Air and Space this Week

Item of the Week

The *James Webb Space Telescope*

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Astronomical observations from Space have been made by hundreds of sounding rockets and early satellites. A Space-based platform is required for the study of some wavelengths of "light: because our atmosphere blocks them from reaching Earth's surface and/or atmospheric turbulence degrades the "seeing." The best data to date have come from four Space-borne observation platforms known as the "Great Observatories." The aging Hubble Space Telescope *is one of them.*

NASA has been leading an international partnership to design, build, and launch the replacement for the HST, *the* James Webb Space Telescope. JWST *will allow astronomers to study the conditions prevailing in the very earliest history of our Universe. JWST is very complex and will operate beyond reach of servicing missions from Earth, so the design and construction process has been more expensive and has taken longer than hoped, BUT….*

Launch of the JWST *is presently set for* ***December 18, 2021****!*

The GREAT OBSERVATORIES and the *HUBBLE SPACE TELESCOPE*

Astronomers have been observing objects in the sky in detail since the days of Galileo, over 400 years ago. Two obstacles have plagued such studies, particularly in the early days: optical quality of the telescope, and having to look through a turbulent atmosphere that is opaque to some wavelengths of electro-magnetic radiation. Telescope technology has moved forward greatly over the years, and observatories were sited atop mountains in order to get above much of the atmosphere's deleterious effect on "seeing." But there was no "easy" solution to atmospheric opacity, except one, put the telescope above the atmosphere entirely. New sensors would have to be developed that operated at the wavelengths that would become accessible.

The above is the backdrop behind the desire to conduct astronomical research effectively. Everything proceeded apace, but by the end of WWII, the projection that access to Earth orbit was only a decade or so away prompted serious contemplation of a Space-based telescope.

The Earth's atmosphere is transparent in the visible light and radio parts of the electromagnetic spectrum. It is opaque to gamma rays, x-rays, all-but-the-longest ultraviolet rays, the infrared, and the thermal infrared parts of the spectrum. Earth-based optical and radio telescopes were growing in their sophistication and capabilities, but there was a lot of key astronomical information kept from us by the air we breathe.

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A number of very successful Space-based telescopes were launched in the 70s and 80s, some orbital, some on sounding rockets. The value of a longer-term view, especially of the blocked wavelengths, was thus proven.

NASA's response was bold. No one telescope could detect the range of wavelengths available in Space, so a series of four "Great Observatories" were planned, constructed, and launched. The four, plus Yerkes Observatory in Wisconsin, were the subject of a 2020 Item of the Week, so I will refer you to there for details on the *Compton Gamma-Ray Observatory*, the *Chandra X-Ray Observatory*, the *Spitzer Space Telescop*e (near/far infrared), and the *Hubble Space Telescope*, which operates in the visible/near-infrared part of the spectrum.

The Great Observatories have been a ***colossal collective success***. *CGRO* was de-orbited in 2000, *Spitzer* operations ceased in 2020, and *Chandra* and *Hubble* are still operational.

The *HST* was designed and built to allow for it to be launched from the Space Shuttle and serviced/updated by subsequent Shuttle missions. It was carried aloft by STS-31 (*Discovery*) on April 25, 1990. Built-in serviceability was put to the test right away. "First light" was a huge disappointment – the images returned were obviously seriously out of focus.

The problem was quickly determined. The *HST* mirror had been ground extremely precisely, to the wrong shape, a ridiculous and expensive demonstration of the difference between "accuracy" and "precision." The mirror testing and oversight process was, to be generous, inadequate and negligent. A piece on the tester was inserted upside-down, which threw everything off. How such a large error could have been made in the first place, and worse, not be detected, is almost incomprehensible.

But there was some good news. We knew what happened and we had the tester, so we knew the exact curve to which the mirror had been ground. Just like a human whose eye lens doesn't focus clearly on the retina can get good vision with corrective lenses, so could *HST* be fitted with "glasses." And that is exactly what happened. Once a set of lenses was added to *HST* by Shuttle astronauts, the images came back with the expected clarity.

Hubble observations allowed astronomical advances on a number of fronts, including but not limited to: refining the age of the Universe (13.7 billion years), ascertaining the prevalence of large black holes in galactic cores, understanding the process of planetary formation, finding the presence of organic chemistry on an exoplanet ("organic" does not necessarily mean "biological!"), and providing evidence in the study of dark matter.

The *Hubble* is now 31 years old. It has performed superbly, but it does have a few infirmities of age, and its systems are increasingly-primitive by modern technological standards (think of what your personal electronics, if any, were like 31 years ago!).

A successor has been planned for and under construction for a number of years now. Its name is the *James Webb Space Telescope* (*JWST*).

The JAMES WEBB SPACE TELESCOPE

Building on Edwin Hubble's Work

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There is a reason why the *HST* was named for Edwin Hubble. One hundred years ago, the prevailing view was that the Milky Way was, in fact, the Universe. But a young Hubble was able to find Cepheid variable stars in the Andromeda and Triangulum Nebulae, and he used the Period-Luminosity Law just-discovered by Henrietta Leavitt to show that those nebulae were much too distant to be part of the Milky Way, that in fact they were independent “Island Universes,” aka “galaxies” in their own right.

Hubble did not rest on his laurels after that. He obtained spectra of a number of nebulae/galaxies and made an interesting observation. The Doppler Effect had already been discovered; the light (energy) emitted by an object would change wavelength depending on the object’s motion relative to the observer. The spectra of objects getting closer is shifted blue-ward; the spectra of objects going away were shifted red-ward. [Sound waves show the same phenomenon. A horn of a car coming at you has a higher pitch than normal, a horn going away from you has a lower pitch than normal.]

The galactic spectra obtained by Hubble all showed a red shift, indicating that they were moving away from us. Even more interesting, the further a galaxy was from Earth, as determined by the Cepheid variables observed within it, the greater its spectra was red-shifted. These were profound observations, and so a major Great Observatory bears his name.

All galaxies having red shifts means that they are all moving away from one another; the Universe is expanding, or at least the objects in it are racing away from one another. One could mathematically model the expansion in reverse to see when the expansion started (the origin of the Universe), the essence of the Big Bang Theory (the prevailing view is ~13.7 billion years).

Hubble’s observation that the rate of recession was a function of distance meant that an astronomer could observe a distant galaxy, determine its red shift, and thereby gain an estimate of its distance, a very powerful astronomical tool.

Let’s pause a moment for another important philosophical observation.

A telescope is in some sense a time machine. The Sun is so far away that it takes about eight minutes for light to go from its surface to the Earth. Any astronomical observation is made using energy that has taken some finite amount of time to reach us. The farther away, the older is the information reaching us at the paltry speed of light. After all, it takes light over four years to get to us from the nearest stars; it takes many millions of years for light to get to us from a distant galaxy.

The *JWST* will be capable of imaging objects that are billions of light-years away. Not only are they incredibly distant, we will be seeing them as they were in the very distant past. If we can see that far, we can see what things were like in the earliest years of the very Universe itself.

The Great Observatories, along with Earth-based telescopes, do a pretty good job of covering a very broad range of electro-magnetic radiation wavelengths. The scientific consensus was that the next generation orbital observatory’s operating spectral range would be driven by the *JWST* research objectives:

- Search for the first galaxies or luminous objects that formed after the Big Bang

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- Determine how galaxies evolved from their formation to the present
- Observe the formation of stars from the first stages of the formation of planet systems
- Measure the physical and chemical properties of planetary systems and investigate the potential for life in those systems

Now recall Hubble's famous observation that the further an object is from Earth, the greater the rate of its receding from us (the greater its red shift will be). A lot of interesting information comes from light that is the visible part of the spectrum. But visible light coming from really distant objects will be red-shifted into the infra-red part of the spectrum. *HST* could see into the near-IR, and *Spitzer* could see even longer-wave energy, but in order to fulfill the objectives above for the next-generation Great Observatory, better coverage of the infra-red part of the spectrum, from near-IR out into the thermal-IR (what we would perceive as heat).

Designing the *JWST*

The requirement for observations across the IR part of the spectrum poses some engineering challenges that drove the design of both the *JWST* telescope and the JWST mission parameters. The primary problem was heat management. After all, if you are trying to detect tiny amounts of heat, any heat source nearby, even that produced by the detection process, would be unacceptable.

The first obstacle was the fact that Low Earth Orbit had much too much stray heat for the delicate observations required by the JWST objectives. No amount of heat shielding and heat management could keep the *JWST* instruments operating properly. The best solution would be to place the *JWST* in the Sun-Earth L-2 position, a spot where the gravity of the Sun and Earth were in balance, because in that location, shading the JWST from the light of the Sun, Earth, and Moon could be accomplished.

ASIDE

Mathematician Josephy-Louis Lagrange, in the 1770's, figured out that there were five points in a two-body system where the gravity from the two bodies more-or-less canceled out. They are today called "L-1" through "L-5," the "L" being for Lagrange. For the Sun-Earth system, L-1 is on the line between the Earth and Sun, about one million miles from us, closer to the Sun. L-2 is also on the Earth-Sun line, but about one million miles further from the Sun than the Earth is. The L-3 point is always on the opposite side of the Sun from the Earth. L-4 is in Earth orbit, 60° ahead of us; L-5 is in Earth's orbit, 60° behind us.

L-1, L-2, and L-3 are only partially stable; a spacecraft can be placed there, but will have to continuously maneuver (gently) to compensate for the instability of those positions. L-4 and L-5 are much more stable, and objects nearing those points can be gravitationally captured, especially if a large planet like Jupiter is involved. We know of several hundred such objects, the Trojan asteroids, trapped in Jupiter's L-4 and L-5, the object of the soon-to-launch *Lucy* spacecraft. We have found objects at the L-4/L-5 point of Saturn, Mars, and even the Earth.

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The vantage point of the Sun-Earth L-1 is a good place from which to make observations of the Sun, and is presently occupied by the *Solar and Heliospheric Observatory* satellite (*SOHO*).

The Sun-Earth L-2 position is ideal for looking outward, not inward. It was the location of the *WMAP* spacecraft, and is presently occupied by the *Planck* satellite. It will soon be the new home for the *JWST*.

The down side of placing an observatory at L-2 is that it will be much too far from Earth to allow for a crewed refurbishing/service mission to be mounted; the spacecraft is on its own.

An International Collaboration

Flagship-level missions like the *JWST* are very expensive; international collaboration can reduce costs and increase capabilities, and *JWST* is no exception. Fourteen countries are involved in some way in the JWST program: Austria, Belgium, Canada, Denmark, France, Germany, Ireland, Italy, the Netherlands, Spain, Sweden, Switzerland, the United Kingdom, and the USA.

The USA is the lead partner in the JWST program; the European Space Agency (ESA) and the Canadian Space Agency (CSA) are significant contributors (their astronomers have some guaranteed *JWST* observing time). Northrop Grumman is the main industrial contractor. They built the spacecraft bus, the telescope, and the sunshield, and are very involved in launch prep.

Instrumentation

The *JWST* satellite has four different instruments: the *Near Infrared Camera* (NIRCam), the *Near-Infrared Spectrograph* (NIRSpec), the *Mid-Infrared Instrument* (MIRI), and the *Fine Guidance Sensor/Near InfraRed Imager and Slitless Spectrograph* (FGS-NIRISS).

NIRCam: NIRCam is the primary sensor for the *JWST*, operating in the wavelength range of 0.6-5 microns. It is equipped with instruments that allow it to observe very faint objects that are very close to much brighter ones, essential in the direct observation of exo-planets.

NIRSpec: NIRSpec operates in the same spectral range as NIRCam, but observes a broad portion of the near-IR spectrum simultaneously, facilitating chemical analysis and other interpretations.

MIRI: MIRI operates in the 5-28 micron wavelength range, where strongly-redshifted diagnostic spectral features would be.

FGS/NIRISS: The FGS is essential for aiming the *JWST* with the necessary accuracy. The NIRISS part of the instrument will be useful in the detection and observation of exo-planets and observing exo-planets in transit in front of their parent star.

Why Does the *JWST* Cost So Much?

The *JWST* is a very complicated spacecraft, with many parts and instruments that have to work well together reliably, especially because the *JWST* will be beyond reach once it is launched. Pretty much every aspect of the *JWST* and its instrumentation are state-of-the-art, and because of the HST mirror debacle, the testing and oversight procedures used in *JWST*'s construction were vastly more-involved (and expensive) compared to the ones in place for *HST*.

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Another cost factor involves the *JWST*'s mirror. It is huge. Construction akin to that used in the creation of the *HST* mirror would have made it much to heavy; *JWST*'s mirror is much less massive than the much-smaller *HST* mirror. The mirror assembly is so large that it can't fit on any rocket booster now flying; it has to be constructed in parts and folded into the payload section of its booster. Making a multi-part giant mirror, with extremely-small error tolerances for its shape, that folds up and deploys in a very cold Space environment, and does so with absolutely reliably, is an extremely formidable engineering challenge.

Heat management is another reason that the *JWST* is complex and expensive. Its instruments, especially MIRI, have to be shielded to stay cold enough to be effective. That means no direct sunlight, and no Earthlight or Moonlight either can fall on the telescope and instruments. Being at L-2 makes shielding possible, but the multi-layer shield itself still had to be an engineering marvel in order for the MIRI to operate effectively.

Any device as complex as the *JWST*, at the very leading edge of technology, is bound to run into problems during the development process, especially when it is expensive and vulnerable to the shifting priorities of Congress. This, too, contributes to both cost and deadline overruns.

Launch Information

Testing is complete, and the launch preparations are well underway for a **December 18, 2021** launch. ESA's principal contribution to the JWST program is the providing of a launch vehicle and launch service, using an Ariane 5 booster launched from Arianespace's launch facility at Kourou, French Guiana.

The public is not invited to attend the launch of the *JWST* in person, because the launch is not being conducted by NASA. However, you can attend virtually, watching this exciting launch on-line. There will be community-led launch-related events this December, around the world, too.

NASA encourages everyone to a virtual observer of all its launches, including* JWST*'s; for information on how you can be a "Virtual Guest," see: https://lp.constantcontactpages.com/su/SCofgRt/NASAvirtualguests.

NASA Invites Media to* JWST *Launch (Register by October 20!): https://www.nasa.gov/press-release/nasa-invites-media-to-james-webb-space-telescope-launch

YOU CAN get Young People Involved – Here are Some Resources to Help!

Check out the *JWST* "Features" and "For Educators" pages for products and programs suitable for kids. The Astrophysics Division at NASA's Goddard Space Flight Center also has various education and outreach programs that may of interest. In addition, NASA has lots of great websites about astronomy for kids (and teachers!) Here are just a few:

- StarChild: http://starchild.gsfc.nasa.gov/ (grades K-8)
- Imagine the Universe: http://imagine.gsfc.nasa.gov/ (ages 14+)
- Amazing Space: http://amazing-space.stsci.edu/

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- Cool Cosmos: http://coolcosmos.ipac.caltech.edu/
- NASA education: http://education.nasa.gov/
- For teachers: http://teachspacescience.org/

REFERENCES

The *Hubble Space Telescope* and the Great Observatories

NASM's former "Explore the Universe" gallery is no more, but its on-line exhibition is still available; see: https://airandspace.si.edu/exhibitions/explore-the-universe/online

NASA's Great Observatories webpage: https://www.nasa.gov/audience/forstudents/postsecondary/features/F_NASA_Great_Observatories_PS.html

A+StW Item of the Week about the Great Observatories: http://www.airandspacethisweek.com/assets/pdfs/20200323%20Great%20Observatories.pdf

NASA *HST* webpages:

https://history.nasa.gov/hubble

https://www.nasa.gov/mission_pages/hubble/main/accomplishments_index.html

https://asd.gsfc.nasa.gov/archive/hubble/technology/summary.html

https://asd.gsfc.nasa.gov/archive/hubble/a_pdf/news/SM2-MediaGuide.pdf

Space Telescope Science Institute: https://www.stsci.edu

NASA: The *HST* Mirror Error: https://ntrs.nasa.gov/citations/19910003124

Hubble Space Telescope Systems Engineering Case Study: https://www.dau.edu/cop/pm/DAU%20Sponsored%20Documents/Hubble%20Space%20Telescope%20SE%20Case%20Study%20JJ%20Mattice.pdf

The *James Webb Space Telescope*

NASA J*WST* Page: https://www.jwst.nasa.gov

Lagrange Points: https://solarsystem.nasa.gov/resources/754/what-is-a-lagrange-point

Spacecraft and Mission: https://www.jwst.nasa.gov/content/about/faqs/faq.html

Instrumentation:

NIRCam: https://www.jwst.nasa.gov/content/observatory/instruments/nircam.html

NIRSpec: https://www.jwst.nasa.gov/content/observatory/instruments/nirspec.html

MIRI: https://www.jwst.nasa.gov/content/observatory/instruments/miri.html

FGR/NIRISS: https://www.jwst.nasa.gov/content/observatory/instruments/fgs.html

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Launch Prep: https://www.nasa.gov/press-release/nasa-readies-james-webb-space-telescope-for-december-launch

NOTE: The American Geophysical Union's "Science News by AGU" webinar series will have a program entitled, "**Will JWST Reveal Earth 2.0**?" on **October 27, 2021 at noon EDT**.

Program Description: "In just a few short weeks NASA's next flagship telescope, *JWST*, will launch and usher in a new era of discovery. In this webinar sponsored by *Eos: Science News* by AGU, astrophysicist and host of "Ask a Spaceman!" Paul M. Sutter talks with exoplanet scientists Néstor Espinoza, Elisabeth Matthews, and Caprice Phillips. These astronomers will be among the first to use the new telescope to revolutionize the study of distant worlds. Just as the *Hubble* and *Spitze*r space telescopes have uncovered fascinating details about the plethora of worlds beyond our solar system, so too will *JWST* seek to answer some of astronomy's most pressing questions: are there other solar systems that look like ours, and is Earth the only planet capable of supporting life?

For registration information, see here.

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