument manager at Goddard Space Flight Center.

Before cooling the chamber, engineers removed the air from it, which took about a week. On 20 July, engineers began to bring the chamber, the telescope, and the telescope's science instruments down to cryogenic temperatures—a process that took about 30 days. During cool-down, *JWST* and its instruments transferred their heat to surrounding liquid nitrogen and cold gaseous helium shrouds in Chamber A. *JWST* remained at 'cryo-stable' temperatures for about another 30 days, and on 27 September the engineers began to warm the chamber back to ambient conditions (near room temperature), before pumping the air back into it and unsealing the door.

> "*With an integrated team from all corners of the [USA], we were able to create deep space in our chamber and confirm that Webb can perform flawlessly as it observes the coldest corners of the Universe*," said Jonathan Homan, project manager for Webb's cryogenic testing at Johnson Space Center. "*I expect [Webb] to be successful, as it journeys to Lagrange point 2 [after launch] and explores the origins of solar systems, galaxies, and has the chance to change our understanding of our universe*."

Lagrange point 2 ('L2') is one of five gravitationally stable regions in the Sun–Earth system from where a spacecraft will not drift away; it is located at about 1.5 million km from Earth, on the opposite side of the Sun.

While the *JWST* was inside the chamber, insulated from both outside visible and infrared light, engineers monitored it using thermal sensors and specialised camera systems. The thermal sensors kept tabs on the temperature of the telescope, while the camera systems tracked the physical position of the telescope to see how its components very minutely moved during the cool-down process.

> "*This test team spanned nearly every engineering discipline we have on Webb*," said Lee Feinberg, *JWST* optical telescope element manager at Goddard Space Flight Center. "*In every area there was incredible attention to detail and great teamwork, to make sure we understand everything that happened during the test and to make sure we can confidently say Webb will work as planned in space*."

In space, the telescope must be kept extremely cold, in order to be able to detect the infrared light from very faint, distant objects. *JWST* and its instruments have an operating temperature of about 40 Kelvin (or about −233 °C). Because the telescope's mid-infrared instrument (MIRI) must be kept colder than the other research instruments, it relies on a cryocooler to lower its temperature to less than 7 Kelvin (−266 °C).

To protect the telescope from external sources of light and heat (like the Sun, Earth, and Moon), as well as from heat emitted by the observatory itself, a five-layer, tennis court-sized sunshield acts like a parasol that provides shade. The sunshield separates the observatory into a warm, sun-facing side (reaching temperatures close to 85 °C) and a cold side (−240 °C). The sunshield blocks sunlight from interfering with the sensitive telescope instruments.

JWST's combined science instruments and optics next journey to Northrop Grumman Aerospace Systems in Redondo Beach, California, where they will be integrated with the spacecraft element, which is the combined sunshield and spacecraft bus. Together, the pieces form the complete observatory. Once fully integrated, the entire observatory will undergo more tests during what is called 'observatory-level testing.' This testing is the last exposure to a simulated launch environment before flight and deployment testing on the whole observatory. The *JWST* is expected to launch from Kourou, French Guiana, in the spring of 2019.

Meanwhile, significant progress has also been made this month as regards the *JWST*'s science operations. More than 100 proposals for DD-ERS observations were submitted in August 2017. Of those, 13 programmes requesting 460 hours of telescope time were selected following review by panels of subject matter experts and the Space Telescope Science Institute (STScI) Director. The 13 teams that submitted successful DD-ERS proposals won't be able to get their hands on any data for another two years, however, following a six-month commissioning period after launch. But from November 2019 until April 2020, these early programmes include examining Jupiter and its moons, searching for organic molecules forming around infant stars, weighing supermassive black holes lurking in galactic cores, and hunting for baby galaxies born in the early universe.

Astronomers around the world will have immediate access to early data from specific *JWST* science observations, which will be completed within the first five months of its mission.

> "*I'm thrilled to see the list of astronomers' most fascinating targets for the Webb telescope, and extremely eager to see the results. We fully expect to be surprised by what we find*," said John C. Mather, *JWST* Senior Project Scientist at the Goddard Space Flight Center.

The resulting observations will comprise the Director's Discretionary Early Release Science (DD-ERS), and cover the gamut of *JWST* science targets, from planets in our solar system to the most distant galaxies.

> "*We were impressed by the high quality of the proposals received*," said Ken Sembach, STScI Director. "*These observing programs not only will generate great science, but also will be a unique resource for demonstrating the investigative capabilities of this extraordinary observatory to the worldwide scientific community*."

The observations will also exercise all four of the observatory's science instruments, so that the astronomical community can explore their full potential. The *JWST* has a minimum scientific lifetime of five years, so the scientific community will have to rapidly learn to use its advanced capabilities.

> "*We want the research community to be as scientifically productive as possible, as early as possible, which is why I am so pleased to be able to*

> *dedicate nearly 500 hours of director's discretionary time to these ERS observations*," said Sembach.

One of the most widely anticipated areas of research by the *JWST* is to study planets orbiting other stars. When such an exoplanet passes in front of its host star, starlight filters through the planet's atmosphere, which absorbs certain colours of light, depending on the atmosphere's chemical composition. The *JWST* will measure this absorption, using its powerful infrared spectrographs, to look for the chemical fingerprints of the atmosphere's gases. Astronomers initially will train their gaze onto gaseous Jupiter-sized worlds like WASP-39b and WASP-43b, because they are easier targets on which to apply this technique. The results will help guide observing strategies for smaller, mostly rocky and more Earth-like super-Earths, where atmospheric composition may give hints of a planet's potential habitability.

Webb also will peer into the distant Universe, examining galaxies whose light has been stretched into infrared wavelengths by the expansion of space. This infrared region is beyond what the *Hubble Space Telescope* can detect. Galaxy clusters are particularly rich sources of targets, since a cluster's gravity can magnify light from more distant background galaxies. DD-ERS observations will target regions of the sky already examined by *Hubble*'s Frontier Fields programme, such as the galaxy cluster MACS J0717.5+3745. *JWST* data will complement *Hubble*'s, giving astronomers new insights into these cornucopias of galaxies.

The successful science teams are hoping for new discoveries, but they've also been selected because of promises to provide baseline information for future observers and computer software tools that those astronomers will need to make sense of their observations on the telescope.

> "*With the telescope's five-year lifetime, we need to use it very efficiently to maximize the return*," Daniel Weisz from the University of California at Berkeley said. "*The early release science program is supposed to produce science-enabling results within five months of the observations, which in the astronomy world is basically yesterday*."

Letting astronomers rather than staff take the telescope for a test drive is a new concept for NASA, said Imke de Pater, a University of California Berkeley professor of astronomy who will lead a team using the telescope for up-close observations of the solar system. She and her team will focus on Jupiter, its moons Io and Ganymede and its faint rings, to see if they can capture fine detail against the bright background of Jupiter, which is actually too bright for the telescope to look at without filters.

> "*We will see if we can image the rings and get rid of the scattered light from Jupiter, which pushes the telescope's limits and really tests the capabilities of JWST*," she said.

Weisz, who studies star systems, from globular clusters with millions of stars to galaxies in the local Universe, will take the long view. He is particularly interested in systems near enough that individual stars can be picked out and counted, which can tell astronomers about the history of the galaxy and ultimately the history of the Universe.

The *JWST* will be ideal for this, because its mirrors will be 2½ times the size of the *Hubble Space Telescope*'s mirror, effectively cutting the time it takes to collect data on a cluster or galaxy by a factor of 10. This allows detailed studies of the very faintest stars, some of which first started to glow when the Universe was still in its infancy, more than 10 billion years ago.

> "*For studies of very faint stars in the Milky Way, the JWST is going to be phenomenal*," he said. "*The telescope will do roughly in its 5–10-year mission what Hubble has done in its 25-year mission for local galaxies*."

During the 20 hours of telescope time allocated to his team, they will take images in both optical and infrared of a globular cluster in the Milky Way, a very faint, dark-matter-dominated dwarf galaxy that orbits the Milky Way, and a close neighbour and travelling companion of the Milky Way, a galaxy at a distance of about 3 million light years.

By counting and determining the age of each star within within these galaxies, for example, he hopes to shed light on what happened early in the Universe when stars first began to shine across the cosmos, the so-called 'epoch of reionisation.'

De Pater admits that two years is a long time to wait, but her team hopes to use their 28.9 hours of observing time to measure the wind speeds in Jupiter's Great Red Spot, observe gases in the atmospheres of Io and Ganymede and see ripples left by comets in the rings around the planet.

> "*The idea is that for any solar system object, you have to assemble a mosaic of the planet or moon from multiple observations when everything is moving and rotating and changing. How do you do that?*" de Pater said. "*We have to develop the software so that astronomers can put their little postage stamps together into a map*."

The prospects offered by the *JWST* are exciting on multiple fronts. Since its data will be immediately accessible by anyone, irrespective of their affiliation or national origin, now is the time to get ready to reap the benefits of what promises to become an amazing treasure trove of novel astronomical observations!

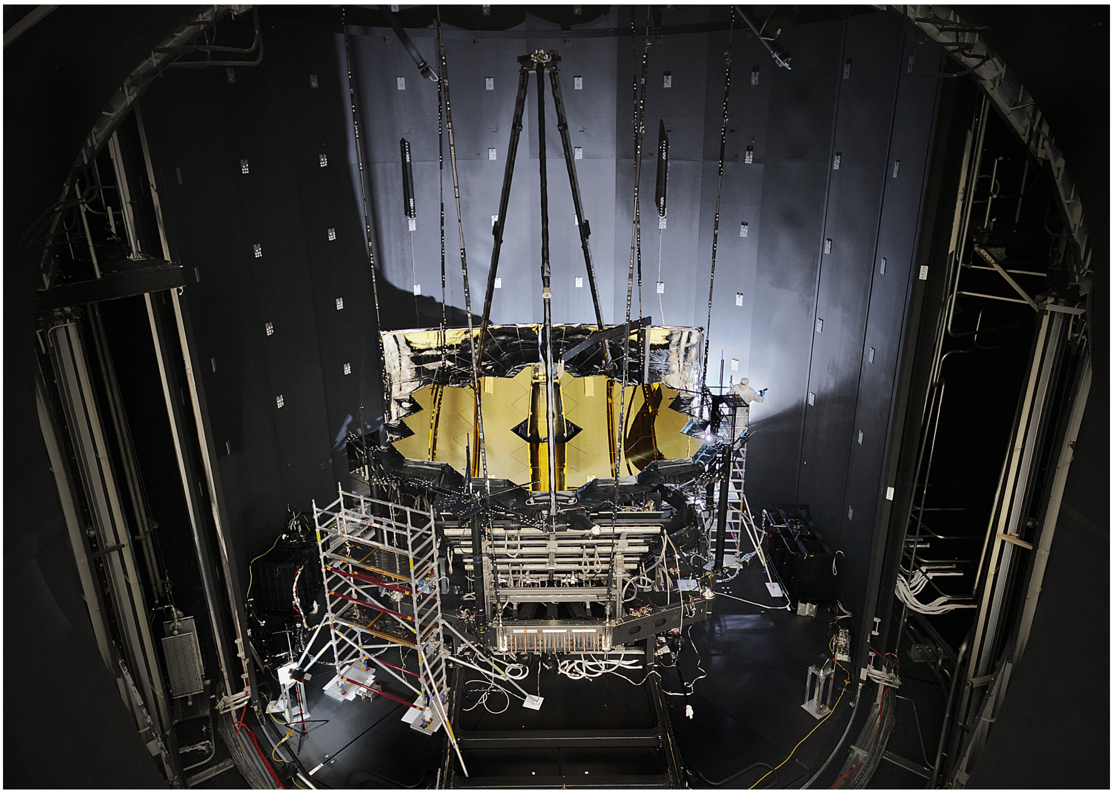

Figure 1: The *JWST* sits inside Chamber A at the Johnson Space Center after having completed its cryogenic testing on 18 November 2017. This marked the telescope's final cryogenic testing, and it ensured the observatory is ready for the frigid, airless environment of space. (*Credit: NASA/Chris Gunn*)

Figure 2: Engineers watch as Chamber A's colossal door closes at the Johnson Space Center. (*Credit: NASA/Chris Gunn*)

Figure 3: *JWST* in front of the vacuum chamber (*Credit: NASA/Chris Gunn*)

Figure 4 (*Credit: NASA/Desiree Stover*)

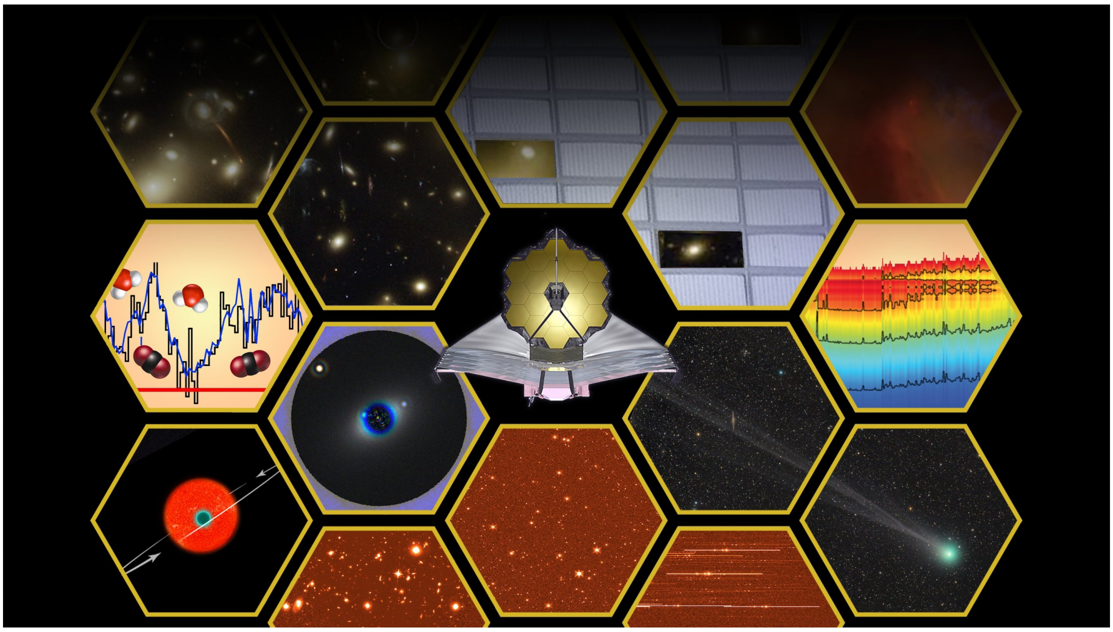

Figure 5: *Credit: NASA, ESA, and A. Feild (STScI)*

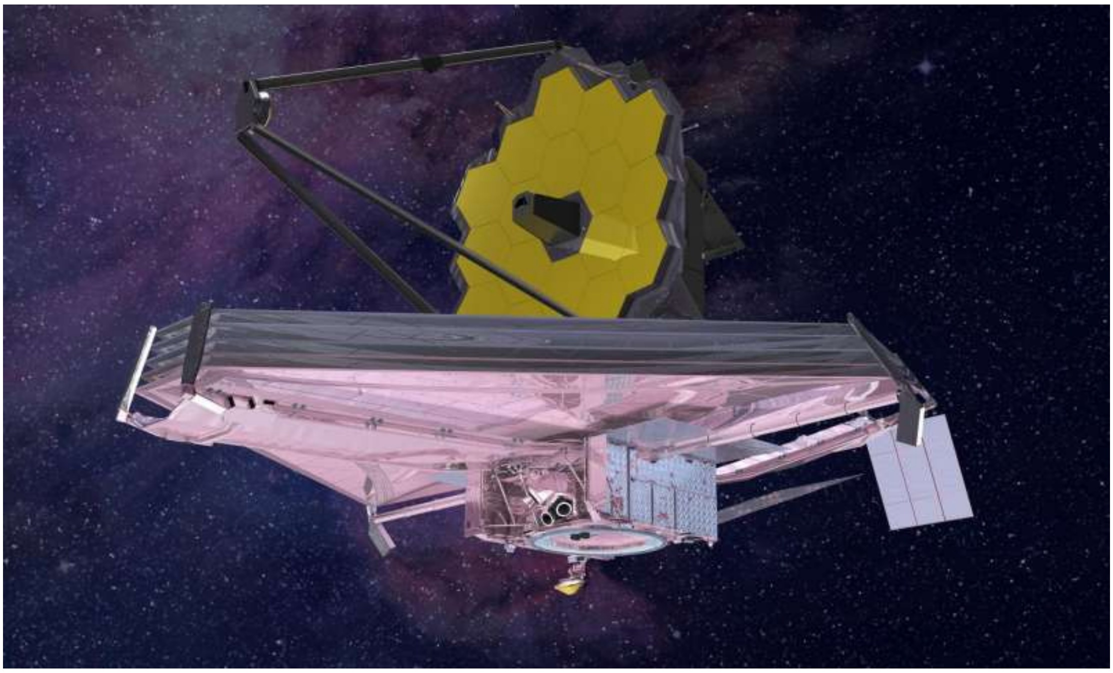

Figure 6: Artist's concept of the *JWST*. (*Credit: NASA*)