**Window to the Universe:**

**How the Hubble Space Telescope Revolutionized the Study of Astronomy**

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Individual Exhibit

Exhibit: 499 words

Process Paper: 498 words

# *Process Paper*

In all my years of participating in NHD, this topic is by far the most personal. Ever since I was a child, I have been fascinated by the night sky. That fascination culminated in 2019 when I built my own robotic star-tracker to photograph nebulae. Though my first images were nothing like Hubbles, they sparked an interest that has only grown in the past 3 years. When I heard about this year's theme, I began to research possible events that led to advancements in the field of photography. What I found was that the recent wave of innovation in camera technology that made hobbies such as amateur astrophotography possible could all be traced back to one event: the launch of the Hubble Space Telescope.

I conducted my research with two goals in mind. First, I wanted to track all photos, quotes, and data back to their primary source. While time-consuming, this led to greater diversity of sources and stronger evidence overall. One source in particular that helped guide my research was Robert Zimmerman's book *The Universe in a Mirror,* because it discussed Hubble's impact on the space program and the general public rather than just focusing on its scientific value. My second goal was to ensure that I incorporated many different perspectives to tell Hubble's story. To understand Hubble's impact on astronomy from an international perspective, I researched the European Space Agency and BBC. To understand Hubble's impact on global society, I examined international newspapers from Ireland, Canada, and Australia and interviewed a European astronomer.

In creating my exhibit, I decided that the most authentic way to convey Hubble's importance would be to build the telescope itself. When standing underneath the model

telescope's giant solar panels, it's hard not to appreciate the incredible history of scientists, engineers, and astronomers that helped make the telescope a reality. I used lightweight concrete form tubes to create the telescope's shell and corrugated plastic sheets for the solar panels. In order to ensure I was not sacrificing board space for aesthetics, I designed rotating solar panels so that I had plenty of room to display my research.

The Hubble Space Telescope shaped the world of astronomy we know today. Hubble led a frontier in technology and astronomical research methods that replaced a far-outdated system that had hindered scientific discovery for years. Hubble also brought new attention to the importance of astronomy and the benefits of research in all scientific fields in a way no observatory had before. Hubble became a model for how to operate an observatory that conducted groundbreaking research by incorporating the public, rather than shutting them out. Seeing the benefits offered by such a system, amateurs and the general public put pressure on existing private observatories to join one of several emerging "telescope networks." We would not have this advanced, collaborated network nor the capacity for research we have today without Hubble. Even after the telescope shuts down, its legacy will be felt for years to come.

# Annotated Bibliography

## Primary Sources:


*ACS WFC CCD.* 2002, European Space Agency,

www.esahubble.org/images/opo0206g/.

This photo is used on my project board to give a visual aid for readers during my discussion of CCD sensors. This source was valuable to my research because it is a photo of the actual CCD installed on Hubble.

"AMATEUR ASTRONOMERS WILL USE NASA'S HUBBLE SPACE TELESCOPE." *HUBBLESITE,* Space Telescope Science Institute, 10 Sept. 1992, www.hubblesite.org/contents/news-releases/1992/news-1992-23.html#:~:text=The%20amateur%20programs%20will%20use,binary%20asteroids%20and%20dying%20comets.

I used this source to both to understand the context of the amateur observing program as well as for a photo on my project board. This helped me understand the potential benefits of the program.

"Astronomers Applaud New Hubble Pictures." *Cambridge Evening News,* 28 May 1994, p. 14.

This newspaper article was used in my media to give an example of the public's fascination with Hubble photos. In addition, this source is important to my research because it provides commentary on one of Hubble's discoveries from an international perspective.

Auerbach, Stuart. “Unmanned Flights: Homely but Helpful.” *The Honolulu Adviser,* 21 July 1969, p. B-7.

This article was mostly used to help me better understand the public’s view of unmanned missions, such as OAO and Hubble, in the wake of the Challenger Accident. This source is important to my research because it provides primary examples of the political and social climate surrounding the space program pre-Hubble.

Aulsebrook, Kerrie. “The Expanding Universe.” *The Sunday Age,* Monash Science Center, 15 June 1997, p. 2-3.

This article was used in my media to show an example of public outreach by the astronomy community as a result of Hubble. This source is important to my research because it discusses the history of telescope astronomy and outlines advancements that have been made since the launch of Hubble.

Ballingrud, David. “Hubble.” St. Petersburg Times, 1 Jan. 1989, p. 10A

This newspaper clipping is used on my project board. This source is important because it represents the excitement surrounding the development of Hubble.

“The Challenger Disaster: ABC News Live Coverage.” ABC News, *Youtube,* uploaded by Zellco321, 28 Jan. 1986,
www.youtube.com/watch?v=Ki_WGCmBhyQ&t=454s.

This video is the recording of ABC news coverage of the Challenger disaster, and I used this source as a visual aid for my media. This source is important because it illustrates the profound impact the accident had on the American people and on morale within NASA.

"Challenger Disaster Saddens The World." *The Times-Mail Bedford,* United Press International, 29 Jan. 1986, p. 3.

This article was used in my media as a visual aid for my discussion of the Challenger disaster's effect on the space program. In addition, it is important to my research on Hubble's background because it proves my argument that the accident put the space program into disarray.

"Diagram of the Hubble Space Telescope." *European Space Agency,* Lockheed Missiles and Space Company, 1981, www.esahubble.org/images/hubble_diagram/.

I used this image both for context and as a visual on my board. This source helped me better understand the physical construction of the telescope.

Dunham, Larry. Personal Interview. 30 Mar. 2023.

This personal interview was most helpful in answering my questions on the role of amatuer astronomers within the Hubble program. Mr. Dunham, the NASA lead engineer for Hubble electronics, also discussed the functions of various instruments aboard the telescope, and detailed how improvements made to instruments during Hubble's life have since diffused out to other fields. I used Mr. Dunham's insight to strengthen my own knowledge of Hubble technology and quoted him on my project board.

Dye, Lee. "Space Exploration Decisions Now at a Critical Point." *Albuquerque Journal,* 30 Oct. 1987. p. C5.

This newspaper article provides a glimpse into the turbulent field of space exploration following the Challenger disaster. I used this source for a graphic in my media and to learn more about funding struggles in space programs worldwide preceding Hubble.

"Edwin Hubble Seated at Hooker Telescope." *Space Telescope Science Institute,* Huntington Library, 1924,

www.Space Telescope Science Institute.edu/who-we-are/our-history/Space Telescope Science Institute-timeline.

I used this source as an image on my project board. This source was important because it gave a representation of astronomy before the introduction of the Hubble telescope while also tying Edwin Hubble into the context of the project.

Emanuel, Richard. "Astronomers Reach for the 21st Century." *Santa Cruz Sentinel,* 24 Jul. 1987, p. E2.

This newspaper article is used in my "Frontiers in Technology" section to provide evidence that other observatories followed Hubble's CCD example. This source is important to my research because it gives an outside-of-NASA perspective on Hubble's early influence.

Erickson, Jim. "Influential Panel Expects Local Group to Lead in Astronomy." *Arizona Daily Star,* 19 May 2000, p. A19.

This newspaper article contains one of the earliest mentionings of the Next Generation Space Telescope (aka Webb) and discusses the benefits of Webb collaborating with ground-based observatories. This source was used mainly for context, and helped me better understand Hubble's impact on future collaboration.

Farrar, Steve. "Scientists Queue for Hubble Telescope." *Cambridge Evening News,* 22 Sept. 1995, p. 12.

I used a clipping from this magazine article on my project board to provide evidence of Hubble's international reach. This source is important to my research because it provides insight into foreign astronomers' aspirations for the telescope.

Farrar, Steve. “Spectacle of Space a Universal Attraction.” *Cambridge Evening News,* 25 Sept. 1996, p. 8.

I used quotes from this newspaper article in the “Impacts on Astronomy” section on my project board. This source was crucial to my research because it laid out in detail how European astronomers use Hubble and how Cambridge University played a role in increasing public support for the project.

Halverson, Todd. “Discovery set to fly today.” Florida Today, 10 Apr. 1990, p. 1.

This image is used on my project title board. This source is important because it represents the moment NASA took a giant leap in its scientific abilities towards an achievement that eventually revolutionized astronomy.

Harwood, William. “Space scope overcoming its obstacles: Instrument takes shape, to cast eye on humans.” Fort Lauderdale News, 13 Nov. 1984, p. 9A.

This newspaper article is featured on the “Frontiers in Technology” section of my project board. This source helped me better understand the challenges regarding Hubble from a press standpoint and provided primary evidence of Hubble’s technological impact.

Harwood, William. “Space Telescope Set For Historic Mission.” *The Times-Press Streator,* United Press International*,* 9 Apr. 1990, p. 15.

This rather extensive article was used for quotes and images on my project board. This source was crucial to my research because it addresses many different positive effects of Hubble’s launch, from the revolutionary new technology it packs inside to its predicted effects on astronomy.

"Hubble Heritage Gallery." *HubbleSite,* NASA,

www.hubblesite.org/resource-gallery/learning-resources/hubble-heritage.

This image gallery is used on my project board as the backgrounds for all of my title boards. This source is important because it showcases the beauty of the nebulae Hubble has captured.

Hubble Legacy Archive. *STScI*, Aug. 2007,

www.hla.stsci.edu/hlaview.html.

This archive contains nearly all Hubble data collected since the early 2000's. While I didn't use this source on my board, I used it to experience first-hand the impact of the astronomical data made publicly available as part of the Hubble Archive. This source is important because it represents a major shift in how astronomical research is done by providing raw data to the public for free.

"Hubble's Instruments: WFPC1 — Wide Field and Planetary Camera 1." *European Space Agency,*

www.esahubble.org/about/general/instruments/wfpc1/.

I used this source as a photo on my project board. This source is important to my research because it shows the viewer the size of a CCD and highlights the technological advances of the sensors since then.

"Hubble Space Telescope Problems." *C-SPAN,* 29 June 1990,

www.c-span.org/video/?12954-1/hubble-space-telescope-problems.

This video is of a senate subcommittee meeting, and I used this source for video and quotes regarding the discovery of Hubble's mirror flaw. This source is important to my research because it discusses the details of the problems that were discovered, and highlights the potential impacts of the flaw on the telescope and the future of NASA as a whole.

"Hubble Telescope Confirms Black Hole." Omaha World Herald, 1994, p.2.

This newspaper clipping is used in my "Impacts on Astronomy" section to give an example of some of the major discoveries made by Hubble. This source is important because it also showcases Hubble's impact on the public's opinion on space.

"The Hubble Telescope." *C-SPAN,* 4 May 2002,

www.c-span.org/video/?169922-2/hubble-space-telescope.

This news interview was important to my research because it provided a glimpse into Hubble's early impact from the point of view of its lead engineer. Dr. Weiler discusses Hubble's success, some setbacks, and his vision for the future of the space program. This source was quoted on my project board.

"Hubble Telescope Image Gallery." *ESA Hubble,*

www.esahubble.org/images/.

This photo gallery is used on my project board to show images of Hubble's launch and some famous images. This source helped me better understand the physical structure of the telescope and its importance.

"Hubble Trouble May Burst NASA's High-priced Bubble." *Hattiesburg American,* 30 Apr. 1990. p.1.

This newspaper clipping is used in my supplemental media to support the argument that Hubble's mirror flaw initially jepordized NASA's future. This source is important because it discusses not only the impact of the flaw but contextualizes it within the broader scope of NASA's recent famous failures.

Jeletic, James. Personal interview. 13 Jan. 2023.

I had the privilege of getting to interview the current Deputy Project Manager for Hubble. This interview gave me insight into things such as tensions within NASA after the Challenger Disaster, technological innovations that helped make Hubble successful, and the telescope's impact on astronomy and society overall.

Jenkner, Helmut. Personal Interview. 17 Mar. 2023.

This personal interview was crucially important to my research because it answered specific questions I had regarding international collaboration as part of the Hubble program. I used this source for guidance in shaping my section on impacts in research and used quotes to support my findings in this section.

"Keep Those Memories Alive." *Calgary Herald*, Sony, 2 Jun. 1997, p.D6.

This newspaper ad was used in my "Significance in History" section to provide an example of a Hubble technology spin-off. This source is important because it represents one of the first consumer adaptations of Hubble technology.

Kimble, Randy. Personal Interview. 23 Mar. 2023.

This personal interview with Dr. Kimble, the head of the NASA Hubble instrument team, was extremely helpful in shaping my section on Hubble's technological frontiers. Dr. Kimble answered many of my questions about the development of CCD technology, and even pointed me to several primary source documents that I was able to use on my project board. I used the information gathered in this interview to revise my CCD section and used Dr. Kimble's words for quotes in my media and on my project board.

Lane, Earl. “Nation’s Space Future Is, Well, Up In the Air.” *El Paso Times,* 24 Aug. 1986, p. 1.

I used an image of this article in my media to support my argument that the Challenger accident had a major impact on Hubble’s launch and on the space program overall. This source is important to my project because it discusses several changes that were made within NASA following the disaster, some of which caused delays in Hubble’s launch.

Lane, Earl.“Hubble’s Snafu in Space.” Newsday Nassau Edition, 1990.

This newspaper clipping is used to provide details to the reader about Hubble’s spherical aberration problem. This source is important to my research because it conveys the idea of perseverance through struggle and highlights a major turning point in Hubble’s history.

“Launch of Telescope Postponed by NASA.” *The Idaho Statesman,* 26 Oct. 1988, p.14.

This newspaper clipping was used in my supplemental media and served as a visual aid in my discussion of Challenger’s impact on Hubble. This source is important to my research because it reveals how complex the Challenger disaster was and highlights a silverlining in chaos.

“LI Stargazer Set for Launch.” *Newsday Long Island,* 30 Nov. 1970, p. 21.

I used this newspaper article (and the image above it) on my project board and in my media to provide a visual aid in my discussion of the Orbiting Astronomical Observatory. This source was important to my research because, in addition to detailing the goals of the OAO program, it includes one of the only photos I could find of the original OAO under construction.

Long, Phil. “The Trouble with Hubble is Over.” Lexington Herald, 1994.

This newspaper clipping depicts Senator Barbara Mulkulski announcing that Hubble has been fixed. This source is important to my research because it marks a drastic change in the public’s perspective on Hubble.

Moore, Arden. “Star Gazer: The Hubble telescope will open a new era in astronomy if all goes as planned.” South Florida Sun-Sentinel, 8 Apr. 1990, p. 4A.

This image is used on my middle project board. This source was important to my research because it helped me develop my understanding of the public’s initial support of Hubble. In addition, provided details on some of Hubble’s technological advancements.

Mutchler, Max. “Amateur Astronomers and the Hubble Space Telescope.” *Space Telescope Science Institute*, 13 June 1996, www.Space Telescope Science Institute.edu/~mutchler/archive/amateur.html.

I used this Astronomical Society meeting transcript both to understand the context for the “Frontiers in Research” section of my project and for quotes on my exhibit board. This source helped me better understand why the amateur observing program was so groundbreaking as well as the problems that resulted because of it.

“NASA at Work: Space Telescope and Spacelab.” Marshall Space Flight Center, *YouTube,* uploaded by The Space Archive, 1981, www.youtu.be/nrp5mC8cV64.

This documentary was used in my media to provide information on the aspirations of astronomers in the 1980's. This source was important to my research because it provides primary evidence of early public support for a space telescope.

"NASA | Goddard Space Flight Center." *NASA, YouTube,* uploaded by NASA Goddard, 1976, www.youtube.com/watch?v=czJgpDcuKT0.

In order to fully understand the creation of the Hubble telescope, I researched the early history of the Goddard Space Flight Center, which is the facility from which Hubble was designed and operated. I used this documentary mainly to provide context for my project overall. This source is unique because it provides valuable historical information on the Center's early projects and discusses its importance in NASA overall.

National Research Council. *Scientific Uses of the Large Space Telescope.* Washington, DC: The National Academies Press, 1969. www.doi.org/10.17226/12399.

This source was used for quotes on my project board. This source helped me better understand the need for Hubble and the evolution of the idea.

"OAO 1." *Space Science Data Coordinated Archive, NASA,* www.nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1966-031A.

I used this source for context on specific telescope projects that NASA completed before Hubble. This source was valuable to my research because it offered specific information on OAO's star-pointing system that was later used on Hubble.

"OAO 2." *NASA, YouTube,* uploaded by Space Observation Channel, 1968, www.youtube.com/watch?v=--5hAj22bi0.

I used this video for context on one of Hubble's predecessors and to create my video media. This source is important to my research because it provides primary evidence of the excitement surrounding NASA launches and an early example of NASA's commitment to public outreach.

"115th Congress House Subcommittee on Space, Science, and Technology Hearing: NASA's Next Four Large Telescopes" *House.gov, Library of Congress,* 6 Dec. 2017, https://docs.house.gov/meetings/SY/SY16/20171206/106693/HHRG-115-SY16-20171206-SD003.pdf

This House Hearing transcript is used for quotes in my significance section. This source was helpful to my research because it provided unique insight on the future of NASA and the public's role in deciding that future. While this source did not exist during the time period Hubble was launched, I marked it as primary because it is an authentic document discussing the current impact of the telescope.

Ptak, Florian. "The Trouble with Hubble." *The Berkshire Eagle,* 22 Sept. 1990, p.6.

This newspaper clipping was used in my supplemental media and helped provide evidence that Hubble was severely crippled right after launch. This source is important because it highlights the intense press coverage of the spherical aberration error, and shows that it was because of this public outcry that NASA received funding to fix the problem.

Rosenthal, Harry. "Hubble Ends its Trouble As Galaxy Pictures Lift Fog." *The Birmingham Post,* 14 Jan. 1994, p.10.

This newspaper clipping is used in the impacts section of my supplemental media to support the speaker's argument that Hubble's fix caught the public's attention. This source is important because it provides primary source evidence of the public's early (and continuing) fascination with Hubble.

Roylance, Frank D. “Astronomers Eye Life After Hubble.” *The Baltimore Sun,* 8 Sept. 1996, p. 2A.

This newspaper article discusses some of the improvements in research capabilities that will be made using the James Webb telescope. I used this source as a graphic for my media and to support my findings that Hubble benefited the future of space technology.

Roylance, Frank D. “Hubble Technology Makes Breast Exams Easier.” *The Baltimore Sun*, 11 Feb. 1997, p.1-p.7.

This newspaper article was used in my impacts section to highlight one way Hubble has impacted society as a whole. This source was important to my research because it gives primary source evidence for how Hubble’s CCD’s have impacted medical science by streamlining breast cancer exams.

Sawyer, Kathy. “After Challenger, NASA’s Star is Fading.” *The Sydney Morning Herald,* 29 Jan. 1987, p.18

This newspaper clipping was used in my supplemental media and was very helpful in proving my argument that NASA’s reputation took a substantial hit after the Challenger disaster. This source is important because it provides primary source evidence that NASA’s reputation was diminished and helps set up my argument that Hubble was responsible for restoring that reputation.

Sawyer, Kathy. “NASA’s Future Riding on Hubble Repair Mission.” *The Wilmington News Journal,* 29 Nov. 1993, p.1.

This newspaper clipping is used in my supplemental media to highlight tensions within NASA around the time of the Hubble repair mission launch. This source is important because it discusses the potential benefits and ramifications of the mission and provides evidence that Hubble was very influential in securing funding for future space missions.

"Seas of Infinity: OAO 2's 50th Anniversary." *NASA, YouTube,* uploaded by NASA Goddard*, 11 Dec. 1968,* www.youtube.com/watch?v=zpfhoXN06FM.

This documentary from 1968 discussed the main objectives of the Orbiting Astronomical Observatory (OAO2) mission. I used this video to understand the history of the development, launch, and operation of OAO 2. This source was particularly helpful because it allowed me to present primary source evidence in my media about the historical impact of the observatory.

Sembach, Ken. Personal Interview. 4 Apr. 2023.

After a successful interview with Mr. Dunham of NASA, I was put into contact with Dr. Sembach, the former director of the Space Telescope Science Institute (STScI). As the impact of STScI is a major focus of my project, this interview was invaluable in providing a unique perspective on the institute's impact on the wider astronomical community. Having served in various areas of astronomy previously, Dr. Kembach also discussed the differences between ground-based and space-based observatories, and highlighted the Hubble model's widespread adoption in recent years.

Smith, Robert W. *The Space Telescope: A Study of NASA, Science, Technology, and Politics.* Cambridge University Press, 1989.

This book was highly important to my research because of its heavy focus on observation methods and technologies pre-Hubble. The information given from this book, paired with the information from *Not Yet Imagined*, gave me a reliable source of information and quotes for my project.

"Spin-offs Put Spacebound Technology Within Reach." *Florida Today*, 27 Apr. 1997, p.2E.

This newspaper article was used for context to support my argument that Hubble impacted the future of technology as a whole. This source was valuable to my research because it helps explain how Hubble led to a revolution in photography.

*Sputnik 1*. 1957, European Space Agency,

www.esa.int/ESA_Multimedia/Images/2007/10/Sputnik_1_before_launch_in_October_1957.

This photo is used in the middle section of my project board as a visual aid for the quote discussing the impact of Sputnik. This source was important to my research because it helped me create historical context around Hubble's creation.

"STS-31 Hubble Space Telescope." NASA, *YouTube,* uploaded by The Space Archive, 24 Apr. 1990,

www.youtube.com/watch?v=_U5n61zXQ60.

This video contains footage from the launch of the shuttle *Discovery* with the Hubble onboard, and I used this source as a visual aid in my media. This source was important to my research because it provides primary evidence of the beginning of a turning point in astronomy.

"The Hubble Space Telescope." *C-SPAN,* 13 Jan. 1994,

www.c-span.org/video/?53735-1/hubble-space-telescope.

This video was used in my supplemental media to support my argument that Hubble helped change NASA and the public's view of the space program. This source is important because it provides primary source evidence of Hubble's impact while also providing a unique perspective on the issue.

Usher, Oli. “Hubblecast 41: Hubble's History Told by Hubble's Scientists.” *European Space Agency,* 14 Dec. 2010, www.esahubble.org/videos/hubblecast41a/.

This interview transcript was used to gain firsthand perspective of Hubble’s success. This source helped me better understand the importance of Hubble both to astronomy and to the space program from a primary source point-of-view.

“U.S. Space Program.” *C-SPAN,* 26 Aug. 1993, www.c-span.org/video/?49394-1/us-space-program.

This video is of a senate subcommittee meeting, and I used this source on my media to highlight the tension within NASA at the time of the launch of the Hubble telescope. This source is important because it discusses several other failed missions that occurred before the launch of the telescope, all of which served to make the success of the telescope even more important.

*Vanguard Launched.* 1958, NASA, www.nasa.gov/directorates/heo/scan/images/history/March1958.html.

This photo is used in the context section of my middle board as a visual representation of U.S. space abilities in the 1950’s. This source helped me draw better conclusions about the political climate surrounding Hubble.

“When Did the Universe Begin?” *TIME Magazine,* 6 Mar. 1995, www.content.time.com/time/covers/0,16641,19950306,00.html.

I used this magazine cover on my project board to highlight media coverage of the Hubble telescope. This source shows how impactful Hubble’s first images were.

Wiseman, Jennifer. Personal Interview. 5 Apr. 2023.

This personal interview with Dr. Wiseman, chief Hubble data scientist at NASA, was very helpful in highlighting Hubble's most important contributions to astronomy. She discussed the impact of Hubble's scientific discoveries on both the astronomical community and on the public, and discussed the advantages of having a publicly accessible data archive. I used Dr. Wiseman's remarks for context and quoted her on my project board.

# Secondary Sources:


Akar, Yannick. “NGC 1499: The California Nebula.”, APOD, *NASA*, 2021, www.apod.nasa.gov/apod/ap210310.html.

I used this image for the background on the “Impact on Astronomy” title on my board. This source was important because it represents the significant improvements in the abilities of amateur astronomers since the launch of Hubble.

Bely, P.Y. “The Pointing Stability of the Hubble Space Telescope and Proposed Concepts for the Pointing Control of the Next Generation Space Telescope (NGST).” *IFAC Proceedings,* vol. 25, no. 22, 1992, pp. 457-462, www.sciencedirect.com/science/article/pii/S1474667017496881?ref=pdf_download&fr=RR-2&rr=794194dd7fd72e57.

This journal article was extremely helpful in my research over the Pointing Control System, because it describes the system, both its flaws and its weaknesses, in detail. I used this source for background information and for quotes in my technology section.

“Case Files: Edwin Hubble.” *The Franklin Institute*, www.fi.edu/case-files/edwin-hubble.

I used this article to give background information on Edwin Hubble. This source was helpful mainly in that it placed Hubble’s research within the context of the evolution in astronomy in the 20th century.

"Career Opportunities." *STScI*, 2022,

www.stsci.edu/.

I used this photo on my board to give a visual representation of how modern astronomers work. This source helped me better understand the collaboration achieved by astronomers today.

"Cosmic Journey: A History of Scientific Cosmology." *American Institute of Physics Center for History of Physics,* www.history.aip.org/exhibits/cosmology/index.htm.

This online exhibit was used for background information and photos on my project board. This source was significant to my research because it relates each technological innovation with corresponding new ideas about the universe while providing detailed information and helpful links to other sources.

Gainor, Christopher. *Not Yet Imagined: A Study of Hubble Space Telescope Operations*. NASA, 6 Jan. 2021.

www.nasa.gov/connect/ebooks/not-yet-imagined.html

I used this source extensively both for information and quotes for my project board. This source is important because it is one of the only historical studies of Hubble created using NASA's own archives and personnel, making it very historically reliable. In addition, though it bears the NASA logo, it was written by an independent historian, reducing the risk of bias in the book.

Garner, Rob. "Hubble Database Guides Telescopes on the Ground." *NASA,* 25 Apr. 2018, www.nasa.gov/feature/goddard/hubble-database-guides-telescopes-on-the-ground/.

I used this source as background for Hubble's contributions. This source helped me understand Hubble's impact on the space program overall.

Garner, Rob. “Hubble’s Mirror Flaw.” *NASA,* 25 Nov. 2019, www.nasa.gov/content/hubbles-mirror-flaw.

This article was used to create my paragraph discussing Hubble’s launch on my project board. This source helped me better understand the function of Hubble’s mirror and why its failure was such a setback.

Heath, Darrell. “The Hubble Space Telescope: 25 Years on the Cosmic Frontier.” *University of Arkansas -Little Rock*, 29 April, 2015, www.ualr.edu/tv/2015/04/29/the-hubble-space-telescope-25-years-on-the-cosmic-frontier/.

I used this article as background on the Hubble’s telescope’s history as a whole. This source helped me better understand Hubble’s contributions to astronomy, as it discusses several major advances.

Hendry, Shealynn. “Amateur Telescope-Making: Popular Astronomy and the Great Depression.” *The Galactic Gazette,* Wolbach Library, 24 Aug. 2022, www.wolba.ch/gazette/amateur-telescope-making-popular-astronomy-and-the-great-depression/.

This article was used to further my understanding of the history of amateur astronomy, which allowed me to measure Hubble’s impact in the field. This article was extremely helpful to me because it was one of very few sources I found that discuss developments in amateur astronomy in the early 1900s.

*Highlights of Hubble's Exploration of the Universe.* NASA.

This short book was provided to me by Deputy Director Jeletic at the Goddard Space Flight Center, and I used it to gain background knowledge on Hubble's scientific discoveries. This book was extremely helpful in helping me understand the complex processes surrounding ultraviolet imaging and spectroscopy, two subjects Hubble is famous for studying. This book usually comes in the form of an informational pamphlet given to guests at Goddard Space Flight Center, and thus has no official publisher or publishing date.

"The Hubble Achievement." *The New York Times,* 3 May 2002, p. A22.

This newspaper article was important to my research because it highlights the ongoing scientific and cultural benefits of the Hubble Space Telescope. I quoted this source on my project board to highlight a unique press perspective on Hubble's importance.

*Hubble: An Overview of the Space Telescope*. NASA's Goddard Space Flight Center, www.nasa.gov/feature/hubble-an-overview-of-the-space-telescope.

This book is used on my project board and media for images and quotes. This source is important because, in addition to providing a collection of high-quality photos for my board, it gives insight into Hubble's construction and the impact of its mirror flaw. This book usually comes in the form of an informational pamphlet given to guests at Goddard Space Flight Center, and thus has no official publisher or publishing date.

"Hubble - 15 Years of Discovery." *European Space Agency, YouTube,* uploaded by HubbleWebbESA, 15 Apr. 2015, www.youtu.be/XeZ3APhUT2Q.

This documentary was used in my media as well as for quotes and context on my project board. There are several ways in which this source impacted my research, the most valuable being the discussion of international collaboration on Hubble from the point of view of European astronomers.

"Hubble's Amazing Universe." *BBC, YouTube,* uploaded by Universe, 10 May 2014 www.youtu.be/_856-7dY0z4.

This documentary was used in my project to better understand the impacts of some of Hubble's scientific breakthroughs. This source was important to my research because it shares the story of Hubble through interviews with several prominent scientists and astronauts who worked on the project.

"Hubble's Cosmic Journey." *National Geographic,* Disney Plus, 2015.

This documentary by National Geographic served as an introduction to Hubble's complex history. In addition, I used the source for quotes on my project board. This source helped me better understand the political climate surrounding Hubble.

Jones, Trevor. "Equatorial Mounts." *AstroBackyard*, 2022, www.astrobackyard.com/equatorial-telescope-mount/.

I used this photo on my board in my "Impact on Astronomy" section. This source helped me better understand how amateur astronomers have benefitted from CCD cameras.

Julio, Michael. *Technological Revolution in Astronomy.* 2015. City University of New York, master's dissertation,
www.academicworks.cuny.edu/cgi/viewcontent.cgi?article=1578&context=gc_etds.
I used this source for background and for quotes on my board. This source was important because it related the technological achievements of Hubble to other telescopes.

"JWST in Space." *ESA Hubble*, 2019,
www.esahubble.org/images/jwst_in_space-cc/.
I used this photo in my Significance in History section to give an example of future projects. This source helped me better understand the impact Hubble had on the future of the space program.

Kessler, Elizabeth A. *Picturing the Cosmos: Hubble Space Telescope Images and the Astronomical Sublime.* University of Minnesota Press, 2012.
I used this source to provide context on the development of CCD cameras. This source helped me better understand Hubble's impact on popular culture.

Koren, Marina. "Our Millennial Space Telescope Hasn't Burned Out Yet" *The Atlantic,* 25 Feb. 2022,
www.theatlantic.com/science/archive/2022/02/hubble-space-telescope-age/622877/
This article was used to help build my argument for Hubble's significance in history. This source helped me understand Hubble's unique scientific capabilities and why the telescope is still needed today.

LaMarco, Kelly. “Telescopes: Our Eyes On The Universe.” *Exploratorium: Origins,* www.exploratorium.edu/origins/hubble/tools/before.html

I used this source to expand my knowledge on the history of telescopes before Hubble. This source is important to my research because it discusses every major innovation in telescope technology starting with the very first telescope designed in 1610, and provided context for me to include in my exhibit.

Lattis, James. “Observations: The World’s First Space Telescope.” *Scientific American,* 7 Dec. 2018, www.blogs.scientificamerican.com/observations/the-worlds-first-space-telescope/

I used this source mainly to understand NASA’s work in developing space observatories. This source was vitally important to the context section of my project board because it helped me understand the scientific motivations that led to the development of Hubble.

“Locations of the EHT Telescopes.” *European Southern Observatory*, 2019, www.eso.org/public/images/eso1907p/.

I used his photo in my “Significance in History” section. This source helped me better understand modern examples of astronomer collaboration.

Meyer, Eileen. “Old Data, New Science.” *Richmond Times-Dispatch,* 2 Jun. 2018, p.C2.

This newspaper article was used in my “Impacts on Astronomy” section to highlight the long-term impact of the Hubble Archive. This source is important to my research because it reflects the claims made in my argument while giving the unique perspective of an amatuer astronomer.

*NASAfacts: Hubble Space Telescope*. Goddard Space Flight Center, NASA, 2020.

This collection of Hubble mission documentation articles was provided to me by Deputy Director Jeletic at the Goddard Space Flight Center, and I used these documents for background information, as well as for images and quotes on my project board. This source was useful in my research because it provided technical details on specific Hubble equipment that I used in my "Frontiers in Technology" section of my board.

National Research Council. *Assessment of Options for Extending the Life of The Hubble Space Telescope: Final Report.* Washington, DC: The National Academies Press, 2005. www.//doi.org/10.17226/11169.

This source provided background on Hubble's servicing missions. This source helped me better understand how Hubble has benefitted researchers.

"Nasa's Incredible Discovery Machine." *YouTube*, uploaded by NASA Goddard, 2020, www.youtube.com/watch?v=Lo43Gq_Xe1M.

I used this video for background information on Hubble. This source helped me better understand the risks involved with launching Hubble and the benefits of its discoveries.

Panagia, N. "From the Hubble Telescope to the James WEBB Space Telescope." *Space Telescope Science Institute,* 2005, www.adsabs.harvard.edu/pdf/2005foap.conf..685P.

I used this document to understand the connection between Hubble and the new James Webb Telescope. This source was important because it detailed the servicing missions completed for Hubble as well as how the telescope will eventually fail.

Reddy, Francis. “NASA’s First Stellar Observatory, OAO 2, Turns 50.” *NASA,* 11 Dec. 2018, www.nasa.gov/feature/goddard/2018/nasa-s-first-stellar-observatory-oao-2-turns-50/

This source provided context on the early history of NASA observatories and their importance. This source is important because it not only contains helpful details on the development of OAO 2, but because it included several useful photos and videos as well.

“Seeing with Hubble-Vision.” *European Space Agency,* Bulletin 142, May 2010, www.sci.esa.int/documents/34247/36339/1567258233965-Hubble_article_Bulletin_142.pdf.

This article provided information on Hubble’s international impact through the testimonies of past STScI employees. This source was helpful in providing biographical information about one of my interviewees Dr. Helmut Jenkner, while also serving as a great primary source collection of quotes.

Smith, Robert. “The Telescope.” *Encyclopedia of the History of Science,* Carnegie Mellon University, www.ethos.lps.library.cmu.edu/article/id/480/.

This article was used for quotes and photos on my project board. This source was important to my research because it provided in-depth information on the innovation of telescopes, which enabled me to put the topic of my project into its historical context.

Strolger, Lou. “Doling Out Hubble TIme with Dual-Anonymous Evaluation.” *Physics Today*, 1 Mar 2019, www.physicstoday.scitation.org/do/10.1063/pt.6.3.20190301a/full/.

This journal article was used in my impacts section to give an example of one way Hubble has impacted society. This source is important to my research because it demonstrates that Hubble has had a long-term impact on the future of astronomy.

Villard, Ray. “The Hubble Space Telescope Observing Program.” *Space Telescope Science Institute,* NASA, 17 Sept. 2008, www.nasa.gov/mission_pages/hubble/servicing/series/How_science_is_done.html.

I used this source for quotes on my project board. This source was very helpful in that it detailed the process for applying for observing time on the telescope and highlights the benefits of the space telescope as compared to a ground-based system.

Vogel, Tracy. “Edwin Hubble.” *NASA,* 12 May 2021, www.nasa.gov/content/about-story-edwin-hubble.

I used this source to provide context on the Hubble telescope's namesake. This article helped me better understand Hubble’s incredible contributions to astronomy as well as the reasons the space telescope was needed.

Wells, Sarah. “Searching Hubble’s Archive for Hidden Gems” *Mercury Magazine,* vol. 49, no. 2, *Astronomical Society of the Pacific,* 2020, www.astrosociety.org/news-publications/mercury-online/mercury-online.html/article/2020/09/28/searching-hubble-s-archive-for-hidden-gems

This source was used in my research over Hubble’s impact on amateur astronomy. It is crucially important to my research because it details Hubble’s interaction with various types of astronomers and also pointed me to several resources including the Hubble Legacy Archive.

Zimmerman, Robert. *The Universe in a Mirror,* Princeton University Press, 14 Mar. 2010.

This book was crucial to my research because it helped me shape my initial research by giving an in-depth overview of Hubble as a whole. This source was used for background information and for quotes on my exhibit board.