The Hubble Space Telescope

History 350

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Introduction

Since before the dawn of civilization the night sky has intrigued humans. Any child today can still point out the same constellations that the great sailors once used to navigate the northern hemisphere hundreds of years ago. We have studied the heavens, mapped its beauty and wonder, and even explored our heavenly neighbors, the Moon and Mars. We have sent men to the moon, satellites into orbit, and probes beyond the reaches of our solar system. The drive of human curiosity has allowed us to examine our universe in ways that were inconceivable as recent as a century ago. But at the root of all our great space endeavors, is the tool that was first used to show us how imperfect, vast, and beautiful our universe really is, the telescope. If this sounds familiar, it is probably because you have read my pervious paper on the history of telescopes. I borrowed it from my previous work because those one hundred and thirty words best carry the significance of the impact the telescope has had on our perceptions of the universe around us.

In this brief work, I have narrowed the focus of my efforts from the history of all telescopes, to one in particular: The Hubble Space Telescope (from here within, HST). Not to point out the flounders of my paper so early, but many issues such as budgets, political effects both before and after the telescope, and in-depth analysis of the many sub-systems used, have been left out for time and space constraints. Volumes of information depict these issues at great length; however, I felt that the nature of this paper was suited towards an engineering, science, and technology perspective, rather than the minutiae of how much things cost, how many politicians loathed the project, how many rejoiced at its launch, and what the NASA guys ate for lunch. Detailed sections about the sub-systems were left out at a greater cost. Their importance should not be over looked, but I was afraid that placing more focus on any one of them would take away from the harmony at which all the systems work together, giving us an unthinkable amount of data about the universe. “Taken more than 330,000 separate observations. Observed more than 25,000 astronomical targets. Created a data archive of over 7.3 terabytes. (That is like completely filling a PC every day for 10 years.) Provided data for more than 2,663 scientific papers.” (The Hubble Project, pg: Overview)

Many people think that if NASA can go to the moon, that putting a telescope in orbit should not be too big of a deal, but that is just not so. Any satellite in space must be self-sustainable, for almost an indefinite amount of time. If something goes wrong, one cannot just walk outside and replace a part. Shuttle missions take time, planning, the right window in order for the shuttle to be placed where it needs to be, and most importantly, lots of money. Every system on the HST is a product of years of development, and as few mistakes as possible. Like all complex machines, before any of the systems were thought of, when thoughts of space were still things of fiction and uncertainty, there was an idea, by a young professor of astronomy, at Yale.

The idea…

Lyman Spitzer was the first to speculate about the benefits of an observatory outside our atmosphere. Spitzer was a professor of astronomy at Yale when he first laid out the details surrounding a space-based telescope in 1946. He later taught at Princeton and created the Plasma Physics Lab at Princeton. NASA named another space-based telescope after the man, the Spitzer Space Telescope, which studies the heavens in the infrared and near-infrared wavelengths. (NASA - Who is Lyman Spitzer, nasa.gov)

Many people are quick to ask why we need such an observatory in space. The short answer is that Earth is an awful place to observe from. Our atmosphere filters many of the wavelengths in the electromagnetic spectrum. It also subjects ground-based observatories to cloud cover and dust. Both can obscure visions of distant objects. Many of the objects that we are currently concerned with are things that are arc-*seconds* in diameter, smaller than the width of a human hair at arms reach. The Earth's terrain and rotation prevent camera exposures of more than a few hours. When trying to photograph a very faint object, this can make things very difficult. Some of the best places to observe from on Earth are in regions so remote, building a telescope of sufficient size and ability would be wasteful. Not to mention, many of these ideal places exist in the middle of oceans where no solid ground resides to build upon (based on common sense, many of the darkest regions of the planet are the farthest from civilization). The light pollution caused by the human population is making amateur observation and discovery a more and more difficult hobby. Our ground-based observatories are getting better and better, but the capabilities that exist in space are much greater. (Arny, Pg: 120-144, 164-168)

Figure 1 Light Pollution

The HST is not affected by light pollution, atmospheric distortion (scintillation), or the Earth's terrain and spin. This allows observations and exposures 24 hours a day, 7 days a week, in that meticulous, calculating, and emotionless stare that only a machine could achieve. It allows researchers to point the HST at a target in space, a very, very small spot, and take an exposure there for an extended amount of time by ‘pausing’ an exposure, and because of the precision of the instruments on board, resume the exposure later (Hubble Space Telescope, Wikipedia). In space, weather does not exist; there is nothing to get between the HST and its targets except a minute amount of dust (maybe a particle per 10 cubic kilometers) and maybe some neutrinos. For these reasons it seems only logical that there be at least one observatory in space, free from the constraints of our planet, studying the heavens around us. (Smith, pg: 14-18)

Design

The HST is a large satellite, measuring over 13 meters long, and over 12 meters wide with its solar panels deployed, and tipping Earth-bound scales at over 12 tons. The design of the HST is largely divided into three areas, the actual telescope, the support systems, and the scientific instruments (Hubble Space Telescope – Wikipedia).

The telescope portion is 8 feet (2.4 meters) in diameter, and is a variation of the Cassegrain-Focus Telescope, whose design was developed in 1672 by Guillaume Cassegrain, a Frenchman. Cassegrain moved the focus of Isaac Newton’s reflecting telescope to the bottom of the barrel, resembling a refracting telescope since the view piece is at the bottom of the tube rather than on a side near the top as in a Newtonian-Focus. Cassegrain’s idea of using a convex mirror with a concave mirror lessens the aberrations visible. Newton denounced the Cassegrain-focus, based both on his own misunderstandings and on the grounds that Cassegrain’s idea was similar to (and he thought based on) another design by a British astronomer. Cassegrain faded out of view, seemingly in disgrace, but his design was used by several of his contemporaries despite Newton’s accusations that it was a flawed and defective design (King, pg: 76). In the twentieth century, two opticians reworked the design, using hyperbola-shaped mirrors, versus the parabola-shaped mirrors used in most Cassegrain-Focus up to that point. This design is properly known as the Ritchey-Chretien, but is still recognized as a Cassegrain first (Chaisson, pg 150).

This design was picked for the HST mainly because it allowed the engineers to balance the telescope and kept the shape roughly cylindrical, rather than having a bulge on one side, as required by a Newtonian focus. The mirror is equipped with several actuators in the back which allow NASA to flex the mirror ever so slightly (0.01 Microns). This is not even close to the amount necessary for it to be similar to the adaptive optics used in ground-based telescopes today, but does allow NASA to make fine adjustments from the ground. The secondary mirror is also equipped with such actuators, but they cannot warp the mirror, merely move it and tilt it ever so slightly, to keep the telescope focused. In order to remain focused, the distance between the primary and the secondary mirrors (~16') must be maintained to within 1/10,000" (Chaisson, pg 154-155). That last line is not a typo, the actual distance is around 16', but needs to be precise to 1/10,000". There was some disbelief among my proofreaders that this was the case. The barrel of the telescope is filled with baffles, and extends several feet beyond

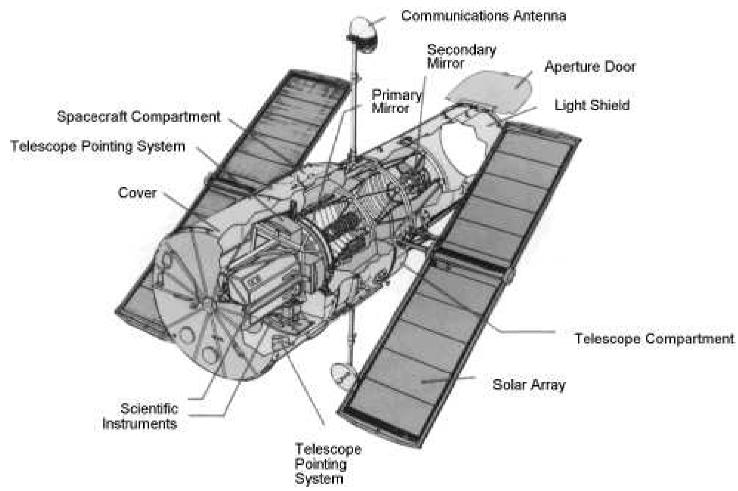

Figure 2: Cutaway of the Hubble (Courtesy of digicamhistory.com)

the necessary length, in order to shroud the mirrors from any extraneous light. The interior is coated with Martin Black, a light-absorbing paint that is known as “The blackest of all materials on Earth” (Chaisson, pg 155).

The support systems are grouped into what is called the “Support Systems Module” or SSM. The SSM is what powers and controls the HST; it also houses the communications systems and other equally important sub-systems necessary to keep the spacecraft fully functional and in orbit. (Smith, pg 81)

The Scientific Instruments should be self-explanatory. This section houses all the instruments that interpret the data received by the telescope and relay it in varying forms to the control stations on the ground. These instruments are modular, meaning they can be exchanged for other instruments during servicing missions by the Space Shuttle. A total of five instrument bays are available, but one of them is occupied by the COSTAR package, designed to correct the optic problems discussed later. Current instruments on the HST include the Near Object Camera and Multi-Object Spectrometer (NICMOS), the Advanced Camera for Surveys (ACS), the Wide Field and Planetary Camera 2 (WF/PC2), and the Space Telescope Imaging Spectrograph (STIS), which failed on August 3rd, 2004. Instruments formerly in operation: the High Speed Photometer (replaced by the COSTAR package), the Wide Field and Planetary Camera (replaced by its successor, WF/PC2), the Goddard High Resolution Spectrograph (replaced by the STIS), the Faint Object Spectrograph (replaced by the STIS), and the Faint Object Camera (replaced by the ACS). (Hubble Space Telescope, Wikipedia) The current instruments are detailed later.

The SSM, engineering, and final assembly of the HST was contracted to Lockheed Missiles and Space Co., currently known as Lockheed-Martin. The primary mirror and the fine guidance system were contracted to Perkin-Elmer. Their screw-ups will be discussed later. The European Space Agency contributed several items, among them the vast solar arrays that provide power for the systems, and the Faint Object Camera, which was replaced in 2002 by the Advanced Camera for Surveys. The remaining instruments and the command system, along with mission planning, were completed by NASA at the Goddard Space Flight Center. (Smith, pg 222-228)

Current Instruments

As reported earlier, there are five modular bays onboard the HST, each allowing the placement of one instrument. Currently only four bays are available, the fifth is occupied with the COSTAR package, discussed later. The last page of this document contains a map/timeline of the instruments onboard the HST during its life, and some projected instruments that may or may not happen. The first instrument to be discussed is the latest and greatest, the Advanced Camera for Surveys (ACS). It replaced the Faint Object Camera, which was aboard for the initial launch of the telescope, and was provided by the European Space Agency (Smith, pg 179). The ACS is actually three cameras. The two lesser-used cameras are for far-ultraviolet and high spatial resolution images. The most used camera is a dual-CCD camera capable of 4096^2 (16 Million) pixels of resolution. It was placed in service during the last shuttle mission to the telescope in 2002. This is currently the 'workhorse' camera for the telescope, taking the title formerly held by the WF/PC2, or the Wide Field Planetary Camera 2 (ACS::Instrument Overview; Advanced Camera for Surveys -- Wikipedia).

The WF/PC2 has been in service since the first service mission in 1993, and was created with corrective optics installed, so it did not need to utilize the COSTAR package as the rest of the instruments did at the time. It is one camera with two modes; one mode is a wide field of view for imaging groups of objects or nebula with long exposures, and the second mode images objects such as planets with short exposures. If you have seen a published picture from the HST, it was more than likely taken with the WF/PC2. Its resume contains some of the greatest discoveries of our time, including the Hubble Deep Field, and the Hourglass and Egg Nebulas. As the name infers, it is also the camera responsible for giving us some of the most gorgeous images of our neighboring planets that mankind has seen. This camera replaced the original WFPC, which was expected to be the most used of the cameras during the HST's early life, only to be replaced on the first service mission. (Smith, pg 414)

The next camera onboard is the NICMOS (Near Infrared Camera and Multi-Object Spectrometer. It was built by Ball Aerospace, a subsidiary of The Ball Corporation, based in Muncie, Indiana. (Guess Indiana's good for something other than corn!) Its primary purpose is to detect infrared light, and as such it is important to keep this detector extremely cold to limit any 'noise' that may be introduced into the image. Originally this was done by using a block of nitrogen ice, but for unknown (or unreleased) reasons, the cooler ran out of ice in less than 2 years. On the next repair mission, astronauts fixed the problem by installing a new cooler that uses a refrigerated neon loop, and allowed the instrument to resume activity. Space for NICMOS was freed up in 1997 when the Space Telescope Imaging Spectrograph replaced the two previous spectrographs (Near Infrared and Multi-Object Spectrometer – Wikipedia).

Last but not least is the Space Telescope Imaging Spectrograph (STIS). The STIS was designed to replace two of the previous onboard spectrographs, the High Resolution Spectrograph, and the Faint Object Spectrograph, thereby consolidating the two instruments and freeing up a bay (which was filled with the NICMOS as the previous paragraph stated). It also enhanced on the two instruments' capabilities. It was installed in 1997 during the second service mission, and was designed to last 5 years. It lasted 7 before failing on August 3, 2004. (Space Telescope Imaging Spectrograph – Wikipedia)

Other instruments on board include the Fine Guidance Sensors, detailed below, which in addition to keeping the HST on target, can also be used to perform various measurements and calculations. Sitting in an instrument bay, but not a science instrument, and currently not doing much, is the COSTAR package, developed by Ball Aerospace and discussed later.

Digital Imaging

In order to get its data back to the ground, NASA had to come up with a scheme to do so efficiently. Photographic plates and film were even considered. These would have required several missions a year (or more) to retrieve captured data and replace plates/film canisters. The next alternative to surface was the Secondary Electron Conduction Vidicon (SECV). These were based on TV tubes, and were not designed with the rigors of space, or even simple astronomy, in mind. (Smith, pg 107) SECVs soon received competition from Charge Coupled Devices (CCDs). A CCD is a silicon wafer, entirely solid-state, that is divided into a grid of receptors, each capable of counting the photons landing on it. This information is then processed and through the wonders of computers we get a digital image. This is an over-simplified definition, but it captures the general concept. Back to the HST, the CCDs had many things in their favor. They were small, light weight, durable, sensitive, and more importantly, they consumed little power and were capable of producing awesome images. They did have a few drawbacks, however. The size of the images they could create was tiny compared to the area of sky the SECVs could capture. They were also subject to imperfections in the silicon chips, and were poor at detecting ultraviolet light, a serious detriment to technology, since the HST needed to see things in the ultraviolet spectrum. The latter of the three problems was fixed by a group at Goddard Space Flight Center, where they created Intensified CCDs (ICCDs). ICCDs use a television tube to convert the incoming photons to electrons, and then used a CCD to detect the electrons. This method made the CCDs very sensitive to incoming ultraviolet light, and was one of the eventual selling points of the technology. (Smith, pgs 108-110) Some of the imperfections in the chips can be overcome by cooling the chips to a frigid temperature, which the HST does. The chips are cooled by what is, in essence, a refrigerator, to temperatures around -130°F (Chaisson, pg 126). The infrared camera and the NICMOS must be cooled to -180°C (-356°F).

Originally, the CCDs were unable to capture color images. By combining processed images that were taken with varying wavelength filters in place, color composites were constructed. I highly doubt that with current technology this is still the case, but was unable to verify it through my research. It just does not seem feasible that a multi-million dollar camera created in the late 1990s/early 21st century would be unable to take color pictures, even at such high resolutions.

While the CCDs throughout the instruments vary; the current 'workhorse' camera of the telescope is the Advanced Camera for Surveys (ACS). One of its three internal cameras has dual CCDs, each capable of a 4096x2048 (pixels, aka: points of light) resolution, more than double what most high-end CRT computer monitors will produce at their highest settings, and triple or quadruple the settings of most LCD screens (ACS::Instrument Overview, McCann). In comparison to another digital camera, my Kodak DX6490, purchased this summer for a sizeable amount of money, is only capable of images of 2304x1728 (pixels).

Communication

In order to get this digital data back to the ground, and to receive commands for its next mission, the HST communicates with scientists via the TDRS System (Tracking and Data Relay Satellite System). This system is used by government agencies for communicating with various other satellites. Ten have been made since their introduction in the early 1980s. The first 7 satellites were originally built by TRW, and the last three were built by Boeing. Only nine ever made it to orbit; one was lost during the tragic *Challenger* explosion of 1986. The TDRSS is an encrypted satellite system, primarily used by the Department of Defense and is based in New Mexico at the White Sands Missile Range (Smith, pg 417; Chaisson, pg 71; TRDS – Wikipedia).

Proposals for observations are sent to the Space Telescope Science Institute at Johns Hopkins University campus in Maryland. The proposals are reviewed, and if approved are weaved into the HST's strict schedule. Commands are assigned and the data is then sent to New Mexico, where the ground station of the TDRSS encrypts the data and uplinks it to the HST. Once there, the HST then executes the commands at the prescribed times and relays data back when a connection is next available. Because of the HST's orbit, constant communication with the satellite is impossible, and the main reason for the TDRSS is that it is easier to track and talk to a constellation of satellites that can relay signals as necessary, rather than trying to track one in particular (Smith, pg 417; Chaisson, pg 71; TRDS – Wikipedia).

Gyros, Fine Guidance Sensors, and Maneuvering

Having a telescope of such great accuracy and ability does not do any good if you are unable to point the thing at an object and keep it steady. Imagine trying to look at a single star with a pair of binoculars. Without a way to compensate for the Earth's movement and the observer's own movement, it is almost impossible to remain fixed on one particular spot. The HST solves this problem by using a combination of gyroscopes to monitor movement, and by the use of the Fine Guidance Sensors, developed by Perkins-Elmer and mentioned earlier, to keep the HST pointed in one direction.

The HST has three pairs of gyroscopes. They are located in the aft equipment bay, in replaceable modules. They float almost frictionless in a solution that is 90% hydrogen and 10% helium. The gyros fail over time, and the HST down to its last three. These three are the minimum required to operate the HST, but when they are all operating 4 are active, mostly for redundancy. (Chaisson, pg 59) The gyros have been replaced on previous service missions, but with the possible discontinuance of missions, the Hubble is expected to become inoperable by 2012. "Without them, the difference in gravity between the top and the bottom of the telescope will cause it always to point perpendicular to the earth in what is known as a gravity-gradient position." (Hubble Space Telescope – Wikipedia) Gyros work by using the physical properties of a spinning wheel, specifically its property to resist motion. By using these properties, gyros are able to detect and report changes in motion, even in a free-falling state, such as Space. “In other words, a spinning gyroscope ‘remembers’ which direction is ‘up’ even though the surface supporting it is no longer level.” (Chaisson, pg 59)

The other tools for aiming the HST are the Fine Guidance Sensors. These sensors are like the ‘spotting’ scopes on top of most amateur telescopes. When the HST is being aimed, these instruments find and lock on to ‘guide stars’ that allow the HST to stay pointed for long periods of time. They feed data to the maneuvering computer, which adjusts the telescopes position accordingly, factoring in data from the gyroscopes and the guidance sensors, and using 4 large flywheels to counter and initiate any movement necessary to maintain its position fix in the sky (Hubble Space Telescope – Wikipedia).

Power Supply

The original solar arrays for the Hubble were provided by the European Space Agency, as part of their contribution to the project. These arrays were what anybody could expect for the time period. They were huge (8 feet by 40 feet), not very efficient, and very delicate. So delicate in fact, that they had to be assembled in a tank of water because they were unable to support their own weight (Chaisson, pg 46). The panels were inefficient only in their size-to-power ratio, and only when compared to today’s technology. They were capable of producing 4100 watts of power. This was enough power for all the original components, but would be inadequate for today’s load. The panels have since been upgraded twice: once in 1993 during the first servicing mission, and again in 2002, during the fourth servicing mission. The latest arrays are two-thirds the size of the originals, produce 30% more power, and fixed a vibration problem that occurred when the satellite passed in and out of sunlight. The smaller size of the arrays lowers the amount of drag on the satellite (drag still exists, even at the extremes of our atmosphere); the increased power production allows all the systems onboard to be run at once. (Hubble Space Telescope – Wikipedia)

Problems

Pre-Launch

The HST was plagued by problems throughout its life, but if one were to step back and look at the complexity of this machine, such problems should be expected. While researching, I found that there were a ton of pre-launch problems. But one problem I came across was particularly funny, and was much greater in magnitude than many, including software bugs, the time, the budget, or the manpower constraints on the project. Apparently, in July 1989, about a year before Hubble's already postponed launch date (It was originally scheduled to go up in 1986, but the *Challenger* explosion restricted shuttle flights until 1990.) it was determined that nobody had bothered to check to see if the secondary mirror had ever been properly attached. That particular step had been done a decade earlier, and there was no documentation of its completion. Whoops! The HST was lowered into its horizontal position inside it's clean room, and a small man sitting on a rapidly engineered, very long, plank was inserted into the 'eye' of the telescope. It turned out that everything was fine, but it was more exciting for some than others:

> Meanwhile, we at the Science Institute were cringing at the thought of a human being with a wrench and a bottle of glue so close to the Hubble's

precious mirrors. "Humans break things" was one of our rallying cries. And, indeed, when the clean-room personnel reoriented the telescope to its dormant vertical state, they somehow managed to drive Hubble's stern into the wall, destroying one of its low-gain antennas. The twin bills for the "diving board" and a new antenna were promptly sent to NASA, which given its spineless procurement and accounting system duly paid up. (Chaisson, pg 155)

After the launch, during the initial setup, there were problems with the solar panels, and even a problem with the cord length on one of the high gain antennas. (Chaisson, pgs 47, 64) But the biggest and most publicized problem was the primary mirror.

Mirror Problems

In 1990, what was probably one of the most exploited screw-ups of a government agency was announced by NASA. The $2 Billion Hubble Space Telescope needed eye glasses. To summarize the problem briefly, the telescope's primary mirror was ground wrong, by a very small amount, but enough that the outer edges of the mirror do not reflect light to the same point as the inner mirror, as telescopes are supposed to do. This caused a blurry image on all the instruments on the telescope.

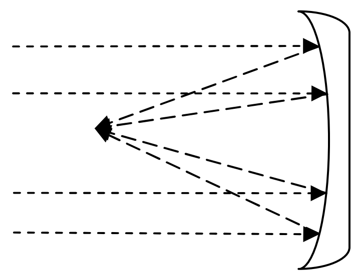

Figure 3: Proper Mirror Alignment

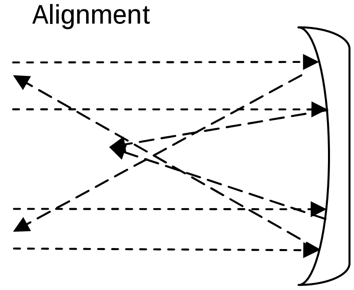

Figure 4: Hubble's Mirror Alignment

From a more technical perspective, the mirror was too flat on its outer edge by 0.0001", "or about one-twenty-fifth of the diameter of a single strand of human hair," (Chaisson, pg 175). Since this error is near the outer edge, and most of a circle's area lies near its outer edge, this is considered a huge error.

The blame of the problem fell almost entirely on Perkins-Elmer, the corporation that ground the mirror, but some blame must also fall with the NASA and Lockheed engineers who neglected to check the mirror for tolerances. Regardless, from one standpoint the expensive blunder can be attributed to simple human error, something inherent in all of our endeavors. From the other standpoint, this is a human error that could have, and should have been found and corrected. The error in the mirror is large enough to have been caught and reported by the testing equipment used by the military on their satellites, but because such testing equipment did not have enough precision for the HST, it was not considered. It is also believed that the error could have been detected by more primitive methods, had anybody bothered to check it (Chaisson, pg 225). Perkins-Elmer claimed that pressure from NASA caused them to lower oversight on the primary mirror project and focus on their other contributions, and NASA contends that for the amount of money they dumped into the company that such oversight ought to have been paid for. These are just personal interpretations of the data I have seen, and are not attached to any particular source on the matter. The amount of money mentioned ended up being around $450 Million, almost 6 times their bid price of $70 Million. A former Eastman Kodak executive commented on Perkin-Elmer's mistake:

> "Their low-balling was sinful." A Kodak-Itek team had bid $100 Million, and this estimate included a thorough "end-to-end" test of mirror quality; this basic overall systems check was not part of Perkin-Elmer's proposal,

> and was not done—a circumstance that ultimately contributed to Space Telescope's myopia in orbit. "A very, very sad story," added the Kodak executive (Chaisson, pg 149).

Eastman Kodak had built a backup mirror under a sub-contract from Perkin-Elmer, by request of NASA. It's reported that they were done on time, within specifications, and within budget, but Perkin-Elmer had wanted their name on the mirror, and NASA went along with them (Chaisson, pg 150).

There was no way to fix the mirror, at least not directly. The mirror itself was too much an integral part of the telescope to replace it in space, and even if it was brought back to Earth, it would probably have been cheaper to just build a new one from scratch rather than disassemble the HST and replace the mirror. So in order to correct the problem, NASA contracted Ball Aerospace to build the Corrective Optics Space Telescope Axial Replacement (COSTAR) package (COSTAR – ball.com). It consisted of several small mirrors that intercept the light coming from the secondary mirror and correct the aberration before sending the light on its path to the science instruments. This assembly unfortunately replaced the High Speed Photometer, but fixed the aberration in the mirror and allowed the HST to focus properly. It was installed during the first service mission of the HST, in 1993 (The Hubble Project – Service Mission 1; COSTAR – ball.com; The Hubble Space Telescope – Wikipedia).

Service Missions

From early on in its design process, NASA had intended on the Hubble being maintained and upgraded through Shuttle Missions. The HST also has to have its orbit boosted by the shuttles in order to stay aloft for long amounts of time. Due to the drag produced by our atmosphere, even at such a high orbit, the HST is constantly spiraling towards Earth. Its rate of decent is dependant upon many things, including the activity of the Sun. Currently there have been 4 service missions, each with specific purposes and goals, and all have been declared successful.

Service Mission 1 was probably the most significant of the four, as it would determine whether or not the HST was able to focus properly. Shuttle *Endeavor* lifted off in December of 1993. The astronauts' primary objective was the installation of the COSTAR package and the successor to the WF/PC2 which had built-in corrective optics and took a step up, technologically speaking, from the original WF/PC. It also installed new solar arrays, two new pairs of gyroscopes, a new computer, added many miscellaneous parts and replacements, and boosted Hubble's orbit. (Hubble Space Telescope – Wikipedia; The Hubble Project – Service Mission 1)

Service Mission 2, flown by shuttle *Discovery* in February of 1997, replaced the two onboard spectrographs with one, superior model, the STIS, discussed earlier. It also added NICMOS in place of one of the removed spectrographs. Both new detectors incorporated correcting optics in their designs, so they do not utilize the COSTAR package. The astronauts replaced many parts, including a fine guidance senor, and installed a new control kit for the FGSs, that enhanced their capability. They also boosted the HST's orbit (Hubble Space Telescope – Wikipedia; The Hubble Project – Service Mission 2).

While originally it was to be the third mission, it ended up being split into the third and the fourth mission. The mission was split because the gyroscopes onboard the HST were failing and needed to be replaced sooner than the scheduled mission allowed.

During mission 3A in 1999, the *Discovery* crew replaced all the gyroscopes, the computer, a FGS, and a whole bunch of other equipment, but no major chores were undertaken. For mission 3B in 2001, the shuttle *Columbia* was tasked to replace the Faint Object Camera with the ACS, install the cooling unit on NICMOS, replace the solar arrays (again), fix miscellaneous parts, and boost the telescope's orbit. By fixing the NICMOS and installing the ACS, Mission 3B allowed the HST to image the Ultra Deep Field, discussed later (Hubble Space Telescope – Wikipedia; The Hubble Project – Service Mission 3A & 3B).

The fifth and what was to be the final service mission for the Hubble has been delayed indefinitely due to the *Columbia* accident. Originally planned for 2004, its mission was to replace the WF/PC2 with the WFC3, an improved version with capabilities comparable to the ACS. The COSTAR Package was also to be removed, and replaced with the Cosmic Origins Spectrograph, an ultraviolet detector. The STIS was to be repaired, and all of the batteries and gyroscopes were to be replaced. A FGS was to be replaced, and several modifications and repairs/replacements were to be made to equip the HST for the rest of its lifespan.

Future of the Hubble

With the indefinite delay of shuttle launches, the HST's future is dim. The telescope's gyros are failing, as mentioned earlier, and this complicates matters. Once four gyros fail, the telescope is no longer operable. It enters a safe mode, stabilizes its movements and awaits help (Chaisson, pg 338). This actually happened prior to the 1999 Service Mission 3A discussed earlier. Also, the batteries, heat shielding, and many other components are going to fail soon unless a mission is undertaken (The Hubble Project –

Service Mission 4). Robotic missions have been discussed, but no solid ideas have taken shape yet. A robotic mission would be subject to enormous errors and I do not think that its risk would warrant its undertaking. Then again if they're willing to sentence the HST to death anyway, what's a few hundred million dollars for them to try to save the thing?

Ever since shuttle *Columbia* exploded, a manned mission has become a subject of politics, and whether or not we should risk the lives of our astronauts. But, if they're never going to get to go into space, why title them astronauts? The *Columbia* accident is unfortunate and tragic; I do not wish to seem insensitive. But in my opinion, we serve the memories of those lost best by continuing our advances into space, for that was their dream. President Bush wishes to put men back on the Moon in short order and men on Mars in a reasonably longer amount of time, but currently we are unable to even maintain our space telescopes. During the course of my research, I was unable to determine if there is even a mission planned to retrieve the HST at the end of its lifespan and bring it safely back to Earth; this was one fact that I specifically look for, but came up short. Bringing the satellite back to Earth seems the only logical end to a tool that has served our race so long and so well. If there is to be no more service missions, at least send a mission to bring it home for the world to see.

From a scientific aspect, there are several of the 'great observatories' left to choose from, but none will be able to give us the images the Hubble did, because none are as focused on the visible spectrum. Some have limited capabilities with visible light, but most do not even detect it. If the Hubble goes away, so will those gorgeous and fascinating images it has given us of the North and South Deep Fields, the Ultra Deep

Field, the series of nebula it has imaged over the years, and the up-close and personal views of the planets it has been able to generate.

Edwin Hubble, The Namesake

Edwin Hubble was an early 20th Century astronomer. His more prominent successes include discovering Red-Shift, the phenomenon that occurs when one object is moving away from another, and he used this principle to discover that the universe is expanding. From his equations on this, we also get Hubble's Law, and the Hubble Constant. Einstein's theories claimed the universe was expanding, even before Hubble determined it, but Einstein could not stand the thought, and refused to accept it as fact.

> For this reason, Einstein revisited his equations and modified them by introducing something known as a 'cosmological constant,' an additional term that allowed him to avoid this prediction and once again bask in the comfort of a static universe. However, 12 years later, through detailed measurements of distant galaxies, the American astronomer Edwin Hubble experimentally established that the universe *is expanding*. (Greene, pg 82)

Hubble's proof later caused Einstein to concede that his theories were correct. (Greene, pg 82) These contributions to cosmology caused Hubble's name to be attached to the HST, as the telescope was to be primarily used to study the expanding universe and cosmology. (Smith, Pg 326)

Hubble was born in Missouri in 1889, and moved to Illinois in the same year. He was a known athlete as a youth, and set the state high jump record in 1906. He went on to study astronomy and mathematics at the University of Chicago, and obtained a B.S.

Degree in 1910. He was then one of the first Rhodes Scholars at Oxford, and obtained his M.A. Degree in law from there. He then returned to the U.S. where he taught high school and coached basketball in New Albany, Indiana. He returned to University of Chicago and obtained his PhD in 1917. (Edwin Hubble, Wikipedia)

Conclusion

When brainstorming ideas for this paper I was looking for ideas from the past century that would give me a berth of information from which to assemble my research. The field of astronomy fascinates me and has been the source of many of my papers throughout my career as a student. The last paper I wrote was attached to a specific time period, one that held some of the original revelations in astronomy including the first telescopes, which led to the topic for my previous paper. For the current class, the time period demanded a more recent development, and I made the decision to make this an extension of my previous paper, targeting a more specific development in telescope history, which ended up being the first telescope to successfully view the heavens from outside our atmosphere. Personally I declare this paper a success. I succeeded in what I set out to do, which was to provide a technical analysis of the Hubble's systems without being bogged down in too much detail, and avoiding the politics and budgets as much as possible. There was room for more detail, yet many analyses of the sub-systems were purposely abbreviated to avoid redundancy and maintain smoothness throughout the paper. When discussing the HST in detail, so many systems affect others and are affected by others that you end up talking about the same part in two or three different sections. Problems also arise when one sub-system takes a page or two, discussing both itself and any sub-sub-systems it may have, and the next sub-system can barely fill a paragraph. I started writing without these downfalls in mind, and soon discovered that I was going to have problems. So I had to sacrifice some details in one section to avoid repeating what I had already said, or was planning to say, in another section. I also had to try to balance the paper out and avoid potential stumbling and rambling on any one particular topic. When I factored in space and time constraints, I determined that my best course was to steer clear of detail and instead work more on keeping topics balanced, non-repetitive, and maintaining the paper's tempo.

Usually a problem with sources surfaces during the construction of my papers, but I didn't have that problem with this paper. I had four backbone sources, and one of those was really several sources in one location. The two books by Smith and Chaisson were excellent primary sources on the conception, design and development, construction, and deployment stages of the Hubble's life. They didn't have any data on the modern instruments or service missions, for which I was unable to find hard copy sources about, but the internet proved its use once again, and between NASA's HST website and Wikimedia's online encyclopedia I was able to find enough information about the modern stuff to give my paper some solid ground to stand on.

I have always been fascinated by the images the Hubble has beamed back to Earth, and several pictures of various nebula have served as the wallpaper on my computer for extended amounts of time. It seems almost illogical that NASA is not willing to send a manned mission to at least bring the Hubble home, if not to repair it one last time and allow the multi-million dollar instruments already created to be installed and used. The HST is very popular among the public, and even has several movie cameos including *Armageddon* where it starred alongside Bruce Willis. I would be willing to bet that the Smithsonian Air and Space museum would build an entire wing on to house the HST; it would definitely make my next trip to Washington D.C. more interesting! As you have already guessed, I personally believe that the HST should be returned to Earth, and possibly replaced with a superior model that learns from prior mistakes and takes outer-atmosphere, visible-spectrum astronomy to the next level. Currently there is no other space telescope, either active or planned, that has the capabilities the Hubble has in the visible spectrum. Even if another visible-spectrum observatory is launched, images from the Hubble will be under study for decades, and its name will be one remembered (in the science and technology community anyway) forever.

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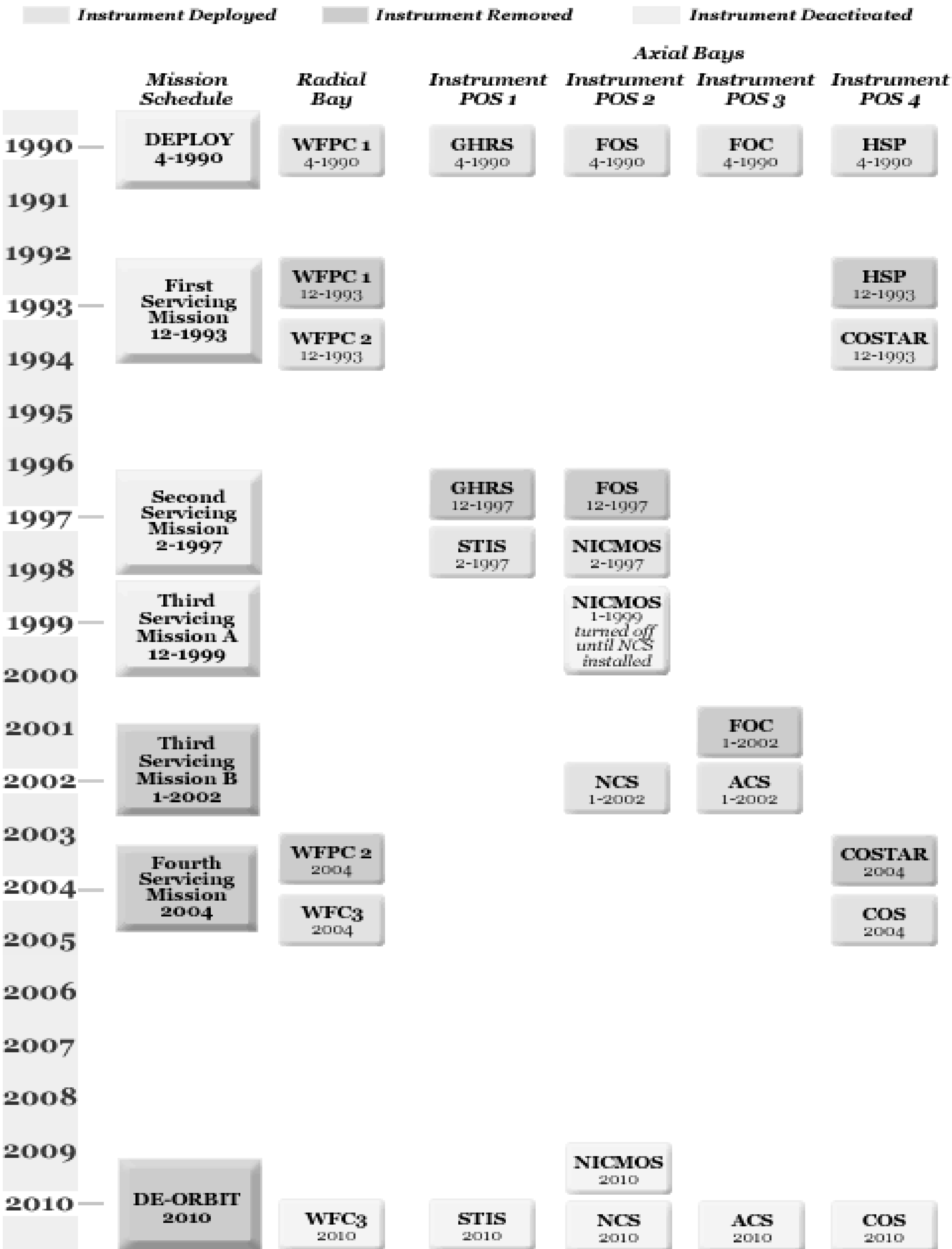

*In February 1999, the Third Servicing Mission was split into SM3A (December, 1999) and SM3B (March 2001).

Couteousy of NASA's Hubble site http://hubble.nasa.gov/technology/science-instruments/index.html