SEEING IN THE DARK:

HOW TO TELL A SUBATOMIC

STORY IN SCIENCE FILM

by

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ABSTRACT

Since its inception in the early 20th century, science film has branched into a diverse phylogeny of methods and styles, informed by the subject matter it portrays as well as the technological advances of the day. Narrowing my focus to the science of quantum mechanics, I look specifically at the methods used for subatomic storytelling in documentary films. Unlike other scientific objects, the subatomic object cannot be easily observed with the naked eye or with research tools, preventing its direct capture by both scientist and filmmaker. Comparing the PBS series "The Fabric of the Cosmos" with the documentary film *Particle Fever*, I investigate the consequences of superimposing a human narrative on the subatomic object as a method of science communication and as a filmic device. This analysis affirms the utility of varied narrative techniques in subatomic storytelling in science film. Expanding on this premise, I examine how the essay films functions within a subatomic story, specifically within my thesis film, *Circumambulation,* which revolves around the 2021 confirmation of the muon's anomalous magnetic moment at Fermi National Accelerator Laboratory. In closing, I connect science film to the practice of art and argue that not only is art necessary for subatomic storytelling, but the art of documentary filmmaking is particularly suited for this purpose.

INTRODUCTION

Six years after Robert J. Flaherty released his genre-defining work documenting an Inuit family in the Canadian Arctic, a young French scientist named Jean Painlevé would screen another groundbreaking piece of cinema at the Académie des sciences in 1928, a short film called *L'œuf d'épinoche* (*The Stickleback's Egg*). Both *Nanook of the North* and *The Stickleback's Egg* were early documentary film prototypes, each utilizing the same cinematic language of silent black and white footage punctuated by expository text cards set in chronological order. However, the content of the two films could not have been more different. Flaherty's film was meant "not just to record natural phenomena, but to dramatize, to interpret, to study, to portray…man and his natural environment, his struggles, his humors, his everyday failures and triumphs in the business of living" (Gray 46). The ethnographic story follows Nanook and his wife, Nyla, as they hunt, travel, and care for their child. In *The Stickleback's Egg,* there are no humans on screen. Over the course of its 26-minute runtime, the only objects we see are magnified fish eggs, writhing and contracting and reforming as they undergo fertilization.

Much like a similar work of micro-cinematography about Treponema pallidum, the bacterium that causes syphilis, shown by Dr. Jean Comandon at the Académie in 1910, Painlevé's ovum opus "was met with intense skepticism, if not outrage" by the scientists in attendance (Berg 17). Even 18 years later, the academic community still bristled at the idea that these films were legitimate forms of scientific discourse, believing cinema to be nothing more than a frivolous pastime. Despite this lukewarm reception, Painlevé would go on to become one of the most prolific and innovative science documentary filmmakers of his time, known for his lyrical yet authentic portrayals of underwater sea creatures and vampire bats. Yet, the anxiety created by the unveiling of science on screen in the early 20th century lingered.

Speaking with Hélène Hazéra and Dominique Leglu in a 1986 interview for *Libération*, three years before his death, Painlevé explained that his films often had three versions, "one version for scientists, a second for universities, and a third, which was shorter and set to music, for general audiences" (Painlevé 179). Like many of his documentary contemporaries, Flaherty included, Painlevé faced criticisms of objectivity and of actuality. How much of what is captured on camera is real? How much of an influence does the filmmaker have on their subject? However, the science documentary also carried a unique encumbrance, delineated by Painlevé's three-pronged distribution strategy. What is the best way to tell a science story? Even at the end of his career, Painlevé still wrestled with this question.

In the years since Painlevé's passing, this question evolved into a robust discourse known as science communication. Building off the AEIOU science communication model of Burns et al., in this work, I will further examine the value of tailoring the method of science storytelling to the science subject matter, specifically looking at the process of how to tell a subatomic story. A subatomic story takes place at the subatomic or quantum scale, with phenomena such as particles serving as the story's focal point. For example, the documentary *Particle Fever* is a quintessential subatomic story with the film's primary focus on the search for the Higgs boson, a fundamental particle long predicted by theorists but, as of the film's release, only newly proven to exist. This kind of story involves not only the dissemination of a hard science like chemistry or physics but, perhaps more importantly, also attempts to view something largely invisible to the human eye.

Through a comparative analysis of *Particle Fever* and the PBS series "The Fabric of the Cosmos," I propose that subatomic storytelling, specifically documentaries dealing with quantum mechanics, benefits from the superimposition of a human narrative onto the subatomic object. Importantly, this premise presupposes the corporeality of a subatomic object, an object that, by its very nature, defies and obfuscates human understanding of it. However, rather than acting as a hindrance, this inscrutability serves as an entry point into a discussion of the utility of narrative techniques within the broader landscape of subatomic storytelling in documentary films.

Further, using my thesis film *Circumambulation* as a model, I demonstrate how the cinematic style of the personal essay film can function as both a narrative technique and as a means of science communication within a subatomic story. In a nod to Chris Marker's 1983 essay film *Sans Soleil, Circumambulation* relies on both montage and the essayistic voice to explain the personal and global significance of a groundbreaking research result in the field of particle physics that occurred in the spring of 2021. Utilizing both the filmmaker's personal archive as well as found footage, the film unfolds over several years and in several locations in a striving to "combine an outward journey…with an inward, interior journey" as Marker's masterpiece, "the high-water mark of the mode," does so well (Elsaesser 243).

In closing, I discuss the role of nonconventional documentary filmmaking techniques in telling subatomic and other hard science stories. In the summer of 2016, in a village near the west coast of France, a group of scientists and artists gathered to voice their concerns about the deleterious effects of human activity on local bats; born of this meeting was a manifesto deemed the so-called Science New Wave. ("The Science New Wave" 0:05-0:16). Much like the French New Wave film movement of the late 1950s, the Science New Wave rejects the rigidity of traditional, educational science documentaries in favor of a "*universe* of science cinema…vastly larger, weirder, and more experimental" that blurs the boundaries between fiction and non-fiction (Shepard). However, it is not a denial of scientific accuracy or integrity. Rather, it is an energetic re-examining of the many intersections of science and art and the myriad possibilities therein. It embraces science documentaries "shot on film, smartphones, field microscopes, DSLR's, telescope mounts, action cameras, and drones…on screens of all sizes or projected up on domes, or streamed in 360 degrees through VR goggles" (Shepard). Both filmmaking and scientific research allow us to gaze at the world around us. The combination of the two pushes our awareness of the cosmos and of ourselves out into uncharted territory.

TO SEE OR NOT TO SEE: THE GAZE OF SCIENCE FILM

Science filmmaking undoubtedly emerged in the early 1900s from the human urge to observe nature, an undertaking already playing out in research laboratories worldwide in the centuries prior. As is still common today, there was a close interplay between the equipment used for filming and the technological advances of the day, resulting in a natural evolution from scientific observation to scientific cinematography. One of the earliest examples of this evolvement resulted from a collaboration between a microbiologist studying human corneal cells infected with the pathogenic spirochete known to cause syphilis and the burgeoning French filmmaking outfit Pathé Frères:

> At Pathé's studio in Vincennes, Jean Comandon began to build a device for making films that represented the microbiologist's viewpoint…Consisting of 25 component parts, the invention combined the camera and microscope. A light source, focusing lenses, and gears made it possible to move the camera to follow motion within the microscopic frame. In order to keep the living biological sample from dying as a result of the light's hot rays, the device had shutters and a cooling system. The image recorded on 35mm nitrocellulose (the likely industry standard of the time). The entire production suite was just a few feet long. Comandon was 32 years old and finishing his doctorate when *Spirochaeta Pallida* (Agent de la Syphilis) was released in the fall of 1909. (Epstein)

Not only did this novel short film present to the public a point of view that was previously only accessible to scientists, which allowed the audience "to participate visually in the sights of scientific work and the mode of experimental looking," but the sped-up, magnified footage also opened up "a whole new world of temporal phenomena, previously below the threshold of perception" (Landecker 123). A motion picture marvel and a conclusive clinical tool, Comandon's *Spirochaeta Pallida* allowed doctors the opportunity to make an early diagnosis and citizens the chance to gaze at the characteristic shimmying of the syphilis-causing spirals plaguing the populace at the time.

Through this manipulation of time and scale and technology, human vision expanded past the limits of biological perception to a new vantage point. It was suddenly possible to not only view never-before-seen moving images of nature but also to put them in context, to infuse them with meaning. Thus, a new cinematic canon started to take shape, fusing the human urge to observe nature with the human urge to tell stories.

One of the most important pioneers in this realm was Jean Painlevé, a former scientist and academic expat who experimented fearlessly with the art of science storytelling onscreen. Covering significant ground, his early work, such as the silent film *The Stickleback's Egg* (1928), and his later work stand in stark contrast. Released in 1945, *The Vampire* is a deft synthesis of Murnau's *Nosferatu*, scientific facts about the South American vampire bat, micro-cinematography of the protozoan parasite carried by the bat, onscreen animal behavior, and elegant narration. Set to a Duke Ellington soundtrack, the 9-minute piece was "the first time jazz music was used in a science film" (Painlevé 178). Perhaps his proximity to and praxis of the French avant-garde enabled this alchemical amalgamation of science and art. Nonetheless, his oeuvre carved an indelible niche where there was none.

Yet, despite his prominence in the art world, he never lost sight of his roots in scientific research, forming the International Association of Science Films (AICS) in 1933 and the Scientific Film Association of London in 1945 ("Scientific Film" 164). Akin to his forward thinking in experimentation with the form, he also foresaw the importance of scientific integrity within the field of science filmmaking:

> Made up of scientists and filmmakers from twenty countries, the AICS was divided into three groups, each concentrating on a different kind of science film: research, educational, or popular. From the beginning, however, there was conflict. Indeed, much of the AICS meetings were spent trying to define just what a 'science film'

> was. 'Some swore by pure research only,' Painlevé would write of these debates, 'and thought that to make a popular film was to prostitute oneself…The discussions were endless, hours and hours spent quibbling and splitting hairs. (Berg 36)

The legacy of Painlevé is vast. He created an enduring body of revelatory cinematic work, such as *The Seahorse* (1934), a highly technical yet poignantly poetic production that was one of the first science films shot underwater (Berg 23). He also carefully cultivated the aforementioned debate throughout his career. Addressing the most appropriate method to disseminate science via film, he acknowledged the practice was "actually a double-edged sword: while film can spark interest in a certain subject matter, it can also gloss over details...fostering the dangerous illusion that one has *understood*, when in fact, one has not" ("Scientific Film" 161). This cultivation by Painlevé and his contemporaries would eventually blossom into an important cornerstone of science film, a field known as science communication, and bring with it a new set of editorial considerations.

In 1957, through the University of Michigan, the Survey Research Center compiled a novel study looking at the attitudes of respondents in the United States towards science media. They found that "only a minority of the public was strongly interested in scientific issues and that the level of public knowledge about science was relatively low," indicating a considerable chasm between scientific research and public understanding (Miller 35). Swiveling the heat of the spotlight to the unwashed masses, Miller's survey laid the groundwork for the seminal 1987 article by Geoffrey Thomas and John Durant, which articulated a provocative question, "What exactly do we mean by the public understanding of science, and why, exactly should we be concerned to promote it?" (1). In addition to providing an exhaustive list of the myriad benefits for the public understanding of science, they emphasized the concept of scientific literacy. However, they expressed dissatisfaction with its definitions to date that “somehow missed the heart of the matter, which is the way in which ordinary people relate to the world of science” (13).

Despite this probing, a strategy to achieve this vital outcome would be slow to develop over the next few decades. In 2003, in their paradigm-shifting report on science communication, Burns et al. examined the evolution of this issue:

> …surveys suggest that the public does not know much about science, and it appears that scientists don’t know much about the public. Recent surveys indicate continued high levels of interest in science but continuing low levels of assessable understanding of science. This is in spite of extensive government-supported science promotion and education programs, especially in the USA and UK. Together, the name “public understanding of science,” and the interpretation of early surveys of scientific literacy resulted in the so-called deficit model of public understanding of science. This model characterized the public as having inadequate knowledge, and science as having all the required knowledge. (189)

The deficit model created a flow of information in one direction, resting the final burden of scientific literacy squarely on the shoulders of the consumer. This responsibility was twofold. The consumer needed to be competent enough to receive the transmissions emanating from the scientific community and have the means to access science media in the first place.

As an alternative to the longstanding deficit model, Burns et al. proposed the AEIOU vowel analogy of science communication, centering the consumer’s “Awareness of science; Enjoyment or other affective responses to science; Interest in science; the forming, reforming or confirming of science-related Opinions (or attitudes), and Understanding of science” (190). Providing, for the first time, a comprehensive definition of science communication, their proposal also notably emphasized the necessity for both formal (e.g., university coursework and educational textbooks) and informal styles (e.g., film, radio, and museum exhibits) of science communication (195). Their report hinted at a new precedent, aimed at demystifying academia and democratizing scientific literacy.

This implication of accessibility is further developed in their addendum to the Koballa, Kemp, and Evans' "model of an individual's scientific literacy that could be visualized as a landscape of mountain-like peaks and valley-like troughs on a three-dimensional x-y-z axis" (192). Mapping out a new metaphor, they liken the pursuit of scientific knowledge to mountain climbing (see fig. 1)

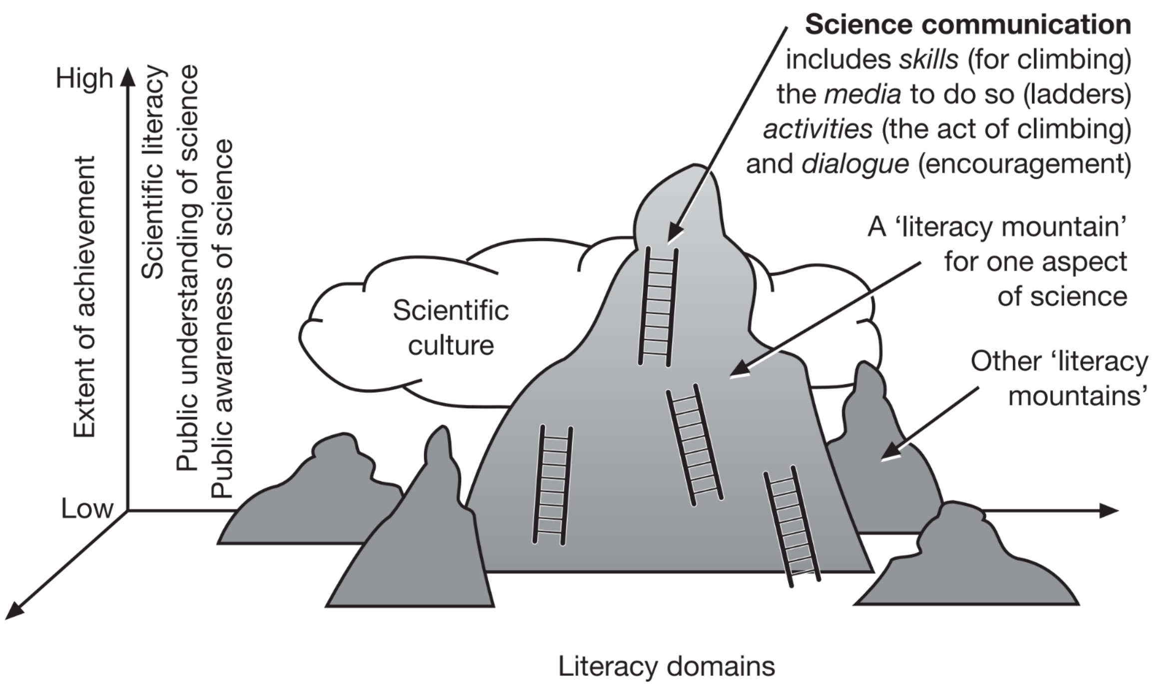

Fig. 1. An analogy that compares science learning to mountaineering from Burns et al.

Not only does this figure demonstrate the multi-faceted nature of science communication, but it also illustrates the futility of applying the same style of science communication to different fields of science, given that "science is actually an expansive mountain range (i.e., multiple literacy's), not a single peak" (193). For example, if a skilled mountaineer is planning to climb Mount Everest

(8,848.86 m) in the Mahālangūr Himāl of the Himalayas, they will need an entirely different set of tools than they would to reach the top of Crazy Peak (3,418 m) in the Crazy Mountains of the Northern Rockies. To further expand on this analogy, unless our mountaineer was of Sherpa descent, they would likely never reach the summit of Everest without an oxygen tank. However, the additional weight of supplemental oxygen would be a laughable addition to the gear list for an ascent of Crazy Peak.

The disparity in summit conditions in the above example is also an apt depiction of the marked difference in science communication styles required for science film. In this light, it is challenging to even comprehend a natural history film concerned with the dissemination of animal behavior and a science film focused on the dissemination of quantum mechanics in the same metaphorical ecosystem. To remove the animal from the frame and replace it with a subatomic object is not to venture from Nepal to the state of Montana. It is more akin to arrival at the astronomical arête leading to Olympus Mons, the tallest mountain on Mars.

TWO CASE STUDIES

The complexities of quantum mechanics are well known. Richard Feynman, co-recipient of the 1965 Nobel Prize for Physics, known for his contributions to particle physics and quantum electrodynamics, reportedly said, “If you think you understand quantum mechanics, then you don’t” (Ball). Despite the fundamental nature of the subatomic object, it remains inaccessible to us, observable only by indirect means, so small as to lack dimension and so unusual as to evade mastery by even the most remarkable human minds, Einstein and Feynman included:

> More than ninety years after the invention of quantum mechanics, we find ourselves in a strange situation. Quantum mechanics works. Indeed, no theory of physics has ever had such spectacular success…And the theory has enabled us to make sense of phenomena far beyond anything technology has yet been able to exploit. Yet despite this unprecedented success there is notorious disagreement about…The sentence fades away because it is not so easy to say what the disagreement actually is about. Everybody who has learned quantum mechanics agrees how to use it. ‘Shut up and calculate!’ There is no ambiguity, no confusion, and spectacular success. What we lack is any consensus about what one is actually talking about as one uses quantum mechanics. There is an unprecedented gap between the abstract terms in which the theory is couched and the phenomena the theory enables us so well to account for. We do not understand the meaning of this strange conceptual apparatus that each of us uses so effectively to deal with our world. (Mermin 1)

This provides a substantial challenge for the documentary filmmaker tasked with communicating quantum mechanics to a lay audience. Unfortunately, the widely held notion that the viewer will know even less about this field of science than any other field tends to push popular science media towards a deficit model of science communication. “Quantum Leap,” the third episode in the four-part series “The Fabric of the Cosmos” produced by PBS NOVA and based on the book of the same name written by the program’s host, physicist Brian Greene, provides a fruitful example of this deficit model style in quantum mechanics storytelling.

Each hour-long episode in the series explores physics concepts such as time, space, quantum mechanics, and the multiverse. A *New York Times* review by Dennis Overbye hails the series "as fresh as last month's Nobel Prizes, uncompromising in its intellectual ambitions and discerning in its choice of compelling scientific issues." Despite the glowing reviews, Greene, like any seasoned science communicator, admitted to struggling with the translation of science on screen. In an interview after the series' release, he spoke of the difficulty he faced choosing what to leave in and what to leave out. For him, the project presented "a huge challenge…trying to find those ideas that really transformed our thinking, stripping away the details and allowing those ideas to really carry the story" (Chow).

While the narrative of a natural history film may allow for a negotiation of the human-animal binary through the nuanced lens of anthropomorphism, there is no clear distinction between the filmmaker and the protons, neutrons, and electrons that make up every known object in the universe, including the body of the filmmaker. Gaining critical distance between ourselves and the subatomic object proves almost impossible, which is perhaps why "Quantum Leap" begins with Greene taking an escalator down to a quantum-level, fictionalized place "where the quantum laws [are] obvious, where people and objects behave like tiny atoms and particles" (3:42–4:33). In the scene that follows, Greene and the show's writers utilize patrons in a crowded bar as a stand-in for atoms and particles.

We see the bartender flitting around at the speed of light and two patrons walking through each other as what looks like lightning crackles between them. As Greene leans over a pool table filled with jiggling, brightly colored spheres, he reiterates one of the more well-known concepts of quantum mechanics, "Here, objects do things that seem crazy…things don't like to be tied down to just one location or to follow just one path. It's almost as if things were in more than one place at a time." (4:45–5:04). To further illustrate this concept, several versions of Greene circle around the pool table, while the same billiard ball simultaneously drops into different pockets. Walking over to the bar to order a drink, he continues, "…if people behaved like the particles inside the atom, then most of the time, you wouldn't know exactly where they were. Instead, they could be almost anywhere, until you look for them" (5:29–5:43).

Surprisingly, very little of the content covered in the remainder of the episode goes beyond these very basic concepts of quantum physics. Instead, it plays like a speed run of quantum mechanics 101: atomic spectra, Bohr's model of the atom, the double-split experiment, wave-particle duality. An unfortunate drawback of the deficit model, Greene strips away too much, leaving nothing but surface-level observations devoid of nuance and intrigue. In a scene where Greene is explaining the quantized energy levels of an atom in relation to atomic spectra, the animation onscreen shows an electron losing energy and jumping from a higher energy level to a lower energy level. As the electron, a glowing round sphere, moves between the circular energy levels, it emits a brightly colored wave animation. Greene explains that "each downward leap would emit energy in the form of light in very specific wavelengths. And that's why atoms produce very specific colors. This is where we get the phrase 'quantum leap'" (9:57–10:10). The viewer is quickly hustled along to the next section about the importance of the discovery of the quantum leap, and a key opportunity for communicating something fascinating about these quantized energy levels is completely lost.

As an undergraduate studying chemistry, it was a significant revelation when I learned how color correlates to the difference in these electronic energy levels. Not to mention the utterly astounding fact the photons are emitted from the electron. The relationship between electrons losing energy and the corresponding emission of light was something that I pondered on for months, while Greene whips past it in less than 30 seconds. As the episode rounds the corner towards the final stretch, it feels more like our host has worked through a checklist of quantum mechanics buzzwords than it does "a report from the frontier of cosmic thought" (Overbye).

Interestingly, among the overall positive review, Overbye identifies a critical misstep in the show, the heavy reliance on special effects. He laments, "No matter how likable he is, you may…get tired of seeing his duplicates pop up over and over again in scenes to demonstrate one quantum paradox or another." Although one could chalk up the repeated use of the same visuals to editorial laziness, this criticism strikes at the heart of why the metaphorical science communication mountain for quantum mechanics can be so challenging to traverse. Unlike a wildlife documentary where the filmmaker can capture the film's subject on camera, the subatomic object is not something we can see with a camera, nor can we see it that clearly with scientific instruments. Without images, the quantum mechanics documentary often falls prey to the frailties of the human imagination. For example, even though particles are dimensionless, they are commonly depicted as perfect round spheres. Even in Greene's day, the billiard ball as particle was a painfully familiar gimmick. Recycling this kind of pre-packaged imagery may function as a way to move the viewer through the undeniably dense subject matter, but when do we reach a saturation point with this kind of generic storytelling? What are we missing out on when we continuously rely on visual tropes to tell subatomic stories?

Besides Greene himself, the other characters in the piece are textbook talking heads. They appear clumped together at intervals throughout the episode as they rapidly fire through their lines.

With no setup or introduction, their connection to the storyline is only evident through their lower third titles, an impressive list of the most prestigious universities and research institutions in Europe and the United States. Without a touchstone providing a chance for human connection between the viewer and the scientists, the audience acts solely as an empty vessel towards which the experts point their firehose.

The 2013 documentary *Particle Fever*, however, foregrounds a human narrative in a sophisticated subatomic story about the search for the Higgs boson, a fundamental particle postulated to exist by theorist Peter Higgs and others in 1964 and detected experimentally at CERN in 2012 by the ATLAS and CMS experiments done with the Large Hadron Collider (LHC). Of course, it does not hurt that Walter Murch, one of the great film editors of our time, is at the helm to navigate the dissemination of this monumental quantum mechanics discovery. Rather than sink into the confusing depths of the science behind the LHC, the viewer floats atop a visually stunning, disarming story centered on six scientists eagerly awaiting the results of the LHC's first experimental run.

The combination of Murch's editing prowess and the film's expert storytelling creates a harmonious balance between science and entertainment. This coherence is evident when Monica Dunford, one of the main characters and a post-doctorate at CERN, details the first time she saw ATLAS, one of the several setups underneath the LHC umbrella. As she excitedly describes the "five stories of microelectronics, all custom designed, all hand soldered," Murch provides the corresponding point-of-view of a person walking down the hallway towards the door that leads to ATLAS (20:47). Set to a soundtrack of dramatic, suspenseful music that builds as the camera gets closer and closer to the door, the scene reaches a crescendo with the loud sound of the door opening and the camera panning swiftly to the left, revealing the mechanical monstrosity. At once, we see the byzantine architecture of the instrument and its massive scale as tiny humans walk on the catwalk next to it. Before the audience can catch their breath, Murch sends them speeding down the magnetic storage ring, then cuts back to the machine in cross-section as the music swells loudly. It is clear that this is a massive scientific undertaking, but with an expertly deployed montage, the viewer can also experience the 30,000-foot view. This view provides relief. The brain can turn off momentarily, and the eye can wander across a rich visual landscape of bright colors and intriguing forms.

As the timeline of the search for the Higgs boson with the LHC unfolds, we learn more about the six scientists. We learn that both Savas Dimopoulos, a particle physicist, and Nima Arkani-Hamed, a theoretical physicist, fled their birthplaces when they were young, each eventually seeking refuge in the United States with their families. We observe Monica in her morning routine, still very much living like a graduate student, as she contemplates her empty refrigerator and suits up in reflective gear to ride her bike to work. We listen as Savas explains he spent the last 30 years of his life waiting for the confirmation of the Higgs boson. Despite their staggering genius, the viewer finds common ground with our scientists. Suddenly, quantum mechanics loses its exoticism, its unknowability, and it's replaced with the commonalities of the human experience. Here is something exciting enough to make up for a tiny apartment with no food in the fridge. Here is something meaningful enough to fuel three decades of tireless work. Here is something powerful enough to create a sense of belonging anywhere in the world.

But perhaps one of the most intriguing scenes occurs between Nima and David Kaplan, a theoretical physicist, on the Princeton campus where Nima works. They stand next to each other and look out a window at a sculpture on the ground below:

> David: "That's a sculpture?"
>
> Nima: "That's a sculpture."
>
> David: "Yeah, doesn't it look like a bunch of broken tiles?"
>
> Nima: "That's what it's supposed to look like."
>
> David: "Oh."
>
> Nima: "…I thought it was just rubble left over from the construction."
>
> (45:25)

They eventually leave their vantage point to investigate the work of art and continue bantering back and forth about its meaning. Their confusion about what makes art *art* is humorous to the third party of the audience as both of these men work on some of the most perplexing problems known to humankind. This moment allows the film to express a self-awareness that excludes the subjects in the film. It creates another 30,000-foot view, and for a moment, we can look down like Jack Torrance at these two men in the maze of life, that despite the grandeur of their day jobs, they are just like us, trying to find their way.

Directed by Mark Levinson, *Particle Fever* was an unequivocal success. Famed film critic A.O. Scott selected it as an "NYT Critic's Pick," calling it "mind-blowing" and "enormously suspenseful." An interesting footnote is that Levinson was a scientist before becoming a filmmaker. While some might argue that this level of execution might only be possible with a scientist in the driver's seat, the primary difference between the "Fabric of the Cosmos" series and Levinson's film is the narrative structure of each. There is no suspense in Greene's work. There is a structure, but it is pedantic rather than filmic. On the other hand, cinematic storytelling techniques employed by Murch create a memorable aesthetic experience that captivates the viewer, despite the confounding subject matter. Which begs the question, does the viewer need to fully understand a science story for it to be a successful mode of science communication?

Brought in as a consultant on *Particle Fever*, physicist Alan J. Friedman approached the job with certain assumptions. He expected to help the filmmakers adhere to strict pedagogical standards. One scene, in particular, stands out in his memory, the first-beam test of the LHC:

> The camera follows Monica Dunford, a young American physicist, through this day of tension and ultimate triumph. Shortly after the successful first beam, she is carrying around her laptop and showing a graph to people in the main control room…My job, I believed, was to point out what pedagogy required: 1). We have to know what that spot of light on the screen meant. Was it a video of the actual beam? Was it a computer-generated diagram of some physical phenomenon? 2). What important things were happening when all those other screens filled with symbols and graphs? 3). What does Dr. Dunford's laptop plot show? What is "Z," what is a nanosecond, and what is being timed?…Much more direct explanation was essential if this film was to work as a vehicle for science education. (5)

Surprisingly, his colleagues were in disagreement. According to Friedman, David Kaplan, a scientist in the film who also acted as co-producer, pushed back against the breakdown of every scientific detail on screen. Eventually, after viewing the scene numerous times, Friedman saw the light, realizing that "we don't need to understand just what Dr. Dunford's graph shows…to appreciate the magnitude of the first-beam event, we need to see the emotion it releases in the faces, voices, and body language…the interests, attitudes, and emotions people feel when they learn and do STEM" (6). The art of documentary filmmaking allows for the complexities of the human experience to be communicated in myriad ways. Because scientists are humans, their experience of doing science is similarly complex. If one of the end goals of science communication is to inspire the public to care about and support the efforts of scientists, the documentary film provides a productive site on which to do so. If a similar end goal of subatomic storytelling is to make the invisible viable, the narrative eclecticism found in the different styles of documentary filmmaking supplies further fertility to that site.

THE USE OF THE ESSAY FILM IN SUBATOMIC STORYTELLING

A counter to the sharp expository style of "The Fabric of the Cosmos" and the sweeping cinematic style of *Particle Fever* is a more amorphous approach to subatomic storytelling known as the essay film. Film historian Thomas Elsaesser speaks to the particular eccentricities of this form:

> The essay film can be like a found-footage film in that it accommodates and even welcomes a certain heterogeneity of materials and moods, of topics and temporalities, of locations and levels of reference. Yet it distinguishes itself from the found-footage and compilation film by having a singular voice: it can be assertive and personal, even autobiographical, but it is also not afraid to question its own status or challenge its own authority...essay films are driven by a structure of thought, however apparently hidden or at first glance imperceptible this thought-process may be. To that extent, even the disparity of sources and the assemblage of heterogenous elements generally results in an order or a sequential logic that is less a matter of *compilation* and more the result of *composition.* (241)

The footage comprising *Circumambulation*, my thesis film, utilizes several archives of footage and images. One archive is my own, accumulated over the last six years from my time spent working as a filmmaker. Another archive was filmed by my father on his VHS camcorder, documenting my childhood in the early 1990s. A third archive draws on internet archives, such as the National Archives and the Visual Gallery of the Fermi National Accelerator Laboratory, containing public records of scientific exploration. Another archive results from public domain found-footage located in the Prelinger Archives.

Divided into three chapters, the story is not structured by chronology. Instead, the film follows my movement through literal and metaphorical darkness as I navigate the partial loss of my hearing one month after the loss of a loved one and as I contemplate what exists in the darkness beyond the limits of human perception. At the core of the film is the study of the darkness of subatomic space, revolving around the 2021 confirmation of the muon's anomalous magnetic moment via the muon g-2 experiment conducted at the Fermi National Accelerator Laboratory in Batavia, Illinois.

The narration is deeply personal but also poetic, drawing on the "literary heritage [of the essay] in the material performance of language…replacing a narrative voice with the essayistic voice of the commentator" (Corrigan 204). In the style of *Sans Soleil*, the film presents a patchwork of memory, experience, and history, creating a multiplicity of meaning in each image. The viewer can digest the image itself, the image set to the narration, or the image in montage. This wandering allows for the aforementioned 30,000-foot view. The eye can linger and explore while the narrator moves through difficult subject matter, whether it is an explanation of muons set to a slow push-in on digital artwork or the recounting of the tremendously painful treatment they received for their hearing loss set to an ethereal sequence of moths at night.

Rather than attempt to painstakingly lay out every detail of the muon g-2 experiment, the film offers a personal, emotional lens on the field of quantum mechanics, providing a window into the filmmaker's ascent out of the darkness as well as the camaraderie of the global research collaborative that carried out the experiment. At the film's end, there is a new world on the horizon that makes space for the darkness and acknowledges it as critical to our path forward, both in the sciences and within ourselves.

Like *Particle Fever*, in Circumambulation, I include a moment of self-awareness, of "reflexivity, a feature also frequently attributed to the essay film" (Elsaesser 242). In the film's opening, Dr. Irene Grimberg defines "the science story." Then, as the film moves out of the introduction and into the first act, I let the viewer know that what they are about to watch is not just about my deceased loved one but also a science story. Hopefully, as the film progresses, the audience begins to contemplate the definition of what makes a story a science story and what makes my film, in particular, a science story. Ideally, the film then serves as a jumping-off point for the viewer's own imaginative re-thinking of how to tell a science story.

CONCLUSION

At the beginning of 2016, the same timeframe in which the discovery of gravitational waves occurred, the United States was experiencing significant political and cultural turmoil. Trump and Clinton were squaring off for the presidency, and it seemed to be pulling at the very threads of society, unraveling something we did not even know could unravel. The detection of gravitational waves was a long time coming, and the work eventually garnered a Nobel Prize in physics in 2017. However, like many scientific discoveries, its benefit to society was not immediately clear, and it seemed to suffer the same fate as many great science stories. Those within the scientific community were elated, and for the most part, those outside it were unfazed. Lawrence M. Krauss, an American physicist, offered this in response:

> Too often people ask, what's the use of science like this, if it doesn't produce faster cars or better toasters. But people rarely ask the same question about a Picasso painting or a Mozart symphony. Such pinnacles of human creativity change our perspective of our place in the universe. Science, like art, music and literature, has the capacity to amaze and excite, dazzle and bewilder. I would argue that it is that aspect of science — its cultural contribution, its humanity — that is perhaps its most important feature.

In a 1955 essay, Painlevé wrote that a compelling science story "is not only a tool, but a grammar and an art" ("Scientific Film" 169). But too often the idea is overlooked that science can exist in the same realm as art. It is this shared territory that allows for the narrative to function within science communication. Although, "many scientists think that it's disingenuous to 'tell stories' about their research…to the contrary, the 'anti-narrative' of most scientific papers obscures understanding by all but specialists in a sub-field" (Padian 1224). Science communication is bolstered by a strong narrative, and one of the most effective modern methods of narrative storytelling is the documentary film. It alone offers the opportunity to combine visual storytelling, music, emotion, education, and anecdote in a format that already has a rabid following.

The unique issue of telling a subatomic science story is the inability to film anything at a subatomic level, but the superimposition of a human narrative on these stories allows for a point of connection between the viewer and the subatomic object, a connection that can be difficult to facilitate in more formal styles of science communication. When attempting to tell complex science stories, it becomes apparent that "narrative is not only natural but necessary" (Padian 1224). It allows us to see in the darkness of subatomic space, to see ourselves illuminated against the backdrop of the cosmos.

Much like the disruption led by Painlevé and his peers in the early 20th century, the Science New Wave attempts to shed the constrictions of more conventional science filmmaking by embracing modern technology. As seen on their streaming platform *Labocine:*

> The Science New Wave is both fiction and non-fiction. Sometimes it's a chimera of the two. Sometimes it's raw lab footage. Sometimes it's avant-garde. Sometimes it's animated, and sometimes it's data-visualized. It's being invented by filmmakers, scientists, students, and curious amateur explorers around the world. Science New Wave films are often expressive, personal, and opinionated. They're shot on film, smartphones, field microscopes, DSLR's, telescope mounts, action cameras, and drones. You watch them on screens of all sizes, or projected up on domes, or streamed in 360 degrees through VR goggles. (Shepard)

A collective formed in western France, the group pushes for the democratization of not just science literacy but also science film. In a harkening back to Comandon on his bench, they report that "many filmmakers of the Science New Wave started as scientists, researchers, and grad students…as observers and information gatherers, scientists make natural filmmakers" (Shepard). They represent a new cynosure within science communication and a new generation of science filmmakers.

As humans, we have been straining to see in the darkness for a long time, and as a means of illumination and exploration, we have created powerful, sophisticated tools to expand our vision. More than a century after Comandon fused his ultra-microscope with a film camera, humans continue to harness technology to satisfy our desire to better see the world around us. Accordingly, our understanding of the cosmos balloons in all directions, round with possibility and ingenuity. So, it is only natural that our storytelling methods expand in response.

REFERENCES CITED

Ball, Phillip. "Will we ever understand quantum theory?" *BBC Future*, 24 Jan. 2013, www.bbc.com/future/article/20130124-will-we-ever-get-quantum-theory. Accessed 20 Nov 2022.

Berg, Brigitte. "Contradictory Forces: Jean Painlevé, 1902–1989." *Science is Fiction: The Films of Jean Painlevé,* edited by Andy Masaki Bellows and Marina McDougall, The MIT Press, 2000, pp. 3–57.

Burns, Terry. W., et al. "Science Communication: A Contemporary Definition." *Public Understanding of Science*, vol. 12, no. 2, 2003, pp. 183–202, https://doi.org/10.1177/09636625030122004.

Chow, Denise. "Unraveling the 'Fabric of the Cosmos': Q&A with Brian Greene." *SPACE.com*, 1 Nov 2011, www.space.com/13465-brian-greene-interview-fabric-cosmos-tv-series.html, Accessed 16 Nov 2022.

Circumambulation. Directed by Evangeline Koonce. 2022.

Corrigan, Timothy. "Of the History of the Essay Film: Vertov to Varda." *Essays on the Essay Film*, edited by Timothy Corrigan and Nora M. Alter, Columbia University Press, New York, 2017, pp. 197–226.

Elsaesser, Thomas. "The Essay Film: From Film Festival Favorite to Flexible Commodity Form." *Essays on the Essay Film*, edited by Timothy Corrigan and Nora M. Alter, Columbia University Press, New York, 2017, pp. 240–258.

Epstein, Sonia S., "The Way They Move." *The Los Angeles Review of Books*, 25 Dec 2019, www.lareviewofbooks.org/article/the-way-they-move/. Accessed 12 Oct. 2022.

Friedman, Alan J. "Reflections on Communicating Science Through Art." *Curator: The Museum Journal*, vol. 56, no. 1, 2013, pp. 3–9, https://doi.org/10.1111/cura.12001.

Frischknecht, Freddy, Matthias Gunzer, and Spencer L. Shorte, "Retrospective: Birth of the Cool – Imaging and microbiology from Ibn all-Haytham to Jean Comandon." *Biotechnology Journal,* vol 4., 2009, pp. 787–790, https://doi.org/10.1002/biot.200900102.

Gray, Hugh. "Robert Flaherty and the Naturalistic Documentary." *Hollywood Quarterly*, vol. 5, no.1, autumn 1950, pp 41–48, https://doi.org/10.2307/1209484.

Krauss, Lawrence M. "Finding Beauty in the Darkness." *The New York Times,* 11 Feb. 2016, www.nytimes.com/2016/02/14/opinion/sunday/finding-beauty-in-the-darkness.html. Accessed 13 Oct 2022.

Landecker, Hannah. “Microcinematography and the History of Science and Film.” *Isis*, vol. 97, no. 1, 2006, pp. 121–132, https://doi.org/10.1086/501105.

Miller, Jon D. “Scientific Literacy: A Conceptual and Empirical Review.” *Daedalus*, vol. 112, no. 2, 1983, pp. 29–48. *JSTOR*, http://www.jstor.org/stable/20024852. Accessed 19 Nov. 2022.

Merman, N David. “Making Better Sense of Quantum Mechanics.” *Reports on Progress in Physics.* vol. 82, 2019, pp. 1–16, https://doi.org/10.1088/1361-6633/aae2c6.

Overbye, Dennis. “Empty Times Square is Fantasy; The Stranger Stuff is Science.” *The New York Times*, 1 Nov. 2011, www.nytimes.com/2011/11/02/arts/television/the-fabric-of-the-cosmos-on-pbss-nova-review.html. Accessed on 16 Nov 2022.

Padian, Kevin. “Narrative and ‘Anti-narrative ’in Science: How Scientists Tell Stories, and Don’t.” *Integrative and Comparative Biology*, vol. 58, no. 6, pp. 1224–1234, https://doi.org/10.1093/icb/icy038.

Particle Fever. Directed by Mark Levinson, Netflix, 2014.

Painlevé, Jean. “Jean Painlevé Reveals the Invisible.” Interview conducted by Hélène Hazéra and Dominique Leglu. *Science is Fiction: The Films of Jean Painlevé,* edited by Andy Masaki Bellows and Marina McDougall, Brico Press, 2000, pp. 171–179.

---. “Scientific Film.” *Science is Fiction: The Films of Jean Painlevé,* edited by Andy Masaki Bellows and Marina McDougall, Brico Press, 2000, pp. 161–169.

“Quantum Leap.” *The Fabric of the Cosmos*, written by Brian Greene, Josh Rosen, Julia Cort, and Joseph McMaster, directed by Jonathan Sahula, Public Broadcasting Services, 2011.

Sans Soleil. Directed by Chris Marker, Argos Films, 1983.

“The Science New Wave: Reimagining Science in Cinema.” *YouTube*, uploaded by Labocine, 11 June 2021, www.youtube.com/watch?v=MRQqd9Tx-s0.

This Stickleback’s Egg. Direccted by Jean Painlevé, Criterion Collection, 1928.

Thomas, Geoffrey, and John, Durant. “Why Should We Promote the Public Understanding of Science?” *MIT Open Courseware*, Spring 2006, https://ocw.mit.edu/courses/sts-014-principles-and-practice-of-science-communication-spring-2006/pages/readings/. Accessed 9 Nov 2022.

Scott, A.O. “To Scientists in Pursuit, a Bit of Matter is No Small Matter.” *The New York Times*, 4 Mar. 2014, www.nytimes.com/2014/03/05/movies/particle-fever-tells-of-search-for-the-higgs-boson.html. Accessed on 16 Nov 2022.

Shepard, Edward. "The Birth of Science New Wave Cinema." *Medium*, 6 Nov 2016, www.medium.com/labocine/the-birth-of-science-new-wave-cinema-7096e94c9722. Accessed on 1 Dec 2022.

The Vampire. Directed by Jean Painlevé, The Criterion Collection, 1945.