The James Webb Space Telescope

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September 25, 2022

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1 History

1.1 Ideas and primary work

Discussion about the next generation of space telescope, after the successful Hubble Space Telescope, seriously began in 1996, six years after HST was launched and three years after the bold mission of the Endeavour space shuttle to repear its optic in 1993 (STS-61), a record-holder mission with 11 days of extra-vehicular intervention by its crew.

The primary objectives of the new telescope, then named the Next Generation Space Telescope (NGST) will be to observe far, far away galaxies, to study celestial bodies on the remote corners of the observable Universe, and to see back in time to the primordial galaxies, not long after the Big Bang. Thanks to this pitch, the NGST project was held of great interest by astronomers, physicist, cosmologist and the public good, granting the NGST a big place in NASA's projects.

Primary design were very ambitious, a primary mirror nearly 8 metres wide (about 8.7 yards) against the conservatively big 2.7 metres wide mirror of Hubble (3 yards), equipped with cutting-edge scientific instruments held at nearly the absolute zero, and all of this while needing this to be sent in an orbit to the second Lagrange Point (L2), 1.5 million kilometers away from earth (932 thousand miles). The telescope would be manufactured using barely discovered composite materials (carbon fibers, berylium) to reduce the mass of the telescope, and at a relatively low price point.

NASA, conscious of the impressive success of the partnership with its European equivalent (ESA), relied on a closer collaboration between the two agencies to raise this truly engineering challenge, to life.

The construction was finally signed and gave to Northrop Grumman Space Technology in 2003, that was this year the incredible journey of the freshly minted James Webb Space Telescope (named after James E. Webb the second administrator of NASA) started.

1.2 Development, construction and multiple delays

The Goddard Space Flight Center, Maryland was responsible for the design of JWST and to give life to this project with an initial budget of 830 million USD (of 2003), the mirror was reduced to a diameter of 6.1 metres (6.7 yards), for a launch in the early 2010s. In april of 2005 the budget was increased and the launch delayed to late 2013, over 4.5 billion USD with 300 million euros from the ESA and 39 million CAD of the CSA (Canadian Space Agency) in the form of a scientific instrument to analyze atmospheric conditions on far away worlds.

In april of 2007, all the scientific instruments were technologically cleared, allowing the Goddard Center crew to advance further into design, staying in the then budget.

The project was cleared in 2008, the scientific mainframe, and optic instruments late 2009, and in January 2010 the solar shield (protecting instruments from solar radiation and heat) was also cleared, allowing the project to pass the Mission Critical Design Review which reviewed from a scientific and engineering standpoint the project feasibility. However, this stage of the project decided to yet again delayed the launch to between 2015 and 2018, and the project was severely out of budget.

In 2011 all reviews were cleared, what started as a dream in the 90s was finally possible, the design and creation of this telescope allowed to develop new technologies, in the material engineering domain, to permit this 6 metres wide telescope to be extremely light weight (only about 6 metric tonnes, or just over 2.2 thousand pounds.

The primary mirror, composed of 18 hexagonal-shaped segments, was assembled at the micro-meters by robotic arms for a complete final diameters of 6.6 metres, and an area of $25\mathrm{m}^2$ (or 270 square foot). The final assembly stopped in November of 2016, unfortunately it wasn't the end for the pre-launch work, a long phase of tests needed to be completed to ensure the satellite was working correctly.

It was while in test the solar shield was destroyed, ultimately caused by a default in the tension of the cables, forcing NASA to delay to May of 2020 and then March of 2021.

In 2019, after 12 years of tests the mechanical tests were over. The JWST was then sent by boat to French Guyana to the European Space Center (Kourou) where the launch finally took place, on Christmas' Day, 2021 on an Ariane 5 ECA. It finally entered service the 12 of July 2022, nearly twenty years after the first designs and with a final budget of over 10 billion USD.

Ultimately, it was an effort leaded by 3 agencies (NASA,ESA,CSA), on over 15 countries (Austria, Germany, Belgium, Canada, Czech Republic, the Danish Realm, Finland, France, Greece, The Irish Republic, Italy, Luxembourg, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom of Great Britain and Northern Ireland, and the United State of America) for a twenty years period by thousands of engineers, researchers and technicians.

2 The technical specification

2.1 The JWST in general

The telescope itself is 21 metres long, 14 metres large, and 8 metres high (23x15x9 yards) with a 6.6 metres wide primary mirror consisting of 18 hexagonal-shaped segments, covered by a thin layer of gold (approximately 100 micrometers thick), each placed on an independent 6 axis-system, allowing each segments of independent 3 dimensional movements, to be self align by the computer alignment system. The mirror itself weigh more than 700 kg (1500 pounds).

As the observation of the JWST is only on the infra-red band (600 to 28500 nm of wavelength) (visible band being between 350 and 750nm) instruments must be protected from outside source of radiation and heat like the Sun, Earth, and the Moon, this is accomplished by a coordination of the Telescope unique location (the L2 Lagrange Point) and its sun shield. It also protects the computer and other instruments from radiation of the sun “the solar wind”. To avoid heat pollution by all cost.

The Telescope has a combined power generation of 2kW by solar panels, one high gain antenna capable of a data-link of 28 mbit/s with Earth, allowing to transmit about 57 gigabytes of data each day.

2.2 The scientific instruments

Even if the JWST only observe in the infra-red, it possess four specialized instruments with their own usages.

1. *NIRCam (Near-InfraRed Camera)* is used to capture light between 600nm and 5000nm of wavelength, it’s composed of ten 2048 by 2048 pixels sensors, for a total of 4 megapixels each, allowing the camera a 2.2 arc-minute by 2.2 arc-minute field of vision (an arc-minute is one sixtieth of a degree) and the chronographs block incoming light from stars to analyze light from their planets (exo-planets) and pass this light to spectrometers. This camera is design to be operated at around 37K (-236.2°C or -393.07°F), and has been used to take the picture of the Carina Nebula.

2. *NIRSpec (Near-InfraRed Spectrograph)* is used between 700 and 5000nm, it’s the spectrograph used to analyze light from primordial galaxies, seeing through the periods when the Universe was visibly opaque, to determine their composition, an era named “The Dark Ages” from 150 to 800 million years after the big bang, which Hubble can’t do. It’s the ESA-provided instrument, and is composed of two 4 megapixel sensors.

3. *MIRI (Mid-InfraRed Instrument)* is the most complex instrument in JWST, it’s “imager” is three 1024 by 1024 pixels sensors, one for the camera and two for the spectrometer, for a total resolution of 74 by 113 arc-seconds (one arc-second being one sixtieth of one arc-minute). Its spectrograph has a field of vue of 3.5 by 3.5 arc-seconds. To be able to see between 5000 and 28800 nanometres wavelength it must be kept at a strict 6K (-267°C or -448.87°F) by a special cryo-cooler and liquid helium. It has been developed by a mixed team of NASA and ESA scientists, and has been used to take the picture of the Cartwheel Galaxy and a composite image of this galaxy with the NIRCam was published at the same time.

4. Finally *FGS/NIRISS (Fine Guidance Sensor and Near Infrared Imager and Slitless Spectrograph)* is the instrument developed by the CSA (Canadian Space Agency), it observe in the near infra-red like NIRCam and NIRSpec, it's the main spectrograph, which has been used to analyze the composition of the atmosphere of the exo-planet published and find proof of water presence. Two sensors like the one on NIRCam are dedicated to that spectrograph. FGS' mission is to point a star to guide JWST in maintaining orbit and feeding the auto-alignment software with data.

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Images

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