Air and Space this Week

Item of the Week

GREAT OBSERVATORIES

Compilation of two Items that originally appeared March 23 and March 30, 2020

[KEY WORDS: Great Observatories Hubble Space Telescope Compton Gamma-Ray Observatory Chandra X-ray Observatory Spitzer Space Telescope Yerkes Observatory]

The topic for the next two weeks' worth of "Item of the Week" are "Great Observatories." I'll be covering three, the Hubble Space Telescope *(HST), the* Compton Gamma-Ray Observatory *(CGRO), the* Chandra X-ray Observatory *(CXO), and – rats – FOUR Great Observatories,* HST*,* CGRO*,* CXO*, the* Spitzer Space Telescope *(SST), and – rats – FIVE Great Observatories:* HST, CGRO, CXO, SST*, and the Yerkes Observatory (Nobody expects apologies to Monty Python). Joking aside, the first four are/were part of NASA's Great Observatory program, and Yerkes has had a long and interesting history, so I'm including it, too. This particular Item is triggered by the recent termination of the SST, the upcoming 30th birthday of the* HST*, and news concerning Yerkes*.

The Earth's atmosphere is rather important to all of us, even though it has made astronomy difficult forever. The atmosphere is opaque to a wide range of wavelengths of electromagnetic radiation, and its turbulence distorts the wavelengths to which it is (relatively) transparent.

A representation of the transparency of Earth's atmosphere to different wavelengths can be found in many places, including here: http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_atmospheric_window.html. Our eyes evolved to take advantage of the transparency of the atmosphere in "visible" light, but the atmosphere is also transparent to radio wavelengths, a "window" astronomers have used extensively since WWII. But all wavelengths shorter than ultraviolet, most of the infrared, and long-wavelength radio waves are completely blocked.

Prior to the Space Age, the only way visible-light astronomers could (partially) overcome the impediments of atmosphere was to place observatories atop high mountains, getting their eyes and film cameras above at least some of the air. This strategy is still employed around the world today in places like Cerro Tololo, Mauna Kea, Pic du Midi, Palomar Mountain, and elsewhere. Since our eyes see only "visible" light, and film recording extends our vision only slightly into the infrared, that was all astronomers could do.

Then rocketry and access to Near Earth Orbit came along.

The notion of eliminating the deleterious effects of looking through Earth's atmosphere became feasible by putting an automated observatory higher than the highest mountain, either for a few moments in a sounding rocket, or for much longer time periods in NEO. A variety of satellites were created that proved the concept (*e.g.* the Orbiting Astronomical Observatory

series and others), but improvements in detector technology in the 1960's and 70's, along with a lessening for funding for lunar exploration, made the next step forward possible.

Astronomers had been steadily learning about the importance of observations in wavelengths normally barred to them, especially gamma rays, X-rays, and infrared parts of the spectrum. Combine that with a glance at the atmospheric transparency as a function of wavelength plot and it's pretty easy to see that a systematic observing campaign, using NEO satellites to cover those wavelength groups (and in visible light to boot) would yield a LOT of important scientific observations. The National Research Council saw this, too, and made the case for a series of four satellites in their 1979 report, "A Strategy for Space Astronomy and Astrophysics in the 1980's." [Aside: the chairperson of the committee that prepared the report, at the time of the report's release, was Harlan J. Smith – who will be the subject of a future "Item of the Week."] Planning for a Space-based observatory for each of the four wavelength zones was already underway, but the "Great Observatories" packaging made a lot of sense.

Lyman Spitzer and Harlan Smith did play a key role in the development of the concept of spaceborne astronomical observation platforms. NASA still had to design an build them. NASA's very-first Chief of Astronomy, Nancy Grace Roman, played a pivotal role in the Orbiting Astronomical Observatory program, laying the groundwork that made the *Hubble Space Telescope* possible.

Spitzer's promotion of a Space-based telescope was so early and so vigorous that he won the informal title, "Father of Hubble," by acclimation. Roman's role was so important that she not only became known as the "Mother of Hubble," but she also is the official namesake of the next generation Space telescope.

Let's save the Hubble Space Telescope for Last…

Compton Gamma-Ray Observatory

Initial Concept: Theoretical studies 1946 through 1960's; VELA observations (VELA satellites were originally designed to detect clandestine nuclear testing)

Precursor Missions: High Energy Astronomy Observatory Program; HEAO-1, HEAO-2, HEAO-3

Launched: From STS-37 (Atlantis) on April 5; the STS-37 press kit is a good info resource

Namesake: Arthur H. Compton; see also here. At launch, the spacecraft was simply the "Gamma-Ray Observatory;" it was named for Compton not long after launch. Compton won the Nobel Prize for Physics in 1927 (for the discovery of the Compton Effect) and played an integral role in the Manhattan Project.

Scientific Agenda: Observations of high-energy astronomical phenomena

Instrumentation: CGRO carried four different detectors: the Burst and Transient Source Experiment, the Oriented Scintillation Spectrometer Experiment, the Imaging Compton Telescope, and the Energetic Gamma Ray Experiment Telescope.

Noteworthy:

CGRO's high-gain antenna failed to deploy properly requiring an unplanned EVA by Jerry Ross to correct the problem

CGRO was the heaviest satellite to be deployed from the Shuttle up to that point.

COMPTEL instrument data were used to make an all-sky map of the distribution of Al-26, a short-lived radioactive isotope of aluminum that is created (only) in supernova explosions. CONNCTION NOTE: Al-26 decays into Mg-26, with a half-life of only 717,000 years. Calcium-Aluminum inclusions (CAI's) in the Allende meteorite have Mg-26 atoms in some of the crystal sites normally inhabited by aluminum. The crystal could not form that way with Mg in those sites, those Mg-25 atoms had to be Al-25 initially, which then decayed in place. This means that the supernova that formed the Al-25 for inclusion in Allende had to be VERY close to the proto-Solar nebula, close enough for the Al-25 to get to the site of our Solar System's formation before it all decayed to Mg-25. So when we look at the CAI's in Allende, we are seeing the chemical signature of the supernova that caused the proto-Solar nebula to collapse, creating the Solar System in which we live! See: https://en.wikipedia.org/wiki/Aluminium-26

Status: CGRO was intentionally de-orbited on June 4, 2000. One of three sets of its attitude-control gyroscopes had failed; if a second failed, controlling the de-orbiting would have been very difficult, a problem because CGRO contained heavy components that would survive re-entry. Therefore, the decision was made to bring the spacecraft down in the ocean while it could be managed safely.

Successor missions: Successors to CGRO include the ESA INTEGRAL spacecraft (launched 2002), NASA's Swift Gamma-Ray Burst Mission (launched 2004), ASI AGILE (satellite) (launched 2007) and NASA's Fermi Gamma-ray Space Telescope (formerly known as GLAST, the Gamma ray Large Area Space Telescope, launched 2008); all remain operational as of 2019.

Documentation: CGRO mission website; STS-37 mission report; press kit; CGRO 25th anniversary conference

Chandra X-ray Observatory

Initial Concept: Observe in the wavelength range of "soft" X-rays

Precursor Missions: High-Energy Astronomy Observatory 2 (Einstein), Rosat

Launched: From STS-93 (Columbia) on July 23, 1999

Original Name: Advanced X-ray Astronomical Facility (AXAF)

Namesake: Nobel Prize winner, astrophysicist Subrahmanyan Chandrasekhar, chosen in an international naming contest

Scientific Agenda: Observations of high-energy astronomical phenomena

Instrumentation: Two High-Resolution Spectrometers, a High-Resolution Camera, and the Advanced CCD Imaging Spectrometer

Noteworthy:

Chandra is in a highly-elliptical orbit, with its apogee a third of the distance to the Moon

Chandra's orbit was too high for Shuttle servicing missions

Chandra's orbit is high enough to (mostly) keep it out of the Van Allen radiation belts

Status: Operational

Successor missions: The Lynx X-ray Observatory is presently in the Large Mission Concept Study phase; an overview

Documentation: NASA webpage; mission website

Spitzer Space Telescope

Initial Concept: Observe in the range of near- and far-infrared wavelengths

Precursor Missions: Shuttle InfraRed Telescope Facility (SIRTF) [concept]

Launched: August 25, 2003, via a Delta II rocket

Original Name: Spitzer was launched separately, still as "SIRTF"

Namesake: Lyman Spitzer, who we saw earlier was a big proponent of telescopes in Space, chosen in an international naming contest after the mission was operational

Scientific Agenda: Observations in the infrared part of the EM spectrum

Instrumentation: Three IR detectors

Noteworthy:

Spitzer was the only Great Observatory not launched from the Space Shuttle.

Spitzer is in a heliocentric orbit, not a geocentric one.

Spitzer's telescope and sensors had to be very cool so as to not flood them with its own IR signature, especially for the longer-wavelength part of the IR spectrum.

Cooling was achieved through an ingenious use of its solar power panels for shading, combined with using onboard liquid helium for cooling. The helium ran out on May 15, 2009, but shading still allowed the near-IR detectors to work.

Ingenious on-the-fly modification of Spitzer's flight profile allowed it to be used to find and study exoplanets, including the TRAPPIST-1 system.

Status: Operations ceased on January 30, 2020. It was this event, along with the 30th birthday of HST, that prompted this two-part summary.

Successor missions:

Documentation:

Scientific American article

Sky and Telescope article; January 2020 issue, vol. 139, no. 1, pp. 18-25

NASA: https://www.nasa.gov/feature/jpl/nasa-celebrates-the-legacy-of-the-spitzer-space-telescope

The fourth "Great Observatory" is not one that ever flew in Space, but rather is one that sits on the shores of Lake Geneva in southern Wisconsin. Conceived by large telescope guy George Ellery Hale, operated out of the University of Chicago, and named for its sponsor, businessman Charles T. Yerkes, it houses the world's largest refractor telescope (lenses, not mirrors), a 40" diameter masterpiece crafted by famed telescope builder Alvan Clark. I like the place because I had the pleasure of a visit with the NSF-funded Astro-science Workshop for high school students back in the fall of 1972. I didn't get to look through the telescope, but the guide's description of the experience fired my imagination. The expression they used has stayed with me all these years, "Looking with the 40" at the core of the M13 globular cluster was just like looking into a bowl of sugar from up close." Wow!

The building and grounds of Yerkes Observatory are almost as impressive as the giant refractor. The building was designed by Henry Ives Cobb, in the "Beux Arts" style. The landscaping was done by the Frederick Law Olmstead firm, the same folks who designed New York's Central Park.

The Yerkes 40" refractor was the pinnacle of refractor design. Because it collects and focuses light with lenses, perfect lens blanks are essential for perfect light transmission, and making blanks larger than 40" proved very difficult. Worse, lenses by their nature, have to be mounted and supported from their edges only; lenses larger than 40" sag under their own weight, rendering the images they produce out of focus. Mirrors don't have that problem, so no refractor larger than the 40" will ever be built.

Alas, the Observatory could no longer compete with more modern Earth-bound and Space-bound instruments, and it ceased active operation in October, 2018.

However, the local community has established the Yerkes Future Foundation, to explore ways to keep the Observatory useful. On November 5, 2019, an "agreement in principle" was announced that would transfer ownership of the Observatory to the Foundation for educational uses. No definite plans have been announced. The YFF does not have its own web presence; about the only item from/about the YFF or its officers is the Linkedin page of YFF VP, Charles Ebeling. Stay tuned!

Here's hoping that this "Great" Observatory will continue to serve the cause of astronomy education!

UPDATE: Since the paragraphs above were written:

The Yerkes Future Foundation took over ownership of the Yerkes Observatory and grounds on May 1, 2020.

The *Chicago Sun-Times* published a story on 6/29/2020 about the YFF's plans for re-opening the Observatory in 2021: https://chicago.suntimes.com/2020/6/29/21307464/yerkes-observatory-future-foundation-university-chicago

Check the Yerkes website for the latest news: https://www.yerkesobservatory.org.

Oh, and BTW, the YFF is looking for a Yerkes Observatory Executive Director….

Hubble Space Telescope

Initial concept: Spitzer, L., *REPORT TO PROJECT RAND: Astronomical Advantages of an Extra-Terrestrial Observatory*, reprinted in *Astr. Quarterly*, volume 7, p. 131, 1990. The original report was in an Appendix to a larger report Project RAND (part of the Douglas Aircraft Company), in September, 1946. You can access this report, by Lyman Spitzer, at: https://faculty.virginia.edu/rwoclass/astr511/spitzer-astron-advan-space-obs-1946-1990.pdf

Precursor Missions: OAO-1, OAO-2, and OAO-3 (among others)

Launched: From STS-31 (*Discovery*) on April 25, 1990

Five Shuttle servicing missions: STS-61, STS-82, STS-103, STS-109, and STS-125

The *HST* was launched from the Space Shuttle *Discovery* (STS-31) on April 25, 1990 (including Charles Bolden, who was NASA Administrator at the time of the 25th anniversary), without problem.

However, the first images returned from the *HST* were a BIG disappointment. They were supposed to be spectacular, but they looked badly out of focus.

Recall from above that the lens for the 40" refractor at Yerkes Observatory was made by the Alvan Clark and Sons firm, probably the finest refractor telescope makers ever. However, the firm was acquired in 1933 by the Sprague-Hathaway Manufacturing Company, who kept the Alvan Clark name but moved manufacturing operations to West Somerville, MA, where they continued on association with the Perkin-Elmer Corporation.

Perkin-Elmer had the contract to build the optical system for the *HST*. In a rather appalling series of Quality Assurance lapses and managerial oversights, the main mirror was ground to the wrong shape.

What an awful way to demonstrate the all-too-often-incredibly-important difference between "precision" and "accuracy!"

The details will curl your hair. Here's the NASA post-mortem: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19910003124.pdf

"Post-mortem" might be a good phrase to use, since the error led to profound changes at P-E!

One of the errors was a lack of full documentation of the mirror construction and testing. However! Engineers were able to figure out exactly what went wrong, which meant that they could figure out how to make a corrective lens system; in other words, they were the opticians who could fix the *HST* with a set of glasses.

Any addition lenses in an optical system are not desirable, because each lens loses a little bit of light. But in *HST*'s case, the fix was much, much better than the relatively-small degradation of image quality it caused, given that the *HST* was barely usable without it.

Space Shuttle Missions Involving the *Hubble Space Telescope*				
Date	**Mission**	**Shuttle**	**Crew**	**Notes**
4/25/90	STS-31	*Discovery*	Shriver, Bolden, Hawley, McCandless, Sullivan	*HST* Deployed
12/2/93	STS-61	*Endeavour*	Covey, Bowersox, Musgrave, Thorton, Nicollier, Hoffman, Akers	New camera system ("glasses") installed New solar panels installed
2/11/97	STS-82	*Discovery*	Bowersox, Horowitz, lee, Hawley, Harbaugh, Smith, Tanner	Instruments and electronics upgrades Repair thermal insulation (unplanned) Boosted *HST* orbit
12/27/99	STS-103	*Discovery*	Brown, Kelly (Scott), Smith, Foale, **Grunsfeld**, Nicollier, Clevoy	New gyroscopes installed Electrical and technical upgrades
3/1/02	STS-109	*Columbia*	Altman, Carey, **Grunsfeld**, Currie, Newman, Linneham, Massimino	Upgrade to power and other systems Advanced Camera installed New solar panel array
5/11/09	STS-125	*Atlantis*	Altman, Johnson, Good, **Grunsfeld**, Feusteil, Massimino, McArthur	Installed two new instruments Repaired two instruments New gyroscopes and batteries

Over the last 30 years, the HST has produced data that allowed many advances in planetology, astronomy, astrophysics, and cosmology. Some of the most significant observations fall into one or more of these general categories: the age and early history of the Universe, dark energy, the structure of galaxies, exoplanet study, and planetary formation.

A roster of the accomplishments of the *Hubble Space Telescope*, the Space Telescope Science Center, and the many others who have utilized the marvelous data *HST* has produced are WAY too voluminous to recount here in detail. For more information, see the following:

Space Telescope Science Institute

Main webpage: http://www.stsci.edu

Research Topics/Programs: http://www.stsci.edu/stsci-research/research-topics-and-programs

(Exo) Planetary Science: http://www.stsci.edu/stsci-research/exoplanet-and-planetary-science

Public Outreach: http://www.stsci.edu/communications-and-outreach

Edwin Hubble: https://www.spacetelescope.org/about/history/the_man_behind_the_name

NASA 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

HST Engineering Case Study:

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

The James Webb Telescope, HST's successor: https://www.jwst.nasa.gov

One of my fondest memories of my time at NASM was the Family Day presented for the 25th anniversary of *Hubble*'s launch. I had recently served a two-year detail assignment at NASA HQ, the high point of my career, where I helped their public outreach efforts for the launches of *GRAIL*, *Curiosity*, *LADEE*, and *MAVEN*, and the *Curiosity* landing. I was duty-stationed in the Planetary Science Division, working for Kristen Erickson (an outstanding boss!). My uber-boss was Jim Green, now the NASA Chief Scientist, and his boss, the leader of the Science Mission Directorate, was former astronaut **John Grunsfeld** (JG), who had flown three of the *HST* servicing missions.

I went back over to NASA HQ in mid-2014 to visit, and ran into JG while I was there. NASM was already gearing up to cover the mid-2015 fly-by of Pluto by the *New Horizons* spacecraft, but when I casually pointed out our looking forward to that event, JG pointedly pointed out that we should consider the 25th anniversary of the launch of the *HST* to be even more important. I chose not to disagree. *Hubble*'s success was legend at that point, and *New Horizon*'s success was in the future (but it proved to be a great success nonetheless).

JG was not blowing smoke. I got a call not long after my visit from KE on how NASM might be able to host a public event with NASA support. She wasn't kidding, NASA was VERY interested in a program with us. They brought a LOT of talent to bear on program planning, it was a wonderful thing working together with them again! NASA's support allowed us to have one of the finest public programs in NASM history (IMHO).

NASM routinely used NASM astronauts in public programming, a few each year. They were outstanding additions to event programming such as African American Pioneers of Flight and Women in Aviation and Space Family Days. For the *HST at 25* event, however, we didn't get the usual one astronaut, we got FIFTEEN!

What a rush! There we were, in the presence of fifteen stalwart astronauts, and the Space Shuttle *Discovery*, from which the *HST* had been launched and serviced twice. In addition to being able to hear about these missions from those who flew them, we had autograph and photo-op stations set up, along with a lot of other learning activities, and the astronauts not on panel roamed the Udvar-Hazy Center, meeting with visitors.

We had a small presentation stage set up in front of *Discovery*, and a larger set up aft of *Discovery* for the panel presentations. One of my best memories of the whole event was helping former astronaut Bruce McCandless II set up on the front stage to talk about his experiences. I was able to get a photo of him in action, looking up from below him. Bruce had also pioneered the use of the Manned Maneuvering Unit, which allowed a spacewalker to jet around untethered. We have an MMU on display, above the *Discovery*, configured as it was for McCandless' flight, and it was in the background of the photo. We also have a high-fidelity Shuttle spacesuit we used for hands-on teaching purposes; for convenience we had been calling it "Bruce," in McCandless' honor (he was the most pleasant of folks to deal with – we all loved him so the name was particularly appropriate). We had Bruce the Suit out that day, of course,

and I had placed it so it would be in the photo, too. So we had the real Bruce, the MMU Bruce, and Bruce the Suit, all in front of *Discovery*. The resulting "Three Bruces" photograph is on a lot of office walls…. The real Bruce was in poor health, but he sure was smiling a LOT that day. Alas, he passed away on December 21, 2017… A fine gentleman, indeed.

[Perhaps one other item from the event is worthy of note. The astronauts would rove the floor in groups, one for each mission, when they weren't busy elsewhere. We never allow the astronauts to fend for themselves unescorted, and I was keeping an eye on one of the crews as they met with the public. One of the activities we had set up for the younger visitors was a Space Shuttle model, made of soft sections that could be assembled/disassembled and "ridden" by children. My group happened by when a group of kids were there playing, to delight of their camera-wielding parents. The crew commander was very nice, and offered to play with the kids, to the laughing delight of both parents and children. When asked, the little girl on the front of the shuttle waved the commander astern, with a "Yes, of course, sit back there!" I thought his crew would burst choking back their giggles; I thought I was going to, too. Now everyone was laughing, but for different reasons. But the commander was a great sport. He took his seat far astern, smiled for the cameras (most now in the hands of his laughter-consumed crew), and had a blast with the kids. I'm betting a LOT of those pictures are still "on the mantle" at home!]

It was a wonderful event! But it wouldn't have been possible with NASA's generous support and the hard work of a large number of people.

Unfortunately for all of us, the coronavirus issue is affecting a number of commemorative events for the *HST* at 30; for example, see here: https://astronomynow.com/2020/03/29/hubble-anniversary-events-impacted-by-covid-19-pandemic/

Important Space Exploration Information Resource: Everyone involved in Space-related outreach should be familiar with this wonderful resource, by noted Space historian Asif Siddiqi, "Beyond Earth: A Chronicle of Deep Space Exploration, 1958-2016!" Get your own pdf copy at: https://solarsystem.nasa.gov/resources/1060/beyond-earth-a-chronicle-of-deep-space-exploration/. All four of the Great Observatories have information-rich entries.

NOTE from the Future: *The orbiting astronomical observatory concept has proved to be very successful, with many more missions flying than the Four. For an interesting summary, see the list at: https://en.wikipedia.org/wiki/Orbiting_Astronomical_Observatory.* The OAO program will be the subject of an "Item of the Week" piece in the Air and Space this Week distributed on December 6, 2020.

Last Edited on 05 December 2020