Hiding the Hand, Framing the Cosmos: Obfuscation, Immediacy and the Dual Authority of Hubble Images

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Abstract

This thesis investigates how images produced by the Hubble Space Telescope (HST, also known as Hubble) gain both scientific credibility and cultural authority through the strategic obfuscation of their mediated nature. Although these images appear to offer an immediate and objective view of the cosmos, they are, in fact, the outcome of extensive technical and interpretive labour. Drawing on key scholars from Science and Technology Studies (STS), visual epistemology, and theories of photographic realism, the thesis critically analyses the data pipeline, visual aesthetics, public outreach practices and institutional branding strategies behind these images. It reveals how Hubble images' *illusion of immediacy* is carefully constructed to inspire trust, awe, institutional legitimacy, and attract funding.

Keywords: Hubble Space Telescope, Visual Epistemology, Authority, Photographic Realism, Illusion of Immediacy, Visual Culture, Scientific Imagery, Strategic Obfuscation

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Introduction

"Hubble Peers Into the Heart of a Dying Star" (Espinoza, 1997a).

"Hubble Captures the Heart of the Orion Nebula" (Espinoza, 1997b).

"Hubble: Eye in the Sky" (NASA Goddard, 2020).

"Through the Eyes of Hubble" (Naeye, 1998).

"Hubble: A New Window to the Universe" (Fischer & Duerbeck, 1996).

While these might seem like lines from a science fiction novel, they are headlines that have been taken from NASA press releases and popular coverage of the Hubble Space Telescope—Hubble, for short. Over the last decades, Hubble has become one of the most popular astronomical instruments ever. Hubble has evolved into a cultural icon, a political and ideological symbol, and "our eye in the sky". And, perhaps more significantly, Hubble has become the image-making machine that reshaped how the cosmos is perceived.

In May 2009, newspapers around the world marked the final servicing mission to Hubble. Space Shuttle Atlantis was preparing to extend the telescope's life by several years. This mission, called STS-125, was seen by many as both technically risky and emotionally loaded (Mars & Uri, 2024). Reflections on Hubble and what it had to offer were plenty during this period. AP Science writer Seth Borenstein (2009) noted in a newspaper article:

> *"Hubble doesn't just illustrate the story of the universe—it has its own story, complete with failure and redemption."*

Borenstein (2009) continued:

> "*Using the power of pictures, the Hubble Space Telescope has snapped away at the mystery of the universe. […] For 19 years, Hubble has shown the epic violence of crashing galaxies, spied on the birth and death of stars, taught cosmic lessons, and even provided cosmic relief."* (Borenstein, 2009)

This language reveals much about the prevailing cultural attachment to Hubble's images—not merely as scientific instruments but as sources of meaning, belief, and beauty. I will let Figures A-D speak for themselves.

Figure A

Tapestry of Blazing Starbirth

Credit: Original image by ESA/Hubble, cropped by the author.

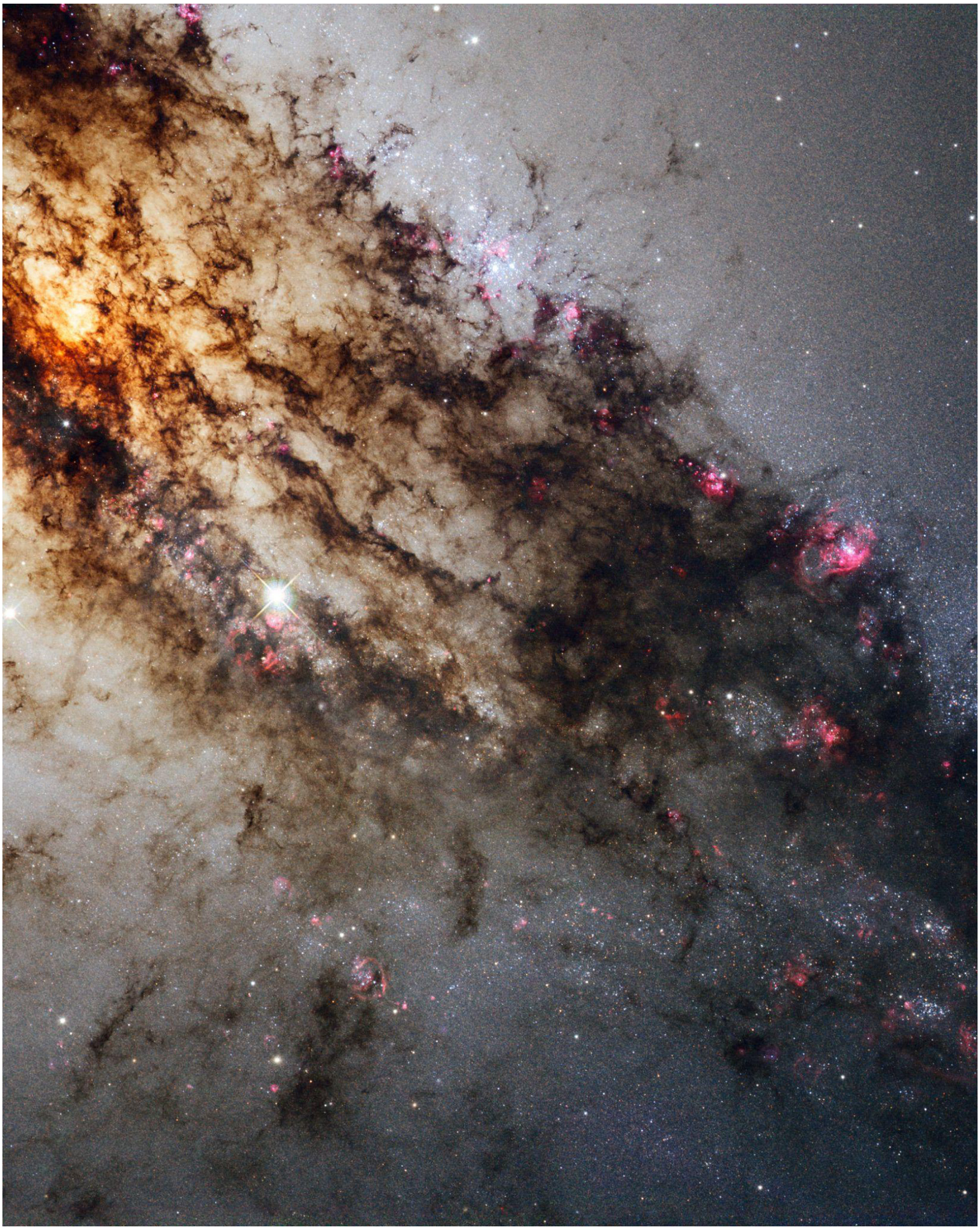
Figure B

The Magnificent Starburst Galaxy Messier 82

Credits: Original by NASA, ESA, and the Hubble Heritage Team (STScI/AURA), cropped by the author. Acknowledgement: J. Gallagher (University of Wisconsin), M. Mountain (STScI) and P. Puxley (NSF).

Figure C

Spectacular Hubble view of Centaurus A



Credits: Original by NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration, cropped by the author. Acknowledgement: R. O’Connell (University of Virginia) and the WFC3 Scientific Oversight Committee

Figure D

New View of the Pillars of Creation — Visible

Credits: Original by NASA, ESA/Hubble, and the Hubble Heritage Team, cropped by the author.

Nowhere is this beauty and mystique more apparent than in one of Hubble's most iconic images: the so-called "Pillars of Creation", seen in Figure D. Borenstein (2009) writes:

> "*Believers see the hand of God, nonbelievers see astronomy in action, and artists discover galaxies worthy of galleries."* (Borenstein, 2009)

The Pillars of Creation image depicts towering columns of interstellar gas and dust. It was first captured in 1995 and later revisited in 2014. The dramatic composition and vibrant colours quickly gained the image the status of scientific success and aesthetic masterpiece. Throughout the years the Pillars of Creation image has appeared in museums (Smithsonian Institution, 2020), documentaries (Riley, 2015), films (Abela & Villiers, 2018), and even on clothing and coffee mugs. For many, Hubble images enable an experience of space as if you were really there (Smith et al., 2015)—in front of that swirling, colourful, distant galaxy or glowing nebula—as if looking through a direct, unmediated window. And yet, these images are anything but direct.

Hubble images are the result of extensive human and technological labour. From filter choices to the layering of different wavelength data to the assignment of artificial colours and compositional framing, the image has depended on interpretation and mediation in its construction. Nevertheless, this constructedness is invisible in the final image. What appears to be "as-is" is in reality "as-made".

This thesis argues that Hubble images gain epistemic and cultural authority because their constructedness is strategically obfuscated. Their credibility as scientific evidence and their resonance as cultural artefacts depend on a carefully maintained *illusion of immediacy* and objectivity. Instead of reducing the illusion's power, the obfuscation strengthens it. This invites people to trust, admire, and even revere the images.

The thesis is rooted in two related theoretical traditions: Science and Technology Studies (STS) and visual epistemology. Drawing on Bruno Latour's concept of black-boxing (1987), I show how the complex technical and scientific processes behind Hubble images become naturally obfuscated once their results are stabilised and accepted. The work of Daston and Galison (2007) on mechanical objectivity, W.J.T. Mitchell's (1984; 1993) critical visual culture studies, and Ihde's (1998) philosophy of scientific instruments offer further foundational tools for this thesis' examination into how images both reflect and shape scientific authority.

Another important factor in the public perception and reception of Hubble images is their aesthetic presentation. Scholars such as Kessler (2012), Greenberg (2004), and Snider (2011) have shown that scientific images rely on artistic conventions, compositional strategies, and colour choices that draw from the traditions of photographic realism. Photographic realism helps Hubble images to extend beyond the scientific communities in which they are conceived by strategically obfuscating their constructedness. This natural obfuscation is not only technical but also epistemic, tied to institutional legitimacy, branding, and visual strategies. The strategic obfuscation through photographic realism has enabled the images to pass into museums, popular media, and everyday life, where they have become symbols of wonder, discovery, and even national pride.

Even though the visual construction of scientific imagery has gained much more traction over the last decades, the authority of images gained through the obfuscation of their constructedness—an authority that extends both into the realms of science and culture—remains underexplored. As a result, this thesis contributes to this growing body of research that challenges the naïve realism of scientific imagery by highlighting the constructed nature of representation and the accompanying politics of visibility.

This thesis unfolds the argument across three chapters:

Chapter 1 explores the technical, scientific and interpretive processes behind the construction of Hubble images. The chapter demonstrates that every stage of the process—from photon to pixel—is embedded in human and technological mediation.

Chapter 2 turns to the visual strategies that shape public perception. It shows how photographic realism and the aesthetics of objectivity work together to obfuscate the image's constructed nature. It illustrates how this process is similar but also different from Latour's notion of black-boxing. This chapter explains how strategic obfuscation contributes to the images’ authority by maintaining and reinforcing the *illusion of immediacy* that makes Hubble’s cosmos feel as cosmic reality.

Chapter 3 zooms out to the institutional level, analysing how NASA and STScI manage the presentation and dissemination of Hubble images. It examines the narrative framing, branding, and strategic obfuscation of constructedness in public outreach to maintain public trust, score political legitimacy, and raise funding.

Together, these chapters demonstrate that Hubble images do not passively reflect the cosmos—they actively participate in its construction. By hiding the hand and framing the cosmos, Hubble images gain power. Understanding this dynamic aids visual epistemology, but it also allows us to remain critical and transparent about the role of scientific imagery in shaping our collective sense of reality.

Constructing the Hubble Image

It is common to be amazed by a Hubble image while thinking little about what goes into creating it. These images have a way of pulling you into a breathtaking, *sublime* experience[1].

Hubble's images enable an experience of space as if you were really there—in front of that swirling, colourful, distant galaxy or glowing nebula (see Figure 1). In doing so, these images appear to simply show *what is out there* in deep space. This sense of *visual immediacy*, however, is deceptive. What appears to be "as-is" is in reality "as-made". Making an image like this is no easy feat. In fact, it is incredibly skilful work, both in terms of engineering precision and artistic mastery, from data calibration to colour composition.

This does not mean that what you are looking at is fake. All of Hubble's images are based on real data, and in that sense they are as real as any other visual representation. Yet, despite the images' photographic realism, which, as noted by Smith et al. (2015, p. 89), gives rise to this sense of *visual immediacy*[2], ultimately the Hubble cosmos is a human and technological cosmos.

[1] More on this in chapter 2.

[2] In philosophy and art theory, visual immediacy is when the viewer is so absorbed by an image or scene that the medium (such as a painting or photograph) seems to "disappear," and the viewer feels present within the experience itself. For example, a hyper-realistic painting may create a sense of immediacy by making the viewer feel as if they are looking at the real object rather than a painted representation. Visual immediacy also implies that information or meaning is conveyed instantly and intuitively, without the need for conscious analysis or interpretation. A good visual, such as a map, allows the viewer to immediately grasp relationships, patterns, or spatial arrangements at a glance. In cognitive terms, immediacy is contrasted with mediated experiences, which require conscious processing or inference. An immediate visual experience feels direct and effortless, while a mediated one involves awareness of the steps or logic behind the perception.

Figure 1

Hubble view of Messier 106

Note. This image of Messier 106 exemplifies the visually immersive qualities that are typical of Hubble imagery. Credit: ESA/Hubble.

This thesis begins from the tension between what Hubble images *appear* to show and what they *actually* show. As I will demonstrate further in Chapter 2, the perception of *visual immediacy* through a photographic realism draws viewers in while simultaneously keeping the complex interpretive labour that makes the images possible hidden. In other words, the mediums—the telescope, the instruments, the software, the human decisions, and the labour—disappear in the image. As the medium fades, it reinforces the idea that the images are immediate views rather than constructed visual artefacts.

This first chapter draws on insights from visual epistemology and science and technology studies (STS) to render the hidden work behind Hubble's images visible and to bring the medium back into the picture. I will be doing this from the ground up. In practice, this means examining how layers of interpretation, calibration, and visualisation practices shape what viewers perceive and what they come to believe about the cosmos as a result. I aim to peel back this "curtain" of *visual immediacy* to reveal the layers of human and technological mediation behind the image, to encourage a deeper understanding of how Hubble's images not only *represent* but also *construct* cosmic reality.

Scientific and Technical Mediation

Light is not a Given

Light is a natural place to start when writing about images—particularly astronomical images. After all, light is what makes seeing and astronomical observation possible. Light not only reveals the universe; it is also the raw material that Hubble collects and that astronomers transform into images.

Seeing with Hubble is not raw "seeing"—but rather "seeing through a chain of translations". Light does not arrive at Earth waiting to be turned into an image; it must be actively detected, interpreted and reshaped before it can become one. Even the *concept* of light as we understand it is entirely dependent on this process of detection, measurement and representation.

Perception—as an embodied and active practice shaped by mediation and translation—is not unique to Hubble. This view resonated with phenomenologists like Merleau-Ponty, who emphasised embodied perception (Merleau-Ponty, 1978); Heidegger, who stressed the tool-mediated nature of world-disclosure (Heidegger, 1977); and STS scholars like Latour, who argued for the interpretative work of science (Latour, 1987). Semioticians such as Barthes also recognised how meaning is constructed, not just received (Barthes, 1972). In that regard, Hubble's modern astronomical observations are not much different from historical traditions of astronomical observation that primarily involved a human observer, an advanced spyglass and a steady hand for sketching (Winkler & Van Helden, 1992; Daston & Galison, 2007).

However, unlike these historical traditions, Hubble's observations are digital through and through, undergoing most of their translations before the observation ever reaches a human eye. Yet, contrary to the appearance, human interpretation is just as important now as it was then. However, as this thesis will demonstrate, it is simply less visible today.

Scholars like Latour (1987) point out a paradox. As the translation process becomes increasingly invisible, images appear more and more objective and self-evident. The added layers of complex technological mediation hide the traces of human interpretation that become obvious after further scrutiny. This makes the images appear as though they result from some mechanical snapshot of reality. As if they provide an immediate access to the cosmos without having to worry about any "subjective" influences that tainted historical astronomical image-making (Winkler & Van Helden, 1992; Daston & Galison, 2007)

Drawing focus to instrumentation and interpretation, rather than raw seeing, aligns closely with Karen Barad's attitude towards measurement (Barad, 2007). Instead of viewing the Hubble Space Telescope's observations as passive recordings of reality, Barad would describe them as *intra-actions*; dynamic entanglements among the observer, the instrument, and the observed. This means that it is the relationship between these elements that enables the observation, rather than separate entities interacting. Therefore, what we observe is not simply discovered but is actively created through these intra-actions.

This perspective not only prevents a separation of the human element from the observation process, but it also highlights how what is observed—in this case, light—does not exist as a stable, self-evident entity. Instead, it is a phenomenon that arises from this specific *intra-action*. In other words, the way we understand light is shaped through its dynamic entanglement with particular instruments and interpretive practices.

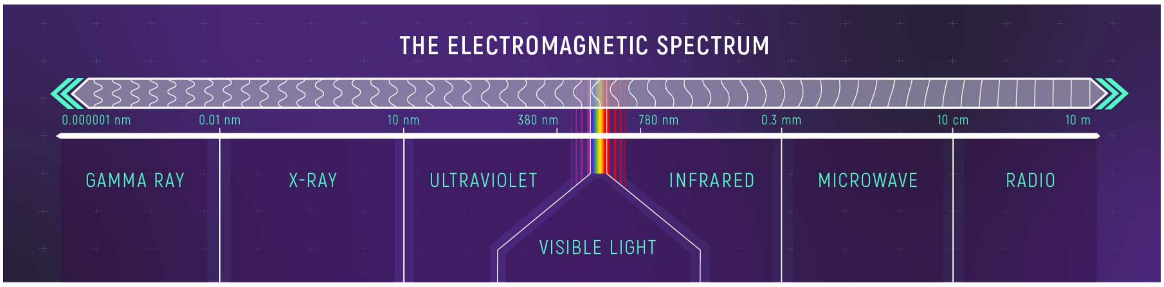
Light, then, is not simply a physical phenomenon but something that becomes interpretable through measurement. While a deeper exploration of this point is outside of the scope of the thesis, this understanding helps to see how Hubble's astronomical image-making process is interpretative through and through. And with this theoretical framing in place, we can now turn to a physical understanding of “light” and how it is made interpretable through image-making.

Rendering the Invisible Visible

"Light" commonly refers to the narrow band of the electromagnetic spectrum[3] (see Figure 2) that is visible to the human eye (STScI, 2022b). Hubble observes primarily in this visible range, with some extension into the near-infrared (STScI, 2022b). This range is illustrated in Figure 3. All objects—not just cosmic ones—emit electromagnetic radiation in some form, whether visible light, infrared radiation (heat), or other wavelengths. Even everyday objects such as human bodies emit radiation, although at wavelengths beyond what we can see unaided or simply too faint to see.

Figure 2

The Electromagnetic Spectrum.

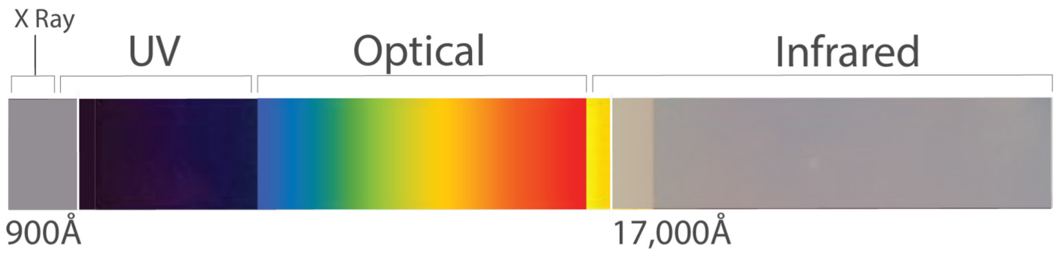


Note. This figure illustrates the range of electromagnetic waves, organised by wavelength from gamma rays to radio waves. Credits: NASA, ESA, L. Hustak (STScI) - (STScI, 2022b).

[3] Electromagnetic radiation, as understood in modern quantum mechanics, is the flow of photons through space. For a more thorough explanation and understanding of electromagnetic radiation, please see Philips et al. (2025)

Figure 3

Hubble Space Telescope's wavelength coverage



Note. This figure shows the range of wavelengths observable by Hubble, spanning from the ultraviolet (UV), through the optical (visible) range, and into the near-infrared. The spectrum begins around 900 Å (angstroms) and extends to approximately 17,000 Å. Credit: (STScI, 2018).

Light exhibits a dual nature: it behaves as a wave and a particle, depending on how it is measured or observed (STScI, 2022b). This *wave-particle duality* is a fundamental concept in quantum mechanics and is important for astronomical image-making, as they are at the foundation of our understanding of how photons behave in astronomical instruments. Experiments like the double-slit experiment (Young, 1804) show that light behaves like a wave, while other experiments, such as the photoelectric effect (Einstein, 1905), show that light transports energy in discrete packages called photons.

To understand how Hubble images become both scientifically valuable and visually persuasive, we must examine how light is transformed into interpretable images through tools, filters, and interpretive decisions. As I will demonstrate, these processes are anything but neutral—they are guided by human judgement and shaped by technological design, even if their traces are erased in the final image.

A typical way to measure light is through its wavelength[4]—the distance between two consecutive crests. Different wavelengths correspond to different parts of the

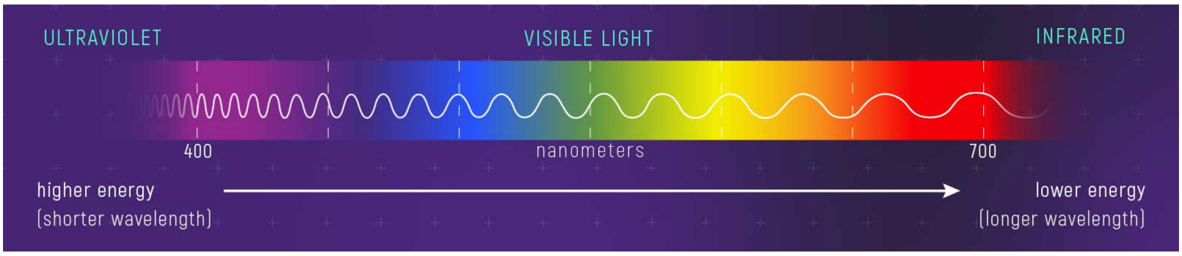
[4] The following explanation simplifies complex physical phenomena for accessibility. For more detailed accounts, see Carroll and Ostlie (2017) or Brown & Weidner (2025).

electromagnetic spectrum. Infrared radiation, for example, spans wavelengths from about 780 nanometres to 0.3 millimetres, meaning that lightwaves that span anywhere between these distances are labelled as infrared. Visible light, the range of wavelengths primarily emitted by our Sun, spans wavelengths from around 400 nanometers to about 700 nanometres. The full range of possible wavelengths, from the shortest gamma rays to the longest radio waves, is collectively known as the electromagnetic spectrum.

The wavelength of light is a rich source of information. It can reveal details about the object—or objects—that the light has interacted with, including their composition, temperature, and motion (STScI, 2022a). These insights are possible because light and matter interact in predictable ways. Matter can absorb, emit, transmit, reflect, or refract light. Knowing the wavelength allows astronomers to calculate how much energy a photon carries (STScI, 2022a). Shorter wavelengths, such as ultraviolet (UV) or gamma radiation, carry more energy than longer wavelengths, such as infrared (IR) or radio waves (Figure 4).

Figure 4

Relationship between wavelength, energy, and the visible spectrum

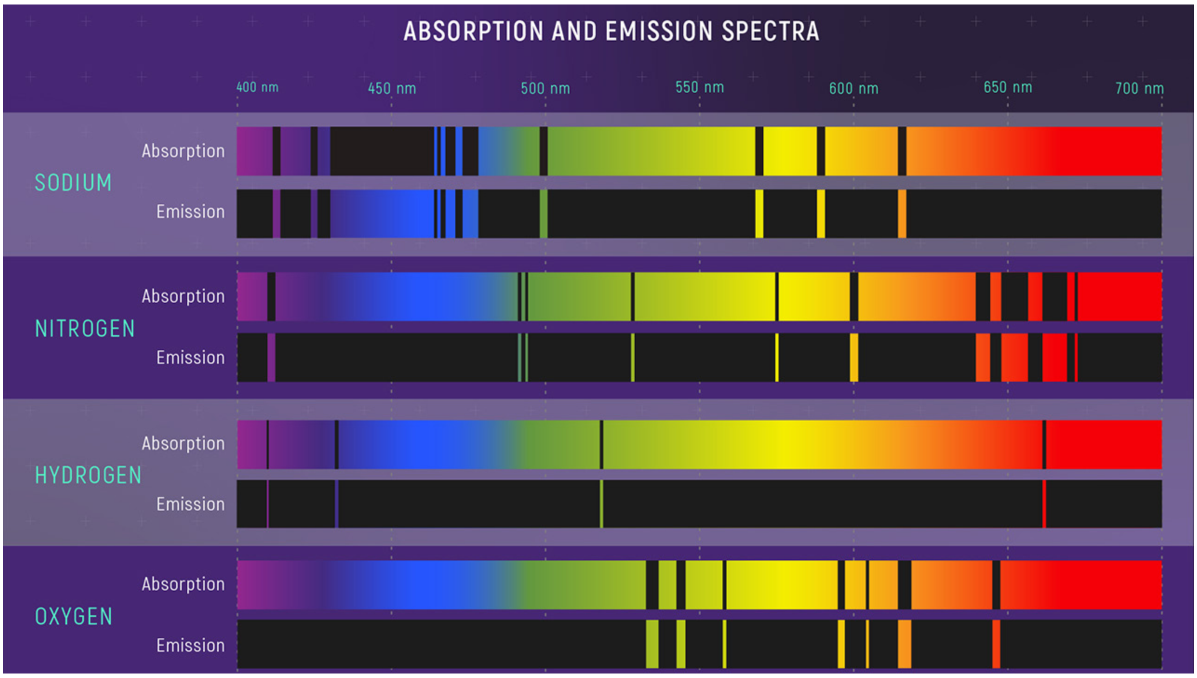


Note. This figure illustrates the visible light range (approximately 400–700 nanometers), showing its position between ultraviolet and infrared radiation. Shorter wavelengths (toward the ultraviolet end) correspond to higher energy, while longer wavelengths (toward the infrared end) correspond to lower energy. Credits: NASA, ESA, L. Hustak (STScI) (STScI, 2022b).

All cosmic objects leave 'fingerprints', called *spectral patterns,* on the light they emit or interact with, as illustrated in Figure 5. These spectral patterns arise from each object's unique atomic and molecular makeup, which determines *how* it interacts with different wavelengths (STScI, 2022c).

Figure 5

Absorption and emission spectra of selected elements

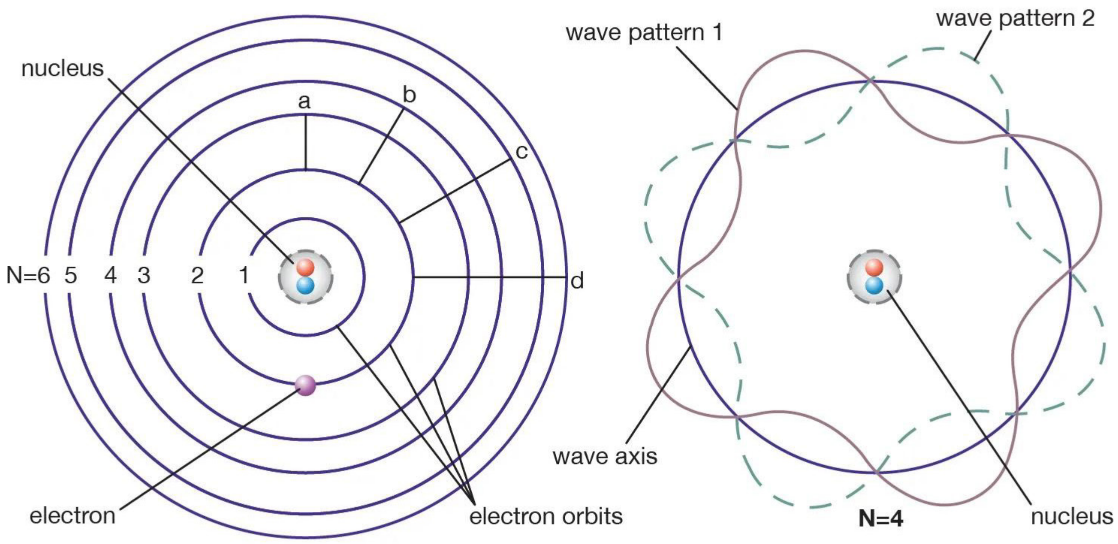


Note. This figure compares the absorption (top row) and emission (bottom row) spectra of sodium, nitrogen, hydrogen, and oxygen across the visible light range (400–700 nm). Dark lines in absorption spectra represent wavelengths absorbed by each element, while bright lines in emission spectra represent wavelengths emitted. Credits: NASA, ESA, L. Hustak (STScI).

Atoms—the building blocks of matter—consist of a core, called the nucleus, made up of subatomic particles called protons and neutrons. This nucleus has a shell of electrons, another subatomic particle, which orbit the nucleus at fixed energy levels (Brown & Weidner, 2025); almost like discrete floors in a skyscraper (see Figure 6). Electrons can shift between these levels, but only in discrete jumps. When an electron gains sufficient energy, it can go up a level through a process called excitation (Carroll & Ostlie, 2017, p. 142; NASA, 2013). Because the excited state is unstable, the electron wants to return to its original lower energy level (the ground state) because systems in nature tend to move toward the lowest possible energy state available to them (NASA, 2013). Through a process called emission, the electron can move to this lower level by releasing the difference in energy as a *photon* (NASA, 2013). The photon's energy—and its *wavelength*—therefore relate precisely to the difference in energy between the two levels the electron jumped between.

Figure 6

The Bohr model of the atom and electron wave behaviour

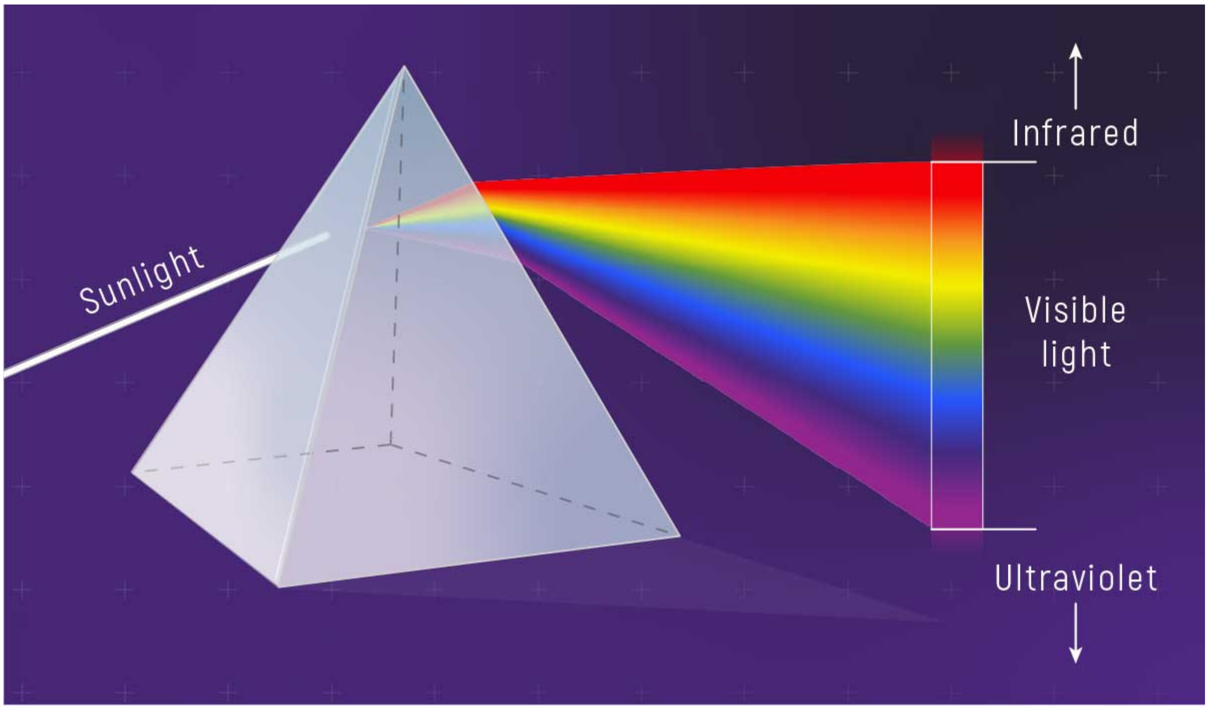


Note. The left panel shows the Bohr model with quantised electron orbits labelled by principal quantum number N=1 to N=6. The right panel illustrates electron wave behaviour, where stable electron orbits correspond to standing wave patterns around the nucleus. Only wave patterns that constructively interfere (e.g., whole-number wavelengths) form stable orbits. Credit: (Encyclopædia Britannica, 2014).

The number of protons in an atom's nucleus determines the identity of the element that is a part of (NASA, 2021). The positively charged protons in the nucleus create an electromagnetic force that attracts the negatively charged electrons. The strength of this attraction dictates the arrangement and energy levels that the electrons can occupy. Each element, therefore, has a unique electron configuration due to its unique number of protons and nuclear charge. This unique electron configuration is responsible for the distinct spectral patterns (absorption and emission spectra) observed for each element (STScI, 2022a). As seen in Figure 7, these patterns can be "read" by separating them into individual wavelengths. One way this can be done is by using a prism – a process called spectroscopy – and then analysing each wavelength individually.

Figure 7

Dispersion of sunlight through a prism

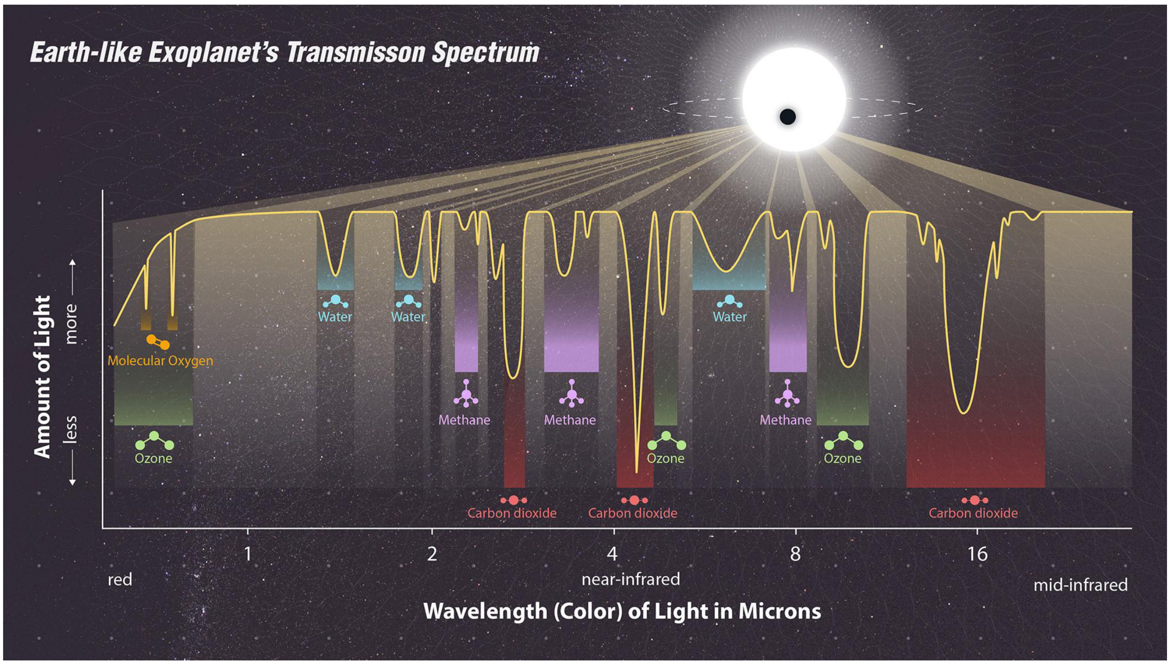


Note. This figure illustrates how sunlight, composed of many wavelengths, is separated into its component colours when passed through a prism through a process called spectroscopy. Credits: NASA, ESA, L. Hustak (STScI) (STScI, 2022b).

By separating light into its component wavelengths, spectroscopy allows astronomers to precisely determine an object's chemical composition, as can be seen in Figure 8 (STScI, 2022a). However, its analytical power extends further: energy distribution across the spectrum also reveals an object's temperature and density (STScI, 2022a). Higher temperatures correspond to shorter wavelengths, while lower temperatures correspond to longer wavelengths; this is known as Wien's displacement law (NASA, 2018). At the same time, the width of spectral lines offers clues about an object's density. In denser environments, increased pressure (pressure broadening) disturbs the energy levels of atoms, causing the spectral lines to spread out (Carroll & Ostlie, 2017; NASA, 2018). While this is a complex topic, its consequences are clearly illustrated in Figure 9.

Figure 8

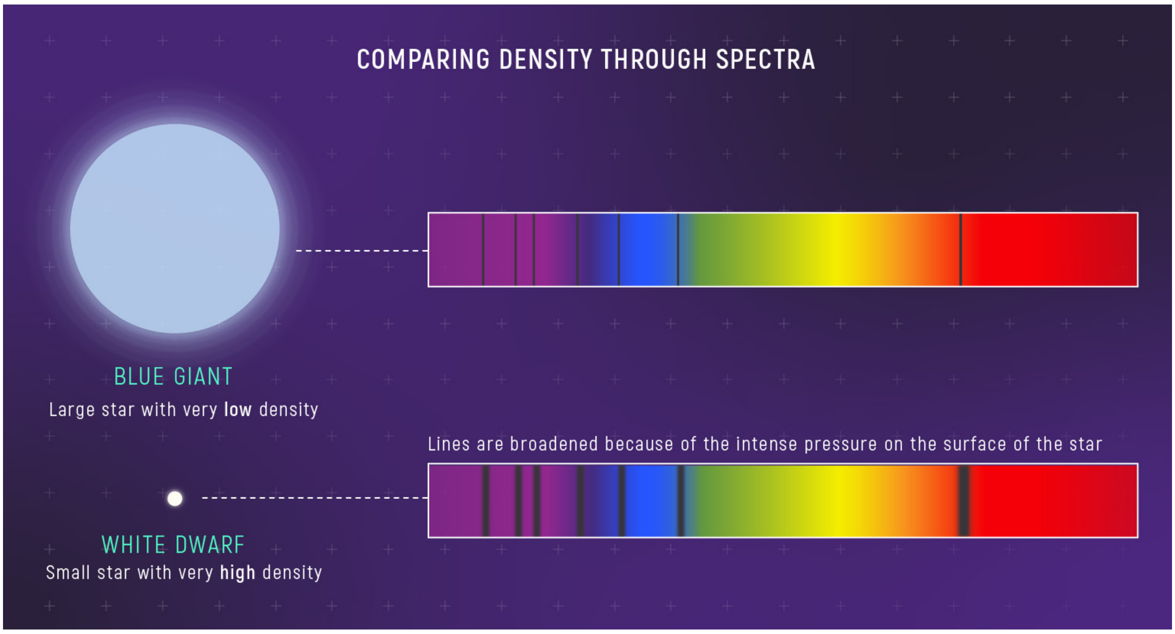
Transmission spectrum of an Earth-like exoplanet



Note. This figure displays the absorption features of various atmospheric gases—such as molecular oxygen, ozone, water vapour, methane, and carbon dioxide—detected in the light passing through the atmosphere of a transiting exoplanet. The x-axis shows the wavelength of light in microns (from near-infrared to mid-infrared), while the y-axis indicates the amount of starlight absorbed. The presence and pattern of these absorption bands can be used to infer atmospheric composition. Credits: NASA, ESA, CSA, STScI, Joseph Olmsted (STScI)

Figure 9

Spectral line broadening as an indicator of stellar density



Note. This figure compares the spectra of a blue giant (large, low-density star) and a white dwarf (small, high-density star). The absorption lines in the spectrum of the white dwarf are noticeably broader due to the extreme surface pressure, in contrast to the narrower lines in the blue giant's spectrum. Spectral line broadening is a diagnostic tool for determining stellar density. Credit: NASA, ESA, and L. Hustak (STScI).

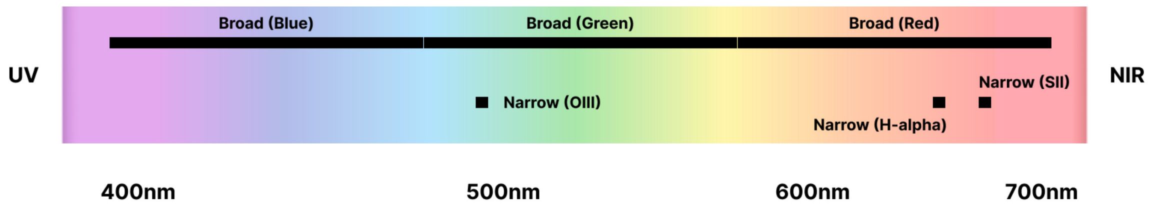
As we can see, spectroscopy is a fundamental method in astronomy, and Hubble conducts many of its observations using spectroscopic instruments. However, an important distinction must be made: spectroscopy does not produce visual images. This is why image-making is done using a different process called astronomical imaging. Astronomical imaging works somewhat differently from spectroscopy. Instead of spreading light across a full spectrum using a prism, astronomers apply physical filters to very sensitive cameras to isolate specific or broad ranges of wavelengths (Arcand et al., 2013, pp. 26-27; Cooperstein, 2014, p. 141; Rector et al., 2015, pp. 68-86; Gainor, 2020, p. 62). Rather than dispersing light into its component wavelengths, these filters selectively allow certain ranges to pass through. How wide that range is depends on the type of filter.

Broadband filters pass a wide range of wavelengths—sometimes up to 100 nanometres—and are typically used for general imaging. This includes tasks such as mapping the structure of galaxies or estimating the temperatures of stars. In some ways, broadband filters are analogous to how the human eye processes light[5].

Narrowband filters, on the other hand, pass only a small range of wavelengths, typically just 3 to 5 nanometres. Astronomers use these for more targeted studies, such as detecting and mapping the distribution of different chemical elements, like hydrogen, oxygen, or sulfur, within a region of space or a cosmic object. The difference in ranges between broadband and narrowband imaging can be seen in Figure 10.

Figure 10

Broadband and narrowband filters plotted on the visible light spectrum



Note. Self-made diagram explaining the difference between broadband and narrowband filters plotted on the visible light spectrum (from ultraviolet, UV, to near-infrared, NIR). The example shows three different broadband filters, in this case RGB (Red, Green, Blue), and

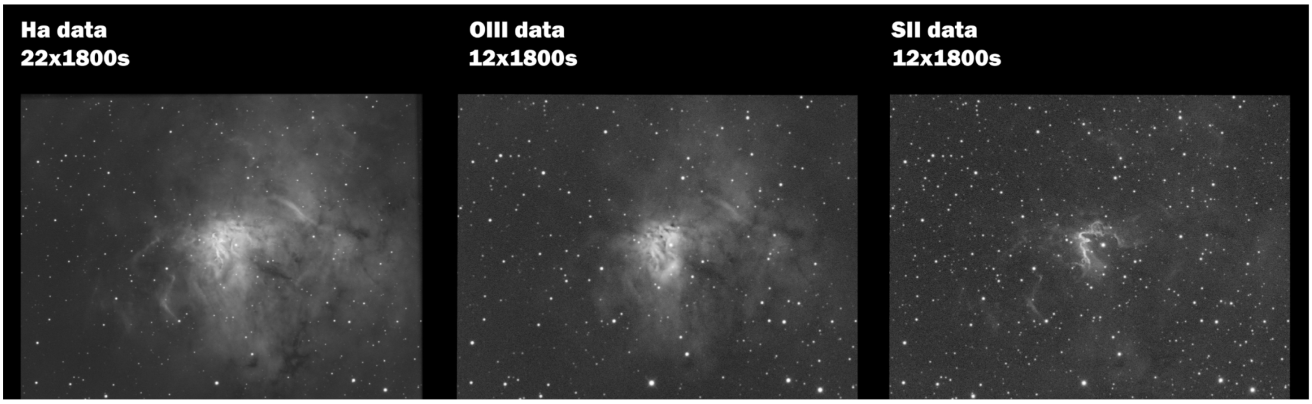
[5] The human network of the eye and the brain has its own unique way of collecting and processing light. Just like the Hubble, the human eye collects photons. The human eye is particularly sensitive to the visible light spectrum, which is only a small range of the electromagnetic spectrum. This visible light spectrum is a range of wavelengths most prominently emitted by our sun, which is likely why the eye evolved to be sensitive to this range of wavelengths. Light that enters the eye is focused through several layers and a lens onto the retina, a very sensitive thin layer of tissue at the back of the eye. The retina consists of photoreceptors called rods and cones. Rods are very sensitive to light, allowing them to function well in low-light condition, such as nighttime. They do not differentiate between wavelengths, which is why in dim lighting we often see things in shades of grey. Rods and cones allow our brains to process wavelengths as “color”.

three different narrowband filters, in this case Oxygen, Hydrogen and Sulphur. The width of the black bars shows the range of the respective filter, spanning a multitude of wavelengths across the spectrum. This shows how broadband filters pass a much wider range of wavelengths than narrowband filters.

Broadband and narrowband filters serve distinct purposes and produce fundamentally different images, both in terms of visual appearance and of the scientific data they represent (Rector et al., 2015, pp. 68-86). The selection of which kind of filter to use is a human process. The astronomer decides what kind of data to prioritise, which wavelengths to isolate, and which phenomena to target based on their own priorities and scientific goals (Pang, 1997; English, 2017). While none of these decisions can be identified in the final image, they have a profound influence on what it shows and also how it looks. They shape what becomes visible, what remains hidden or what is excluded from the frame. Figure 11 shows the distinct difference between what a camera captures based on the filter that is used. All three images show the same region of space, shot with different (in this case H-alpha, OIII and SII) narrowband filters. These three images correspond with the three narrowband filters plotted in Figure 10 above.

Figure 11

Effect of filter choice on nebular imaging



Note. This figure compares the visual structure of a nebula using three narrowband filters: H-alpha (Ha), doubly ionised oxygen (OIII), and singly ionised sulfur (SII). Each filter reveals different structural features based on the emission lines of specific elements. The images demonstrate how varying wavelength sensitivity enhances contrast and detail in astrophotography. Credit: (Narrowband Information, 2025)

While these filters themselves do not leave visible traces on the image, they certainly impact what is visible (Kessler, 2012, p. 145; Cooperstein, 2014). This emphasises that every Hubble image is not just some mechanical snapshot that shows space “as-is” but that decisions have had to be made as to how to capture it; decisions that structure what counts as observable, what is considered meaningful, and ultimately, what will be presented as a cosmic truth (Daston & Galison, 2007). This is the first indication that every Hubble image is embedded within a history of silent but deliberate decisions, an idea that will continuously develop throughout this thesis. As will become clear throughout this chapter, human labour is inscribed at every stage of the image-making process, stretching far beyond the choice of a filter.

Together, these technical processes demonstrate that what appears as *immediate* is, in fact, a mediated and interpretive construction.

How Hubble’s Design Shapes What Can Be Seen

While filter choices clearly influence what appears in Hubble images, a less obvious but equally important factor is how the telescope’s design shapes what is visible in the image.

To help visualise what I am about to demonstrate, it can be helpful to think of an astronomical image more as a sculpture than a photo on your smartphone. Try to think of the astronomer as the sculptor of an image, of light as the base material of the sculpture, such as clay or stone, and then finally of Hubble as the chisel. Using this analogy, clearly, the sculpting process does not occur in isolation.

The sculptor operates within an environment. They have a vision of what they want to make and might or might not have an artistic tradition that they adhere to or at least inspire them. The sculptor also has to deal with constraints like technical specifications, limitations in budget and/or time, institutional priorities, and/or disciplinary norms.

Just as a sculptor's vision is defined by the properties of the clay or stone and the properties of the chisel, an astronomer's ability to “sculpt” the cosmos is defined by the nature of light and the so-called *technological affordances* of the Hubble telescope. The sculptor must work within the limitations and possibilities of their materials, just as astronomers are constrained and enabled by Hubble's design and the characteristics of the light it captures.

The final sculpture reflects not only the sculptor’s intent but also the inherent qualities of the clay or stone and the marks left by the chisel. Similarly, one of Hubble’s images embodies both the astronomer's goals and the mediating influence of light, the telescope and all other intermediaries.

We can now understand how Hubble’s design alters the conditions that make observation possible. As Maslow (1966, p. x) famously remarked:

“If the only tool you have is a hammer, it is tempting to treat everything as if it were a nail”.

This insight echoes Ian Hacking’s (1983) argument that scientific knowledge is based on material intervention instead of passive reception. In other words, we see and understand the world[6] by actively engaging with it. Hubble images will prove to be a good example for demonstrating this.

NASA and ESA designed Hubble, at least in part, to overcome the limitations of ground-based telescopes (Rector et al., 2015, pp. 180-183; Gainor, 2020, pp. 134-135)—not only to enhance clarity, but to gain access to wavelengths that Earth's atmosphere would otherwise absorb or distort (National Research Council, 1969; Orchiston, 2005). Hubble itself

[6] World here refers to “the universe” in a broader sense, not Earth per se.

is a material intervention into the world for the purpose of attaining new scientific knowledge. By placing the telescope in orbit, astronomers could detect ultraviolet and infrared light that was previously out of reach (Rector et al., 2015, pp. 180-183). Hubble's design represents a significant transformation in how we can explore, manipulate, and understand the cosmos.

The concept of a *technological affordance* helps to anchor this notion of how the materiality of Hubble determines what can be seen. As Donald Norman (2013, p. 11) argues, an *affordance* is:

> *"a relationship between the properties of an object and the capabilities of the agent that determine how the object could possibly be used"*.

In simpler terms, technological affordances define the perceived and actual possibilities for action that a design enables. Hubble's design affords a specific kind of vision: high-resolution, multi-wavelength imaging of distant astronomical phenomena. These affordances are neither neutral nor incidental; they result from intentional design choices guided by scientific objectives, historical traditions, and technical constraints.

Norman's framework of affordances overlaps with Don Ihde's (1998) exploration of scientific instruments and his philosophy of technoscience. Ihde too emphasises that instruments are not transparent intermediaries between the observer and the world but that they actively shape the phenomena that are being studied. He calls the outputs of a scientific instrument, shaped by its affordances, a scientific inscription. Extending his analysis, Ihde highlights that instruments not only generate these *scientific inscriptions* but often become invisible in the process. For this analysis, Ihde draws heavily on Bruno Latour, who notes (Latour, 1987):

> *"What is behind a scientific text? Inscriptions. How are these inscriptions obtained? By setting up instruments. This other world just beneath the text is invisible as long as there is no controversy. A picture of moon valleys and mountains is presented to us as if we could see them directly. The telescope that makes them visible is invisible and so are the fierce controversies that Galileo had to wage centuries ago to produce an image of the Moon."* (quoted in Ihde, 1998, p. 149)

The main take-away here is that Hubble does not reveal a pre-existing cosmos; it actively produces what becomes visible. In doing so, it influences both the perception and the interpretation of the cosmos in the process of creating astronomical knowledge.

While the affordances enable certain functions, they limit others. Hubble’s limited field of view (in particular for some of its instruments, such as the WFPC2) (Gainor, 2020, p. 133), fixed spectral sensitivity, and need for periodic servicing by astronauts (Gainor, 2020, p. 143) are limitations inherent to its affordances. As a result of these limitations, Hubble cannot operate independently. This means that its continued functioning relies on ongoing coordination between space-based hardware and Earth-based teams of engineers, scientists, and image processors. While Hubble is often seen as an autonomous observer, its success in observations depends on the efforts of many individuals and the infrastructure that extends well beyond the telescope itself.

For these reasons, Hubble should not be seen as a passive observational tool. The images it creates are not representations of an objective reality but the result of a complex network; including instrumentation, calibration, data processing, and interpretive judgement. The images are influenced by the physical properties of light and by design choices, scientific priorities, and technological conditions that underlie the image-making system.

The following sections will address some of these mediating layers with a focus on the technical translation process. The configuration and calibration of Hubble's instruments—including Charge-Coupled Devices (CCDs), Analogue-to-Digital Converters (ADCs), filter stacks and gain settings—require continuous human input and decision-making. Just as the choice of filter or Hubble’s design, these interventions are invisible in the final image, yet crucial to the image-making process.

The Data Pipeline

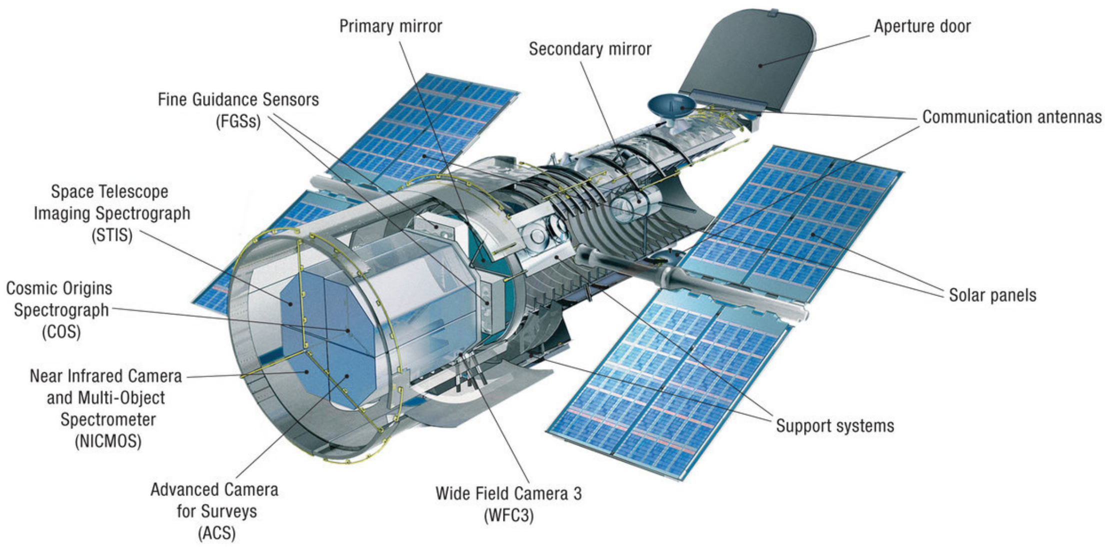
From Photon to Data

Discussions about the constructed nature of astronomical images often focus on colour manipulation (Arcand et al., 2013; Cooperstein, 2014; Chadwick, 2019). However, Hubble's data undergoes extensive mediation long before colour is added (Mackinnon, 2014; Christensen et al., 2015; Rector et al., 2015). Even the most "neutral"-looking greyscale image results from a series of technical translations that begin when a photon enters Hubble's optical system. In this section, I will outline the journey from photon to greyscale image, demonstrating the decisions, calibrations, and physical interventions along the way. As Gitelman (2013, p. 2) writes, “Raw *data is an oxymoron.”* It will become evident that what is often called "raw" observational data is, actually, already "cooked". Referring to it as "raw" obscures the complexity of how data is already structured by acquisition methods, instruments and assumptions.

Like any telescope, Hubble’s first objective is to focus faint incoming light onto a small focal point (Rector et al., 2015, p. 136), in order to make its observations visible and meaningful. For this purpose, Hubble uses a Ritchey-Chrétien refracting mirror system (Neal, 1990, p. 58) (see Figure 12). This sequence of mirrors folds the path of the incoming light back onto itself, allowing it to be reflected multiple times before reaching Hubble's instruments (see Figure 13).

Figure 12

Hubble's Instruments Including Control and Support Systems



Note. This labelled diagram illustrates the major components of the Hubble Space Telescope, including its primary and secondary mirrors, scientific instruments (such as the Wide Field Camera 3, STIS, COS, NICMOS, and ACS), and operational systems like solar panels, communication antennas, and fine guidance sensors. These components enable Hubble to perform high-resolution imaging and spectroscopy across ultraviolet, visible, and near-infrared wavelengths. Credit: NASA, STScI.

Figure 13

Optical light path through the Hubble Space Telescope

Note. This diagram illustrates how light enters the Hubble Space Telescope, is reflected off the primary and secondary mirrors, and is directed through internal baffles into instrument bays. It shows how light is channelled to Hubble's suite of instruments, including STIS, COS, ACS, NICMOS, and WFC3, for scientific analysis. Credit: NASA, STScI

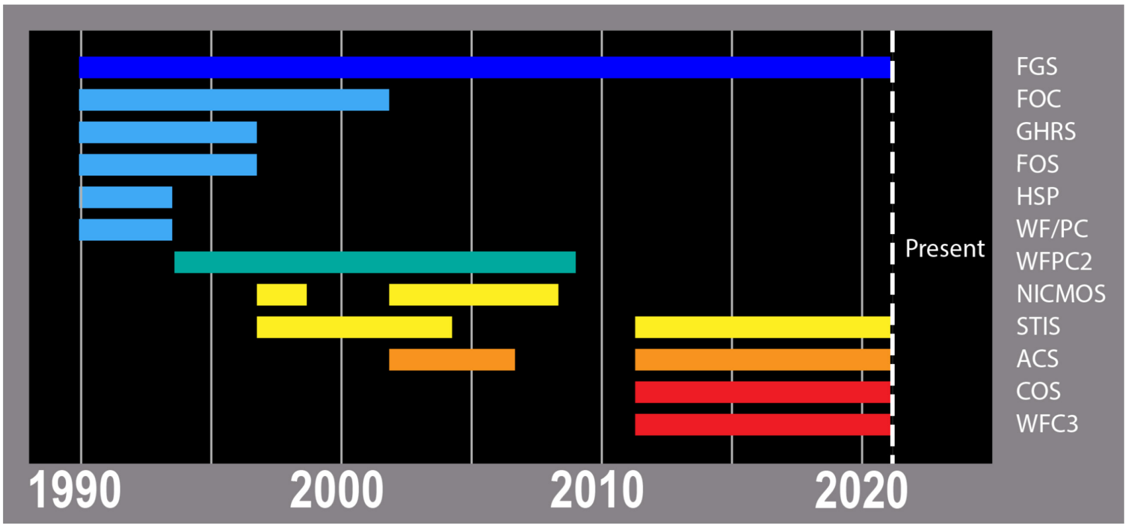
Light first lands on Hubble's 2.4-metre-wide primary mirror (Neal, 1990, p. 58), which reflects it toward a smaller secondary mirror suspended above it. The secondary mirror redirects the light through a hole in the centre of the primary mirror to reach the focal plane, where it enters Hubble's scientific instruments. This system enables Hubble to detect objects up to 10,000 times fainter than what the human eye can perceive (Neal, 1990, p. 60). In addition to this, the design minimises optical distortion, which allows the telescope to capture sharp and detailed images (Neal, 1990, p. 58).

These strengths also come with weaknesses. The complex mirror system relies on the perfect alignment and shape of its mirrors, and even the smallest error will result in the light not focusing properly on the focal point. This was discovered the hard way after Hubble's initial launch, as a minuscule grounding error (Gainer, 2020, pp. 53-56) rendered all Hubble's observations blurry. What this demonstrates is that even the earliest stages of observation—in fact, before observation even begins—are deeply mediated. What becomes visible is shaped long before it is actually seen. We can then see that astronomical image-making begins with inscription, not with perception. This point will become increasingly clear as we follow data through its translation pipeline.

After the faint incoming light passes Hubble's mirror system, it is ready to be converted into measurable data by one of Hubble's cameras or spectrographs (see Figure 14). Some of Hubble's instruments include the Advanced Camera for Surveys (ACS), the Wide Field Camera 3 (WFC3), and its predecessor the Wide Field and Planetary Camera 2 (WFPC2)—the latter of which captured the iconic 1995 “Pillars of Creation” image (Gainor, 2020, pp. 132-133; STScI, 2025a).

Figure 14

Timeline of Hubble Space Telescope instrument service periods.



Note. This figure presents a chronological overview of scientific instruments onboard the Hubble Space Telescope, showing their operational timelines from 1990 to the present. Each bar represents the period during which a specific instrument, such as NICMOS, ACS, COS, or WFC3, was active. The data highlights instrument replacements, upgrades, and ongoing contributions to Hubble's scientific output. Credit: (STScI, 2018)

For photon detection, all these cameras are equipped with Charge-Coupled Devices (CCDs) (Gainor, 2020, p. 168)—sensors that convert incoming photons into electronic signals. Teledyne Imaging (2020), the company that produced Hubble's CCDs, gives a good overview of how CCDs operate. Each CCD consists of a grid of light-sensitive photodiodes on a silicon plate. When a photon strikes a photodiode, it generates an electrical charge known as a photoelectron. The number of photoelectrons produced corresponds to the intensity of the incoming light. Each photodiode contains a storage bucket, or pixel well, where the charge is temporarily held. After a predetermined exposure time, the wells are "closed", and the charges are read out by shifting them across the CCD array toward an output node. At this point, each charge is converted into a voltage and *amplified* to help detect faint signals.

However, this process also introduces *noise* into the data. Noise refers to unwanted variations in the signal that degrade the quality of the measurement (Rector et al., 2007). Thermal noise, or *dark current*, is a common type of noise which consists of random voltage fluctuations caused by heat generated by the electronics of the CCDs (STScI, 2025b). To minimise dark current, scientific CCDs are often cooled (Teledyne Imaging, 2025), which improves the *signal-to-noise ratio* of the data (Rector et al., 2007, p. 602). In other words, the meaningful data is carefully balanced against background interference.

Noise is not just a technical problem; it is also philosophically interesting because it foregrounds the difference between signal and interference. What is preserved as a meaningful signal versus dismissed as noise involves both technical calibration and *epistemic* judgement. *Epistemic* relates to knowledge—how we come to know things, how reliable our knowledge is, and what counts as a good reason to believe something. How we decide to balance between signal and noise reflects broader scientific norms about what counts as legible and trustworthy data. As Kessler (2012) notes, balancing signal versus noise is related to objectivity and the different historical notions of it that Daston and Galison (2007) describe. But Kessler (2012) adds:

> *“It is neither an example of mechanical objectivity nor trained judgement. Instead, it sits in between, using a machine—computer software—to make a trained judgement”* (Kessler, 2012, p. 138).

This example highlights how even the most technical elements, such as the treatment of noise, are embedded in deeply interpretive and ultimately subjective decisions.

Digitising the Signal

Once the signal has been amplified and noise reduced, the CCD's analogue output has to be digitised using an Analogue-to-Digital Converter (ADC). This process is carefully described in the Hubble Space Telescope User Documentation (STScI, 2015). During this process each pixel is assigned an Analogue-to-Digital Unit (ADU)—also known as a Data Number (DN)—based on the voltage it generates. Technicians can adjust the gain of an ADC, defining how many electrons correspond to one ADU (STScI, 2015) (see Appendix B). This adjustment affects the trade-off between sensitivity to faint light and the retention of detail in bright areas.

Each ADU value is interpreted in relation to the ADC's bit depth—typically 12 or 16-bit on Hubble (STScI, 2025d)—which defines the range of values and thus the amount of detail that can be recorded in an image. These settings establish the *dynamic range*—the span between the faintest and the brightest detectable signals in the image. At this point, the output is not yet an image but a digital matrix in which each pixel contains an ADU value corresponding to the light intensity recorded during exposure.

Although often referred to as "raw", these data have already been shaped by gain, bit depth and dynamic range settings, as well as some forms of error correction. These technical interventions influence what information is preserved, emphasised, or lost before the data even leaves Hubble. Thus, even prior to any visual manipulation, the data has already passed through a series of technical filters and epistemic decisions that shape what can and cannot be seen.

Despite efforts to reduce noise on board, most calibration and noise correction occur after the data is received on Earth—and for good reason. As Kessler (2012) argues, astronomers prefer to apply calibrations manually because it allows them greater flexibility in tailoring the data to their specific research goals and allows them to preserve data integrity as much as possible. Calibration often involves adjusting parameters—sometimes literally through a few buttons or sliders—to refine the data according to the scientific context. Performing these steps on Earth might also be preferential due to Hubble's limited computational and energy resources, as NASA (1990, p. 38) suggests.

Daston and Galison (2007) have proposed that it is scientists' trained judgment that guides them in this interpretative work. Their historical analysis of the concept of objectivity in science is highly relevant to our thesis because it shows that scientific images have never been purely objective or free from human judgment. Their concept of "trained judgement" highlights that, even with advanced technologies such as Hubble, the production and interpretation of scientific images requires the expertise and interpretive skills of scientists. This is clearly reflected in the calibration pipeline that we have discussed so far, as it highlights that Hubble images emerge through a process where subjective interpretation is embedded in technical practice.

Data Transmission

After the initial translation process is finished, the next challenge is transmitting that data back to Earth. NASA (1990, p. 38) notes that data transmission is a critical part of the imaging pipeline and generally a huge bottleneck for astronomers and mission planners. Because of Hubble's limited onboard storage capacity, mission planners must make compromises about what can be observed, when, and in what form (Neal, 1990, p. 38). There is only one Hubble and a great number of astronomers who want to use it.

Hubble communicates with Earth through NASA's Tracking and Data Relay Satellite System (TDRSS). This network of satellites is in sync with Earth's rotation and relays information between almost all space-based instruments and their corresponding ground stations (NASA, 1990, p. 41). Typically, Hubble's data is redirected to a receiver located at White Sands, New Mexico. Although TDRSS covers approximately 85% of the Earth's surface, there are times when direct data transmission is not possible (Nmonterey et al., 1988). At these times reliance on Hubble’s finite onboard storage capacity is a necessity. Once transmitted and received, Hubble’s data is validated at the Space Telescope Operations Control Centre (STOCC) at NASA’s Goddard Space Flight Centre (GSFC) in Greenbelt. After validation, it is sent to the Space Telescope Science Institute (STScI) in Baltimore, where it is archived, calibrated, and prepared for scientific analysis (Neal, 1990, p. 41).

Because of Hubble's limited onboard storage capacity, it must regularly release its data to accommodate new observations. This asks for the careful and detailed scheduling of observation times and data dumps, balancing bandwidth, telescope visibility, orientation, and scientific priorities. These constraints require mission planners to decide what can be observed, when, and how often. If data is stored on board for too long, it may become corrupted due to cosmic radiation. Since Hubble operates above the Earth's protective atmosphere, the telescope is consistently bombarded by cosmic radiation and ionised particles from the Sun. When these high-energy particles strike electronic circuits, they can cause what is called a 'bit-flip' (Hancock, 1993)—altering a bit from 0 to 1—introducing more unwanted noise in the stored scientific data.

To optimise bandwidth usage during transmission, data is typically compressed before downlink (Beser, 1994; White & Becker, 1998). Compression methods can vary: lossless compression preserves all information, while lossy compression may discard some detail, though still within acceptable scientific thresholds. Again, these decisions are not arbitrary but reflect an interpretive trade-off between signal fidelity, storage limitations, and transmission efficiency. Despite the common intuition that space telescopes send back “pictures”, the digital data matrix only reaches Earth after a complex negotiation between engineering constraints and scientific priorities. This logistical mediation goes unnoticed once the data is visualised.

Once data arrives on Earth, it enters a structured access pipeline (STScI, 2025g). Most newly received datasets face a proprietary period (STScI, 2025e), typically lasting six months to one year, during which only the research team that proposed the observations can access the data. After this period, the data is added to the public archive, allowing broader access for reprocessing and reinterpretation by the scientific community (STScI, 2025e).

Upon receipt and validation at STScI, the scientific preparation process begins. Incoming files are classified, archived, and subjected to initial calibrations and error corrections. This early processing is crucial because, as mentioned, the data may contain various artefacts introduced by onboard electronics, radiation exposure, or thermal noise—any of which could compromise its scientific usability. Calibrations correct for these instrument-specific distortions and ensure consistency across observations. Both the "raw" (uncalibrated) and the reduced (calibrated) versions of the data are stored in the Mikulski Archive for Space Telescopes (MAST), which is publicly accessible worldwide.

To ensure long-term accessibility and interoperability, all Hubble data is stored in the Flexible Image Transport System (FITS) format, the standard in astronomical data sharing. FITS is designed to accommodate complex scientific datasets, including one-dimensional spectra, two-dimensional images, three-dimensional data cubes, and structured tables (STScI, 2025b; STScI, 2025f).

FITS files are not limited to numerical arrays but also store extensive metadata. This includes observation time, instrument settings, observation coordinates and calibration history (STScI, 2025f). This makes FITS a fully integrated scientific data model, not just a storage format. Although FITS files can be relatively large due to their lossless compression and metadata, their robustness, transparency, and compatibility render them essential for the astronomical domain.

As such, the FITS format does not only store data; it enforces a standardised epistemological frame. What it includes, how it is labelled, and what counts as metadata reflect shared assumptions about what makes data interpretable and reusable. Hubble’s archive preserves both raw and calibrated data. This approach helps to make sure that astronomers can revisit and reinterpret Hubble’s observations long after they have been made. Keeping in mind the limited availability of Hubble, this is extremely beneficial.

Astronomers can often find previously acquired data in MAST, which they can repurpose for their own scientific enquiries.

Transmitting Hubble data is not a passive relay of information. It is a technologically mediated and institutionally coordinated process, shaped by hardware limitations, operational planning, and prioritisation decisions. Like the other stages in the data lifecycle, transmission reflects human judgement, infrastructural constraint, and interpretive labour—even if these factors remain invisible in the final image.

The data that ends up in MAST is not a finished product but an intermediary. It is a structured dataset, but it is full of noise, instrumental signatures, electronic artefacts, and other distortions. These traces must be carefully untangled before the data can be considered as scientific evidence. By framing the data this way, it becomes clear that scientific interpretation does not in fact begin with discovery; it starts with correction.

In the following section, we will focus on the next phase of the image-making pipeline where the uncalibrated data that is stored in MAST is calibrated and translated into greyscale images fit for the scientific enquiries of astronomers.

From Raw Data to Grayscale Image

Before a Hubble dataset can be transformed into a greyscale image, it must go through several corrections and calibrations to eliminate any distortions that may have formed during data acquisition. This calibration process, also known as data reduction, is crucial for scientific accuracy and integrity and prepares the data for the eventual visualisation.

One of the most significant sources of distortion in raw Hubble data is noise—unpredictable or systematic fluctuations caused by the detectors or the observing environment. Besides *dark current* noise (STScI, 2025b; STScI, 2025h), which has been previously mentioned, another common type of noise is *read noise* (STScI, 2015). Read noise arises from fluctuations during the conversion of the electron charge to digital values. Additionally, there is the problem of cosmic rays (STScI, 2025h), highly ionised particles that strike CCDs during observation and appear as bright artefacts that must be algorithmically removed during post-processing. Other inconsistencies occur due to the non-uniformity of the CCDs (STScI, 2025h), where certain pixels respond differently to the same light input, resulting in fixed-pattern artefacts. These non-uniformity artefacts depend on exposure time, manufacturing tolerances, and prolonged exposure to radiation.

To address calibration issues, Hubble's data calibration pipeline follows a standard sequence of operations. These steps include:

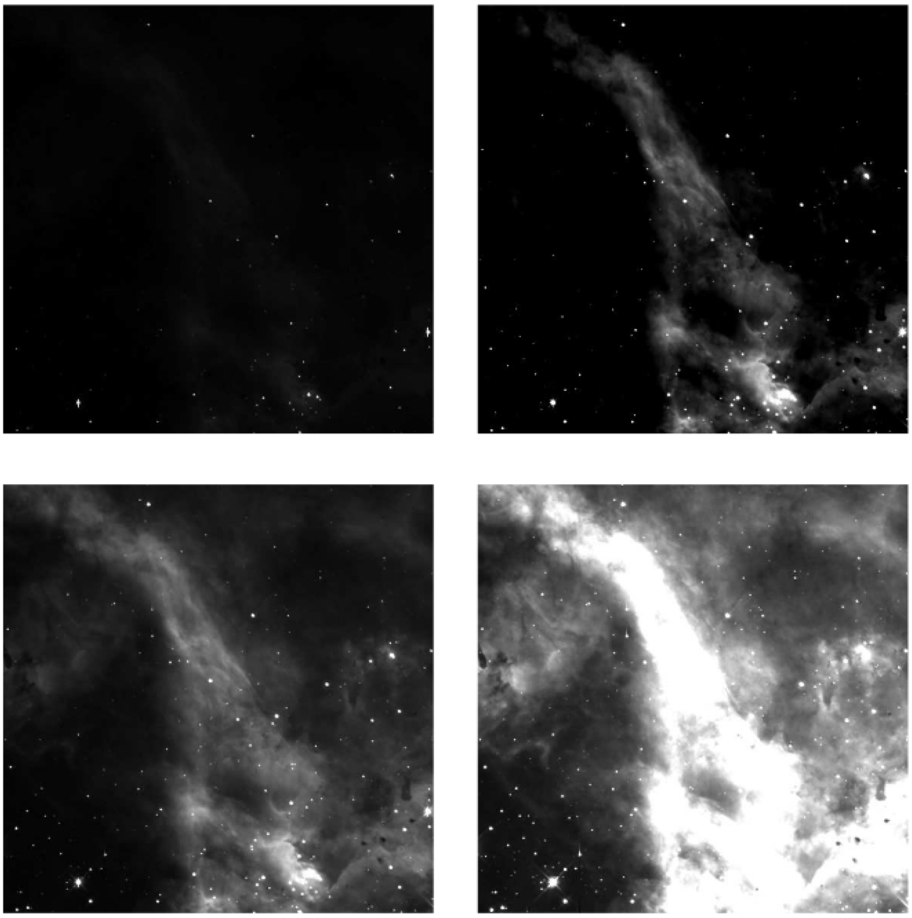
1. Bias Correction (STScI, 2025h): This involves using bias frames—exposures taken with zero exposure time—to subtract the electronic baseline from each image.
2. Dark Frame Correction (STScI, 2025h): This step subtracts thermal noise captured during dark exposures of the same duration as the actual exposure.
3. Flat-Field Correction (STScI, 2025h): This uses exposures of a uniformly illuminated surface to eliminate variations in pixel sensitivity.

Astronomers must scale and project the intensity values of the digital matrix to visualise it into an image (Frankel, 2004, p. 6). This involves translating each pixel's ADU into a corresponding shade of grey on a standard 8-bit or 16-bit greyscale scale. Hubble's sensors typically produce 16-bit data (65,536 levels), while most display formats use 8-bit (256 levels) (Frankel, 2004, p. 6). Therefore, dynamic range compression is necessary in this process.

To compress the dynamic range of the image, astronomers must select a scaling function. Common scaling functions include linear, logarithmic, square root, or custom-defined options. These scaling functions determine which parts of the dataset are emphasised and which are suppressed (Rector et al., 2007, p. 601). Although there are guidelines and common practices when it comes to the selection of scaling functions, ultimately this comes down to an interpretive decision by the astronomer. This decision can lead to noticeable visual differences in the image. Rector et al. (2007) give a detailed overview of all the different scaling functions and the impact it has on the appearance of the image; see Figure 15 for one example of those. A poorly chosen dynamic range may conceal subtle details or exaggerate insignificant noise. If the range is too broad, fine details can be lost as multiple data values collapse into the same grey tone. Conversely, if the range is too narrow, large areas may become over- or undersaturated, resulting in flat white or black regions. At the same time, there is no good or bad choice when it comes to scaling functions. Even a mathematically correct scale can create visual artefacts, such as banding, if the transitions between greyscale levels are too abrupt.

Figure 15

Impact of linear scaling functions on astronomical image visibility



Note. This figure presents four renderings of the same astronomical data using different linear scaling functions. Each variation adjusts brightness and contrast to emphasise different structural features in the nebula, demonstrating how data interpretation can vary significantly based on image processing choices. Credit: (Rector et al., 2007)

Astronomers typically experiment with several scale functions and sometimes apply image manipulation techniques to tackle this issue (Rector et al., 2007, pp. 601-602). For example, they might subtract a model of a galaxy's disc or use an unsharp mask to compress the dynamic range or enhance faint structures. Quite frequently, multiple versions of the same dataset—each optimised for a different brightness range—are combined to create a composite image. The result is a visually smooth greyscale image that presents a unified view of space. However, as has become clear, this is hardly the case.

As Smith et al. (2015, p. 89) argue, Hubble’s images are both *“translations”* and *“data-based representations of objects that are incredibly far away from human experience in space and time”*. Yet, they are not a *“record of the real”.* (Smith et al., 2015, p. 89). From the moment light enters Hubble's optical system to the point where data is archived on Earth, image-making is already well underway. What is often referred to as "raw" data is already influenced by various decisions regarding what to measure, how to measure it, and how to represent those measurements. These layers of mediation are not just incidental; they are essential to what becomes visible and knowable. However, these complexities are often overlooked. When a greyscale dataset is displayed on a screen, much of the labour that enabled it has already been done and turned invisible.

The next section explores how these greyscale images are transformed into the iconic full-colour image that the public is familiar with.

Colours as Construct

From Greyscale to Colour

Colour is one of the most visually striking and culturally charged features of Hubble’s astronomical imagery. While often celebrated for giving images their aesthetic appeal, colour in scientific images is also one of the most contentious aspects of their production, particularly among non-experts.

For experts this is a bit different. Astronomers usually find it easier to analyse greyscale images than false-colour images. Lynch and Edgerton (1987) take note during an interview with an astronomer, who argued:

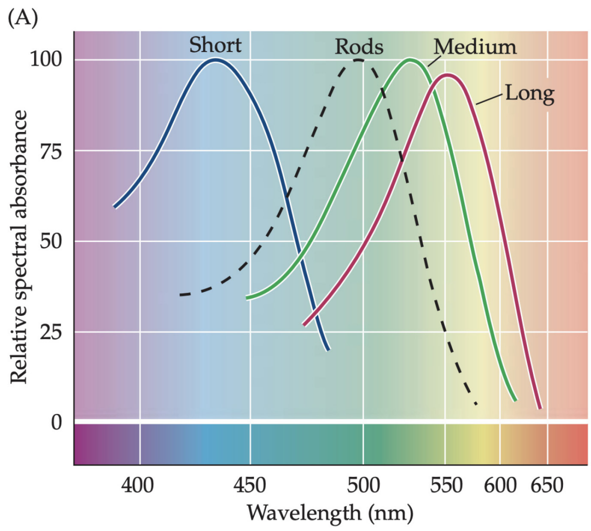
> *"You can't do any numerical analysis with [these false-colour images]. These [false-colour images] are all made with digital arrays. You can very precisely measure the intensity at any point. But you do that with the digital data, not with these [false-colour images]." (Lynch and Edgerton, 1987, p.197 in Greenberg, 2004, p.85)*

That being said, numerous studies in STS and visual culture have shown that colour frequently becomes a point of confusion or controversy in public interpretations of astronomical images (Smith et al., 2015; Ventura, 2013; Arcand et al., 2013). To scientists, colour can function as a tool for clarity, used to distinguish wavelengths, elements, or intensities. To non-experts, however, colour in astronomical images often appears as a direct equivalent to what objects in space would "actually" look like to the human eye (Arcand et al., 2013; Smith et al., 2015). This divergence highlights a deeper epistemological tension between *colour as translation*—a mode of scientific representation governed by instrumental constraints—and *colour as disclosure*, which carries the visual weight of realism and truth in public perception.

To unpack this, it helps to briefly consider how colour is perceived by the human visual system. Photons within the visible light spectrum—typically between 400 and 700 nanometres—stimulate specialised photoreceptor cells in the retina called cones. These cones are divided into three types (see Figure 16): S-cones, which are most sensitive to short (blue) wavelengths; M-cones, which respond to medium (green) wavelengths; and L-cones, which are tuned to longer (red) wavelengths (Purves et al., 2018, pp. 247-258). Perceived colour results from the relative activation of these three cone types. Mars, for example, reflects mainly red-orange light (~600–700 nm), stimulating L-cones and appearing red to the human eye. Neptune reflects shorter wavelengths, stimulating primarily the S-cones, and appears blue (see Figure 17).

Figure 16

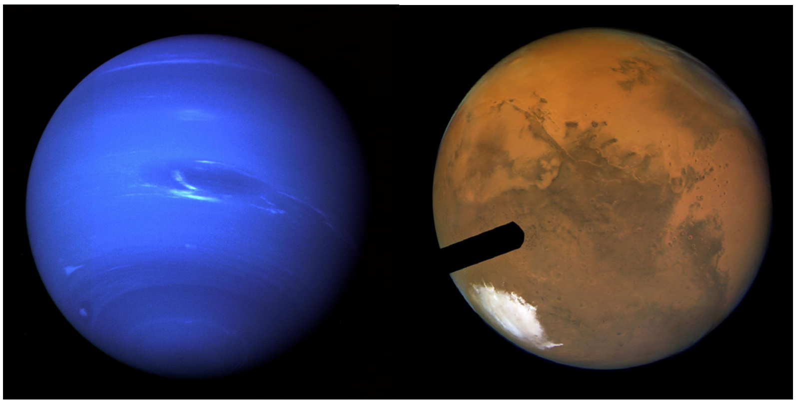
Spectral absorbance of photoreceptors in the human eye



Note. This graph shows the relative spectral absorbance of different types of human photoreceptors: rods and three types of cones (short, medium, and long wavelength sensitive). Each curve indicates the wavelengths of light to which the respective cells are most responsive, forming the basis for human colour vision and low-light perception. Credit: (Purves et al., 2018, p. 248)

Figure 17

Images of Neptune and Mars captured by space telescopes



Note. The left image (a) shows Neptune with visible atmospheric features; the right image (b) shows the surface of Mars, including polar ice and dust patterns. Credit (a): NASA/JPL, (b): NASA, J. Bell (Cornell U.), and M. Wolff (Space Science Inst.) Additional image processing and analysis support from: K. Noll and A. Lubenow (STScI); M. Hubbard (Cornell

U.); R. Morris (NASA/JSC); P. James (U. Toledo); S. Lee (U. Colorado); T. Clancy, B. Whitney and G. Videen (SSI); and Y. Shkuratov (Kharkov U.)

But crucially, colour does not exist “out there” in the world. It is not an inherent property of objects or light. Instead, it is a “qualia” (English, 2017, p. 27), the product of neural interpretation shaped by the stimulation of our eyes, the environmental context, and learned expectations. The first systematic study on the physiological effects of colour was published in 1810 by Johann Wolfgang von Goethe (Von Goethe, 1810; as cited in Smithsonian Libraries, 2015), who tried to prove that colour is a subjective experience that each viewer perceives differently.

Our perception of “white”, for example, emerges from the equal stimulation of all three cones, while other colours result from more complex combinations (Purves et al., 2018, pp. 247-258). The same star may appear violet due to high-frequency emissions or simply because it appears more violet relative to its nearby neighbours. In every case, the eye detects light, but the brain produces colour. This complexity mirrors the situation in astronomical image-making.

As discussed in previous sections, Hubble does not produce colour images. Its instruments record differences in brightness in specific wavelength ranges, which results in greyscale data (Rector et al., 2007). In many cases, Hubble’s data comes from the invisible part of the electromagnetic spectrum, ranges of light that humans have not evolved to see, such as infrared or ultraviolet. In these cases, “colour” is a non-sensical concept. However, even when observing in the visible spectrum, Hubble only records a matrix of intensity values, not a photograph.

In the following section, we will specify some specific colourisation practices and outline how they work to balance scientific meaning with visual coherence. These methods offer insight not only into the mechanics of image production but also into the values, constraints, and communicative goals that underlie the images.

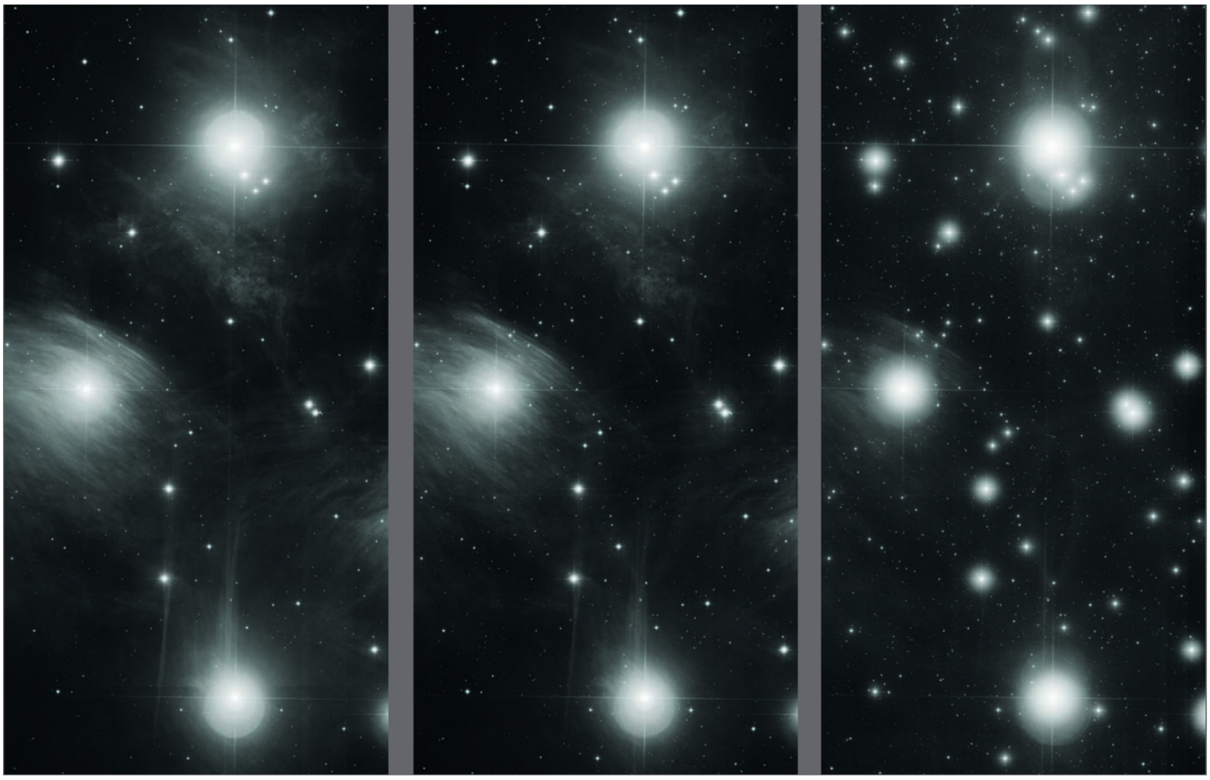
How Colour is Built

While colour is a mental phenomenon rather than a physical property of light or a cosmic object, that does not mean that it is *fake*. Instead, in astronomical imaging, colour is *representative*. It encodes and communicates data in ways that are both scientifically meaningful and visually legible. As Christensen et al. (2009) note, if there is public distrust in the images, it often stems from the term “false colour”, which suggests fabrication. In practice, however, colour in Hubble images is not meant as a feat of artistic expression, but as a structured mapping of wavelengths to visible hues. Although it might eventually serve an artistic meaning once applied purely for public outreach purposes.

Colour mapping starts with the scientific data of Hubble’s observations. Every data set, whether obtained through a narrowband or broadband filter, in the ultraviolet, visible, or infrared range, isolates a specific band of the electromagnetic spectrum. Each of these exposures is captured in greyscale, where pixel brightness represents photon intensity at that particular wavelength. In constructing a colour image, astronomers (or more often, image-making specialists) assign visual colours—typically red, green, and blue—to these datasets, as Rector et al. (2015) show in significant detail. When combined, the resulting image creates a full-colour composite that encodes different spectral regions (see Figures 18, 19 & 20).

Figure 18

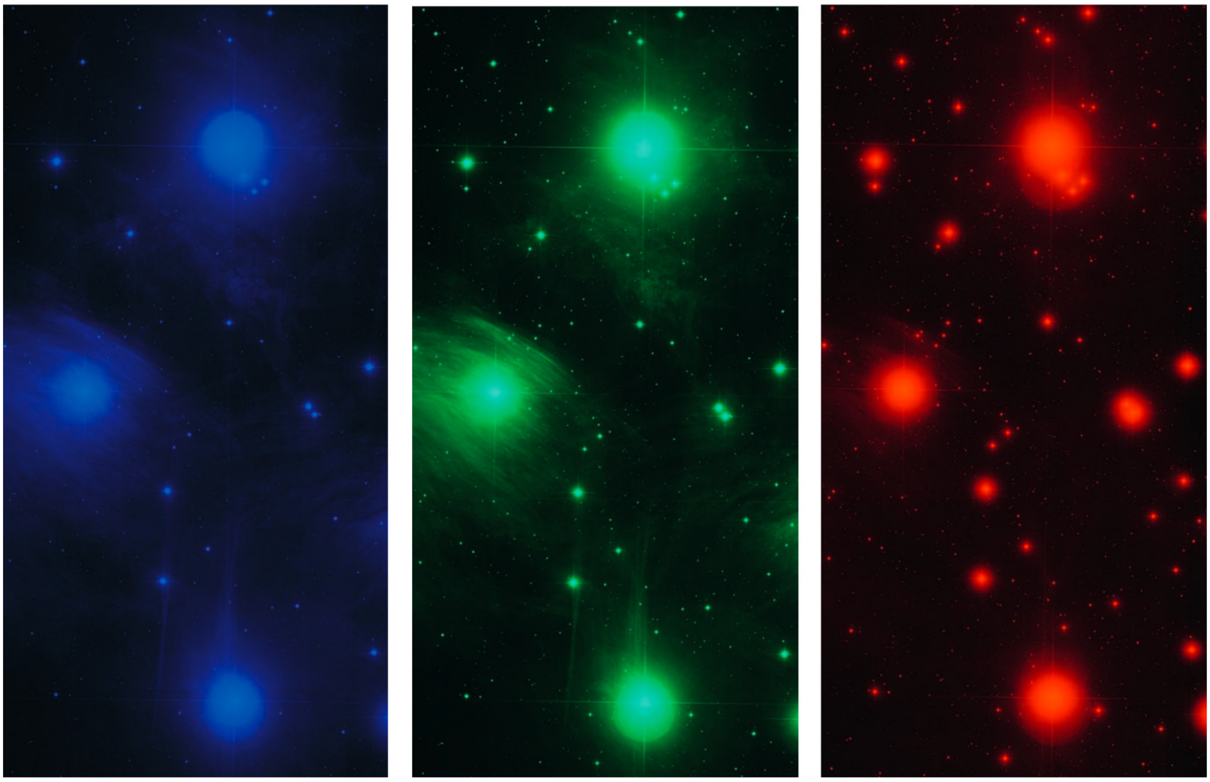
Effect of wavelength filters on star cluster imaging



Note. These three images of the same star cluster were taken using different filters: blue light (left), visible light (middle), and infrared (right). The nebular structure is more prominent in the blue and visible bands, while the infrared image reveals a clearer view of the star field, with less apparent gas and dust. This demonstrates how different wavelengths can reveal distinct features of astronomical objects. Credits: T. A. Rector (University of Alaska Anchorage), Richard Cool (University of Arizona), and WIYN. (Rector et al., 2015)

Figure 19

Colour mapping of star cluster images using different filters



Note. This composite presents the same star cluster imaged through three different bandpass filters, with each filter's data mapped to a specific colour: blue for blue light (left), green for visible light (middle), and red for infrared (right). This colour-assignment technique enhances contrast and reveals structural differences, especially in the surrounding nebula, that vary with wavelength. Credit: T. A. Rector (University of Alaska Anchorage), Richard Cool (University of Arizona), and WIYN. (Rector et al., 2015)

Figure 20

Colour composite of the Pleiades star cluster using multi-filter data

Note. This image combines data from blue, visible, and infrared filters into a single colour composite. The colour assignments enhance the visual contrast between different stellar populations and highlight surrounding nebular material. Credit: T. A. Rector (University of Alaska Anchorage), Richard Cool (University of Arizona), and WIYN. (Rector et al., 2015)

Please take note that, while colour assignments could in theory be arbitrary, best practices usually involve assigning colours that approximate the wavelength of the original data as closely as possible, where possible (Smith et al., 2015). This is also known as “true colour mapping”. During true-colour mapping, data from the red part of the spectrum are typically mapped to red in the final image, blues to the blue part of the spectrum, and so on. This convention promotes internal consistency in images across the astronomical domain, which is helpful for scientific comparison and public understanding.

Making Invisible Light Visible

When data is collected outside the visible spectrum, such as in the ultraviolet or infrared wavelengths, there is no direct visible analogue. This is a common occurrence in modern astronomy (Frankel, 2004). Cooperstein (2014) refers to this data as "non-reproductive" data, meaning it cannot be visually reproduced in any straightforward or naturalistic way. Because there is no visual analogue to non-reproductive data, image-makers must choose colours to "stand in" for this invisible data. As numerous scholars, including Kessler (2012), Cooperstein (2014) and Smith et al. (2015), note, these colour choices often borrow from the aesthetics of *photographic realism*, where images are composed to resemble high-resolution photographs even when the colours have no physical correlate in nature.

There is a strong historical connection between photographic realism and the tradition of Renaissance naturalism. Photographic realism draws on visual conventions established during the Renaissance, where artists such as Galileo first began to systematically replicate the appearance of the natural world with scientific accuracy and empirical detail (Daston & Galison, 2007; Winkler & van Helden, 1992). Techniques, such as linear perspective, anatomical accuracy, and the scientific study of light, were developed to enhance visual accuracy and spatial coherence. When photography emerged in the 19th century, it inherited many of these principles.

Today, Hubble images continue to evoke this aesthetic and naturalistic tradition. Hubble's images, although often constructed from data outside the visible spectrum, are still typically rendered using colour palettes and compositional techniques that evoke the look and feel of high-resolution photographs (Kessler, 2012; Rector et al., 2015; Arcand et al., 2013). This approach intends to make complex scientific data visually accessible and compelling, drawing on the viewers' familiarity with photographic and naturalistic representation.

By replacing non-reproductive data with a stand-in colour, a new layer of mediation is introduced that can easily go unnoticed, especially to the untrained eye (Cooperstein, 2014).

While an astronomical image might *resemble* a photograph, that does not mean it actually is one.

By embedding themselves in the tradition of photographic realism, Hubble images tap into a cultural idea that visual fidelity is closely tied to epistemic reliability (Cooperstein, 2014). As a result, the images inherit not only the look but also the *authority* of photographs. Colourisation embeds the image within a representational tradition that obfuscates interpretation through *visual realism*.

Choosing Colours

Colour serves both scientific and aesthetic purposes (Kessler, 2012; Rector et al., 2015; English, 2017; Levay & Villard, 2002; Ventura, 2013). Scientifically, colour can facilitate the identification and distinction of structure in an image—such as hot gases, dust clouds, or specific chemical elements—by encoding their emission properties in colour space. Aesthetically, it serves to produce coherent, compelling images that resonate with the viewer.

Because the choice of a stand-in colour serves many purposes, it is an important decision. As English (2017, pp. 7-12) highlights, it is rarely a mechanical or solitary process and often a collaborative effort involving both scientists and artists. As a result, the decision-making process reflects a negotiated balance between scientific accuracy, visual communication, and even political considerations[7].

Artists routinely explore various filter combinations, contrast levels, and colour assignments to construct images that are not only faithful to the data but also visually persuasive, as Kessler (2007) demonstrates. This interplay underscores English's (2012)

[7] The term *political consideration* refers here to the institutional and social dimensions of image-making. As Jayanne English notes, outreach images must not only communicate data effectively, but also align with the expectations of collaborating scientists and the reputational standards of their institutions. Such decisions—about colour, composition, or scientific fidelity—are political in the sense that they involve negotiation, consensus-building, and sensitivity to the values of various stakeholders in the scientific and public spheres. I quote (English, 2017, p. 9): "*We learned to strike a balance between visual creativity and scientific content that ensured that astronomers felt that their research was accurately represented and that their institute would be proud to be associated with the image.*" See English (2017).

point that colour choices are not automatically dictated by the data but are shaped through the culturally embedded practices of both science and art.

This is not a straightforward process. There is no single “correct” colour for most celestial objects. This is true in particular for nebulae, which emit light at specific and sometimes overlapping wavelengths. If a nebula contains both sulphur (S-II) and hydrogen-alpha (Hα) atoms, they would, in true colour imaging, both be assigned “red”, as their wavelengths overlap in the deep red spectrum (Rector et al., 2015). This, of course, would make it impossible to visually discern any structural differences between those two elements.

Unlike planetary images, where surface colours can be calibrated to sunlight reflection, deep-space images rely on an astronomer’s interpretive discretion (Rector, 2015). They are much harder, if not impossible, to calibrate to the same degree. As a result, decisions must be made about how to handle perceptual gaps, where multiple emissions occur at similar wavelengths, or where no visible analogue exists. These decisions are guided by both scientific conventions and the communicative intent of the astronomer.

The labour behind this process—deciding which filters to use, how to assign colours, and how to balance fidelity with accessibility—is rarely visible in the final product. While scientific publications may detail the steps involved, these decisions are not embedded in the image itself. Instead, they are rendered invisible through a visual coherence that invites trust rather than scrutiny.

While colour is arguably the most revealing element to examine, it is by no means the only aesthetic or compositional decision made during this stage of the image-making process. Other impactful elements, such as compositional framing (English, 2017, pp. 29-30), depth of field (English, 2017, pp. 33-35) or contrast (English, 2017, pp. 35-37), also play significant roles. However, given the scope and limitations of this thesis, it is not practicable to explore these aspects, or other aesthetic choices made by astronomers and image-makers at this point in time, in detail.

Summary: The Hubble Image as a Constructed Artefact

We are starting to understand the image as a constructed visual argument, rather than an instance of visual *immediacy*. This chapter has attempted to demonstrate that what is typically hidden is, in fact, a requirement for its conception. Hubble images are not these transparent windows but constructed artefacts shaped by technology and humans. From the moment a photon enters the telescope to the publishing of an image, the human element is a given at every step. Seemingly “raw” data is already processed and encoded with value-laden decisions. Colour is not some inherent property of the cosmic object but, in fact, a method of scientific communication, imbued with epistemic and cultural significance. The Hubble image is more akin to a sculpture than to a photograph.

Although I have demonstrated that the Hubble image is not an “as-is” picture, but rather an “as-made” image, the main questions remain: why do they appear that way, and what is the consequence of them doing so?

In the next chapter, I turn from how Hubble images are constructed to how they are perceived. I show how photographic realism, an *illusion of immediacy* and an underlying ideal of objectivity grant the images epistemic and cultural authority. Chapter 3 will build from that foundation, shifting focus to how institutions—such as NASA and the Space Telescope Science Institute—amplify that authority through strategic framing, branding, and narrative design.

The Visual Construction of Authority: Obfuscation, Realism, and Objectivity

Building on the previous chapter’s claim that Hubble’s images are constructed rather than captured, this chapter explains how these constructions are made to disappear.

In order to do so, we start off this chapter with a clear idea in mind: Hubble images are not direct captures of cosmic reality; they are complex visual translations—produced through layers of data manipulation, interpretation, and aesthetic design. Yet, they rarely appear this way. Their construction is systematically concealed, giving rise to the illusion of immediacy: the sense that we are looking at the universe itself, rather than a visual interpretation of it.

The chapter proceeds in four sections: (1) how interpretive labour is obfuscated in the image and its dissemination; (2) how photographic realism reinforces an *illusion of immediacy*; (3) how this illusion of immediacy is not only visual but also epistemic; and (4) how scientific accuracy and aesthetic awe converge to grant these images dual authority. Together, these mechanisms reveal how the Hubble image gains authority through the obfuscation of its construction.

Obfuscating Mediation

The Black Box and Latourian Theory

Given that Hubble images are heavily mediated, an important question emerges: if they are constructed, why do they appear so natural and direct?

Earlier in this thesis, several references were made to Bruno Latour, who spent much of his work answering a similar question: how do scientific and technical facts become accepted and taken for granted, such that their complex origins and inner workings become invisible? Latour (2002) attempts to answer the question through a concept called the “black box”.

This metaphor of a black box illustrates that, in science and technology, once something is established as a fact or a reliable tool, people stop questioning how it works internally and simply rely on its outputs. As Latour states, what remains in this case “are not even images, but the world itself” (Latour, 2002, p. 21). The internal mechanisms, debates, and controversies that led to its creation are hidden from everyday view. The image is no longer seen as a representation – it is mistaken for the thing itself.

Only when a black box is challenged or breaks down is attention drawn back to it, and people encouraged to understand it or scrutinise it. This prompts what Latour calls “depunctualisation”, a moment when the inner workings re-emerge into view (Latour, 1999).

Latour’s concepts could help to explain why Hubble’s images appear as direct representations: the processes behind them have become stabilised and consequently fade from view. However, in this particular case, blackboxing as a concept seems insufficient, as I will touch upon later.

Epistemic Distancing and the Limits of Accessibility

Much of the interpretive labour and mediation behind Hubble imagery is well-documented and publicly accessible through archives like MAST. NASA and others also provide many educational materials, blog posts, and videos explaining how Hubble images are constructed – including how data is processed, colour added, and visual coherence achieved (NASA, 2022). The root cause for the *illusion of immediacy*, then, is not a lack of documentation but that this information does not lead to depunctualisation. This could mean that while the information is out there, it does not reach the public. What is more likely is a broader epistemic distancing. This means that the complexity and technical nature of the processes – even if they are well-documented and communicable – render them opaque to most viewers. In that case, the interpretive labour becomes blackboxed, not because it is deliberately hidden, but because the specialised knowledge required to grasp it acts as a barrier.

Astronomers engage with Hubble's data through an epistemic infrastructure: FITS files, metadata tags, calibration logs, and reduction histories that are essential to interpreting the image. As argued in Chapter 1, these elements are not supplementary; they are the image.

The public, by contrast, typically engages with compressed JPEGs accompanied by short captions and surrounded by metaphor-laden, dramatic language (as explored in the next section) (Kessler, 2012). These images are encountered through museum exhibits, outreach publications, or digital media and not through technical platforms such as MAST.

Epistemic distancing would not only affect lay audiences but also extend to astronomers as well, although to a different degree. An astronomer might have access to all available data and still not fully grasp the internal operations of the Hubble telescope, and neither are they required for their general functioning as an astronomer. As long as the instruments remain reliable, validated, and stable, there is little incentive or necessity to question the underlying processes.

Epistemic distance would also pose a challenge for the public communication of the images. Explaining both the astronomical discoveries and the technical construction of the image to diverse audiences – while still engaging their attention and their enthusiasm – is a challenging act.

While black-boxing clearly applies here, it is less a matter of secrecy or absence of information and more a result of practical inaccessibility.

Can the life of a single Hubble image reveal how blackboxing unfolds in practice? Greenberg (2004) set out to investigate just this in his case study of Hubble's "Pillars of Creation" image.

Greenberg draws thoroughly on Latour (1987) when he traces the life of the "Pillars of Creation" image from its scientific origins to its public release. In his investigation, he examines how the image was created, processed, and interpreted by astronomers, and then how it transformed as it moved from the scientific community to the public sphere.

Greenberg's work echoes several other influential perspectives in the domains of visual epistemology and semiology. For example, Mitchell, an influential media and visual culture theorist and author of "What do Pictures want?", suggests (1993) that to understand images we must not only trace,

> *"how photographs … are made, but also how they are used – how their potential uses are established, how they are appropriated and exchanged, how they are combined with words and other pictures and made to play roles in narratives, and how they may have the effect of creating beliefs and desires."* (Mitchell, 1993, p. 192)

Mitchell's emphasis on use and narrative is particularly relevant to how Hubble images are recontextualised in public communication.

Another influential example is Roland Barthes, an influential semiotician who developed a theory of visual rhetoric that focuses on the "linguistic message" of the image located in captions and advertisement copy (Barthes, 1972). Barthes argued that the textual context of an image *"... remote-controls [the viewer] towards a meaning chosen in advance"* Barthes, 1977, p. 41), often shaping or constraining their interpretation.

Of course, Hubble's images circulate in a far more open fashion than advertisements, as Snider (2011) notes. A single image, like the Pillars of Creation, may appear in scientific archives, news broadcasts, art books and religious blogs. In each of those different contexts, the same image has different linguistic messages and, so, different meanings.

Greenberg (2004) argues that blackboxing is aided by how science is presented to the public as an absolute authority. As the public becomes increasingly removed from the centres of scientific production, communication becomes a one-way flow of information via mass media.

While astronomers are aware of many of the aesthetic enhancements that are made to the images to make them more visually appealing, these are often not communicated to the public. The result is a polished, authoritative image that goes unquestioned by the public. This widens the gap between what scientists know and what the public is allowed or able to understand.

Another of Greenberg's key arguments is that blackboxing makes Hubble images more susceptible to reinterpretation. As long as the new meanings do not conflict with science's perceived authority or the idea that the images are "absolute and unquestionable representations of the natural world" (Greenberg, 2004, p. 83), images can be repurposed – including by religious groups or educators. Occasionally, this repurposing leads to meanings far removed from their original scientific intent.

By emphasising visual drama over scientific explanation, public communication reinforces the image's status not just as data, but as an iconic, almost mythical object.

Paradoxically, the more technology and science succeed, the more invisible they become. While Greenberg attributed this primarily to the public's displacement from scientific centres, Latour emphasises that blackboxing is a structural feature of how knowledge is stabilised – not a trick played on the laypeople, but a necessary consequence of efficiency and trust in established facts.

From Data to Truth

The Aesthetics of Realism

The structural invisibility of mediation is not unique to science communication. Phenomenology and post-phenomenology offer parallel insights into how technologies recede from view when functioning seamlessly. Two influential figures in this domain are Martin Heidegger and Maurice Merleau-Ponty.

Heidegger's concept of the ready-to-hand (1977) comes to mind: tools, when functioning properly, recede from our conscious awareness. Their transparency is shattered only when something breaks – when colours seem "wrong", artefacts disrupt the composition, or, more dramatically, when a technical flaw like Hubble's 1990 mirror aberration is exposed. In such moments, the hidden scaffolding is forced back into view. In the 1990 Hubble crisis, a 2.2-micron error (only 1/30th of a human hair) made all observations blurry, transforming Hubble from a symbol of mechanical objectivity into a site of public embarrassment (Gianopoulos, 2025). The black box was opened, and its mechanisms scrutinised, until the 1993 servicing mission restored both its technical function and scientific authority.

Merleau-Ponty (1978) offers a similar example through his analysis of the habits of the body and perception. In "Phenomenology of Perception", he describes how, for someone who is blind, a cane ceases to be noticed as a separate object and de facto becomes an extension of the body's perceptual reach. Like Heidegger's (1977) hammer, Merleau-Ponty's cane recedes from the conscious awareness of the user while still mediating experience. The incorporation of tools into our bodily schema is not limited to hammers or canes; it can be extended to anything, from a driver's car to a set of glasses. Through habitual use, any of those becomes transparent in experience. These phenomenological accounts reveal that the invisibility of mediation is a fundamental aspect of how we inhabit and make sense of our technologically saturated world.

Both scientists and the public rely on black boxes to function efficiently, although the degree of this dependency will vary. This variation in dependency suggests that black boxes are not isolated but nested. One black box conceals many others. This aligns with the asymmetrical epistemic distancing discussed earlier. While the public often misses the constructedness of the outer aesthetic layer, astronomers may overlook elements of the technical infrastructure beneath it. Each black box adds a layer of mediation, and these layers operate recursively, obscuring their own conditions of possibility. As Latour notes, this process of rendering complexity into apparent simplicity is called punctualisation, where an entire network collapses into a single functional entity.

This tendency to conceal mediation is also explored in media theory, particularly by Bolter and Grusin (1999), who introduce this concept as immediacy. They argue that certain media are designed to erase their own constructedness by offering the illusion of unmediated presence, or a “transparent” view into the world. The more immediate the medium appears, the more successfully it masks the representational scaffolding that lies underneath. In this view, technologies such as Hubble images do not function merely as scientific instruments, but as media that participate in a visual regime of transparent immediacy.

Immediacy reinforces the very effects of blackboxing described earlier. It relates to Latour’s punctualisation, Heidegger’s ready-to-hand tools (1977), and the visual strategy of photographic realism: to disappear as media and be experienced as reality itself. By appearing frictionless and natural, Hubble images exemplify this aesthetic of immediacy – even while they are composed of layered mediation, selective data processing, and aesthetic choices. This is not simply a side effect but a defining characteristic of how these images derive their authority.

In contrast to immediacy, Bolter and Grusin (1999) also describe a mode they call hypermediacy – where the medium deliberately foregrounds its own constructedness. Rather than offering a seamless window into the world, hypermediated images remind the viewer of the processes, interfaces, and human decisions involved in their creation. Scientific data visualisation often operates in this mode. For instance, FITS files, calibration overlays, metadata or uncertainty maps all exemplify hypermediacy in astronomical practice. These images are not meant to be aesthetically coherent or emotionally resonant, but epistemically transparent – they expose selective parts of the scaffolding. In this sense, hypermediacy functions as a counterweight to blackboxing: it resists some of its erasure by maintaining a visible connection between representation and process. While hypermediacy exposes certain elements, others, like underlying software, instrument design, algorithmic assumptions, and broader infrastructure, remain undisclosed.

These related theories – blackboxing, ready-to-hand tools, immediacy and hypermediacy – all point to a shared insight: that technologies and media, when functioning effectively, tend to conceal their own mediation. In the context of Hubble's imagery, this illusion of immediacy allows constructed images to circulate as if they were objective windows onto the cosmos. But how exactly does this process unfold in practice? To answer this, we now turn to a concrete example: the construction, circulation and reception of Hubble's iconic "Pillars of Creation" image. This case reveals how aesthetic decisions, Institutional framing and media translation work together to naturalise mediation – and how, through this process, the image becomes both epistemically authoritative and culturally iconic.

Greenberg (2004) traces the trajectory of the "Pillars of Creation" image from its scientific origins to its public release to examine how an astronomical image is transformed across contexts. The image, which depicts a region of the Eagle Nebula (M16), underwent extensive changes before its presentation to the public. This case offers a concrete view of how aesthetic choices and institutional practices contribute to blackboxing.

The Eagle Nebula has always been a curiosity for astronomers, but up until the launch of Hubble, it had been out of reach for detailed observation (Gainor, 2020). In 1995, Hubble was aimed at the nebula to study the early stages of star formation within so-called EGGs (Evaporating Gaseous Globules) (Espinoza, 2025). This investigation, led by Jeff Hester and Paul Scowen from Arizona State University, marked the beginning of what would become one of Hubble's most iconic images.

Once the observation and validation process was complete, Hester and Scowen received the raw observation data from STScI and converted the binary data into a greyscale projection. According to their own account, the initial result left them "pretty speechless" (Greenberg, 2004, p. 84)

This greyscale version – the scientific precursor to the iconic image – contained several bright stars that obscured the featured Hester and Scowen intended to analyse. These stars were subsequently filtered out during processing to clarify the relevant scientific structures.

In the National Geographic documentary "Hubble's Cosmic Journey" (Riley, 2015), Hester reflects on the shift from an aesthetic to a scientific mode of viewing:

> *"... we were just blown away when we saw [the pillars]. We spent a while looking at them, just in awe of how gorgeous they were, and then … we found that not only were they gorgeous pictures, but there was a lot of fascinating science in them … It was fun the day that we got a hold of the data. We made a copy of the pictures and kind of ran up and down the hall in our department, finding anybody that we could find to show them to, and say, wow, look at this, and, you see this object? Here's a star being uncovered, and there's material boiling off this cloud."* (Greenberg, 2004, pp. 85-86).

While both Hester and Scowen initially responded to the image with aesthetic awe, their focus quickly shifted to the scientific potential it held – particularly its insights into early star formation.

Although the astronomers' primary interest lay in the image's scientific content, its public release required a more visually engaging version, and for that they had to be colourised. As Scowen explained, the chosen colours – red for singly ionised sulphur, green for the hydrogen and blue for doubly ionised oxygen – were *"not terribly real"* (Riley, 2015). The colours were meant to be representative but were ultimately selected because they *"looked better"* (Riley, 2015). This shift from functional greyscale to aesthetic colour marks a key moment of interpretive mediation that we recognise from Chapter 1.

Colour was only one of several aesthetic modifications made to make the image more attractive to the public (Greenberg, 2004). The composition was rotated so that the pillars appeared perfectly vertical, even though the true orientation of the observation is about 60 degrees more clockwise. This is supposed to make it come across as more “inspirational”. The framing of the pillars was changed to align them with the triangular field of view of Hubble’s WFC2 camera. In addition, the image’s contrast was greatly enhanced, and star diffraction spikes (the characteristic twinkles of the stars) were artificially added to evoke a more familiar and dramatic visual experience.

These aesthetic enhancements are not intended to deceive astronomers – and they generally do not. When professional astronomers are shown the false-colour version, their responses often reflect scepticism. Comments such as “It is so artificial looking, you wonder what part of it is right”, “I think this looks fake”, or “the stars should be white” (Achenbach, 1997) reveal a critical awareness of the image’s constructedness. Or, at least, its outer aesthetic shell. While the image may appear visually persuasive to the lay public, its modifications are often immediately apparent to experts.

Astronomers, although not immune to the beauty of an astronomical image – as Hester and Scowen’s initial reactions show – eventually rely on their disciplinary knowledge to interpret them. The aesthetic layer is often seen as secondary, or even as visual “noise”, when it comes to scientific analysis. As Lynch and Edgerton (1987) observe, astronomers conducting serious research almost always return to binary data and greyscale projections, which are more epistemically transparent.

Even if astronomers are less affected by the outer aesthetic layer of the black box, they remain embedded within its deeper structures. As discussed in Chapter 1, the complex processes of image acquisition, calibration and data reduction – though often taken for granted – form their own blackboxed network of practices.

While astronomers are often aware of the aesthetic enhancements of Hubble’s images, this awareness does not seem to filter through to the public domain (Greenberg, 2004). As previously discussed, this is likely in part due to the epistemic distance between the public and the image-making process – a gap that poses significant challenges for science communicators. This becomes especially clear in how images like the Pillars of Creation are disseminated: typically first through press releases, then filtered into scientific and mainstream media, and eventually embedded in broader cultural contexts.

To understand how public understanding of the images is given shape, Snider (2011) identifies three modes in which astronomical images function within publications – each with their own rhetorical effects.

First, an image can serve as an *illustration*. In this case, images are subordinate to the text. They function as visual evidence supporting a scientific narrative, with their meaning largely defined by the surrounding discourse.

Secondly, the image can serve as a *picture*. In this instance, images are presented primarily for aesthetic effects. As Snider (2011) notes, often these images cover full-page spreads with stunning visuals. Descriptions tend to be metaphorical, and beauty and emotional resonance are prioritised over scientific context.

Finally, an image can serve as *content*. Here, the image itself is treated as an object of analysis. Both the scientific data and the image's constructed nature are foregrounded. Often these images are accompanied by long descriptions, and almost no meta-narratives are present.

Snider's typology highlights how the same image can be framed very differently – sometimes as evidence, sometimes as artwork, and sometimes as an epistemic object.

The original "Pillars of Creation" press release clearly places the image within Snider's "picture" category. No effort is made to foreground its constructed nature, nor any suggestion made that the image was not an immediate window into space. The image is accompanied with metaphor-laden and emotionally charged language, using terms like "eerie", "dramatic", "striking", "ghostly pillars" and "elephant trunks" (Greenberg, 2024). This tone set the standard for media coverage that followed, as newspapers and magazines often replicated the same rhetorical framing established by the press kit. This further reinforces the image's status as both scientifically significant and visually sublime.

As Greenberg (2004) observes, the visual representation of the image often outweighs its textual explanations. In the New York Times, for instance, the image occupied nearly as much space as the accompanying article, while the Washington Post devoted twice as much space to the image as to the text (Greenberg, 2004, p. 87). Such layout decisions underscore a media logic where the image is treated not as something to be explained but as a spectacle – implicitly self-explanatory and thus epistemically autonomous. Greenberg (2004) writes:

> *"The overwhelming impression given by these various articles was that the real object of interest was the photograph, with (in some cases very little) text alongside to explain the real 'scientific' meaning of the image." (Greenberg, 2004, p. 87)*

The photograph becomes the focal point – not as a representation constructed through layers of scientific interpretation, but as a direct visual encounter with the cosmos. The minimal text offers little opportunity to reverse-engineer the image's production, reinforcing its blackboxed status.

The persistent separation between image and explanation enables black-boxing, even when explanatory information is publicly available.

Realism as Epistemic Shortcut

Since such materials rarely circulate alongside the images themselves, viewers are offered no cues that would prompt critical reflection. This structural decoupling results in a subtle but powerful form of obfuscation: not the hiding of facts, but the erasure of signals that would hint at the image's constructed nature.

The increased significance of the image over its description is even more apparent in television broadcasts, where visuals already dominate text. During the initial release of the "Pillars of Creation", CNN news anchors repeatedly referred to the images as "raw pictures" and emphasised that "only Hubble could show [these views]" (Greenberg, 2004). Such framing suggests a direct and unmediated capture of cosmic reality – a textbook example of immediacy, where the medium disappears and leaves only the illusion of presence.

This contrast is notable. In written media an author typically disappears in their writing, becoming an invisible authority – much like how Hubble images gain authority as the work behind them disappears. On television, by contrast, the reporter is visibly present. In theory, this presents an opportunity to reintroduce mediation into the picture, but in practice, this rarely happens. Reporters often position themselves as members of the lay public, distancing themselves from the science. As Greenberg (2004) notes, they adopt a "discourse of ignorance", presenting themselves as ordinary viewers who do not need to understand the technical details or mechanics of construction – because "that is the scientists' job" (Greenberg, 2004, p. 88). This rhetorical stance reinforces the epistemic distance between the public and the astronomers and further naturalises the authority of the image and equally the authority of science.

We see then that the way in which the "Pillars of Creation" are presented creates a metaphorical barrier between science and the public, thereby increasing the epistemic gap between them. This reinforces the blackboxing of its inner workings and implicitly positions the public as incapable of fully understanding the image, thus discouraging them from questioning it. Through this dynamic, the image is ceded to the domain of science, to be accepted rather than questioned.

This epistemic widening is not a unique occurrence in the history of astronomy. Crowther and Barker (2013) note that it has a striking resemblance to how the "intelligent eye" was trained in early modern astronomy. In this period, students were trained in the art of mental visualisation. This training had the intention to cultivate the student's "intelligent eye"—the ability to mentally manipulate and animate static diagrams into dynamic models of the cosmos. Only the students who had mastered this technique could claim to "see" and "understand" the cosmos. The rest—those without the "intelligent eye"—were left outside the circle of true comprehension, even if they could physically observe the heavens. This coincides with how Daston & Galison (2007) propose we understand atlases. In a similar fashion, the accounts of how astronomers process Hubble data are, essentially, training manuals for how to read the images, as well as how to make them (Kessler, 2012, p. 137).

This historical parallel highlights a persistent tension in the communication of scientific knowledge: the balance between making discoveries accessible and maintaining the authority of expert interpretation.

Strategic Obfuscation and Epistemic Authority

Photographic Realism as Visual Obfuscation

While Greenberg (2004) and Snider (2011) are valuable for understanding how astronomical images are transformed and circulated, one of Greenberg's claims merits closer scrutiny. He suggests that the public remains ignorant of the constructed nature of such images deliberately, writing that:

> *"These discoveries themselves can remain black-boxed and unquestioned by a deliberately ignorant lay public."*

This implies a conscious decision to avoid understanding. This framing, while provocative, overlooks an important nuance.

In this framing, images remain unchallenged until they break down or are problematised. But, in the case of astronomical imagery, the issue is not one of willful ignorance. Rather, it is the product of structural and aesthetic forces that render the images' constructedness invisible.

More often than not, the public is not wilfully ignorant but structurally uninformed. As Snider (2011) shows, the technical processes behind Hubble's image – including wavelength translation, colour mapping, and composition – are rarely made visible in public-facing formats.

The *illusion of immediacy* is not a result of active avoidance but rather of the seamless integration of scientific and aesthetic choices that present these images as direct representations of reality. The seamlessness is what makes the illusion so effective: it leaves viewers with no perceptual reason to suspect mediation.

An important factor for creating this seamless experience is the aesthetic of photographic realism. Astronomical images like the "Pillars of Creation" are created to maximise both scientific accuracy and aesthetic appeal. As English (2012) notes from her experience as an astronomical image-maker, this visual language – through choices in colour, contrast, and framing – mimics familiar photographic cues. These cues reinforce a sense of natural coherence (Cooperstein, 2014; Smith et al., 2015). This coherence renders the image intelligible to viewers but simultaneously conceals the layers of interpretive labour embedded within it.

The more persuasive the image, the more thoroughly its construction is concealed. As a result, this realism encourages viewers to interpret the image as a straightforward window onto the universe, rather than a constructed visualisation. In this sense, photographic realism functions as a visual strategy of obfuscation, erasing signs of mediation and presenting the image as a direct encounter with the cosmos.

Image processors at NASA and Hubble openly acknowledge the constructed nature of the aesthetic layers of the images; however, they hardly actively foreground it. Their goal is not concealment but engagement. They want to create images that resonate emotionally and visually with the public, often by using colour theory and compositional choices that make the image “catch the public’s eye” (Chandra, 2019). The public’s lack of critique, then, is not a matter of deliberate ignorance but a response to the persuasive power of the image.

Greenberg’s claim may hold in the case of other scientific visualisations, such as MRI scans or weather maps, where viewers readily acknowledge that they are seeing scientific representations, not literal photographs. In these cases, blackboxing happens naturally over time as a result of scientific and technical closure—people do not need to know how it works, only that it does. Though technically similar in their construction to Hubble images, these scientific visualisations retain visible traces of mediation, or, in the terms of Bolter and Grusin (1999), they are hypermediate. Their constructedness is not hidden – it is simply no longer disclosed.

Photographic realism, to the contrary, is deceptive: it conceals the constructedness while simultaneously eliminating the cues that might prompt viewers to notice it.

This is also where strategic obfuscation differs from Latour’s blackboxing. Latour emphasises stabilised scientific facts or technologies whose internal workings are no longer questioned once they work. Blackboxing happens over time, as the result of a natural process of closure. Strategic obfuscation, on the other hand, is intentionally maintained by actors and operates not on this level of scientific facts but in the public representation of these facts – especially through the awe-inspiring imagery. Strategic obfuscation is sustained through aesthetic choices, rhetorical techniques and media strategies – not just through technical reliability. Latour's blackboxing is about stability through use, while strategic obfuscation is about managing perception through design.

Until now, the discussion of obfuscation has focused primarily on its technical and visual dimensions. Yet, strategic obfuscation is also epistemic: it hides the mechanics of image construction and also distorts how knowledge itself is perceived and validated. In this context, the term epistemic refers to the conditions under which knowledge is produced and rendered credible. Astronomical images, especially those shaped by aesthetic choices, mediate – and sometimes distort – public understanding of cosmic phenomena.

Three Mechanisms of Epistemic Obfuscation

The public is not only unaware of how these images are constructed – they are also unaware that the image itself constitutes a knowledge claim. Each visual is shaped by scientific and aesthetic choices that frame what counts as truth. Photographic realism reinforces this effect by asserting – implicitly and powerfully – that what is shown is objective reality, rather than a contingent and interpretive reconstruction of data.

The first mechanism of this epistemic obfuscation occurs when aesthetic decisions are perceived as objective qualities. When this happens, elements such as colour, contrast, and composition are naturalised and taken as features that are natural to the cosmos, instead of being recognised as the products of subjective and institutional choice. For instance, the colours in the "Pillars of Creation" were carefully selected, not for accuracy, but to evoke emotional resonance and convey a sense of the sublime (Kessler, 2012). These aesthetic strategies shape public perception of cosmic beauty, but in doing so, blur the boundary between visual appeal and epistemic legitimacy.

The second mechanism involves the removal of visual indicators of ambiguity. Public-facing astronomical images often omit noise, artefacts, or data gaps that would signal the inherent uncertainty of the observation. While internal scientific analysis includes tools such as uncertainty maps and error margins (CalTech, 2012), these are rarely shown alongside public images. As a result, the final visual product appears seamless and definitive – encouraging viewers to interpret it as an ambiguous truth, rather than a best-fit interpretation bounded by limitations.

The third mechanism draws on Donna Haraway's (1988) concept of the "god trick" – the illusion of a neutral, all-seeing perspective that denies its own positioning and framing. In astronomical imagery, this is achieved by erasing the presence of astronomers, institutions, funding priorities, and even Hubble itself that determine what is observed and how. The result is a simulated "view from nowhere" – a representation that appears to float outside human subjectivity. By concealing its constructedness, the image reinforces its authority as a self-evident glimpse into cosmic truth. In Latourian terms, this is the final step in stabilising a network: the transformation of a complex, contingent process into an unquestioned fact.

As we have seen, obfuscation is not only a matter of hiding technical details – it plays an active role in shaping how the cosmos is conceptualised. When constructed Hubble images are presented as immediate, science is framed not as an interpretive practice but as a passive and transparent recording of nature.

This dynamic creates a self-reinforcing feedback loop. As the public interprets Hubble images as immediate depictions of reality, they are more likely to accept institutional narratives as unquestionable truths. In doing so, they overlook the role of aesthetic design, funding structures and cultural values in shaping those outputs. This oversight, in turn, strengthens the illusion of objectivity, further reinforcing the notion that science merely records nature rather than interprets it – and the cycle continues.

In short, the black box hides how images and knowledge are made and who decides what is real. This produces a closed epistemic loop, in which public understanding is shaped – and limited – by the very images meant to inform and inspire.

This insight brings us to a pivotal point in the thesis. We have now seen several things:

(1) Hubble images involve extensive human labour and technological mediation in their production.

(2) These layers of mediation are progressively blackboxed through what Latour calls punctualisation; meaning that they fade from view as they become accepted and successful.

(3) Photographic realism is a contributing factor to this obfuscation by creating an illusion of visual immediacy.

(4) Epistemic distance is another contributing factor, as it leads to a gap in what can be communicated and how between the public and science.

(5) Thus, this process of blackboxing is not only technical or visual but also deeply epistemic – affecting what is seen, what is known and by whom.

With these dynamics in place, we can now turn to the final step in this chapter: reiterating how this process of obfuscation contributes to the epistemic and cultural authority of Hubble images.

Obfuscation as a Source of Authority

Scientific Objectivity and Visual Credibility

Now that we have traced the multiple layers through which Hubble imagery is constructed, blackboxed, and visually naturalised, we are in a position to restate the central thesis of this chapter: the authority of Hubble's images is not simply a result of what they show but of how convincingly they conceal the fact that they are showing anything at all.

In science, authority is closely tied to the ideal of objectivity (Daston & Galison, 2007). Scientific objectivity is widely regarded as a foundational principle that underpins the credibility and authority of science in society. This connection arises because objectivity is understood as the practice of minimising personal biases, value judgements, and community interests in scientific claims, methods, and results (Daston & Galison, 2007). The authority of scientific knowledge is thus rooted in the perception that it is produced through neutral, reliable, and replicable methods, rather than being shaped by individual or collective preferences.

Objectivity is often cited as the primary reason for valuing scientific knowledge and trusting scientific expertise (Daston & Galison, 2007). When science is seen as objective, its findings are more likely to be accepted as authoritative and legitimate by both the scientific community and the broader public. The scientific method – characterised by structural observation, hypothesis testing, experimentation, and peer review – serves to reinforce objectivity and, by extension, the authority of scientific conclusions.

We can start to see how the illusion of immediacy plays into this dynamic. Despite their reliance on “subjective” human interpretation and technological mediation, Hubble’s images are presented in a way that suggests direct, unfiltered access to cosmic reality. This illusion of immediacy makes the images appear as though they are neutral, objective records of the universe, rather than the result of complex technical and interpretive processes.

Essentially, what happens then is the evocation of authority through apparent neutrality. The authority of Hubble images, and by extension the authority of science, is reinforced by the perception that these images are objective, mediated and trustworthy. The illusion of immediacy conceals the interpretive work behind the scenes, making the scientific process appear more neutral and authoritative than it actually is. This aligns with an argument Daston and Galison (2007) make that authority in science is historically tied to the ideal of objectivity, which is itself a constructed and evolving standard.

Daston and Galison (2007) show that objectivity in science is not just about the content of images or data but about the practices and visual conventions that render the process of mediation invisible, creating an impression of direct immediate access to nature. In their study of scientific atlases, they demonstrate how the authority of images is constructed through the suppression of visible traces of human intervention – whether through idealisation, mechanical reproduction or expert judgement. This concealment is not accidental but is a deliberate feature of the pursuit of objectivity, which seeks to minimise the appearance of subjectivity and bias.

Hubble images function through similar dynamics. Their authority is evoked through the convincing appearance of neutrality and the illusion of immediacy, achieved by hiding the interpretive labour that makes the images possible and visually naturalising them.

To a large extent, this explains the epistemic authority that the images gain, but what about the cultural authority?

The Cultural Power of Awe

The cultural authority of Hubble's images has a strong connection to the emotional and aesthetic impact that they have. This impact goes far beyond the images' capacity to serve as reliable and accurate scientific evidence. Kessler (2012) notes that while the images' scientific value is rooted in their perceived objectivity, their cultural power arises from their beauty, recognisability, and ability to evoke awe and sublimity. These would then be the qualities that transform them into icons and symbols within popular culture.

This is reflected in the fact that Hubble's images are not just scientific data; they have become part of the cultural fabric, appearing on everything from stamps and clothing to art, music, and movies. Kessler (2012) also argues that part of that power comes from the fact that their colours and compositions resemble familiar landscapes (see Figure 21). She argues that this resemblance makes them both accessible and breathtaking to the general public. Whether this is true or not, one thing is clear: these images inspire excitement, imagination, and a sense of connection to the cosmos, even among people with no scientific background. This emotional resonance is what Mitchell refers to as the "Medusa effect" (Mitchell, 1995, p. 36) – the power of images to arrest viewers, provoke wonder, and become objects of fascination and reverence. At the same time, this emotional resonance (see Figure 22) amplifies the *illusion of immediacy*, making the viewer feel as if they are witnessing an immediate cosmos, which intensifies their emotional response.

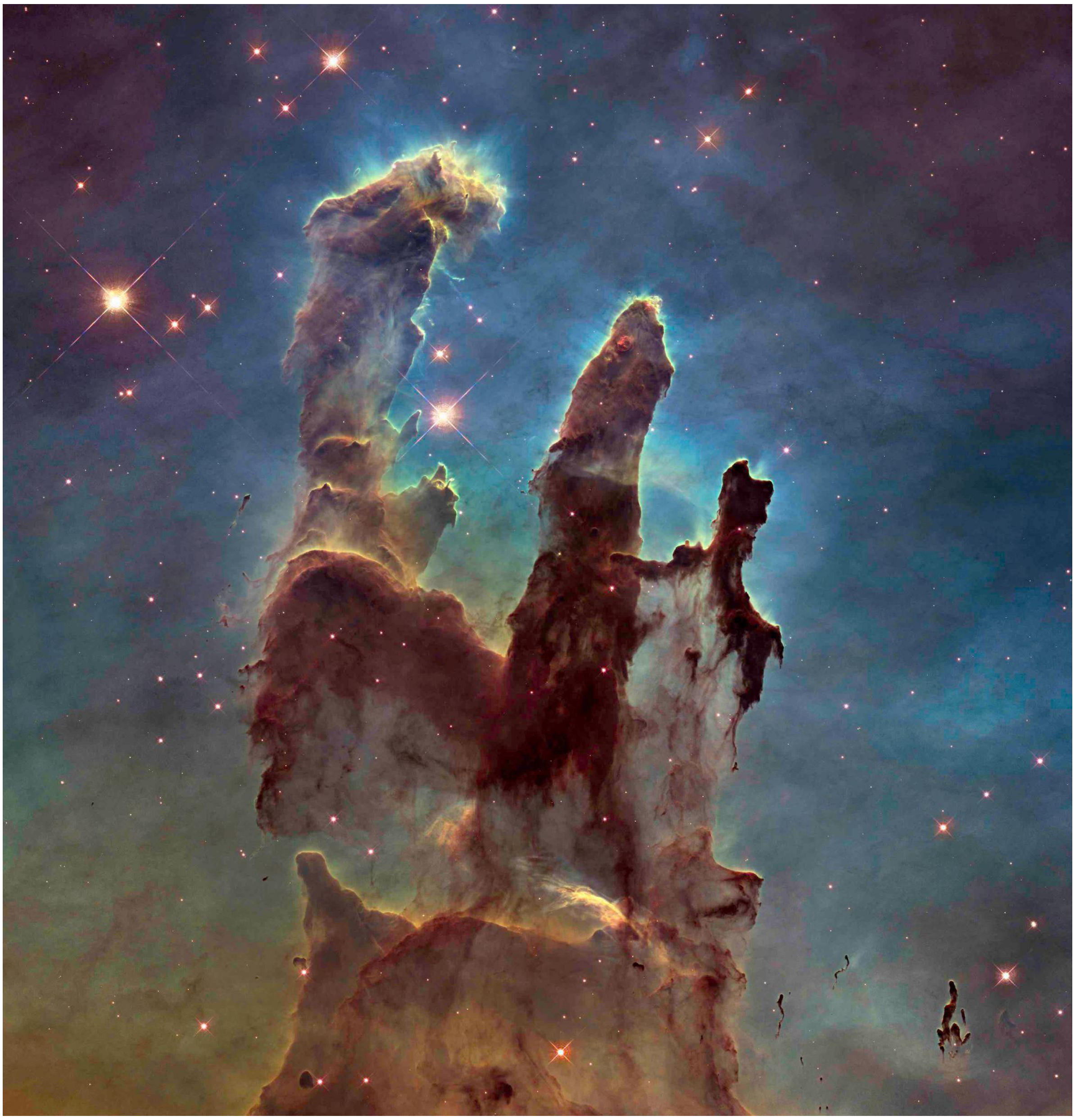
Figure 21

(a) Left: The Keyhole Nebula. (b) Right: Cliffs of the Upper Colorado River, Wyoming Territory, by Thomas Moran (1882).

Note. This juxtaposition highlights visual and thematic parallels between astronomical imagery and romantic landscape painting. The Hubble image of the Keyhole Nebula (left) reveals intricate interstellar gas formations, while Moran's painting (right) captures dramatic geological forms and atmospheric effects. Both images evoke a sense of sublime natural grandeur and emphasise the use of light, colour, and texture to convey depth and dynamism. Credits: (a) NASA/ESA, The Hubble Heritage Team (AURA/STScI); (b) Smithsonian American Art Museum; Bequest of Henry Ward Ranger through the National Academy of Design.

Figure 22

The Pillars of Creation in the Eagle Nebula, captured by Hubble.



Note. This image shows the Pillars of Creation in the Eagle Nebula, originally photographed by the Hubble Space Telescope in 1995. The version reproduced here is a later, higher-resolution image captured in 2014 to commemorate Hubble's 25th anniversary. In this updated version, improved imaging techniques and different wavelengths, including infrared, were used to provide a sharper and more detailed view of the gas columns. Although the aesthetic choices involved in rendering the image remain interpretive, the presentation emphasises a sense of direct, natural vision. Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA).

One way to understand the emotional power of Hubble imagery is through the concept of the sublime. Rooted in the aesthetic theories of Burke and Kant, the sublime describes a form of beauty that overwhelms the senses—an encounter with vastness, power, or mystery that exceeds the capacity for rational thought. When viewers confront the scale, complexity, or apparent timelessness of Hubble's cosmic scenes, they are often moved not by the content of the image but by its affective force. As Lyotard (1984, p. 78) suggests, "The *sublime ... takes place ... when the imagination fails to present an object which might, if only in principle, come to match a concept."* In other words, the sublime is not linked to the pleasure of understanding but rather to the pleasure of recognising the limits of understanding—a feeling that resonates strongly with astronomical imagery, where the cosmos appears infinite, indifferent, and beyond human scale. This experience of cognitive and emotional awe grants the image a kind of spiritual or metaphysical gravity, reinforcing its cultural authority not through explanation, but through felt significance.

The cultural authority of the images is not just about what they show or how convincingly they conceal their constructed nature. It is also about how they move us – how their beauty, familiarity, and sublimity foster awe, wonder, and even reverence, making them powerful symbols that shape collective imagination and cultural identity. This emotional and symbolic dimension is what elevates Hubble's images from scientific documentation to a cultural phenomenon.

To restate an argument Mitchell (2005) makes, images do not simply show; they act. They act as if they are a person. They have an aura that seems to speak, to want, and to compel. Hubble's images demonstrate this logic. They ask the viewer not only to see them but also to believe them. Their authority is enhanced by the obfuscation of the processes that construct them. The less visible these are, the more natural the image seems, the more believable the image, and the more credible the knowledge.

Strategic Obfuscation: NASA's Visual Regime and the Politics of Awe

In the previous chapters, I have shown how Hubble images are mediated artefacts, yet perceived as immediate views of the cosmos. I have also argued that this obfuscation—and the resulting *illusion of immediacy*—contributes to the epistemic and cultural authority of the images. Now that this central thesis has been established, we can examine how these dynamics are further amplified by institutions such as NASA and the STScI.

In summary of the previous chapters, the *illusion of immediacy* results from the strategic obfuscation of the interpretive labour (Lynch & Edgerton, 1987; Daston & Galison, 2007) and technological mediation behind the images. This obfuscation is strategic because it is both deliberate and goal-oriented. It refers to the conscious shaping of how scientific images are presented to the public in order to achieve a specific outcome. This distinguishes it from unintentional obfuscation, which might arise from the technical complexity of the scientific image, or blackboxing, which happens as a natural process due to how scientific and technological artefacts become stabilised (Latour, 1987). Strategic obfuscation is therefore not deception in a malicious sense. This chapter will demonstrate that. Rather, strategic obfuscation is about selectively disclosing and framing information to maximise rhetorical and political impact while minimising friction and misunderstanding. As a result, the *illusion of immediacy* is what viewers experience after strategic obfuscation has taken place—it is the feeling that they are seeing the universe "as-is".

In this chapter, I examine how institutions like NASA and the Space Telescope Science Institute (STScI) amplify the *illusion of immediacy* of Hubble images through strategic positioning and branding. I argue that this strategy serves both epistemic and institutional goals as it enhances public trust while securing political legitimacy (Keltner, 2007; McCray, 2014) and funding (Keltner, 2007; McCray, 2014) for space science. Through this process, the Hubble image becomes more than just a visual artefact but also a rhetorical and political tool, designed to capture, persuade, and mobilise the public.

While blackboxing can occur in all scientific artefacts—as Latour argues in "Science in Action" (Latour, 1987)—the *illusion of immediacy* is aided by an aesthetic tradition of photographic realism (Kessler, 2012) that sustains a sense of objectivity (Daston & Galison, 2007) and by public dissemination practices that emphasise visual spectacle while downplaying interpretive labour (Greenberg, 2004; Snider, 2011). These traditions contribute to a communicative style that affirms the epistemic distance between scientific institutions and the public.

Historical and Institutional Context

Several empirical studies (Arcand et al., 2013; Smith et al., 2015) have pointed out that the effects of the visual choices made in public outreach strategies are generally not well understood. These studies suggest that astronomers are increasingly concerned about how certain aspects of images, such as colours, are perceived by the public and how this affects their trust in science (Arcand et al., 2013, p. 25). While it appears as if this contradicts the notion of *strategic obfuscation*, in reality it does not. NASA or the STScI need not understand the deeper epistemic and cultural effects of their strategy to see that it is an effective way to achieve their goals.

Similarly, studies suggest that during the early stages of the Hubble mission, public outreach was not yet a concern (Christian & Kinney, 1999). A NASA survey conducted among the scientific community (Brown, 1993) indicates that the agency's focus, when selecting cameras for installation on the telescope, was exclusively on their scientific utility. Notably, this study dates back to 1992, while the release of the "Pillars of Creation" image in 1995 and the thousands of images that followed are a good indication that priorities may have shifted over time.

The Rise of Public Outreach

Indeed, there is evidence that public outreach and the dissemination of Hubble images to the public have become increasingly important (NASA, 2023; STScI, 2025i). One key example is the establishment of the Office of Public Outreach (OPO) at the STScI, which tracks and actively promotes Hubble's discoveries through what it describes as "high-impact products" (Marcucci et al., 2019, p. 1). The OPO has developed many diverse outreach programmes. Their website (STScI, 2025i) lists programmes ranging from interactive websites, multimedia content, and public events to collaborations with artists and musicians, all aimed at engaging the public.

Web statistics also reflect a spike in public engagement with Hubble images following major image releases. Christian and Kinney's (1999) report on the public impact of these images notes that the release of the "Hubble Deep Field" in 1996 attracted 4.46 million unique visitors to the STScI website, while the "Pillars of Creation" in 1995 drew 2.45 million visitors. This widespread access only became possible due to a set of significant technical advances in the late 1970s and 1980s, including the proliferation of personal computers and the emergence of the World Wide Web. However, accessibility to the internet at that time was still limited for most people, making these numbers very impressive.

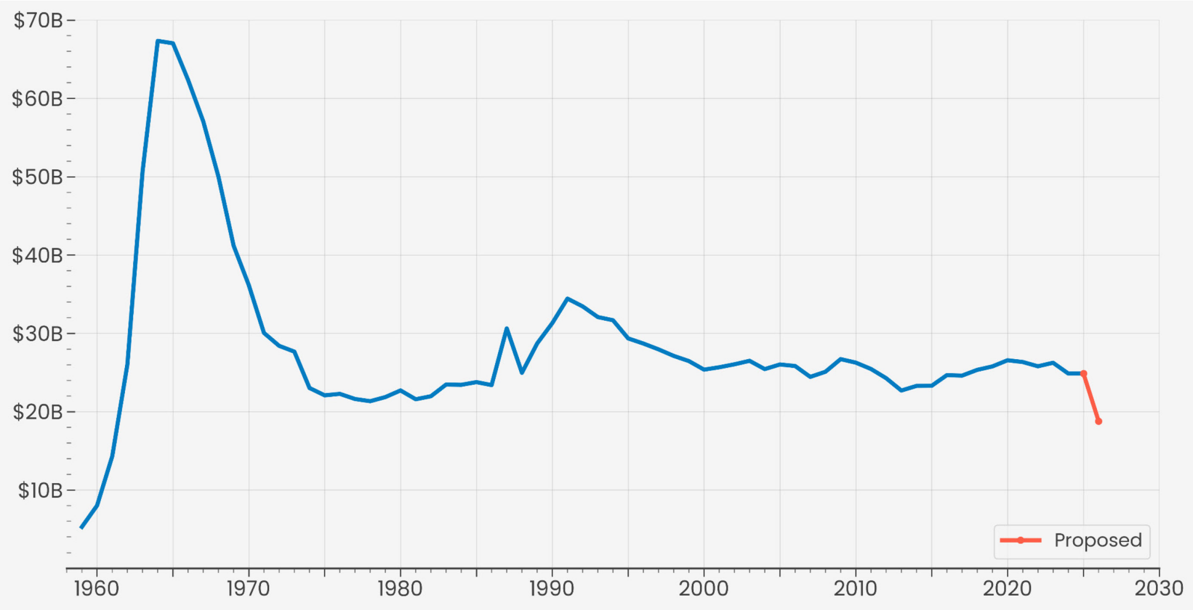
Hubble's Origins, the Cold War and NASA's Funding

When the United States wanted to send men to the moon, astronomers initially lacked information on the exact distance to the destination (Crease, 2023). While distances to stars and galaxies are expressed in light-years, in reality, these are simply estimates. For a complex undertaking like bringing people to the moon, exact distance measurements were essential. More broadly, distance is crucial to almost anything else in astronomy. Hubble was designed to accurately measure cosmic distances, a capability that would be crucial for future astronomical research and programmes (Gainor, 2020).

Astronomy is largely dependent on taxpayer money (Dick & Launius, 2012). During the Cold War, NASA's funding was mostly given shape by the geopolitical rivalry between the United States and the Soviet Union (Dick & Launius, 2012; Gainor, 2020). The launch of Sputnik in 1957 triggered a spike in U.S. government investment and interest in space and science, motivated by their desire to demonstrate technological and ideological superiority (Dick & Launius, 2012). NASA's budget grew from virtually nothing in 1948 to over 100 million in 1957, peaking at $7 billion in 1967 (Dick & Launius, 2012)—equivalent to over $67 billion in today's dollars; see Figure 22—representing over 4% of the entire federal budget (The Planetary Society, 2024). This period, especially the Apollo programme, is widely regarded as NASA's "golden age".

Figure 22

NASA Budget Justifications, FYs 1961-2026



Note. This line graph shows the inflation-adjusted budget for NASA from 1961 through 2026. The steep peak in the 1960s reflects spending during the Apollo program. Since then, NASA's budget has generally declined or remained stable in real terms. The red segment near the end represents proposed budget values for upcoming fiscal years. Credit: (The Planetary Society, 2024).

This extraordinary level of funding was justified politically as essential to winning the space race and countering Soviet advancements (Gainor, 2020). However, following the successful Moon landing in 1969, both public and political interest faded. NASA's budget was subsequently reduced to less than 0.5% of the federal budget. By the 1970s, as the Cold War tensions shifted and other national priorities emerged, NASA's share of federal spending dropped and never returned to its Apollo-era high (The Planetary Society, 2024). Without the existential competition of the space race, NASA had to find new ways to justify its funding to Congress and the public.

As a result, NASA was forced to cancel[8] or scale back many of its programmes (Gainor, 2020). Over time, the agency began to rely increasingly on public support to secure political backing and funding for its remaining and future missions (Dick & Launius, 2012).

Conceived in the 1970s and launched in 1990, Hubble became an icon for NASA's efforts to justify and secure funding in the post-Apollo era. Ironically, at several points throughout the years, Hubble's funding had been in jeopardy. The U.S. Congress questioned its high costs, and at one point, all funding was temporarily cut (Kessler, 2012; Gainer, 2020). The situation prompted a nationwide lobbying effort from the scientific community.

This pattern has continued: NASA's ability to maintain or grow its budget often depends on its capacity to generate public enthusiasm and demonstrate the value of its missions to policymakers. The use of Hubble's images of the universe became a powerful tool for NASA to demonstrate the value and impact of its scientific missions to lawmakers and the public.

Hubble's images helped NASA build public and congressional support (Christian & Kinney, 1999), making the case that space science could inspire, educate and yield profound discoveries even in the absence of Cold War rivalries. The visual impact of Hubble's photos had a big role to play in rallying this support for continued funding, especially when budget cuts or mission cancellations were threatened Christian & Kinney, 1999).

When Hubble first launched, it was plagued by its spherical aberration; it was deemed a massive failure and embarrassment, and public support was at an all-time low, as Hubble had become a super expensive piece of space junk. It almost never got repaired (Kessler, 2012). Only with the release of its first images did NASA redeem itself in the eyes of the public.

Another example is the crisis in the aftermath of the Colombia crash. All future servicing missions to the telescope were cancelled by the government, as they were

[8] One of those cancelled programmes includes the "Grand Tour", a program that would have attempted to sent robotic probes to all planets of the outer Solar System

deemed too dangerous (Gainor, 2020). This has shown and emphasised how important it is to have public opinion on your side. Hubble's images have played a major role in keeping this public opinion and in mobilising the public for persuasive power on the government to keep funding going.

Cold War funding for NASA was driven by geopolitical competition, but after the Cold War, NASA relied more and more on the scientific and inspirational value of missions like Hubble – using its stunning images to maintain public and political support for its budget.

Engineering Awe

From its inception, NASA has understood that the success of space missions depends not only on scientific outcomes but also on public visibility and emotional engagement. As scholars like McCray (2014) and Dick & Launius (2012) have argued, NASA's public image is as constructed as its missions. Hubble images occupy a unique place in this strategy. They offer beautiful views of the cosmos that captivate audiences, often divorced from the scientific data or processes that produced them.

The beautiful views and inspirational experience became something entirely different. This face of the Hubble images is what bolstered the public, not the science. The illusion of immediacy, making the viewers feel as if they are seeing the universe directly through Hubble's "eyes", is of vital importance for the image. This immediacy creates a sense of connection with the universe and creates a feeling of awe and wonder, allowing people to experience the cosmos as if they are witnessing it firsthand. Hubble is, in this sense, an extension of their own mind. If this illusion is broken, and people are reminded that Hubble images are the result of a whole chain of human interventions, it can diminish the emotional and inspirational power of the images. It is like watching a movie after first watching the "making of". It takes away the magic.

Maintaining the illusion of immediacy helps preserve the sense of authenticity and wonder, which is essential for public engagement and continued support for space science. This has everything to do with the authority of the images. When viewers believe they are seeing the universe "as-is", the images gain credibility as direct, trustworthy evidence of astronomical phenomena. This perception underpins the scientific and cultural authority of Hubble images because they are not simply seen as artistic renderings but as authentic records produced by a sophisticated objective instrument in space capable of extending their first-hand experience to a different place in space and time. If the illusion of immediacy is broken, an image not only loses its magic, but its authority as scientific evidence may be questioned.

The Hubble Heritage Project (established in 1998) exemplifies this institutional intent. Its goal was not only to process scientific data but also to curate it into compelling visual narratives. Image-makers selected targets for aesthetic value as much as scientific merit. As Jayanne English—an astronomer and image processor—has noted, outreach images often serve a dual function: they communicate scientific information while also fulfilling “cultural, educational, and political objectives” (English, 2017, p. 10).

A Celestial Monopoly

Since the 1990s, NASA, via STScI and via the Hubble, has maintained an almost unrivalled monopoly on how the public visually engages with the cosmos. This dominance is both technical and scientific, as well as cultural and political. The sheer volume and quality of Hubble images circulating in educational, media, and even artistic contexts have made sure that STScI's visual style and narrative framing have become almost synonymous with “what space looks like”. Even in amateur astrophotographer circles, this influence is unmistakably there. They adopt things such as the “Hubble Palette” in their astrophotography and draw on the same tropes.

This “monopoly” of astronomical images has several implications. It gives NASA disproportionate influence over the public's imaginative relationship with space. Alternatives to imaginaries struggle to gain comparable traction or simply remain very niche. Second, it reinforces a specific epistemic and aesthetic regime. This politics of dominance becomes clear when we consider how rarely the public encounters space imagery that does not pass through NASA's visual pipeline. Even ESA and other international partners often adopt

NASA's outreach templates. As such, the institutional voice of NASA becomes conflated with the voice of astronomy itself.

This near-monopoly serves NASA's strategic interests. It centralises public attention, maintains funding legitimacy, and consolidates institutional authority. However, it also marginalises alternative ways of seeing and knowing the universe – whether through less spectacular imagery or through interpretations that foreground scientific uncertainty and interpretative labour.

Institutional Intermediaries

The construction and circulation of Hubble images involve not only scientists and artists; a crucial role is played by science information professionals, such as NASA’s public affairs officers and outreach teams, who serve as mediators between science, the media, and the public. These professionals, as Jackson (2013, p. 6) notes, “are not usually trained in science and often are seen by both scientists and reporters as representatives of organisational administration” (Jackson, 2013, p. 6). They occupy a hybrid position, translating complex scientific data into accessible stories while simultaneously safeguarding institutional reputation and maintaining public interest.

This tension is compounded by mutual mistrust. As Jackson (2013, p. 6) observes, there is a *“general impression that scientists don’t communicate very well on their own”*, and many scientists perceive media engagement as a threat to their integrity. At the same time, media professionals seek compelling narratives, often prioritising drama, simplicity, or emotional appeal. “Media creators are all trying to tell an engaging story within the bounds of their type of media,” whereas scientists are primarily focused on being accurate in their research and in the reporting of their study (Jackson, 2013, p. 6). These divergent goals produce a constant negotiation of accuracy, appeal, and authority.

Science information professionals are thus not neutral brokers. They are, as Jackson (2013) emphasises, “invested in trying to control the attention paid to and the reputation of their organisations” (Jackson, 2013, p. 6). This includes curating which Hubble images are released, how they are framed, and what explanatory context accompanies them. Their role supports the broader institutional strategy of amplifying public awe while avoiding epistemic or reputational disruption.

Importantly, the communicative challenge is also shaped by assumptions about the public itself. The audience is often treated as scientifically illiterate, which justifies the simplification or aestheticisation of scientific content (Jackson, 2013, p. 6). However, this "deficit model" of science communication—where laypeople are seen primarily as lacking knowledge—is not unproblematic. As scholars such as Alan Irwin (1996) and Brian Wynne (1992) argue, communicators should not assume their role is simply to "correct" public ignorance. All data is subject to interpretation—including by laypeople. The historical ideal of the "citizen scientist", capable of engaging directly with scientific ideas, has faded as expertise became more institutionalised and less accessible (Wynne, 1992; Irwin, 1996).

This layered mediation—from scientist to public outreach officer, from public outreach to media, and finally to public—creates a chain of representation that distances the public ever further from the construction of scientific knowledge.

Visibility, Authority, and Institutional Power

NASA's visual strategy is part of a broader rhetorical tradition. Historical studies reveal how NASA has long fused technological achievement with narrative mythmaking. Keltner (2007) writes in her doctoral dissertation, "From Myth to Metaphor to Memory", how televised Apollo coverage deployed themes of nationalism, romanticism, pragmatism, and technological glorification to build public support (Keltner, 2007). These rhetorical strategies persist to this day—only now, they are embedded in visual media, such as Hubble images.

Roger Launius, a former NASA chief historian, proposes a deeper cultural reading: the American investment in spaceflight is underpinned by what he calls the "religion of spacecraft" (Dick & Launius). According to Launius, space exploration is framed as an almost sacred pursuit—a manifestation of national destiny, innovation, and transcendence (Dick & Launius, 2012). In this view, NASA becomes not only a scientific authority but also a spiritual and cultural beacon.

Together with Steven Dick, Launius has analysed how NASA imagery, public outreach, and media relations reinforce this cultural mythology (Dick & Launius, 2012). Their work shows how spaceflight advocacy draws on narratives of frontier pioneering, free enterprise, and boundless progress—concepts central to American self-identity (Dick & Launius, 2012; Kessler, 2012; Keltner, 2007). These themes are not abstract: they are made visible in images of deep space, where vast, awe-inspiring vistas evoke a sense of grandeur and purpose.

Kessler has extended this analysis to Hubble imagery (Kessler, 2012), showing how its photographic realism and compositional style align with traditions of American landscape painting and Romantic naturalism. These visual tropes support a narrative of discovery that is both nationalistic and metaphysical.

In this way, NASA’s use of Hubble images is not just about communicating science. It is about performing cultural leadership, justifying funding, and reinforcing institutional legitimacy. Obfuscation, here, becomes a strategic asset: by hiding the layers of interpretation behind an aesthetic of immediacy, the image appears as both evidence and icon.

Conclusion

This thesis set out to critically analyse how Hubble images gain epistemic and cultural authority. The central argument has been that the authority that the images have come to possess is not due to their scientific accuracy or to the images' awe-inspiring or wonder-inspiring nature. Instead, this authority is aided by a deeper process of strategic obfuscation, wherein the interpretive and technological mediations that construct the image are systematically concealed. Through a detailed analysis of Hubble's imaging pipeline, theoretical insights from several domains (e.g., science and technology studies, semiology, visual epistemology, visual culture studies, history of art, and phenomenology), and a critical analysis of the institutional amplification of obfuscation to secure political legitimacy and funding, this work has highlighted how an illusion of immediacy is constructed, amplified, and mobilised.

Throughout the three chapters, a clear, multi-layered picture has emerged. Chapter 1 revealed that Hubble images are not the naturalistic depictions of cosmic reality they appear to be, but instead sculpted visual artefacts that come to life through a chain of technical and interpretive translations, including instrumentation, calibration, and aesthetic decision-making. Chapter 2 demonstrated that these layers of mediation are obfuscated by an outer aesthetic layer of photographic realism and the reinforcement of an epistemic gap between the public and science. These two elements aid an illusion of immediacy that imbues the images with a dual authority through scientific legitimacy and cultural resonance. Chapter 3 extended and deepened this analysis by showing how institutions like NASA and STScI strategically amplify this illusion of immediacy through public outreach, branding and PR strategies, thereby reinforcing a political economy of visibility, trust, legitimacy and funding.

This thesis contributes to the domains of STS and visual epistemology by showing that epistemic authority does not arise only from data or facts. Instead, it can be co-produced through visual aesthetics (photographic realism) and institutional narratives. It challenges the idea that science speaks for itself by arguing that Hubble images gain their authority because they are carefully constructed to appear objective and awe-inspiring, aided by how they are framed visually and narratively. Drawing on Latour’s black-boxing, Barad’s notion of intra-action, and Ihde’s material hermeneutics, I have shown that Hubble images have a certain agency: they do not just reflect cosmic reality but actively participate in its construction, both visually and epistemically. Moreover, I have argued that scientific objectivity is not opposed to aesthetic design but rather entangled with it. This challenges the common idea that science is neutral and art is subjective. Instead, I show that scientific objectivity depends on aesthetic choices, such as how colours are chosen, how contrast is adjusted or how images are framed. This supports Daston and Galison’s concept of trained judgement by arguing that objectivity does not mean the absence of interpretation and that this interpretation is informed by expertise and standards. By framing these interpretive decisions as essential to the construction process, I demonstrate how Hubble images' credibility is the result of this tension: they are not exclusively data-driven nor exclusively aesthetic but positioned epistemically in the productive middle.

While the thesis deliberately emphasised the hidden, often invisible work that goes into producing Hubble images, it did not analyse how diverse publics interpret or emotionally engage with the images. Neither did it compare how they aesthetically or epistemically differ from the images of other telescopes that operate in similar or different electromagnetic ranges, such as the James Webb Space Telescope, the Chandra X-ray Observatory or ground-based telescopes. Moreover, while I hinted at some of the political stakes behind these images—such as how the images contribute to public legitimacy and trust in science and how they are used to source funding for NASA—a fuller political analysis—for example, about how the images operate as rhetorical or ideological tools within neoliberalism or nationalism—lies beyond this thesis’ scope. These limitations reflect the necessary trade-offs that had to be made in order to give a full and detailed account of the construction and authority of Hubble images.

This thesis highlights a broader ethical and educational need for transparency and the critical engagement with scientific imagery. In a time where data visualisation and technological “seeing” are everywhere, it becomes increasingly important that the public understands how these images are made. If people are being misled by the aesthetics of scientific images, that is not just a philosophical issue; it also affects how science is funded, taught, and believed and could ultimately negatively impact the public’s trust in science, media literacy and democratic discourse. Future research could explore how other telescopes or scientific instruments match or differ from the aesthetic and epistemic strategies behind Hubble images. They could also investigate how different publics interpret Hubble images in the same or different contexts. One relevant question could be: What happens when AI is increasingly introduced into the imaging pipeline? Another could be: how do viewers feel or react when they learn about the *illusion of immediacy?* Does this influence how enchanted they feel? Do they feel misled, or, perhaps, informed? Does the medium qualitatively affect the interpretation of Hubble’s images? Or, on the science communication side: what would be more ethical ways of disseminating and presenting astronomical images?

Ultimately, this thesis is not an attempt to dispel the magic of Hubble images, but rather to give them context. It starts with the philosophical belief that wonder and criticism can coexist and even enrich one another. You can be emotionally or existentially moved by an image, while simultaneously recognising that it is constructed, ideological and historically contingent. We can begin to understand that reality is not degraded by being mediated; it is produced and made meaningful through mediation. In doing so, we come to see the image not only as a window to the stars but as a mirror reflecting our tools, our choices, and our ways of knowing. Hubble’s Cosmos is a human and technological cosmos, but it is breathtaking nonetheless.

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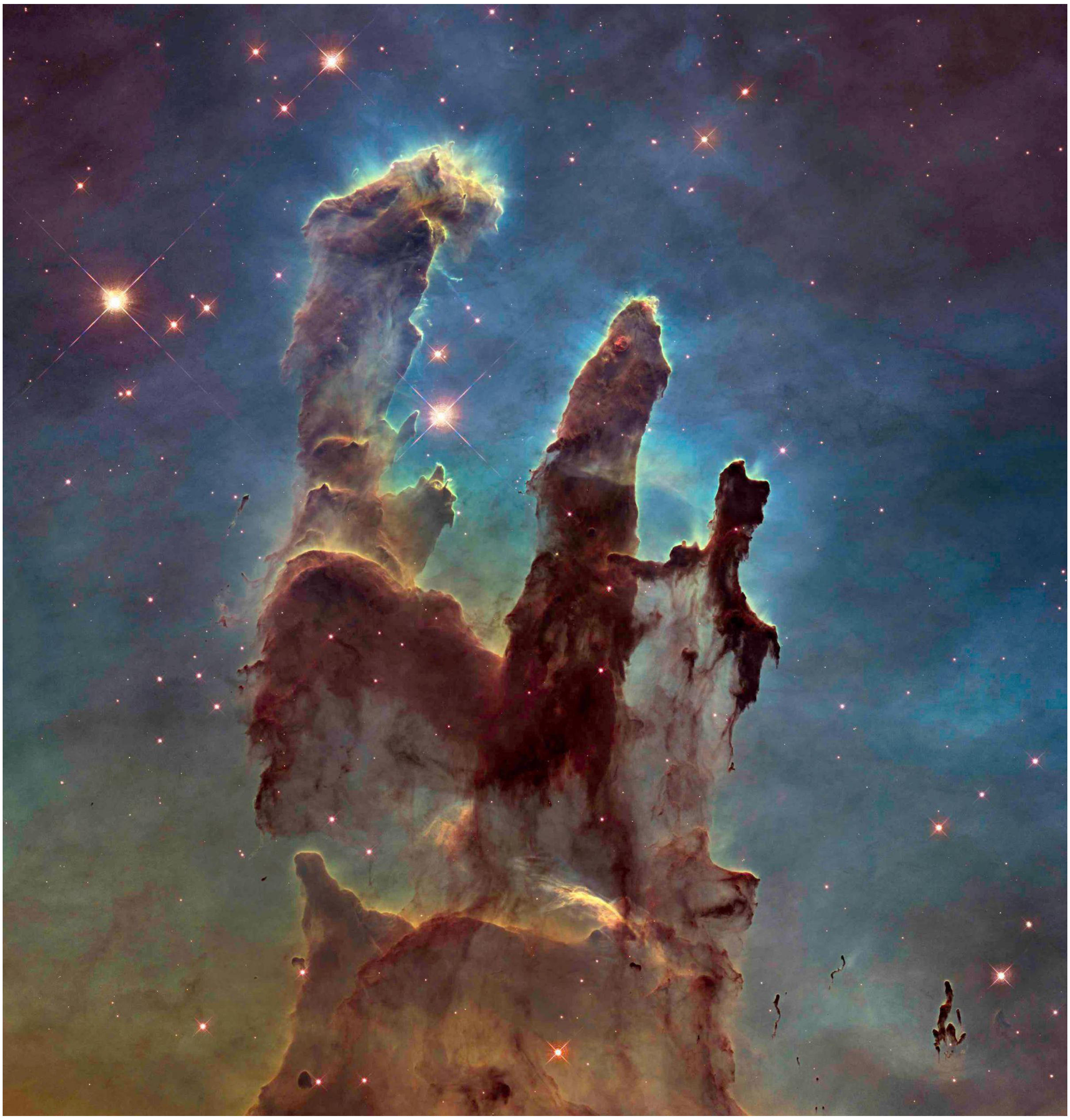
Appendixes

Appendix A - Key Hubble Images

Pillars of Creation

(Temporary lower quality to keep filesize down - hq file from:

https://esahubble.org/images/archive/top100/ - heic1501a.tif Image by ESA/Hubble)



Appendix B - Conversion of Electrons to ADU/DN Values

% of Full Well	*Electrons (e–)*	*DN Value (DN)*	*16-bit Binary Representation*
0%	0	0	0000 0000 0000 0000
10%	8,400	4,200	0001 0000 0110 1000
20%	16,800	8,400	0010 0000 1101 0000
30%	25,200	12,600	0011 0001 0011 1000
40%	33,600	16,800	0100 0001 1010 0000
50%	42,000	21,000	0101 0010 0000 1000
60%	50,400	25,200	0110 0010 0111 0000
70%	58,800	29,400	0111 0010 1101 1000
80%	67,200	33,600	1000 0011 0100 0000
90%	75,600	37,800	1001 0011 1010 1000
100%	84,000	42,000	1010 0100 0001 0000

Note. An illustrative example of the conversion of electrons to ADU/NU assuming a 2 electron per DN (2e-/DN) user gain. In this instance, a user gain of 1e-/DN would mean that no signal above 65.536 electrons can be measured. The choice for gain settings is ultimately up to the human operator. (STScI, n.d.)