The James Webb Space Telescope

Session: **ENGINEERING THE SEARCH FOR EARTH-LIKE EXOPLANETS**

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Abstract

NASA's James Webb Space Telescope is the premier space telescope of its time. Set to launch in Oct. 2018, it is designed to look at "First Light", peering into the beginning of the universe to imaging the formation of stars and galaxies, looking back more than 13.5 billion years. Building on the successes of the Hubble Space Telescope, JWST will look farther back in time, to dimmer, redder targets that are some of the very first objects to form in the dawn of the universe. JWST is an engineering marvel unlike any space telescope before. The 6.5m aperture is accompanied by a 14m by 22m Sunshield to passively cool the entire telescope portion of the Observatory to cryogenic temperatures. Getting a ride aboard an Ariane 5 launch vehicle, JWST must fold up like an origami and get to the Second Lagrange Point, 1.5 million km away from the Earth. Being so far away, JWST is not serviceable like the Hubble, and must deploy and operate flawlessly. Engineering this time machine is no easy feat. This talk will describe some of the science goals for the James Webb Space Telescope to motivate the challenges inherent in this exquisite Observatory. The talk will outline the path to JWST Technology Readiness, and highlight some of the engineering challenges along the way. Finally, the latest status of the Observatory will be given, and a countdown of the activities to launch.

Keywords: James Webb Space Telescope, Large Deployables, Aerospace Engineering

Introduction: Observatories In Space

Wavelengths inaccessible from ground-based astronomical observations are opened up by launching telescope observatories to space. NASA has launched a series of observatories that have opened up wavelength ranges previously unobservable from the ground, and significantly advanced our understanding of the universe. One of the greatest current space-based observatories is the Hubble Space Telescope (HST). HST has revolutionized just about every aspect of astronomy, but has made the greatest contributions in observations of the early universe. One of the most iconic images is the Hubble Deep Field; Figure 1 shows the eXtreme Deep Field (XDF) taken by HST of a small region in the

Fornax constellation. This is one of the most sensitive images ever taken in the visible wavelength, and shows some of the oldest galaxies ever imaged (Illingworth, 2013).

Figure 1: Hubble XDF, showing some of the oldest galaxies ever imaged, forming when the universe was just 450 million years old. ***(Credit: NASA; ESA; G. Illingworth, D. Magee, and P. Oesch, University of California, Santa Cruz; R. Bouwens, Leiden University; and the HUDF09 Team)***

Using data from the XDF, astronomers are able to probe the structure and organization of the beginning of the universe. The oldest galaxies are shown in the XDF as dim, red, fuzzy blobs, and while these are the oldest galaxies ever imaged, they are not the oldest galaxies ever formed. Due to their distance and age, these oldest galaxies are too dim to be for HST and are redder than the longest HST wavelength. As the successor to the HST, The James Webb Space Telescope is designed to have higher resolution with optics seven times the surface area of HST, making it 100 times more powerful. It will also probe the Infrared portion of the EM spectrum to see these “First Light” objects. Additionally, compared to HST, JWST has capabilities to 28 microns, versus HST’s maximum wavelength of 2.5

microns. JWST will be able to image objects as old as 13.5 billion years, or ~200 million years after the Big Bang. Details of JWST science goals can be found in a wide range of sources; see e.g. Gardener et al., 2006.

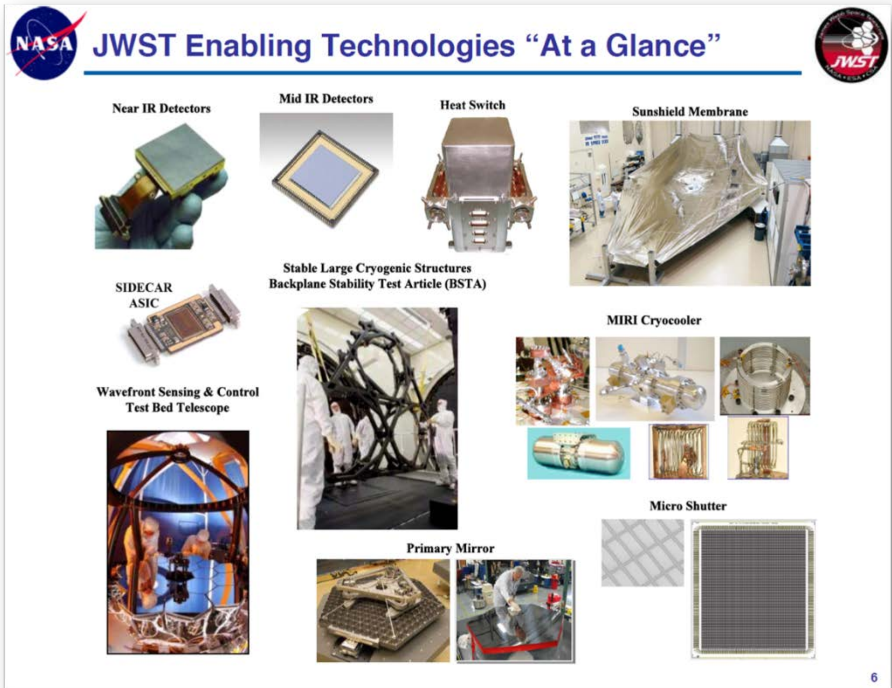

Figure 2: James Webb Space Telescope Technology Development items identified at the start of the flight program. All of the items completed TRL 6 development by 2007. Image credit: NASA/GSFC.

Engineering James Webb Space Telescope

Driving requirements for JWST the Webb Telescope from First Light science may be distilled to:

- image targets anywhere in the sky
- image faint targets => high sensitivity with low background
- image small targets => high resolution with low jitter
- Infrared objects => cool telescope to reduce background

The resulting architecture required a significant amount of technology development. In the late 1990's, NASA initiated Phase A technology development for JWST, with the goal of bringing a set of 10 JWST critical developments to Technology Readiness Level (TRL) 6. Shown in Figure 2, these ten technologies were all brought to TRL 6 by JWST's Preliminary Design Review in 2008 (Gardener, 2006), and was in fact a criteria for program confirmation.

Among the technologies developed for the James Webb Space Telescope, the sunshield was one of the most interesting. Spanning 14m by 22 m when deployed, the size of a tennis court, the sunshield is charged with protecting the sensitive telescope and instruments from visible and thermal radiation from the Sun, Earth, Moon, and the JWST spacecraft. Rather than a traditional barrel assembly forming a cylinder centered on the primary optics (e.g. the HST sunshade), the open James Webb Space Telescope sunshield design left the telescope exposed to space in order to facilitate the passive cooling of the optics to cryogenic temperatures of 40 to 50 Kelvin. The unique shape of the Sunshield provides shadow over JWST's pitch angles of +5 to -45 degrees, and roll angles of +5 to -5 degrees. Shown in Figure 3, the Sunshield performs three major functions: 1) Telescope is shielded from direct sunlight, earthlight, and moonlight, enabling the rejection of incident solar radiation such that only ~1 part in 300,000 is transmitted; 2) the upper layers of the sunshield, which are cold, do not get illuminated, and let stray light into the telescope; 3) the lower layers of the sunshield, which are hot, do not have a path to bounce light into the telescope. This ensures the telescope is able to be cold, and limits the background noise contribution to the science images.

In order to meet these performance requirements, the JWST sunshield needs to be carefully aligned: the deployed Sunshield structure needs to maintain its edges within a few cm of the nominal location. In order to achieve this, a series of detailed analyses of the sunshield performance was necessary. Starting with the on-orbit environment, perturbations to the sunshield once it was deployed needed to be assessed and controlled. Environmental effects affecting the sunshield on orbit are: thermal distortion, composite dry out, the elastic response of the Sunshield structure under tension, and the inelastic, or creep, of the sunshield structure under tension. These effects were carefully modeled and quantified. Even though rigorous processes are used to control the dimensions of spacecraft parts, there are still manufacturing and installation tolerances that are examined and quantified. Exposure of the observatory to the harsh launch vehicle environment can induce otherwise solidly attached parts to shift slightly at joints that are not bonded; these launch shifts are calculated based on design tolerances and allocated. The fact that the sunshield needs to be deployed also affects the ultimate alignment of the sunshield, as the precision of the deployment is dependent on the details of the mechanical part performing the deployment. An extensive error budget has been constructed to account for these effects: environmental distortion, manufacturing and installation error, launch shift, and deployment repeatability.

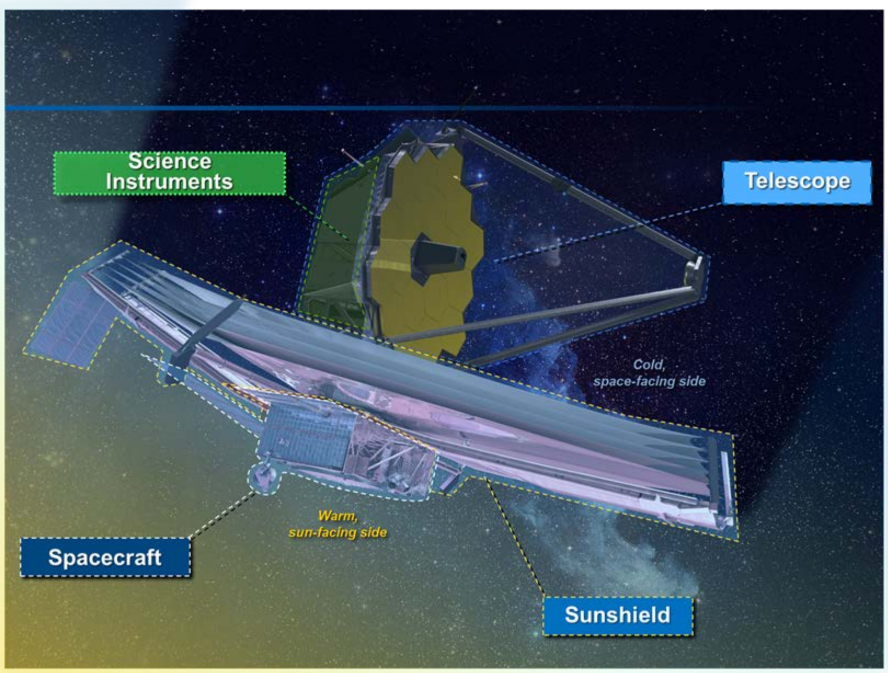

Figure 3: Main Elements of JWST, with the tennis court sized Sunshield shading the Observatory from the intense solar radiation.

A thorough set of alignment tests where baselined for the JWST sunshield to measure and exercise the Sunshield in order to verify and/or demonstrate the values in the alignment error budget and quantify its on-orbit performance. Starting at the unit level and extending all the way to the end of the Observatory integration and test program, every major piece of the sunshield is measured, tested, and measured again to ensure it has been properly characterized and its on orbit performance understood.

As of the writing of this paper, the bulk of the JWST sunshield is in the process of being manufactured and some subassemblies are undergoing testing. A high fidelity pathfinder for the sunshield has recently completed its final deployment. The alignment program is well underway with measurements of the sunshield being compiled, and pre-test analysis being performed to prepare for tests. Regarding the rest of the Observatory, all mirrors have finished fabrication and are awaiting installation at Goddard Space Flight Center (GSFC). Also at GSFC are all four of the science instruments, integrated into their holding structure and undergoing extensive testing. The telescope structure is complete and will be shipped to GSFC in August of 2015. The mirrors and instruments may then start installation in the fall of 2015. The spacecraft bus structure is complete and is in testing, with many of its subsystems also in test, preparing for integration into the spacecraft.

In 2017, the completed telescope portion along with mirrors and instruments return to Northrop Grumman's Space Park facility in Redondo Beach, California to be integrated with the spacecraft and sunshield. Finally, the observatory will undergo final testing, and be shipped to French Guiana for launch, with a launch date of Oct. 2018.

References

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