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Alternative Abstractions: Art and Science in Twentieth-Century Los Angeles

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Alternative Abstractions: Art and Science in Twentieth-Century Los Angeles

DISSERTATION

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for the degree of

DOCTOR OF PHILOSOPHY

in Visual Studies

by

Sharrissa Iqbal

Dissertation Committee:
Professor Cécile Whiting, Chair
Professor James D. Herbert
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2021

Dedication

It is a great honor to dedicate this dissertation to the memory of my incomparable older brother Arif Arshad Iqbal (1987-2007), whose compassion, love of studying philosophy and political science, and talent in photography will always inspire me to keep wondering, dreaming, and looking in new ways.

To my magnificent parents Miriam and Dr. Arshad Iqbal- this is also for you, with all my admiration.

Table of Contents

List of Figures

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Thank you Fred Eversley and Maria Larsson for generously hosting me for interviews in Venice Beach and Soho. Thank you to Mary Corse for our conversation about abstraction, math, and the philosophy of Wolfgang Pauli. Thank you to Malcolm Warner and many others at Laguna Art Museum for helping to launch this research into a prospective 2024 Pacific Standard Time exhibition. Thank you to Michael Duncan my co-curator for sharing your expertise. Elizabeth Easton, director of the Center for Curatorial Leadership in New York City, thank you for inspiring me to work towards making an impact in the museum world through curating. Thank you to Lynn Gamwell for your inspiring scholarship and for meeting with me on two memorable and meaningful occasions in New York City to discuss art and science. Gregory Harwell, I am beyond grateful that I found your classes in visual studies when I was an undergraduate at USC. Thank you for sparking my curiosity in the history of abstract artwork in Los Angeles.

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Education

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2018	Harvard University, Visual and Environmental Studies Graduate Student Conference Speaker, “Mediating Memory: Ellsworth Kelly’s *Ground Zero* and Virtual Sites of Public Memorial”
2017	Case Western University and Cleveland Art Museum, 43rd Annual Cleveland Symposium, *Ars et Scientia: Intersections of Science and the Visual Arts* Speaker, “Among the Planets: Helen Lundeberg’s Cosmic Imaginary”
2016	University of California, Irvine, Visual Studies Graduate Student Conference Speaker, “Disposable Treasures: Echoes of Iraq's Looted Antiquities in Michael Rakowitz’s Sculpture”

Events & Exhibitions Organized

2021-	Postdoctoral Research Associate, *Fred Eversley,* Benton Museum of Art at Pomona College *forthcoming 2024*
2019-	Lead Curator, *Particles and Waves: Southern California Abstraction and Modern Physics, 1945-1980,* Laguna Art Museum *forthcoming 2024*
2017	Co-Organizer, “Into the Sun: Light and Atmospherics of the American West,” Visual Studies Conference and Film Screening, University of California, Irvine
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Abstract

Alternative Abstractions: Art and Science in Twentieth-Century Los Angeles

By

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University of California, Irvine, 2021

Professor Cécile Whiting, Chair

The following dissertation, *Alternative Abstractions: Art and Science in Twentieth-Century Los Angeles* investigates how the histories of astronomy and modern physics impacted the production of abstract artwork in Southern California. In the artistic practices of Helen Lundeberg, Bettina Brendel, Mary Corse, and Frederick Eversley, histories of observational cosmology, quantum mechanics, astrophysics, and aerospace engineering both converge with and complicate existing art historical narratives of abstract painting and sculpture in Los Angeles. By examining Lundeberg, Brendel, Corse, and Eversley's artistic explorations of space, light, and energy alongside the scientific sources influencing their work, these case studies reveal how theories and technologies derived from subfields of modern physics prompted artists to consider the subjectivity of human vision, experience, and knowledge. Through the project's interdisciplinary approach, abstraction emerges as a process of mediation between the realms of the conceptual and the material central to theoretical debates in both modern art and science over the twentieth century. Synthesizing insights from histories of art, science, and technology in the United States and Europe, this research sheds new light on the prevalence of scientifically inflected modes of artistic abstraction in Southern California.

Introduction

New Views of the Universe

Working from Mount Wilson Observatory outside of Pasadena, California in 1923, astronomer Edwin Powell Hubble (1889-1953) produced a series of glass plate photographs imaging a distant, spiral-shaped, celestial object known as Messier 31, or the Andromeda nebula. A few years earlier, during his doctoral research in astronomy at the University of Chicago, Hubble had analyzed photographic images taken through powerful telescopes at the university's Yerkes Observatory to formulate his 1917 dissertation entitled "Photographic Investigations of Faint Nebulae." Hired by astronomer and founder of Mount Wilson Observatory George Ellery Hale in 1919, Hubble continued his research using the observatory's 100-inch lens reflecting mirror telescope, the world's most powerful telescope between 1917 and 1949. A glass-plate photographic negative taken at Mount Wilson Observatory on October 6, 1923 reveals the astronomer's astonishment upon noting a visual aberration within a sequence of long-exposure images of the Andromeda nebula (figure I.1). In red ink, the annotation "VAR!" beside a crossed-out letter "N" documents Hubble's discovery of a Cephid variable where he had expected to find a Nova. The identification of this Cephid variable, a kind of star which radially pulsates at regular intervals, carried a shocking implication: the Andromeda nebula, thought for centuries to be gaseous cloud of dust, proved instead to be the first identified neighboring galaxy beyond the Earth's Milky Way.[1]

[1] The image provided a conclusive resolution to the "Great Debate" held in 1920 at the Smithsonian Natural History Museum between astronomers Harlow Shapley and Heber Curtis regarding the size of the universe and the nature of spiral nebula as objects within or beyond the Milky Way galaxy. Marcia Bartusiak, *The Day We Found the Universe* (New York: Vintage Books, 2010), 199-205. To measure this distance, Hubble utilized a method pioneered by astronomer Henrietta Swan Leavitt (1868-1921), who first observed a relationship between the period and luminosity of radially pulsating stars through her work as a "computer" at Harvard College Observatory during a historical period in which women were

During the 1920s and 1930s, Hubble established the scientific fields of extragalactic and observational astronomy through his research at Mount Wilson Observatory. Like many scientists in the early twentieth century, he published articles and delivered lectures aimed at explaining the indications of his work to both scientists and general audiences. In both sets of texts, Hubble credited the 100-inch telescope at Mount Wilson Observatory as chief catalyst in reshaping the field of nebular research into the empirical methodology he identified as observational cosmology. In his 1936 series of lectures at Oxford University entitled "The Observational Approach to Cosmology," Hubble explained:

> As late as fifteen years ago the observable region was restricted to our own systems of stars, the system of the Milky Way. Since that time great reflectors have identified the nebulae as independent stellar systems, the true inhabitants of space. Explorations, using the nebulae as gigantic landmarks, have swept out beyond the Milky Way to the very limits of existing telescopes. The observable region, our sample of the universe, has been suddenly magnified a million million fold. Now, for the first time, the sample may be fair.[2]

Whereas cosmology, the study of the origins and nature of the universe, laid for most of human history in the realm of speculation beyond the purview of scientific investigation, technological advancements provided new modes of empirically investigating the size, structure, and behavior of the physical universe during the interwar period. As Hubble articulated, the "great reflectors," or reflecting mirror telescopes including the 60 and 100-inch telescopes at Mount Wilson afforded new visual and theoretical perspectives of the universe. Providing paradigm shifting visual evidence regarding the size and nature of the physical universe, Hubble's discoveries attracted the attention of specialists and non-scientists alike while drawing worldwide attention to Southern California as a hub of advanced scientific research and technology.

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not allowed to operate telescopes. Historians of science identify philosopher Immanuel Kant (1724-1804) as an early exponent of the "island universe" hypothesis.

[2] Edwin Powell Hubble, *The Observational Approach to Cosmology* (Oxford: Oxford University Press, 1937), i-ii.

A combination of Southern California's physical and cultural landscapes contributed to the region's outsized role in the global histories of astronomy, aviation, physics, and aerospace engineering over the twentieth century. The same inversion layer responsible for trapping smog over the city of Los Angeles steadies the air above neighboring Mount Wilson. Before the intrusion of light pollution accompanying the World War II economic boom in Los Angeles, the area's climate as well as its preeminent technological resources funded through the philanthropic efforts of local patrons rendered the site ideal for astronomical observation and studies in interferometry, the investigation of wave interferences in light and other electromagnetic frequencies. In the 1920s and 1930s, scientists at the forefront of developments in astronomy and particle physics traveled to Southern California to utilize powerful optical apparatuses and consult an array of American and international colleagues centered around Mount Wilson Observatory and the California Institute of Technology in Pasadena. As Los Angeles and the surrounding area developed into the global capital of aviation and aerospace research and technology over the twentieth century, artists drew inspiration in myriad ways from scientific findings regarding the nature of physical structures, forces, and systems shaping the universe from the subatomic through the cosmic scales.

By focusing a lens on how scientific theories and technologies impacted the emergence and development of abstract artwork in Southern California, this dissertation reframes and expands existing art historical understandings of abstract artwork and its relationship to scientific discovery and technological invention. Combining insights from regional and international histories of art, science, and technology, my research investigates how artists in Los Angeles explored scientific concerns through abstract artwork. In the following four case studies of artists Helen Lundeberg (1908-1999), Bettina Brendel (1922-2009), Mary Corse (1945-), and Frederick Eversley (1941-), I trace the flow of scientific ideas into artwork through distinct pathways in each artist's practice.

By investigating how these practices foreground abstraction as a conceptual process shared by scientists and artists alike, this research contributes to broader theoretical understandings of abstraction in art history and visual studies. At the same time, by placing these artists' practices within historically specific artistic discourses and frameworks of scientific knowledge, my project examines how the production of knowledge across disciplines is situated, or contingent upon sociohistorical and cultural contexts including time period and place.

Existing studies on the emergence and development of artistic abstraction in Europe and the United States locate scientific ideas from mathematics and science as key influences among artists working in a range of non-figurative styles of painting and sculpture beginning in the early 1900s. Art historians including Linda Dalrymple Henderson and Lynn Gamwell examine how mathematical descriptions of space and time as well as advances in microscopic and telescopic imaging prompted a wide range of artistic experiments with abstract, or nonfigurative, modes of artwork throughout the twentieth century. Additionally, art historians Gavin Parkinson and Vanja Malloy consider how ideas from modern physics impacted the development of Surrealism and other styles of modern art in Europe and the United States during the first half of the 1900s. However, existing art historical scholarship has not focused on addressing the prevalent relationships between the histories of artistic abstraction and scientific research and engineering in Los Angeles. By investigating how the history of physics and aerospace engineering in the twentieth century impacted the trajectory of abstract artwork in Los Angeles, my research contributes a new perspective on the history of artistic experimentation in the region.

This research examines how and why abstraction took shape as a central concern in both modern art and modern physics beginning in the early twentieth century. As philosopher and political theorist Hannah Arendt analyzed in her 1963 essay "Man's Conquest of Space," although the advent of quantum mechanics in the early 1900s emerged from physicists' search for objective scientific truths underlying the structural foundations of the universe, this avenue of scientific inquiry ultimately revealed a degree of unknowability regarding subatomic processes inaccessible to human senses, inherently disrupted by scientific measuring instruments, and seemingly ruled by chance and probability. Arendt articulated: "The progress of modern science has demonstrated very forcefully to what an extent this observed universe, the infinitely small no less than the infinitely large, escapes the coarseness of human sense perception but even the enormously ingenious instruments that have been built for its refinement."[3] In her text, Arendt cites physicist Niels Bohr's observation that atomic phenomena "defy deterministic pictorial description." She identifies abstraction as a primary characteristic of modern science after quantum mechanics owing to the complete detachment of human sense perception from the purely mathematical descriptions of atomic and cosmic phenomena supplied by theoretical physics. According to Arendt:

> The categories and ideas of human reason have their ultimate source in the human senses, and all conceptual or metaphysical language is actually and strictly metaphorical. Moreover, the human brain which supposedly does our thinking is as terrestrial, earthbound, as any part of the human body. It was precisely by abstracting from these terrestrial conditions, by appealing to a power of imagination and abstraction that would, as it were, lift the human mind out of the gravitational field of the earth and look down upon it from some point in the universe, that modern science reached its most glorious and, at the same time, most baffling achievements.[4]

For Arendt, the modern scientific enterprise presupposed an impossible, objective position outside of itself, detached from both the terrestrial confines of Earth and indifferent towards humanistic concerns altogether. As the human astronaut physically occupied the previously

[3] Hannah Arendt, "Man's Conquest of Space," *The American Scholar* 32, no. 4: (Autumn, 1963), 527-540.
[4] Ibid, 532.

purely theoretical position of Einstein's "observer freely poised in space," the development of manned space flight in the early 1960s enabled human beings to "conquer space" by physically occupying a position outside of Earth previously only accessible to human imagination. However, at the same time, Ardent argued that the astronaut imprisoned within a technological capsule represented a "symbolic incarnation" of Heisenberg's man, who in searching for objective truth and reality apart from anthropocentric concerns is directly confronted by his own human and technological limitations.

Across the following case study chapters, the themes of positionality, the subjective nature of perception, and the limits of human vision and knowledge arise as shared concerns in both modern art and modern physics during the twentieth century. The designation modern physics generally refers to the field of physics after 1900, when the theories of special and general relativity along with quantum mechanics revolutionized scientific understandings of phenomena at the extremes of scale and velocity. While classical or Newtonian physics provides accurate descriptions of the behavior of matter and energy at the human scale of everyday macroscopic events, studies in modern physics take into account the dynamics of occurrences at intensely high speeds and energies at the atomic and cosmic scales. Despite the efforts of physicists and popularizers of physics in the early twentieth century who attempted to translate newly emerging mathematical theories into written descriptions intended to be widely accessible to non-specialists, modern physics developed a reputation in the United States as an abstruse and incomprehensible subject.

Culturally, the field of modern physics took on another layer of obscurity within the United States through secrecy surrounding the Manhattan Project dedicated to weaponizing nuclear energy during World War II. The historical impact of McCarthyism on the histories of both science and artwork in Los Angeles is perhaps most clearly visible in the comparison between the careers and cultural afterlives of physicists Richard Feynman and Frank Malina, both associated with significant advancements in modern physics while working at Caltech. As historian of science David Kaiser examines in his texts such as *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics,* Feynman's method of diagramming equations from the late 1940s provided physicists with new ways of visualizing and calculating sets of formulas representing subatomic particle interactions. Feynman diagrams enabled physicists to reconsider which kinds of questions might be asked.

Less visible in histories of science than Feynman is pioneering rocket scientist Frank Malina, whose work at Caltech in the 1930s led to development of the Jet Propulsion Laboratory in the 1930s. As historian Patrick McCray analyzes in *Making Art Work: How Cold War Engineers and Artists Forged a New Creative Culture,* Malina's political association with the Pasadena Communist Party in the late 1930s plagued the scientist's personal life due to McCarthyism during and after World War II, and ultimately contributed to his exile in Paris after 1947. After leaving rocketry due to his ethical objections to the weaponization of advanced science technology research at Caltech during World War II, Malina took a position at the headquarters of UNESCO, and created artwork in Paris before producing a forum for other contemporary artists also concerned with science and technology through *Leonardo* journal, first published in 1968. Like Feynman, Malina created a widely influential theoretical tool for working practitioners, however the latter channeled his efforts into stimulating interdisciplinary, global discourse between practicing artists.

The highly mathematical nature of theoretical physics, which describes and predicts the behavior of natural phenomena and systems using calculus, shaped mainstream perceptions of the subject as abstruse or incomprehensible to non-specialists since the early twentieth century despite efforts by scientists to translate their work into common language. However, artists including Brendel and Corse produced artworks in response to the philosophical implications of theoretical physics despite approaching the topic as artists rather than mathematicians or scientists. Considering mathematics as a science of patterns, my study investigates how the probabilistic quality of quantum mechanical descriptions of subatomic phenomena and processes through matrix mechanics prompted artists including Brendel, Corse, and Eversley and to reconsider human experience and the nature of reality through their artwork.

Physicists and historians of science have noted the highly abstract character of modern physics due to its expression through mathematical theories, equations, and formulas since its emergence in the early twentieth century. Abstraction often refers to the conceptual process of generalization, or the derivation of broader ideas or rules from specific concrete examples. In metaphysics, the branch of philosophy concerned with examining the nature of reality, abstract objects are characterized as immaterial concepts including numbers and propositions while concrete objects occupy physical space, for example books or trees.[5] As a conceptual negotiation between ideas and physical phenomena, the process of abstraction underlies human beings' development of symbols, metaphors, and language. My research examines how and why abstraction took shape as a central concern in both modern art and modern physics beginning in the early twentieth century by focusing the interrelated histories of abstract artwork and advanced scientific research and engineering in Southern California. Each chapter reveals ways in which different scientific ideas and technological advancements inspired individualistic modes of articulating meaning through visually abstract artistic forms.

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[5] Gideon Rosen, "Abstract Objects," *The Stanford Encyclopedia of Philosophy* (Spring 2020 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/spr2020/entries/abstract-objects/>.

The term abstraction carries particularly disciplinarily entrenched connotations in the fields of modern and contemporary art history. As art historian Caroline A. Jones identifies in *Eyesight Alone: Clement Greenberg's Modernism and the Bureaucratization of the Senses*, critic Clement Greenberg's metacritical practice drew from the theoretical framework of philosophical positivism in order to pursue a "science" of aesthetic experience.[6] Philosopher Isidore Marie Auguste François Xavier Comte originated the doctrine of positivism in his work *Cours de Philosophie Positive* from 1842 by proposing a circular dependence between theory and observation in science. Often regarded as the first philosopher of science, Comte proposed a fundamental law regarding epistemological developments. He wrote: "The law is this: that each of our leading conceptions – each branch of our knowledge – passes successively through three different theoretical conditions: the theological, or fictitious; the metaphysical, or abstract; and the scientific or positive."[7] As Jones addresses, linking abstraction with positivism allowed for the "scientism" of Greenberg's formalism, in which disinterested, objective observers measure and compare optical sensory information against testable criteria.[8]

This dissertation offers the first focused examination of artistic abstraction influenced by science in Los Angeles. The title of my project, *Alternative Abstractions: Art and Science in Twentieth-Century Los Angeles,* identifies the topic and time period of this study while also indicating a predominant theme layered into my study. By "alternative abstractions," I refer to a pattern in art historical scholarship wherein artwork from the West Coast is positioned as different and apart from predominant stylistic movements categorizing the work of practitioners in New York City and Europe. At times, artists themselves have insisted on this difference. In 1934,

[6] Caroline A. Jones, *Eyesight Alone: Clement Greenberg's Modernism and the Bureaucratization of the Senses* (University of Chicago, 2008), 97-99.
[7] Ibid, 98.
[8] Ibid, 139.

Lundeberg articulated the artistic objectives of New Classicism or Post-Surrealism by directly contrasting the aims of the Los Angeles movement in opposition to many central tenants of European Surrealism. Critics and curators have frequently characterized the work of abstract artists in Los Angeles in opposition to predominant styles of artistic abstraction in New York. In 1959, art critic and curator Jules Langsner and art historian and curator Peter Selz created the term hard-edge painting to describe the work of artists in Southern California reacting against the spontaneous gestural abstractions of New York artists through precisely delineated, flat planes of solidly painted colors in predefined configurations. More recently, critics and art historians have used terms including the LA Look, West Coast Minimalism, and Light and Space art to describe styles of postwar artwork in the region.

While certain stylistic designations including hard-edge painting and West Coast Minimalism point to salient formal characteristics unifying groups of practitioners on the West Coast, my case studies reveal how these existing art historical categorizations present a fragmented and incomplete historical narrative of abstract art in Los Angeles. In particular, I argue that art historical categorizations including Light and Space art have historically excluded the work of women artists and artists of color. A number of recent art historians and curators have sought to amend the exclusion of female artists including Mary Corse and Helen Pashgian from histories of postwar art in Los Angeles through belated solo-exhibitions and scholarly examinations. However, these efforts have not sufficiently addressed the systemic sexism and racism underlying the historical and continued exclusion of other underrecognized practitioners.

Through studies of Lundeberg, Brendel, Corse, and Eversley's artwork, this dissertation studies interconnections between vision and knowledge. In asking how and why abstraction functioned as a compelling means for artists concerned with science in Los Angeles, my dissertation draws attention to a broad interest shared by many practitioners in Southern California. Lundeberg, Brendel, Corse, and Eversley are by no means the only artists who worked at the nexus of scientific concerns and nonfigurative artwork during the last century in Los Angeles. However, each rigorously engaged with scientific concepts through abstract artwork in ways that are not articulated in existing scholarship. As an investigation of the relationship between vision and knowledge in both science and artwork, this sampling of artists enables my research to identify a range of interconnected social factors including overt instances of structural sexism and racism and normalized cultural biases underlying the continued exclusion and invisibility of women and individuals of color from historical and contemporary discourses in the fields of science and the visual arts.

Chapter Overviews

Taken together, my case studies shed light on how theories in modern physics prompted artists to consider new modes of conceptualizing relationships between human vision, perceptual experience, and knowledge through abstract form. I first consider how Lundeberg's astronomy-themed paintings invoke period-specific modes of visualizing of cosmic phenomena from the 1930s into the 1960s. The artist's early representational works from the 1930s articulate relationships between vision, technology, and knowledge derived from the artist's interest in technical scientific illustration. My research situates Lundeberg's artistic explorations of cosmic scale within the contemporaneous context of Hubble's groundbreaking discoveries from Mount Wilson Observatory as well as the artist's own experience taking an astronomy course at Pasadena Junior College (now Pasadena City College) in the late 1920s. I then examine how Lundeberg merged geometric abstraction and figuration in her series of planet paintings from 1964 to 1969. The artist's imagined views of planets render cosmic spatial depth through the juxtaposition of crisply edged physical layers of colors and forms. Merging colorful hard-edge forms with cosmic subject matter, Lundeberg's highly abstract renderings of planets from the 1960s align with new views of outer space propelled by the United States' creation of the National Aeronautics and Space Administration (NASA) in 1958 to succeed the National Advisory Committee for Aeronautics (NACA) started in 1915. I argue that Lundeberg's hard-edge planets draw attention to the significant influx of imagined views of outer space that circulated alongside contemporaneous news coverage on scientific advancements in outer space exploration during the Space Race.

From the late 1960s to the late 2000s, Brendel continually explored the theme of atomic motion in her paintings and digital artworks. Following the artist's studies of the history and theory of atomic physics, she created abstracted compositions that visualized themes including the wave-particle duality of subatomic phenomena, ionization, the coherent light of laser beams, and spectroscopic views of atoms to name only a few. My second chapter analyzes how Brendel's movement between international artistic communities significantly shaped the production and reception of her atomic themed abstract paintings beginning in the 1960s. Immigrating to the United States after concealing her Jewish heritage throughout the Nazi regime in Germany, Brendel's experiences living and working in both New York and Los Angeles in the 1950s and 1960s added new dimensions to her early stylistic and thematic concerns. This chapter considers how the artist's early exposure to the work of German Expressionism and Bauhaus artists contributed to her lifelong interest in the role of abstract communication. Brendel's career as an artist as well as a writer and lecturer specializing in the interrelated histories of art and science in Europe and the United States evidences the transnational character of postwar artistic abstraction as well as the contributions of European émigré artists to the cultural landscape of Southern California.

Corse's interest in perceptual phenomena informed the material and compositional qualities of her abstract paintings and sculptures from the onset of her artistic career in the early 1960s. However, the artist's scientific investigation of the physical nature of light radically transformed her understanding of her formal approach to abstraction by the late 1960s. My third chapter closely examines Corse's experimentations with different forms of light in her paintings, sculptures, and mixed media work from the 1960s. The various physical media Corse experimented with during this time, including acrylic paint, plastic, high frequency coils, and glass microspheres enabled the artist to work with light itself as an immaterial yet compliant artistic medium. Concurrently, the artist's introduction to quantum mechanics through a physics course at the University of Southern California fundamentally transformed her worldview and artistic production. My research reveals how concepts from quantum physics including the uncertainty principle, the observer effect, and wave-particle duality prompted the development of Corse's *White Light* paintings. In this case study, I argue that Corse's reconceptualization of subject/object relations stemming from her introduction to quantum theory in the late 1960s can be productively situated in dialogue with theories of closed and open systems.

As an aerospace engineer turned artist in 1967, Eversley approached sculpture from a perspective distinctly shaped by scientific and mathematical understandings of material and form. My fourth chapter examines the role of energy transfer in his resin parabolic-lens series started in 1969. The particular shape of these lenses, known as a plano-concave, cylindrical paraboloid, indexes the centrifugal casting of liquid polyester resin rotated about the vertical axis. As optical lenses and reflective paraboloids, Eversley's sculptures allude to the parabolic curve's widespread applications in engineering as a technological means of concentrating physical energies from electromagnetic to acoustic. To centrifugally spin cast larger lenses in the early 1970s, the artist acquired and reconfigured two antique industrial turntables from 1936 along with variable speed motors salvaged from World War II submarines. The large turntables, he learned, were purportedly used in machining the casings of the atomic bombs dropped by the United States on Japan in 1945. The material history of this machinery attests to two radically divergent modes of harnessing energy: for destructive military warfare on one hand, and artistic experimentation on the other. My study examines how Eversley's hybrid scientific/artistic approach doubly employs the paraboloid shape as both an abstract visualization of diverse forms of energy as well as a means of physically engaging surrounding light waves through the final highly polished sculptural work. I also consider how debates surrounding identity politics as well as Einstein's theory of relativity conjointly contributed to Eversley's series of opaque black mirrored lenses beginning in the mid 1970s.

This study asks how artists engaged with forms of visual abstraction in their considerations of modern science and technology in Southern California. In the following chapters, artworks themselves lead the way by signaling which sets of scientific issues, phenomena and technical concerns I address and historically contextualize. Although I am not a scientist by formal training, Lundeberg's planets, Brendel's symbols of atomic motion, Corse's interest in quantum theory, and Frederick Eversley's paraboloids have required me to closely research specific subjects and themes within the extended histories of science and mathematics. As I explore through these artists' practices, histories of astronomy, quantum physics, and astrophysical engineering in Southern California contribute nuance and intricacy to existing narratives of artistic abstraction on the West Coast. By examining the cross section of histories of artistic abstraction and modern physics, this research analyzes abstraction as a conceptual process shared by scientists and artists alike, thus contributing to broader theoretical understandings of nonfigurative artwork in art history and visual studies.

Chapter One
Among the Planets: Helen Lundeberg's Cosmic Imaginary

Introduction: Picturing Outer Space

In a self-portrait from 1944, Helen Lundeberg depicted herself at work in front of a painting of moonlit landscape (figure 1.1). By portraying the act of painting, specifically the visual translation of a spherical form onto the flat surface of a canvas, Lundeberg's composition reflexively acknowledges the role of the painter as an intermediary between the physical world of three dimensions and the illusory realm of the picture plane. Against a neutral background suggestive of an indoor environment, Lundeberg looks out from the pictorial space of the painting to meet the viewer's gaze. Her easel and canvas appear in front of a blue outdoor landscape as her hands reach towards a darker navy and purple skyscape in the painting within the painting. While accenting the illuminated portion of a bright blue crescent moon with her paintbrush, the artist holds a round blue spherical model spotlit to simulate a lunar phase. Lundeberg's composition accounts for the separate spatial positions occupied by the artist and viewer through the different patterns of light and shadows on the smaller moon and the blue sphere. Whereas the artist's position presumably affords a view of an illuminated crescent on the model which she then paints, the viewer sees the same sphere in phase known as a waning gibbous. Visually modeling lighting effects in this way, Lundeberg's composition draws attention to the nuanced interconnections between positionality and the appearance of light, shadow, and depth in both human and cosmic spatial scales.

Despite the artist's detailed consideration of illusionistic lighting effects and attention towards rendering visually distinct spatial depths and pictorial environments, Lundeberg's *Self Portrait* remains open-ended in its layered compositional structure. Hovering near the horizon of her moonlit landscape, the blue sphere in Lundeberg's *Self Portrait* doubles as both an everyday object in the artist's studio as well as the uncanny image of an unusually large planet or moon suspended in the smaller painting's evening skyscape. Just as the artist seems to hold a spherical model in front of her canvas, she also appears to reach into the illusory space of the picture plane as though she could somehow grasp an imagined celestial body. With multiple potential visual readings made possible through her arrangement of pictorial forms, Lundeberg's *Self Portrait* typifies the artist's interest in producing thought provoking compositions dependent on a viewer's engagement and subjective interpretation. In this painting as well as many of Lundeberg's other compositions, the artist's close attention to interrelationships between observation, positionality, and subjectivity takes shape through layers of overlapping physical environments and spatial scales. Merging the everyday and the extraordinary, Lundeberg's visual motif of indoor environments opening into cosmic space recurs throughout her work over several decades in varying degrees of figuration and abstraction.

From the start of her artistic career in the early 1930s, Helen Lundeberg alluded to the Earth's position within a vast cosmic universe through a range of references to astronomy in her paintings. This chapter analyzes Lundeberg's artistic visualizations of cosmic space within two distinct styles of her paintings: "Post-Surrealism" in the 1930s and 1940s and "hard-edge abstraction" in the 1950s and 1960s. Through distinctive stylistic means, Lundeberg produced a wide array of compositions concerned with extending the illusory space of her paintings into the depths of outer space beyond Earth's atmosphere. As I examine in the first section of this chapter, Lundeberg's introduction to telescopic and microscopic imagery through college courses in astronomy and biology in the late 1920s significantly impacted her formulation of "New Classicism," or "Post-Surrealism" in artwork and statements from the 1930s into the 1940s. For the artist, recurring structures, processes, and cycles across natural forms at varying spatial scales in the universe emerged as a central thematic concern in her practice. In particular, Lundeberg imagined specific planets and views of the Earth's Moon from terrestrially grounded viewpoints and telescopic technologies characteristic of advanced astronomical research in the interwar period. By tracing a number of the artist's source images to astronomy and biology textbook diagrams from the 1910s and 1920s, I analyze how Lundeberg's conception of Post-Surrealism emerged from her interdisciplinary consideration of structural form in scientific illustrations as well as in painted artistic compositions.

As this research demonstrates, Lundeberg's paintings of cosmic phenomena relate to broader histories of image production and circulation within the fields of astronomy and space exploration in the twentieth century. Shortly before astronauts on NASA's 1968 Apollo 8 and 1972 Apollo 17 lunar missions captured the highly influential first photographs of Earth taken by humans in outer space often referred to as *Earthrise* and *The Blue Marble*, Lundeberg prefigured related compositional perspectives from outer space in her imaginative series of hard-edge planet paintings between 1961 to 1969. The second section of this chapter contextualizes Lundeberg's hard-edge *Planet* series of roughly twenty paintings from the 1960s within the contemporaneous Space Race era's cultural atmosphere of rapid advancements in outer space exploration. In her hard-edge paintings of planets, colorful geometric compositions suggest imagined views from outer space vantage points. Using a limited range of colors and curvilinear forms in each composition, Lundeberg's *Planet* series from the early 1960s to 1969 as well as her serigraph prints of planets from 1972 exemplify the artist's imaginative stylistic reconfigurations of themes she considered in earlier artwork, including spherical forms fluctuating between spatial scales, diagram views, and patterns of planetary motion. Through arrangements of cleanly defined shapes in smooth planes of evenly layered colors, her hard-edge abstract planets distill earlier conceptual concerns, including the viewer's involvement in constructing meaning from visual forms, into refined geometric compositions picturing planets from vantage points in cosmic space.

Throughout her sixty-year career as an artist in Los Angeles, Lundeberg incorporated astronomical subject matter into her paintings in ways that draw attention to the nature and conventions of both artistic and scientific images. By exploring spatial relationships between the Earth, Moon, and neighboring planets in her works self-identified as Post-Surrealist in the 1930s and 1940s, Lundeberg synthesized artistic and scientific considerations of spatial organization and scale. The artist's views of cosmic space in her figurative Post-Surrealist paintings layer multiple viewpoints as well as biological and technological modes of seeing. As Lundeberg shifted towards higher degrees of visual abstraction in her geometrically refined renderings of moonlight and planets in the 1960s, she articulated spatial depth and atmospheric lighting effects through even planes of solid colors in experimental combinations of acrylic, alkyd, and enamel paints. By situating the artist's planet-themed paintings within the context of contemporaneous scientific research and image production in interwar and postwar Los Angeles, this chapter examines how Lundeberg's artworks relate to a larger collective shift in cultural understandings of cosmic space during the 1960s.

Part One: Post-Surrealism, Observation, and Physical Cosmology

In 1937, Lundeberg's painting *Cosmicide* (figure 1.2) appeared in the exhibition "Fantastic Art, Dada, and Surrealism" curated by art historian Alfred Barr at the Museum of Modern Art in New York City. The exhibition focused on the work of artists associated with the European Dada and Surrealist movements while also including a section of artists in Europe and the United States practicing independently yet in related ways. Lundeberg's painting fell into the latter category, showing in the exhibition section entitled "Artists independent of the Dada and Surrealist movements."[1] Although the exhibition catalogue does not include an image of her work, the text lists Lundeberg and her painting *Cosmicide* from 1935 in the published checklist. A brief biographical entry identifies the artist as a member of the "California Post-Surrealist group."[2] As the co-creator of New Classicism or Post-Surrealism in the early 1930s along with artist Lorser Feitelson, both artists' inclusion in the MoMA exhibition marked a significant achievement for the Los Angeles based practitioners. Together, both aimed to draw rational correspondences between compositional forms and thematic subjects in their paintings.

Cosmicide's unconventional trapezoidal shape evidences Lundeberg's interest in formal artistic experimentation, as well as her effort to align compositional structure with subject matter. The work's material support as well as the painted arrangement of forms follow a pyramidal structure with three levels of depicted objects. At the top, a detailed and naturalistic depiction of the Earth's Moon in its third quarter, also known as a Half Moon, stands out before the blue portion of a gradient background. In the center, cross section view of a carnivorous pitcher plant holding a drowned fly is rendered in the style of contemporaneous botanical illustrations. Against a red background at the work's base, a vaguely delineated ledge supports a number of small objects. On the left, a pair of pliers pulls out a bent and no longer usable construction nail. To the right, the illustrated sun on a matchbox appears to cast shadows from the nearby cactus and fallen toy horse. In *Cosmicide,* the cycles of night and day signal the passage of time as well as transitions between physical states. The artwork's title and imagery symbolically convey an allegorical cycle of life

[1] Museum of Modern Art, "Press Release," December 6, 1936.
[2] Alfred H. Barr Jr., *Fantastic Art, Surrealism, Dada* (New York: The Museum of Modern Art, 1936), 280.

and death through relationships between animate and inanimate objects in various forms and spatial scales.

Lundeberg's artwork from the 1930s and 1940s combine the pictorial languages of Post-Surrealist painting and scientific illustration in order to articulate relationships between natural phenomena and patterns across microscopic and macroscopic spatial dimensions in the universe. In light of contemporaneous scientific findings regarding the size, shape, structure, and motion of the physical cosmos, artists in the 1930s including Lundeberg took interest in the structural organization of the Earth's Solar System as well as its position among other galaxies in the universe. Lundeberg's artistic explorations of the individual human's position within an expansive cosmic framework in the 1930s followed shortly after a series of astronomer Edwin Powell Hubble's groundbreaking discoveries regarding Earth's location within a vast and expanding universe full of distant galaxies. Juxtaposing human and cosmic spatial scales in her artwork by including scientific images and diagrams, Lundeberg's astronomy-themed compositions from the 1930s and 1940s attest to her close consideration of artistic and scientific modes of observation, visualization, and experimentation.

From her earliest artistic compositions, Lundeberg foregrounded the theme of recurring structural forms across diverse life forms and varying spatial scales through references to astronomy and biology textbook imagery and diagrams. While referring to images from scientific sources, Lundeberg also alluded to her studies of Classical Italian Renaissance compositions under Feitelson's instruction. Contemplating the shared and distinct aspects of scientific illustration and artistic composition appealed to Lundeberg, who entered Pasadena's Stickney Memorial School of Fine Art in 1930 intending to work towards a career in scientific illustration. Upon their introduction, Feitelson appreciated Lundeberg's technical drawing skill evidenced by her portfolio of biology diagrams. As her teacher and mentor, Feitelson encouraged Lundeberg to pursue painting rather than illustration.

Entering painting from a background in technical illustration, Lundeberg took a strong interest in Feitelson's teaching method of diagramming artistic compositions with lines and arrows to indicate structural relationships among depicted forms. Feitelson's technique is visible in his diagram *Maternity*, drawn from his 1932 painting with the same title (figure 1.3). While Lundeberg previously created biological illustrations through precise observations of dissected organisms and textbook diagrams, Feitelson prompted her to closely analyze the formal compositional structuring of European paintings and sculptures from the Renaissance through Impressionism. Handwritten assignments from Feitelson to Lundeberg dated 1930 instruct her to analyze the "dynamic forms" of Luca Signorelli and Antonio Pollaiuolo, as well as the "static (perpendicular) compositions of Andrea Mantegna and Piero della Francesca." A separate assignment asks her, amongst other tasks, to "investigate the principles of perpendicular 'static' compositional constructions by making analytical drawings" of Seurat and Fra Angelico, emphasizing the "Ingres Contour."[3] Paralleling Lundeberg's earlier lessons in biology, which required her to study the structural form of natural organisms, Feitelson's assignments called for the close observation of structural forms in classical, neoclassical, and impressionist artistic compositions. As Lundeberg later described:

> The same turn of mind which stimulated my college interest in the biological sciences and the technical aspects of literature, undoubtedly motivated my eagerness to investigate the intricacies of aesthetic structure and mechanism in all the significant phases of art, from the ancient masters to those of our own period; in other words, that which makes a graphic expression a work of art.[4]

[3] Suzanne Muchnic, *Helen Lundeberg: Poetry, Space, Silence* (Orange: The Feitelson/ Lundeberg Foundation, 2014), 35.
[4] Lorser Feitelson and Helen Lundeberg papers, circa 1890s-2002, bulk 1919-1999. Archives of American Art, Smithsonian Institution. Box 8, Folder 64: Artist Statements, circa 1950s-1970s.

For Lundeberg, the process of closely considering the compositional structure of artwork aligned with her broader interest in analyzing structural form across disciplines.

Lundeberg's attraction to scientific illustration and visualization emerged as a predominant theme in her conceptualization of New Classicism or Post-Surrealism beginning in the early 1930s. After studying painting as Feitelson's student at the Stickney Memorial School from 1930 to 1933, Lundeberg went on to collaborate with him in formulating the artistic movement they called New Classicism. A self-published statement entitled "New Classicism" written by Lundeberg in 1934 identified the style as "a Post-Surrealist movement" originating in Los Angeles in her work as well as Feitelson's. As the first organized artistic response in the United States to European Surrealism, Lundeberg's "New Classicism" text articulated both artists' shared goal of attaining a new degree of balance, rhythm, and unity between forms and ideas in their artworks. Unlike European Surrealist artwork which sought to highlight the irrationality of the human subconscious through illogical juxtapositions of subject matter, New Classicism instead appealed to "conscious, intellectual nature" through the integration of subject matter and pictorial structure.[5] Rather than the original term New Classicism, the designation Post-Surrealism instead gained popularity among critics to describe the artist's approach. Both founding artists as well as other painters in Los Angeles with shared concerns including Grace Clements, Philip Guston, Reuben Kadish and Knud Merrild exhibited as Post-Surrealists in the mid to late 1930s.[6]

Lundeberg's 1934 "New Classicism" manifesto included a reproduction of her painting *Plant and Animal Analogies* (figure 1.4) from the same year in order to illustrate the movement's aesthetic ideal of establishing both visual and thematic relationships between depicted objects. As

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[5]Helen Lundeberg, "New Classicism," in Muchnic, 41.
[6] Michael Duncan, "Helen Lundeberg's 'New Classicism,'" in *Helen Lundeberg: A Retrospective* (Laguna Beach: Laguna Art Museum, 2016), 102.

the work's title suggests, this composition draws attention to visual correspondences between the physical structures and reproductive processes of plants and animals by juxtaposing cross section views of visually similar forms. Lundeberg invoked the visual language of scientific illustration through her appropriation of cross section views, her use of black and white in rendering biological diagrams, and by including dotted lines and arrows pointing out particular formal relationships between the depicted objects. Her graphic symbols indicate visual similarities between pairs of forms including cross sections of a cherry seed and a pregnant human womb, an overlay of blood vessels on a tree, and a cross section diagram of a fetal brain next to a cut open bell pepper. Notes from Lundeberg's preparatory drawings for the work indicate a page number of a 1921 textbook on embryology from which she closely copied the womb and fetal brain diagrams.[7]

The schematic roadmapping of arrows and dotted lines traversing Lundeberg's *Plant and Animal Analogies* alludes to instructional diagrams implying particular relationships between forms, including Feitelson's analytical drawings from the 1930s. In both Lundeberg's *Plant and Animal Analogies* and Feitelson's instructional diagrams including *Maternity,* arrowed lines function as graphic annotations highlighting structural correlations between visual forms. In both examples, formal interconnections between compositional elements emphasize the image's overall subject matter through structural relationships. Whereas Feitelson's compositional chart functioned as a pedagogical device and method of training students, Lundeberg incorporated the visual motif of instructional lines and arrows into her completed artwork as a means of directly indicating the organizational logic underlying her artwork's juxtaposition of forms. The artwork merges her training in biological illustration with her close consideration of compositional organization through Feitelson's analytical diagram approach. In so doing, Lundeberg's *Plant and*

[7] Helen Lundeberg, Studies for Plant And Animal Drawings (pencil drawings on paper), reproduced in Muchnic, 39.

Animal Analogies exemplifies the artist's ideal of visualizing ideas and concepts through informative, allegorical, and interdisciplinary pictorial arrangements.

In sampling illustrations from biology and astronomy textbooks, Lundeberg's works from the 1930s recall her own training in scientific illustration during a range of college courses in the late 1920s at Pasadena Junior College (now Pasadena City College). As she described in a 1980 interview:

> I was always the last one out of the lab, and I enjoyed doing my notebook... Even in beginning college zoology I enjoyed the dissections and making drawings of what I saw. About that time I had read a story about a woman who had gone on some scientific expedition into, I think, the South Pacific, in the area of Java. She was the scientific illustrator for this expedition. Her job was to draw and do in watercolor these marvelous creatures which they drew up from the sea before they could lose their color… I thought that would be an interesting career."[8]

Accompanying Lundeberg's interest in producing biological drawings was the possibility of working towards a career in scientific illustration evidenced by magazine articles including the kind described in this statement. During Lundeberg's college years, a number of articles on scientific illustrator Isabel Cooper circulated in magazines describing her travels on several scientific expeditions sponsored by the New York Zoological Society. In colorful and precise watercolor illustrations, Cooper documented tropical fish and other animals in the Galapagos Islands and British Guiana in the early 1920s while writing essays about her work. Articles on Cooper appeared in *Cosmopolitan*, *The Woman Citizen*, and *American Magazine* during the 1920s. Her essay "Wild Animal Painting in the Jungle" in a 1924 issue of *Atlantic Monthly* provided a firsthand account of her adventurous field work as a scientific illustrator.

As historian Suzanne Le-May Sheffield examines, women's contributions to scientific endeavors in the past have been marginalized nearly to the point of invisibility within histories of

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[8] Oral history interview with Helen Lundeberg, 1980 July 19-Aug. 29. Archives of American Art, Smithsonian Institution.

science.[9] Particular examples including Lundeberg's description of encountering the work of a female scientific illustrator in her youth point to the influential impact of articles featuring women in scientific careers circulated across mainstream periodicals. While Lundeberg ultimately did not pursue a career in scientific illustration, she continued her interest in studying, observing, and depicting the natural world through her paintings. Her works from the 1930s and 1940s combined the artist's close observation of scientific imagery in ways that contrast distinct spatial scales between microscopic, telescopic, and human ranges of vision.

In her paintings from the 1930s, Lundeberg's references to scientific themes and her incorporation of images derived from scientific textbooks serve the function of exploring the production and communication of concepts and knowledge through images and abstract models in both the natural sciences and visual artwork. Lundeberg first explored astronomy and cosmic spatial scale in her painting *The Red Planet* from 1934 (figure 1.5). In the painting, a black and white image of a comet as well as a book entitled *Mars* signal the work's cosmic theme, inviting the viewer to gather further meaning from the arrangement of forms in the depicted interior space. In this context, the small red marble evokes the distant planet Mars while resting atop a table whose elliptical shape recalls the path of a planet in orbit. Additionally, the brass doorknob doubles as the suggestion of a sun, subtly functioning as a light source casting shadows off of the table legs. In employing text and symbolic forms, Lundeberg's work signifies Mars without directly representing a planet in space. As a result, Mars is conveyed as an idea mediated through language and images in addition to its existence as a remote planet. At once physically inaccessible yet nonetheless available to the imagination with the aid of mediated representations, the Red Planet

[9] Suzanne Le-May Sheffield, "Gendered Collaborations: Marrying Art and Science," in *Figuring it Out: Science, Gender, and Visual Culture*, ed. Ann B. Shteir, Bernard V. Lightman (Lebanon: University Press of New England, 2006), 241.

takes shape in this work as an abstraction between substance and thought. The concept of a distant planet, its orbital motion, and its position within a wider solar system are transferred in the composition from the cosmic realm into the spatial dimensions of human scale.

As Lundeberg began incorporating the motif of planets in her work several decades before either space flight or photographic images from satellites became a reality, her earliest paintings of cosmic subjects draw from terrestrially grounded observations and descriptions of outer space. Perhaps not surprisingly given the representation of a stack of books in *The Red Planet*, Lundeberg acquired a number of source images for her astronomy themed paintings from contemporaneous textbooks. The comet image shown propped against the book, for example, is visually similar to an image of Donati's comet published in John Charles Duncan's *Astronomy* from 1927 (figure 1.6). Lundeberg likely encountered this text while taking an astronomy corse at Pasadena Junior College in the late 1920s. According to the textbook caption, this illustration of Donati's comet was drawn by American astronomer George Phillips Bond as it appeared to the unaided eye 1858. Brightly visible to the naked eye from Earth's Northern Hemisphere for roughly four months, Donati's comet prompted a wide array of scientific and artistic representations.[10] As the first comet to be photographed, this celestial occurrence marked a transitional moment in the recording and documentation of astronomical images. The duration and brightness of this comet facilitated early technological advances in astrophotography, although these still nascent experiments did not result in clear or lasting images of Donati's comet itself compared to conventional astronomy illustrations at the time.[11]

[10] Antonella Gasperini, Daniele Galli, and Laura Nenzi, "The Worldwide Impact of Donati's Comet on Art and Society in the mid-19th century," The Role of Astronomy in Society and Culture Proceedings IAU Symposium No. 260, (2011): 340, https://doi.org/10.1017/S174392131100250X.
[11] Jay M. Pasachoff, Roberta J. M. Olson, and Martha L. Hazen, "The Earliest Comet Photographs: Usherwood, Bond, and Donati 1858" *Journal for the History of Astronomy,* xxvii (1996): 132.

By including a painted representation of an astronomical illustration in her work, Lundeberg alluded to scientific images in a meta-visual manner. As literary scholar Carla Taban describes, meta- and inter-images can be defined broadly as images about images. Meta-images refer to their own nature as images, while inter-images refer to themselves and/ or other images.[12] Many of Lundeberg's works throughout her career, including *The Red Planet* and her 1944 *Self Portrait* include paintings or illustrations within their compositions. *The Red Planet* and other works by Lundeberg from the 1930s include representations of scientific imagery including hand-drawn illustrations as well as painted representations of astrophotography. These works self-reflexively address various forms of image production, from painted canvases to scientific illustrations and diagrams. In *The Red Planet,* the comet image functions as a physical object as well as an illusory window into the depths of cosmic space. Over the span of her career, Lundeberg frequently drew attention in her work to the paradoxical duality of images as both material objects and virtual picture planes.

The way in which a room of familiar objects signifies planets and cosmic space in *The Red Planet* relates to an exercise for imagining dimensions of the Solar System found in several contemporaneous introductory astronomy textbooks from the late 1920s and early 1930s, including Duncan's *Astronomy.* This exercise demonstrates a method of conceptualizing the vast spatial expanses described in astronomy by imagining the size of everyday objects within a familiar scale of distances. A reader is prompted to envision a model of the planets as familiar everyday objects as a means of grasping their relative dimensions and the distances of their orbits. In this exercise, the Sun is visualized as a two foot tall globe around which the planets revolve at various distances. For example, the Earth is a pea traveling the circumference of a circle of 430

[12] Carla Taban, "Introduction," *Meta- and Inter-Images in Contemporary Visual Art and Culture* (Leuven: Leuven University Press, 2013), 23.

feet in diameter, Mars is the head of a large pin revolving around a circle 650 feet in diameter, Saturn is a small orange, and so on. As Duncan states, "the reader may readily apply these distances to familiar objects in his own neighborhood."[13] Whether consciously alluding to such an exercise or not, Lundeberg's painting is chronologically situated in a period where scientific exercises regularly called upon both the human imagination and the spaces of familiar day-to-day experience as a means of visualizing and apprehending distant cosmic phenomena. By adjoining the scene of a domestic interior with the notion of the distant realms of outer space, *The Red Planet* effectively conflates human and cosmic scales. Scientific inquiry may usher in new forms of understanding the world around us, the image suggests, while also sparking our imaginations in ways that defamiliarize the ordinary.

By picturing a scaled down version of the Solar System conceptualized in one's own range of spatial experience, the astronomy exercise as well as Lundeberg's painting *The Red Planet* encourage readers and viewers to contemplate the cosmic organization of planets and their elliptical movements around the Sun through familiar forms. Similarly, Lundeberg's painting of collaged images on a visible masonite support entitled *Relative Magnitude* (figure 1.7) from 1936 merges interior space with cosmic depth in ways that allude to the vast spatial scale of the universe. While the stack of books and comet image in *The Red Planet* signal the role of text and image as mediators between physical astronomical phenomena and the study of scientific concepts, *Relative Magnitude* considers the role of optical instruments in augmenting human vision. This work includes several images derived from Duncan's astronomy textbook within a multipart, layered composition. Each of two main scenes unfolding diagonally in the work is portrayed from multiple viewpoints and scales at once. On the left, a magnified illustration of an ant bridges two views of

[13] John Charles Duncan, *Astronomy: A Textbook* (New York: Harper & Brothers, 1926), 257.

an open book rendered from a human and an ant's perspective. The book's blank page and the orange marble help orient the viewer between two registers of sight. Similarly, the scene of the astronomer on the right leads diagonally up and to the left, traversing between a human scale and an astronomical one.

The title *Relative Magnitude* references the shifts in perspective occurring as the same environment is viewed simultaneously from different positions and scales. In addition to alluding to relationships in size, the title *Relative Magnitude* is likely a reference to the astronomical use of "magnitude"; "absolute magnitude," and "apparent magnitude," refer to the levels of a star or other celestial body's brightness.[14] While absolute magnitude indicates a hypothetical measurement of intrinsic brightness, the calculation of apparent magnitude takes into account the inherent "extinction" or loss of brightness through its absorption and scattering in the environment separating a viewer and a celestial body. In this context, the painting's title alludes not only refers to relative visual perspectives based on scale, but also to the inherent situatedness and subjectivity of the human viewer. Just as galactic dust mediates views of the stars from Earth, the work suggests, human subjectivity and perception inevitably condition attempts at ascertaining empirical scientific knowledge.

The scene of the astronomer in *Relative Magnitude* directly corresponds with an image from Duncan's *Astronomy* entitled "A Transit Instrument of the Early Nineteenth Century," originally in W. H. Smyth's *Speculum Hartwellianum* from 1860 (figure 1.8). Lundeberg's version adds color to the illustration as well as an additional blue globe in the foreground. The viewpoint from a transit instrument is shown within the finely lined circular field known as the reticle, also illustrated in the Duncan textbook (figure 1.9). Through this layering of images, Lundeberg

[14] Hale Bradt, *Astronomy Methods: A Physical Approach to Astronomical Observations* (Cambridge: Cambridge University Press, 2004), 231.

simultaneously depicts an astronomical device in use as well as a simulated view through the eyepiece of this same instrument. As the illustration of the astronomer shows, this device was fixed between large supports in a manner that restricted movement of the telescope to a north and south plane; the subsequent stable view allowed an observer to chart the ascension and descension of planets and stars relative to Earth over time. Due to the accurate determinations of star positions made possible by observing stars as they cross a meridian, the transit device played a crucial role in the history of astronomers' efforts to map the celestial sphere following its development in the late seventeenth century.[15]

Although most illustrated astronomy textbooks in the 1920s and 1930s featured photographs or diagrams of more recently developed telescopes including the 100-inch Hooker telescope at Mount Wilson Observatory, Lundeberg's depiction of the nineteenth century instrument foregrounds an interplay between human observation and technological device less visible in contemporaneous images. Situated in a fixed position between the sturdy telescopic supports, the astronomer in both the painting and illustration is shown activating the transit instrument through his observation and note taking. In the photographs of twentieth-century telescopes featured in the Duncan textbook, no humans are shown alongside the instruments. Instead, the telescopes appear within lofty, immense domes of observatories whose scale is only perceptible by the diminutized windows and stairwells in the surrounding spaces. Lundeberg's anachronistic depiction of an earlier technology therefore enables her to feature the astronomer not yet completely outsized by the vast size of later telescopic instruments.

During a period in which scientific understanding of the structure of the universe transformed radically owing to advances in research and technology, Lundeberg investigated both

[15] John Lankford and Marc Rothenberg, eds., *History of Astronomy: An Encyclopedia* (Oxfordshire: Taylor & Francis, 1997), 326.

spatial scale and scientific images themselves as a means of contemplating relationships between vision and knowledge, as well as humankind's place within an increasingly vast cosmos. The layering of telescopic views in *Relative Magnitude* includes a background image of the Milky Way galaxy similar to multiple hour-long photographic exposures taken from Mount Wilson Observatory in the early 1920s (figure 1.10). The combination of these vantage points conflates biological and technological modes of viewing, situating photographic and telescopic views as extensions of human sight. The collage of images merges distinct perspectives, modes of viewing, and spatial dimensions into larger visual consideration of positionality, scale, and relativity.

The conception of telescopic vision as an extension of human sight persisted throughout the early-to-mid twentieth century despite changes in telescopic technology and modes of astronomic study. While working from Mount Wilson Observatory outside of Los Angeles in the 1920s and 1930s, Hubble utilized the 100-inch Hooker telescope, the world's largest aperture telescope from 1917 to 1949. Across newspaper and magazine articles on Mount Wilson Observatory from the 1920s and 1930s, writers routinely described the 100-inch Hooker telescope in terms of an eye capable of seeing. For example, a 1924 article in *Outlook* magazine states, "The 100-inch reflector on Mount Wilson is not merely the world's hugest telescope, it is the super-keen eye that has plumbed new depths of space."[16] As a 1932 *Los Angeles Times* article on astronomer Edwin Hubble describes, "what the world's largest telescope sees… is only a part of the universe, the part nearest us."[17] In a related manner, a *Life* magazine article from 1937 speculates that "a new universe will greet astronomers when the 200-inch telescope is put into operation in 1940. This fantastic eye will see twice as far as is possible today, will peer at stars one

[16] Charles Fitzhugh Talman, "A Window Toward the Infinite," *Outlook*, September 24, 1924, 123.
[17] Ransome Sutton, "Savant Pictures Universe," *Los Angeles Times,* January 1932, A1.

billion light years distant."[18] In these instances, the kind of "seeing" ascribed to telescopic devices is broadened beyond a human physiological sense of the term to include technological processes including lengthy photographic exposures and the spectroscopic analysis of light.

In his publications intended for both scientific and non-specialist audiences from the 1920s and 1930s, Hubble addressed the 100-inch reflecting telescope's centrality in defining the boundaries or "frontiers" of the known universe.[19] Through his study of photographs of the Andromeda nebula taken through the 100-inch telescope at Mount Wilson in 1924, Hubble transformed scientific and popular understandings of cosmic space by proving that Andromeda was in fact another galaxy, or an independent stellar system in extragalactic space.[20] In so doing, he resolved a longstanding theoretical debate regarding the spatial scale of the universe. For centuries, astronomers and philosophers observing luminous clusters described as nebulae questioned if these celestial objects represented clouds of dust within Earth's own galaxy or if they instead might be independent galaxies hypothesized as "island universes." Hubble's research on Andromeda confirmed the theory of island universes. In addition, Hubble's observation that light from distant galaxies is red-shifted, indicating a relative velocity away from Earth, provided groundbreaking visual evidence of the universe's constant expansion, a notion which had only previously existed in theory.[21]

The subfield of astronomy and physics known as physical cosmology describes the characteristics and patterns of behavior of the physical universe. A 1932 *Los Angeles Times* article

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[18] "Carnegie Institution's Mt. Wilson Observatory Makes Astronomical History," *Life* Magazine, Nov 8, 1937, 52.
[19] Edwin Powell Hubble, "The Exploration of Space," *Harper's Monthly Magazine* 158 (1929): 732. 1929 and *The Realm of the Nebula* (New Haven: Yale University Press, 1936), i.
[20] Hubble, *The Realm of the Nebulae*, 28.
[21] John Gribbin, *In Search of the Big Bang: Quantum Physics and Cosmology* (New York: Bantam Books, 1986), 113.

on Hubble entitled “Savant Pictures Universe" conveys a distinction between the two subfields of research in astronomy and astrophysics: Hubble’s observational cosmology and the mathematical descriptions of theoretical physicists. Science writer Ransome Sutton compared Hubble’s use of photographic images and telescopic ‘sight’ as modes of empirical investigation capable of providing more concrete evidence than theoretical astrophysicists’ mathematical hypotheses. He expressed:

> Dr. Hubble is the man who has been throwing monkey wrenches in the mathematical mills of Einstein and De Sitter. His observations are realities- things photographed. His universe is an actual one. A mathematical cosmos, on the other hand, is merely an equation or a series of equations, and mathematicians are satisfied if their figures come out right.[22]

At Mount Wilson, Hubble combined high powered telescopic magnification with long-exposure photographs to observe the structure and motions of distant celestial phenomena including large, pulsating stars known as cepheid variables. Through his research, Hubble contributed telescopic evidence to support the mathematical descriptions and predictions of theoretical astrophysicists concerning structures and phenomena at the cosmic scale of the universe. As the 1932 Los Angeles Times article conveys, Hubble’s scientific findings through his close observation of photographed images were perceived and described as a more concrete form of evidence than the abstract mathematical hypotheses of theoretical astrophysicists also concerned with determining the size and structure of the universe.

Lundeberg’s appropriation of imagery from astronomy textbooks exemplifies the New Classicist ideal of aligning logically arranged pictorial forms with larger thematic concepts by taking into account scientific descriptions of structures in cosmic space. Like *The Red Planet* and *Relative Magnitude,* Lundeberg’s *Microcosm and Macrocosm* from 1937 foregrounds the role of

[22] Ransome Sutton, “Savant Pictures Universe,” Los Angeles Times, January 1932, A1.

human observation in the apprehension of scientific phenomena (figure 1.11). The background of this vertically oriented composition spans between an underwater view and the subtle gradation of a blue sky, which takes up the greater surface area of the painting. At the left edge, a disproportionately large figure gazes contemplatively onto the scene, holding a small lens in one hand and resting the other along the side of her face. The thin red outlines of circles are again used to signal to the viewer that a certain detail is magnified and presented in a closer view. In the upper portion, a small arrow points to a nearly indistinguishable speck made recognizable as the planet Saturn once enlarged in the adjoining circle. The three progressively expanded rings in the bottom portion of the canvas depict images of microscopic protozoa. Using both images and diagrammatic conventions derived from scientific textbooks, Lundeberg presents views of microscopic and telescopic realms otherwise imperceptible to unaided human vision.

As in her earlier paintings, the scientific imagery in *Microcosm and Macrocosm* can be traced to contemporaneous textbook images. The microorganism diagrams correlate to images from Gary L. Calkins's 1926 text *Biology of the Protozoa* (figure 1.12). Lundeberg carefully reproduced specific, identifiable biological forms while also slightly emphasizing structures which resemble eyes. The enlarged image of a protozoa in the largest red circle recalls her scientific illustration of the form the artist's drawing of an amoeba proteus dated 1928 (figure 1.13). Rather than presenting a cross-section view of the amoeba as visualized in her scientific illustration, however, the painting's singled out and enlarged amoeba slightly mimics the shape of a few thin surrounding clouds. The enlarged image of Saturn in *Microcosm and Macrocosm* echoes the visual magnification and isolation of the microscopic single-cell organism. Lundeberg's painted image of Saturn magnified from a smaller cluster closely resembles a specific hand drawn rendering of the planet in Duncan's *Astronomy*, featured amongst blurrier photographic images of the planet (figure 1.14). Identifiable through telescopic observation due to its unmistakable rings, Saturn nonetheless appears small and somewhat indistinguishable from other stars in less magnified views.

In *Microcosm and Macrocosm,* lens technologies and scientific images provide the human observer with glimpses into otherwise unseen worlds. A combination of microscopic and telescopic views in this composition suggests the human figure's consideration of life forms and physical phenomena at a range of spatial scales. As in several of her other Post-Surrealist paintings appropriating scientific images and diagramming conventions, *Microcosm and Macrocosm* takes on scientific subject matter while also highlighting how modes of scientific illustration in turn contribute to human observation and understanding. By appropriating scientific imagery and instructional graphic conventions within her paintings, many of Lundeberg's works from this period draw attention to the ways in which ideas are communicated through visual information in both artwork and scientific illustrations.

Whereas human figures and representational images populate Lundeberg's Post-Surrealist paintings from the 1930s and 1940s, in the 1950s the artist experimented with varying degrees of abstraction to explore spatial depth and visual ambiguity. In this stylistic transition, Lundeberg's interest in structural relationships among natural phenomena as well as her tendency to merge multiple viewpoints or images within images take shape through compositions appearing both figurative and abstract. As I examine in the following section, Lundeberg's hard-edge *Planet* paintings from the 1960s draw attention to the roles of imagination and visual abstraction within scientific news imagery circulated during the United States Space Race.

Part Two: Space Age Abstraction

In the 1950s, Lundeberg turned to higher degrees of visual abstraction in her artworks while continuing to explore the themes of spatial depth and scale, atmospheric lighting effects, and views extending into cosmic space. For example, her artwork *The Wind That Blew the Sky Away* from 1950 (figure 1.15) simplifies a visual concept explored in her 1947 work *The Veil* (figure 1.16). In both paintings, one layer of colorful sky is visualized as a rippling curtain revealing a black night sky and darkened landscape further beyond. By removing the representation of a hand pulling back the curtain in *The Veil,* her later artwork streamlines the previous visual motif of a double sky with a colorful layer of atmospheric light giving way to the darkness of outer space. Similarly, whereas oversized representations of the Moon, Mars, and other planets, stars, and two possible spiral galaxies in distance of *The Veil* signal cosmic space through specific iconic references, *The Wind That Blew the Sky Away* features only one indistinct sun or moon and as well as a very small dot indicating a moon or planet in the triangular section of black sky in the artwork. Both compositions convey a shared idea of re-envisioning a naturalistic environment through the imagined transformation of the Earth's atmosphere into a tremendous curtain. The human figure, which played a significant role in her Post-Surrealist work, appears significantly less frequently in Lundeberg's works after 1950 as the artist transitioned towards painting in the style of hard-edge abstraction.

Whereas Lundeberg's earlier astronomical references in the 1930s and 1940s included overlapping layers of figurative imagery, her works after 1950 instead layer geometric forms and unmodulated planes of color into arrangements simultaneously evocative of both abstract shapes and physical forms or environments. Lundeberg's 1957 painting *The Studio, Moonlight* (figure 1.17) demonstrates the artist's transition into a higher degree of visual abstraction through her handling of color and form while also structuring illusory depth. In the composition, multiple different spatial depths are inferred through flat areas of suggestive of a green floor and blue-green walls. A table with a bowl of fruit in a roughly similar shape falls between a line of shadow and moonlight. The turquoise glow of the painting within the painting seems to emanate a moonlit glow onto the easel's surroundings.

In *The Studio, Moonlight,* Lundeberg's painting within the painting recalls her slightly earlier works conveying colorful atmospheric lighting effects such as *Moon, Sea, Mist* from 1955 (figure 1.18). The smaller painting's surface in *The Studio, Moonlight,* recalls Lundeberg's blended fields representing mist and clouds, however this more modeled area of color is cleanly demarcated by the thin beige vertical line representing the illusory canvas's edge. This boundary aligns with the border between moonlight and shade in the space between the easel and the table. Through the alignment of spatial forms in the painting, moonlight appears to illuminate the studio in distinct layers. The painting on the easel depicted in Lundeberg's *The Studio, Moonlight,* is positioned in a way that visually suggests a double layer of moonlight on the bright surface of the painted painting, which appears to both reflect and emanate moonlight from within the otherwise darkened studio space. In the double painting, flatness and depth, abstraction and figuration, and darkness and light are conveyed through the geometrically abstracted depiction of spatial depth, moonlight, and shadows in shaped planes of colors.

Moonscape from 1966 (figure 1.19) reveals how Lundeberg transformed her earlier stylistic approach by portraying the Moon and surrounding atmospheric effects through precisely edged areas of solid, evenly mixed colors. The horizontal composition of *Moonscape* recalls Lundeberg's *Moon Sea and Mist* from 1955. However, whereas a large rock formation framing one edge of *Moon Sea and Mist* grounded the earlier composition within a terrestrial perspective, her later *Moonscape* visually abstracts the environment into subtly differentiated layers of overlapping wavelike forms apart from land or any distinguishable horizon. Through Lundeberg's handling of opaque layers of light blue and neutral beige acrylic paint, the work's gently curved, hard-edge shapes visually convey a sense of the sheerness, translucency, and fluidity of atmospheric mist between the viewer and a light colored moon. By increasing the relative size of the moon within the composition and eliminating traces of an earthbound horizon, *Moonscape* conveys a view of an unusually large or close moon. At the same time, the flat planes of color grant an idealized smoothness to the otherwise rough and cratered surface of the Earth's Moon. Lundeberg's title and image Lundberg's *Moonscape* as well as her larger series of planet paintings from the 1960s forego specification and detail in favor of abstraction and ambiguity.

In the 1960s, Lundeberg produced at least twenty hard-edge paintings referring to planets through their titles and imagery. Created as the artist switched to exclusively using acrylic paint in the 1960s after thirty five years of working in oil paint, Lundeberg's hard-edge planet paintings are both experiments in structural compositions and color as well as explorations of new combinations of media. Lundeberg produced three paintings, *Among the Planets* from 1961 (figure 1.20), *Planet Rising* from 1964 (figure 1.21), and *Planet* from 1959 to 1964 (figure 1.22) before extensively exploring the theme of planets in a series of ten small and large square canvases with centered circles in 1965. The artist continued to produce planet paintings from 1966 to 1969 in seven additional compositions. Her planet paintings from the 1960s reexamine visual motifs from her earlier Post-Surrealist compositions including fluctuations and contrasts between extremely diverse spatial scales. Certain planet artworks also conflate natural environments with biomorphic forms in ways that recall both her earlier work as well as her contemporaneous landscape paintings from the late 1960s.

Lundeberg investigated partial views through archways in the late 1950s and early 1960s leading up to her glimpses of curved planetary horizons in *Among the Planets* and *Planet Rising*. In her abstracted spaces from the 1950s, small circles representing the Sun or Moon indicate depth within expanses of flat, solid color. For example, a small yellow semicircle in *Untitled* from 1959 (figure 1.23), creates a sense of depth, establishes a horizon line, and casts subtle shadows from a line of columns. The decreasing width of each column moving left to right as well as the slight angles of the darker shadows indicate a diagonal right to left recession of equal sized columns. According to the artist, after producing numerous artworks arranging sharply-edged, angled rectilinear forms in the late 1950s and early 1960s, she wanted to reincorporate curves into her painting through a number of compositions featuring partial views of arches and shadows. While producing her 1964 *Looking Through* series of colorful and geometrically abstract views through archways including *Untitled (Looking Through Series),* (figure 1.24), Lundeberg created *Planet Rising* (figure 1.21). Using similar unnaturalistic colors to her *Looking Through* artworks, *Planet Rising* produces a highly out of the ordinary view of a purple and olive green planet against a bold turquoise sky. The form floats above a slightly convex horizon, possibly suggesting an aerial view. In the image, the relative sizes of the planet and the curved horizon produce the visual effect of a seemingly large or close planetary form. Following her paintings of curved arches, Lundeberg's *Planet Rising* further explores both spatial symmetry as well as combinations of round curves and straight lines.

The angular green shapes on the planet recall Lundeberg's geometric renderings of boundaries between water and land in terrestrial spaces from the early 1960s including *Untitled (Water Map)* (figure 1.25). Through two shades of blue implying a distinction in water depth, this artwork identifies mapping as a symbolic process transforming natural phenomena into geometric images and data. Referencing maps through certain titles and images, a number of Lundeberg's works from the 1960s point to the role of abstraction inherent to cartographic practices on Earth and in outer space. As Claire Reddleman describes, creating maps is "an active process of producing visual conceptions - visualizations - that posit a structure 'a point of view on space' that is complex, constructed and abstract."[23] Drawing on the work of theorists of critical cartography including Denis Wood and J.B. Harley, Reddleman considers how maps produce a range of ideologically inflected viewpoints that shape social and cultural ways of knowing. In attempting to reproduce topographical realities, maps also re-interpret these landscapes.[24] By alluding to the visual language of mapping and cartography in a number of her planet paintings, Lundeberg layered additional levels of subjective interpretation through her abstract forms and bright colors. Whereas the cartographer aims for objectivity through scientific and mathematical methods, Lundeberg's processes of rendering three-dimensional space on flat surfaces acknowledges the intervening roles of both the artist and the viewer in actively interpreting visual information from color and form.

The majority of Lundeberg's planet paintings feature a centered circle within a square format, yet the stylistic range of her compositions within these parameters attests to the artist's highly experimental approach to hard-edge color, form, and materials in this series. As she addressed in interviews, Lundeberg considered her 1965 series of planets as experiments in artistic composition. With a set format of circle within a square canvas, she described "arbitrarily" using shapes and colors within the circle.[25] Art historians including Diane Moran and Hunter Drohojowska-Philp have analyzed Lundeberg's combination of circles painted in square canvases

[23] Claire Reddleman, *Cartographic Abstraction in Contemporary Art: Seeing with Maps* (New York: Routledge, 2018), 3.
[24] Reddleman, 4-7.
[25] Lundeberg in "Helen Lundeberg American Painter," Tom Boles, film, 1984.

in symbolic terms. In an introductory text to art historian and critic Fidel Danieli's 1974 interview with Lundeberg, Drohojowska-Philp expressed that the *Planet* series "defined the union of opposites, melding the circle of the planets, symbolic of the eternal, with the square of the canvas, symbolic of the transitory." Similarly, in her introductory text for a 1979 Lundeberg retrospective exhibition at the Los Angeles Municipal Art Gallery, Moran wrote:

> The squared circle is a geometric allusion to the eternal (heaven) and the transitory (earth). For the alchemists the quadratura circuli was the symbol of wholeness and the union of opposites, the concrete matter of earth and the spirituality of God. Thus, intended or not, these are the dualities inherent in Lundeberg's planets.[26]

In addition to contrasting symbolic dualities through her convergence of the square and circle as Drohojowska-Philp and Moran suggest, Lundeberg's works visually contrast the round circle and the angular square as a means of exploring a range of other visual dualities including flatness and depth as well as interiority and exteriority through the arrangement of colorful forms within her planet paintings.

Lundeberg's planets centered within square format relate to a common cartographic mode of depicting circular diagram views of the Earth, Moon, and planets in various geographical and astronomical illustrations throughout the history of planetary observation. This convention appears as early as Galileo Galilei's 1609 ink wash drawings and engravings of the Moon, which represent the first detailed representations of the phases of the Moon from telescopic observations (figure

[26] Diane Moran, "Introduction," *Helen Lundeberg: A Retrospective Exhibition* (Los Angeles: Los Angeles Municipal Art Gallery, 1979), 4. This interpretation is referenced by Hunter Drohojowska-Philp in her introduction to the Fidel Danieli UCLA Oral History Project interview with Lundeberg in 1979. Drohojowska-Philp's statement that "These works [Planet Series] defined the union of opposites, melding the circle of the planets, symbolic of the eternal, with the square of the canvas, symbolic of the transitory," is misattributed to Lundeberg in Ilene Susan Fort's *80th Birthday Salute to Helen Lundeberg,* (Los Angeles: Los Angeles County Museum of Art, 1988), 16.

1.26).[27] When directed towards Earth, cultural geographer Denis Cosgrove identifies this view as the Apollonian gaze, or a viewpoint positioned outside of the planet from which it appears as a spherical body.[28] Cosgrove's term derives from the god-like position of this viewpoint at the height of a body in orbit, which invokes both a sense of embodied viewing as well as a vantage point afforded through technological means. Originating first in mapmaking practices and subsequently realized through spaceflight, the Apollonian gaze portrays a view of Earth not accessible to unaided, terrestrial human vision yet virtually inhabitable through maps and images.[29]

Primarily working with centered circles in square canvases, the artist explored a wide range of stylistic configurations in her planetary compositions. Setting the initial limiting parameters of the artworks' geometrically refined, symmetrical format, Lundeberg approached the circular area of each planet as a space to experiment wildly with forms, colors, and materials. Lundeberg's *Planet*, created between 1959 and 1964 (figure 1.22), is the artist's third planet composition the 1960s. Like many of her subsequent planet works, this painting features a centered planetary body against a solid black background. However, this work is unique amongst Lundeberg's series in its depiction of a planet as a horizontally elongated oval rather than a circle. Additionally, unlike most of her works from this period, this painting utilizes modeling to render the appearance of a planet through blended hues rather than hard-edged, solid areas of color. As a river-like body of water wraps along the bottom right of the planet before receding in the distance, the soft blending of colors creates a sense of atmospheric haze. A sharp contrast between the oval

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[27] Ronald Greeley and Raymond M. Batson, *Planetary Mapping* (Cambridge: Cambridge University Press, 2007), 12.
[28] Dennis Cosgrove, *Apollo's Eye: A Cartographic Genealogy of the Earth in the Western Imagination* (Baltimore: Johns Hopkins University Press, 2001), 8.
[29] Reddleman,12.

and the pitch-black background seems to delineate the form of a planet in space, yet it also seems to circumscribe a partial aerial view of an Earth-like planet.

A similar mixture of a modeled planet against a sharply outlined round form appears in a square painting entitled *Planet* from 1965 (figure 1.27). In the acrylic painting, swirls of gray suggest landforms while a green ovular form somewhat recalls the "Great Red Spot" storm system visible in depictions of Jupiter. While suggesting the massive spherical structure of large planetary bodies, the purple blue planet against a black background also recalls the swirled patterns of glass marbles pictured in Lundeberg's earlier compositions including *The Red Planet* and *Relative Magnitude*, 1936. After both the 1959-1964 and the 1965 *Planet* paintings, Lundeberg painted the center of her circles with hard-edge forms rather than swirled or blended colors. Bold colors and forms attest to the artist's material exploration of clean boundaries between bright colors afforded by synthetic paints including acrylic and enamel in the mid 1960s.

Lundeberg's hard-edge planets coincide with the years of the United States' most active push towards human spaceflight. In a May 1961 address to Congress, President John F. Kennedy proposed the goal of landing a man safely on the Moon's surface and returning them safely to Earth by the end of the decade. By July 1969, NASA succeeded in landing the Apollo 11 lunar on the Moon's surface, fulfilling the late president's hope for the United States. However, as historians including Howard E. McCurdy note, human exploration of the solar system represented only one of many possible directions the U.S. civil space program might have taken. As McCurdy argues in *Space and the American Imagination,* human space travel possessed one major advantage of technological modes of exploration: it was easier to visualize.[30] At the start of the 1960s, many Americans perceived the U.S. to be losing the Space Race to the Soviet Union after the launch of

[30] Howard E. McCurdy, *Space and the American Imagination* (Washington D.C.: Smithsonian Institution, 1997), 9-10.

Sputnik in 1957 as well as Russian cosmonaut Yuri Gagarin's successful orbit around the earth on April 12, 1961. Convinced that the United States needed a decisive technological achievement to demonstrate political superiority, Kennedy was advised by officials from the National Aeronautics and Space Administration that the best option would be to land a man on the Moon before the Soviet Union. Also the most expensive of proposed options, these officials estimated that landing an astronaut on the Moon would require around 22 billion dollars to achieve by 1970. Consequently, in order to secure the symbolic image of American power by landing astronauts on the moon first, a flood of boosterism in the 1960s resulted in the circulation of outer space imagery intended to convince U.S. citizens to support the government's tremendously costly human spaceflight missions.[31]

Although her painting *Moonscape* refers in its title and composition to a lunar image, most of Lundeberg's planet paintings from the 1960s are not identified or readily identifiable. For example, in the 1961 composition *Among the Planets,* a view of a small, light gray circle framed within the muted turquoise area between two partial beige circles positions the viewer in outer space. Without recognizable planets, the scene nonetheless evokes a perspective of a distant planet framed by two larger planetary bodies. Lundeberg's interest in conveying distances in cosmic space takes shape through a selectively limited amount of visual information. Through the placement of only three visual forms, the artwork visually articulates great cosmic distances, implying a view from outer space looking beyond into even further spatial depths. Like Lundeberg's interior scenes and landscapes from the late 1950s and early 1960s, *Among The Planets* is subdued in its color tones and austere in its arrangement of forms. However, the work

[31] Ibid, 29-45.

is Lundeberg's first composition to apply her style of hard-edge abstraction to the subject of planets in cosmic space.

Among the Planets from 1961 as well Lundeberg's square version from 1965 (figure 1.28) relate to a widespread cropped-planet motif visible across scientific and pop cultural images. While the cropped-planet viewpoint has a long history within science fiction illustrations, this format became increasingly prominent in mainstream media imagery after the first photographic image from outer space was taken in 1946. Shortly after it was taken by the US Navy at an altitude of 65 miles using cameras attached to V-2 rockets, this photograph circulated widely in an issue of *Life* magazine (figure 1.29). As art historian Stephen Petersen describes in *Space Age Aesthetics: Lucio Fontana, Yves Klein, and the Postwar European Avant-garde,* the first photograph from outer space is both representational and abstract, as the defining features of Earth's surface blur into a more generalized picture of the globe.[32] In addition to locating visual abstraction at the heart of early space photography, the V-2 rocket photographs exemplify how new views of Earth, first foreshadowed by science fiction imagery, subsequently prompted further imagined representations.

During the 1950s and 1960s, the cropped planet motif appeared frequently in advertisements for satellite technologies, science fiction imagery, and scenes in movies. The cropped format not only suggests the large size of a planet that cannot fit into the frame of an image, but it also situates the viewer in outer space. In Lundeberg's image, the cropped planets do not bear any visual similarities to Earth, which might instead be visible as the distant, pale blue dot among these giant foreign worlds. While this painting relates to contemporaneous imagery, it also distinctly differs. In most articles, advertisements, and pop cultural imagery from this period,

[32] Stephen Petersen, *Space Age Aesthetics: Lucio Fontana, Yves Klein, and the Postwar European Avant-garde* (University Park: The Pennsylvania State University, 2009), 7.

planets are imagined alongside technological apparatuses racing to explore and potentially colonize new lands. While Lundeberg's planets suggest a viewpoint afforded by spaceflight, the planets themselves, as well as the distances between them, are the primary focus.

The wide range of cosmic imagery in popular media outlets from the late 1950s leading up to the U.S. Moon landing reveals the blurred boundaries between science fact and science fiction in mainstream discourses of space exploration during this period. Coverage of NASA's 1962 Mariner II voyage exemplifies this prevalent phenomenon. In December 1962, the Mariner II robotic space probe conducted the first successful planetary flyby as it came close to Venus and returned data on the planet's atmosphere, magnetic field, charged particle environment, and mass. Although no cameras were included amongst the instruments attached to the Mariner II probe, news reports of the planetary flyby exploration in popular sources framed the spacecraft's findings in particularly visual terms.

A headline in the December 14, 1962 issue of *Life* Magazine (figure 1.30) reads: "Mariner's prying eye: far out news from Venus," stating: "until now, man has studied his neighboring planets with earthbound eyes and ears and instruments. But this week, hurtling through harsh-lit space, a complex 446-pound vehicle carried human curiosity within 25,000 miles of the mottled yellow visage of the planet next door, Venus." The text describes how Mariner II's sensors measured particle charges and heat waves, sending back information signals to the JPL lab in California. Yet the vast amount of page space is dedicated to an artist's colorful rendering of Venus and the Mariner II probe. A very similar theme appears in a subsequent *Life* magazine article from 1963 which proclaims: "Venus Glows in Mariner Portrait" (figure 1.31). Although no actual visual data was recorded by Mariner II, the text emphasizes how the accompanying image is based solidly on data transmitted across 36 million miles and interpreted after ten weeks of decoding at the JPL labs.

Simultaneously in these examples, the notion of seeing and observing extends to encompass the nonvisual collection of scientific data, while illustrations visualize these findings. Through Mariner II's journey, the physical, material, and sensory qualities of the planet Venus, in other words, were fundamentally abstracted into the immaterial realm of numerical data. Scientific interpretation of this information was then passed along to the illustrators. Notably, both depictions of Venus were produced by illustrators Walter Hortens and Mel Hunter who also created imaginative and visually related covers for science fiction magazines. While based on scientific data, these visualizations are nonetheless highly mediated through human imagination and closely tied to the artistic strategies employed in science fiction illustrations to render visible the otherwise unknown and largely unseen terrains of distant planets. As this example suggests, Lundeberg's planet paintings emerged from a sociohistorical context in which imaginative visualizations of astronomical phenomena significantly influenced popular understandings of cosmic space.

Lundeberg's 1960s paintings of planets do not directly incorporate specific source images in the manner of her earlier astronomy-themed paintings. Instead, her works explore geometrically structured visual motifs that distill related thematic concerns from her Post-Surrealist compositions into abstract configurations. By combining formal experiments with color and composition along with a synthesis of imagined and actual views of outer space, Lundeberg's hard-edge planet paintings correspond with a broader cultural imaginary of planets and cosmic space leading up to the 1969 US moon landing. As historian Emily S. Rosenberg describes, the postwar Media Age fueled multiple visions, narratives, and meanings of outer space, creating a sense of "undefinability and semiotic expansiveness." As aerospace engineers in the United States and the Soviet Union raced to develop crewed and robotic spaceflight technologies, mass media images brought outer space into the American home and into the forefront of visual culture.[33] The diverse and widespread range of scientific and science fiction representations of outer space in the 1950s and 1960s increased the visibility of actual and imagined cosmic phenomena while also abstracting the notion of "planets" from any singular image or visual source. Within the vast array of visual representations of planets and outer space during this period, Lundeberg's artistic experimentation in her planet paintings aligns with a conceptual open-endedness and imaginative range of possibility characteristic of American understandings of outer space imagery at the time.

Many of Lundeberg's 1960s planets direct a kind of Apollonian gaze towards colorful, unknown planets. Whether Lundeberg's planets are seen as images viewed from a telescope or from the perspective of outer space, the posited viewpoint in these artworks draws attention to the abstract nature of planets as celestial bodies known only to humans through the technologies that allow us to observe, measure, and probe specific aspects of their material composition. In so doing, Lundeberg's 1960s planets locate the conceptual processes of abstraction and imagination as fundamental characteristics of human understandings of cosmic space. Whereas basic principles of space travel were not well understood in prewar popular culture and human space exploration remained solidly fixed in the realm of fantasy, space boosterism in the 1950s helped shape Americans' view of human spaceflight as not only possible, but forthcoming in the near future.[34] A convergence of real technologies and highly imaginative possibilities developed throughout Space Race era news coverage, advertisements, and science fiction imagery. At the same time,

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[33] Emily S. Rosenberg, "Far Out: The Space Age in American Culture," in *Remembering the Space Age: Proceedings of the 50th Anniversary Conference*, ed. Steven J. Dick (Washington, DC: NASA, History Division, 2008), 184.
[34] Howard E. McCurdy, *Space and the American Imagination* (Washington: Smithsonian Institution Press, 1997), 32-33.

they challenge distinctions between visual abstraction and illusory representation by simultaneously combining aspects of both.

Lundeberg's 1960s planet paintings draw attention to abstraction as an interdisciplinary process as well as a central aspect of both artistic and scientific image production. As quantum physicist Werner K. Heisenberg described in a 1967 lecture entitled "Abstraction in Modern Science:"

> Abstraction denotes the possibility of considering one object or a group of objects from just one viewpoint while disregarding all other properties of the object. The isolating of one characteristic, which in a particular relationship is looked upon as especially important in contrast to all other properties, constitutes an essence of abstraction.[35]

Heisenberg's statement addresses abstraction as a process of generalization, where complexity and detail are reduced in order to provide a distilled sense of a certain quality in an object or phenomenon. As he further describes in the text, abstraction denotes the filtering out of common features, or the isolation of one characteristic while omitting others. The case of mathematics, Heisenberg proposes, emphasizes how counting and the concept of numbers exemplify a "decisive step from the sphere of the immediately given sensible world into the framework of rationally graspable thought structures."[36] Lundeberg's *Planet* paintings exemplify how the transformation from complex, concrete physical phenomena into imagery in both scientific illustration and painting relies on conceptual and visual processes of abstraction.

In his study of scientific methods of visualization, social scientist Michael Lynch examines how scientific diagrams transform photographic images into schematic illustrations. These processes, which he groups under rubrics of "filtering," "uniforming," "upgrading," and "defining"

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[35] Werner Heisenberg, "Abstraction in Modern Science," in *Nishina Memorial Lectures: Creators of Modern Physics* (Tokyo: Springer, 2008), 2-3.
[36] Ibid, 1.

relate to Lundeberg's mode of abstracting planets in her 1960s works. Lynch first describes "filtering" as the removal of excess visual information from a diagram. This can be seen in diagrams showing objects isolated in front of blank or empty backgrounds. "Uniforming" refers to the visual convention of using color fields or uniform crosshatching or shading in diagrams, which results in less variation in shading or texture than in a photographic image. "Upgrading" renders shapes in a diagram structurally clearer through distinct borders, lines of uniform thickness where fragmentary lines or no lines at all were visible in photographs. Through upgrading otherwise dim differences become apparent and visibly distinguished. Finally, "defining" works to visually distinguish the significant qualities of an image in tandem with a diagram's textual captions and descriptions.[37] As Lynch describes, visual displays "systematically transform specimen materials into observable and mathematically analyzable data."[38]

Lundeberg's 1960s planet paintings convey a sense of the visual transformations underlying the translation of scientific objects into diagrams and images. However rather than providing scientific data, the artist's geometrically abstract planets subvert the visual languages of scientific illustrations and diagrams by replacing specificity and fixed meanings with visual ambiguity and open endedness. Given the pairing of title and imagery, Lundeberg's 1965 painting *Planet No. 1* (figure 1.32) and *Untitled (Sectioned Planet)* from 1969 (figure 1.33) particularly recall the transformation of complex visual phenomena into simplified diagrams characteristic of scientific illustration. A pink form in *Planet No. 1* recalls both the nuclei depicted in Lundeberg's own scientific illustrations of protozoa as well as suggesting a landform or storm system on a planetary scale. Similar to the conflation of forms from vastly divergent spatial scales in

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[37] Michael Lynch, "Discipline and the Material Form of Images: An Analysis of Scientific Visibility," *Social Studies of Science* 15 (1985), 37-66. https://doi.org/10.1177/030631285015001002
[38] Ibid, 37.

Microcosm and Macrocosm, the biomorphic appearance of *Planet No. 1* converges biological and astronomical visual imagery.

Lundeberg's *Untitled (Sectioned Planet), Soft Planet* (figure 1.34) and *Planet* 1967 (figure 1.35) feature planets removed from any recognizably outer space setting and instead shown against white and neutral backgrounds for the first time in her *Planet* series. As both the title and the image suggest, the 'sectional view' is employed as a means of showing both the exterior and interior appearance of the planet. Lundeberg's work is visually analogous to section views of Earth's core as seen in astronomy and geology diagrams and imagery. A related cross-section image of Earth illustrating magnetism and Earth's core appeared in both a November 1960 *Life* magazine article as well as in the 1961 *Life Pictorial Atlas of the World* (figure 1.36). Lundeberg appropriates the "section view" in a meta-representational way, drawing attention to this illustrative convention as a mode of visual explanation. In so doing Lundeberg's *Sectioned Planet* directs a viewer's attention to the ways in which abstraction is inherent to both artistic and scientific representation, functioning in both domains as a means of depicting, explaining, and imagining. In distinct ways, *Sectioned Planet No. 1, Soft Planet,* and *Planet* 1967 recall Lundeberg's explorations of biomorphic forms in Post-Surrealist compositions including *Plant and Animal Analogies.* Across these works, Lundeberg draws attention to structural similarities between different kinds of geological, biological, and botanical cores as well as scientific and artistic modes of visualization.

Lundeberg's 1960s planet-themed works blur the boundaries between abstraction and representation as well as the distinction between the imagined versus the actual. Through the subject matter of planets, Lundeberg created some of her most experimental compositions. Lundeberg's planet paintings from 1964 are amongst the artist's first works in acrylic paint, which she would switch to almost exclusively for the remainder of her career. She went on to experiment with other media in her planet paintings, including alkyd enamel and opalescent paint, in order to test different optical effects. Additionally, a series of serigraphs of planets from 1972 to 1973 constitute the artist's first and only venture into silkscreen printing. Merging hard-edge abstract forms with cosmic subject matter, her planet paintings and prints combine her stated interest in viewers' subjective perceptual experiences with new culturally specific modes of visualizing planets amidst contemporaneous Space Race era technological advancements in space flight.

Despite working within a historical context in which critics and scholars perceived a more dichotomous relationship between abstraction and figuration, Lundeberg explored the indeterminate space between these poles in her work after 1950. Lundeberg's 1960s planet paintings, the artist's imaginative coalescence of color and design relate to contemporaneous explorations in outer space through their formal arrangements as well as their thematic subject. As theorist and social scientist Donna Haraway argues in her 1988 essay "Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective," "the 'eyes' made available in modern technological sciences shatter any idea of passive vision; these prosthetic devices show us that all eyes, including our own organic ones, are active perceptual systems, building on translations and specific *ways* of seeing, that is, ways of life."[39] Through their relationships to period specific discourses of artistic and scientific image production, Helen Lundeberg's astronomy themed artworks throughout her career reveal specific historically and culturally contingent ways of seeing and knowing cosmic space. Beyond their imaginative coalescence of color and design, her 1960s planet paintings attest to the artist's lifelong exploration of the role of vision and observation within the processes of making meaning.

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[39] Donna Haraway, "Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective," *Feminist Studies* Vol. 14, no. 3 (Autumn, 1988), 583.

The changes in style, perspective, and materials in her 1960s planets index the artist's response to specific postwar developments in the discourses of scientific technology, popular culture, and visual arts. Rendering planets through flat planes of solid colors, Lundeberg's hard-edge planet paintings foreground the processes of visual abstraction inherent to cartographic practices, scientific illustration, and human visualizations of planets more broadly. At the same time, her highly abstracted depictions of unknown planets point to both uncertainty and imagination at the heart of popular and scientific conceptions of space exploration in the postwar United States. Lundeberg's series of planet paintings from the 1960s demonstrate changing cultural understandings of cosmic spaceflight, the role of early images from outer space, and shifting relationships between subjectivity, vision, and knowledge amidst rapid technological developments in outer space exploration.

Lundeberg's astronomy themed paintings throughout her career effectively examine the astronomical gaze through the lens of artistic inquiry. Throughout her work, cosmic phenomena are positioned as subjects of human observation and wonder. Yet the distinct perspectival shift in her 1960s series of hard-edge planet paintings invokes fundamentally altered relationships between human vision, scientific technologies, and astronomical phenomena compared to her 1930s astronomy themed works. In her earlier works, figurative depictions of telescopic instruments and inter-images of scientific illustrations established the astronomical gaze as an objective, technological extension of human vision across vast distances. In her 1960s planets, however, human and technological means of viewing are collapsed and rendered both inseparable and highly subjective. Whereas her works from the 1930s allude to exact scientific modes of visualization and representation through illustrations and diagrams, her 1960s planets locate abstraction, imagination, and experimentation as fundamental aspects of both astronomical inquiry and artistic composition.

Conclusion: Ways of Knowing

Lundeberg explored a wide variety of subject matter throughout her prolific career, yet the motif of planets persistently recurs across six decades of her work. While the artist's depictions of abstracted architectural settings and environmental landscapes are the focus of much existing literature on her work, her representations of planets prove equally fascinating and insightful. Representative not only of her personal artistic vision, Lundeberg's planet paintings extend into the discourse of twentieth-century visual representations of cosmic space in scientific literature as well as the popular imagination. As astronomer and astrophysicist Carl Sagan described, "in all the history of mankind there will be only one generation for which in childhood the planets are distant and indistinct discs moving through the night sky, and for which in old age the planets are places, diverse new worlds in the course of exploration."[40] Lundeberg's paintings attest to this shared experience of a radical shift in cultural understandings of outer space travel and exploration.

The visual languages of artistic form and scientific illustration converge throughout Lundeberg's compositions in varying degrees of representation and abstraction. Lundeberg's planet-themed compositions in two distinctive styles highlight the interconnected roles of individual subjectivity and collective cultural frameworks of knowledge production in the construction of meaning through images across disciplines. The distinction between Lundeberg's engagements with astronomy in her Post-Surrealist work from the 1930s and 1940s compared to her later hard-edge paintings of planets in the 1960s is notable for the ways in which it productively directs attention to

[40] Carl Sagan, *Planetary Exploration: Condon Lectures* (Eugene: Oregon State System of Higher Education, 1970), 71.

broader histories of scientific image production and circulation in the twentieth century. Combining her interests in astronomy with considerations of the subjective nature of vision, Lundeberg's paintings of planets throughout her career merge the rational and scientific with the mysterious and personal in ways that prompt further consideration of the construction of knowledge and meaning.

Chapter Two
Unseen Worlds: Abstraction and Atomic Physics in Bettina Brendel's Paintings

"The field of ideas is the territory of the artist as well as the physicist."[1]

-Bettina Brendel "The Painter and the New Physics," 1971

Introduction: Space, Time, and Motion

In Bettina Brendel's painting *Resonance* from 1978 (figure 2.1), two sets of parallel white lines run vertically and horizontally across the painted composition. Each white band reveals a substructure of short white and gray-black lines interspersed and intersecting at various angles within precisely defined rectilinear parameters. Taking as its subject a phenomenon occurring in all forms of vibrations and waves including sound and light, *Resonance* recalls a broadscale pattern of behavior across mechanical and electromagnetic waves studied in physics. The term refers to the combined amplitude of two or more oscillating forces vibrating in equal or close frequencies. Describing her painting, Brendel defined the term resonance as "the vibrations produced by the combined forces of two separate systems."[2] To convey this meaning through visual forms, she depicted one vertically oriented system of line segments paired with a second, aligned horizontally.

Resonance defines a system of harmonious relationships originating in studies of acoustics. Coming from the Latin word resonatia, meaning to echo, the term for resounding frequencies is now used to describe related phenomena in mechanical, acoustic, electromagnetic, nuclear magnetic, and quantum wave functions. The term resonance is one of many abstract scientific

[1] Bettina Brendel, "The Painter and the New Physics." *Art Journal* 31, 1 (1971): 41-44. https://doi.org/10.2307/775634.
[2] Bettina Brendel "Atomic Length - A Basic Unit in Physics - As a Visual Metaphor in Art," *Leonardo*, Vol. 21, No. 3 (1988), 247-250.

concepts Brendel contemplated through her artwork. In her many published writings on scientific themes in her artwork, the artist addressed the role of abstraction in physics. Influenced by Albert Einstein's process of conceptualizing scientific experiments in theoretical physics as well as Werner Heisenberg's emphasis on mathematical descriptions of atomic phenomena through combined sets of probabilities, Brendel envisioned abstract painting as a means of sharing insights from the field of physics through the compositional "universes" she created in her artwork. [3] Particularly drawn to the fields of theoretical physics and atomic theory because of the subject matter's abstract, highly mathematical nature, Brendel described her paintings on quantum theory as "thought experiments" and "visual metaphors." [4] For the artist, developments in science and technology inspired new experiments in visual communication. Just as her artwork's title *Resonance* describes the intensified effect resulting from simultaneous systems in harmonious ranges, the conceptual alignment between the title's text and the painting's image draws attention to the amplification of a shared meaning across the systems of artistic composition, written language, and scientific description.

The thin straight marks in Brendel's painting *Resonance* evidence Brendel's interpretation of the microstructures of matter and energy described mathematically in the field of quantum mechanics. After studying the history and theory of atomic physics between 1968 and 1969, Brendel designated the three-inch line indexing the edge of her palette knife dipped in paint as a symbol in her paintings for the interconnection of space and time as well as motion and energy characterizing forces at the quantum scale. Brendel documented her consideration of lines as abstract descriptions of the probabilistic behavior of elementary particles in her artwork titles as

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[3] She described her work as visual universes throughout her career, including an artist statement from 1962, Norton Simon archives, as well as her 1988 statement in the text *Bettina Brendel, Paintings 1970-1982.*
[4] Brendel, "Atomic Length as Visual Metaphor," 248.

well as her scholarship on the histories of physics and art published between 1971 to 2002. In the written component of her practice, the artist described how her method of using lines as symbolic forms emerged from studying the role of statistical probabilities underlying mathematical and metaphorical descriptions of quantum phenomena.

This chapter investigates how Brendel's abstract compositions and collages on canvas from 1960 into the 1980s evidence the artist's efforts to visually communicate fundamental concepts from the field of theoretical physics through expressive artworks. To do so, I provide an overview of her *Densities* and *Gravitation* series from 1960 and 1961 as examples of Brendel's interest in physical cosmology leading up to her academic research in the history of atomic physics in 1968. I then focus on the development of her atomic-themed paintings in Brendel's artworks comprised of two or more canvases started in 1969 and continued into the 1980s. In particular, I analyze how the interplay between individual and multiple "views" combined into these works relates to the concepts of wave-particle duality and complementarity outlined in the Copenhagen interpretation of quantum mechanics. To do so, I draw on Brendel's own scholarship on the history of atomic theory in art and science as well as broader histories of quantum physics in Europe and the United States over the twentieth century.

Addressing how graphic patterns in Brendel's compositions visually signal specific concepts and laboratory experiments suggested by their titles, I consider the visual and textual meanings encoded by the artist into the formal compositional arrangements of her works. I extend this analysis further by examining Brendel's published articles and referenced scholarship as a "paratext," or supplementary framework through which her physics-themed artworks can be examined. The artist's annotated descriptions of specific artworks and references to particular scientific studies in her essays clarify the relationships she sought to convey between phenomena described in modern physics and her artistic visual articulation of geometric structures and patterns. Through this case study, I analyze how the artist's scientifically inflected practice took shape in dialogue with culturally and historically specific discourses surrounding modern physics and modern artwork in Europe and the United States during the postwar period.

Advances in theoretical physics led to tremendous developments in scientific technology in the United States, displayed in an extreme form during World War II and the Cold War through the weaponization of atomic energy. In a series of lectures delivered at the University of Saint Andrews in Scotland from 1955 to 1956 published as *Physics and Philosophy: The Revolution in Modern Science* in 1958, physicist Werner Heisenberg expressed: "When one speaks today of modern physics, the first thought is of atomic weapons." Pointing to the global significance of the discipline in an era defined by the politicization and weaponization of atomic physics, Heisenberg argued that philosophical implications of modern physics warranted ongoing consideration. In his view, the theoretical paradoxes central to modern physics had drawn attention to larger relationships between the human mind and reality as well as the inherent limitations of human scientific knowledge. He expressed, "…We have to remember that what we observe is not nature in itself, but nature exposed to our method of questioning… our own activity becomes very important when we have to deal with parts of nature into which we can penetrate only by using the most elaborate tools."[5] In 1927, Heisenberg formulated the uncertainty principle to describe the fundamental impossibility of identifying both the position and momentum of subatomic particles. In the Cold War "atomic era" or "nuclear age" initiated by the detonation of the first atomic bombs in 1945, the dual promise and threat of atomic physics and technology contributed an additional layer of uncertainty to Heisenberg's philosophical concerns.

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[5] Werner Heisenberg, *Physics and Philosophy: The Revolution in Modern Science* (New York: Harper and Brothers Press, 1958), 58.

Energy in Motion: Approaching Theoretical Physics in Brendel's Artwork

Brendel developed an interest in the interdisciplinary processes of abstraction and symbolism in visual artwork, poetry, and science throughout her training in fine art and art history in Hamburg and Munich, Germany before and after World War II.[6] After surviving the Holocaust, Brendel continued her education in art from 1945 to 1947 at The Hochschule für bildende Künste Hamburg (now the University of Fine Arts, Hamburg). She exhibited her paintings in the earliest postwar exhibitions of abstract artwork in Germany, held in Munich in 1949 and 1950, alongside artists associated with the "ZEN 49" group of postwar German abstract painters. For Brendel and other postwar abstract artists, the style of non-figurative artwork intrinsically functioned as a political expression in the aftermath of the German Reich. As inheritors of cultural traditions targeted by the Nazis as "degenerate" including German Expressionism and Bauhaus modernism, postwar abstractionists in Germany furthered non-objective painting as a progressive, constructive mode of interpersonal and cross-cultural communication.[7]

Brendel interacted with many international modernist artists through her travels and migration after World War II. Shortly after moving to Los Angeles in 1953, Brendel found camaraderie and support exhibiting with West Coast artists including Lorser Feitelson, Helen Lundeberg, John McLaughlin and Oskar Fischinger through the Los Angeles Art Association as well as through museums including the Los Angeles County Museum of Art. In the late 1950s, she met art historian and curator Michel Tapié and artists Hans Hartung and Pierre Soulages in Paris, France. Tapié included Brendel's work in exhibitions of international contemporary artwork

[6] Bettina Brendel "Atomic Length - A Basic Unit in Physics - As a Visual Metaphor in Art," *Leonardo*, Vol. 21, No. 3 (1988), 247-250.
[7] Rupprecht Geiger, recollections of ZEN 49, quoted in *Stunde 0 / Zero Hour*: *Rupprecht Geiger and Hilla von Rebay,* exhibition text, Museum Villa Stuck, Munich, 2005. Accessed https://www.villastuck.de/05/stunde0/english.htm

including the 1962 show *Strutture e Stile: Pitture e Sculture di 42 artisti d'Europa, America e Giappone* (Structure and Style: Paintings and Sculpture from 42 artists from Europe, America, and Japan) at the Galleria civica d'arte Moderna in Turin, Italy. Having first coined the term Art Informel in his 1952 book and exhibition *Un Art Autre* (art of another kind) to describe the unconventional, often gestural approaches of innovative postwar painters, Tapié became a leading spokesperson for the international art movement. He included Brendel's artwork in his 1964 to 1965 exhibition and catalogue *Museé-Manifestee* which traveled between Italy, Austria, and Germany.[8] Meanwhile at home in the United States from 1958 to 1966, Brendel exhibited her work in several solo exhibitions held at Southern California art museums including the Long Beach Museum of art in 1958, the Pasadena Art Museum in 1962, and the Santa Barbara Art Museum in 1966. The artist's shows in California featured Brendel's abstract paintings and statements on the themes of kinetic energy and physical cosmology in her work.

From the late 1950s into the early 1960s, Brendel produced large abstract paintings combining formal considerations of geometric space with ideas and concepts regarding the interconnectedness of space, matter, motion, and time from the field of modern physics. Brendel's paintings from the series entitled *Densities* and *Gravitation,* which she started in 1960 and 1961, pair abstract scientific concepts central to developments in theoretical physics through visually abstract compositions. In certain paintings such as *Density I* (figure 2.2)*,* the virtual space of the picture plane fluctuates between illusory depth and flatness based on areas of concentrated similar colors. The repeated, consistent lengths of colored lines index the physical materiality of the painting process as the artist applied pigment from the edge of a palette knife. These lines cover the canvas surface, yet densities of color simultaneously seem to emerge and recede within the

[8] Bettina Brendel, *Bettina Bendel* (Self published: Los Angeles, 2007), 46.

work's abstract illusory space. Between the concrete materiality of the painting's picture plane and the immaterial space suggested through the overlay of painted lines in *Density I*, the artwork creates a visual effect of movement or energy across scattered forms. Density, a mathematical description of the mass per volume of physical substances, is transformed into an immaterial and perceptual experience of dynamic, loosely nebulous clusters in Brendel's series of paintings started in 1960.

A work entitled *Gravitation* (figure 2.3) from Brendel's 1961 series of paintings by the same name alludes visually and through its title and composition to a physical connection between space, matter, motion and time outlined in Einstein's theory of general relativity. In the painting, the negative space of the white ground seems to compress inward on a section of gray and black lines. The same form in the center of the canvas might also be viewed as an abstract body in arial suspension. In each case, the arrangement of space suggests dynamic movement between compressing or suspending forces. Paintings from both Brendel's *Densities* and *Gravitation* series appeared in her 1962 solo exhibition at the Pasadena Museum of Art as well as the Art Center in La Jolla, California. In 1966, Brendel showed her work concerned with the dynamics of large-scale physical structures and combinations of forces in the universe in an exhibition entitled *On Mass and Energy* at the Santa Barbara Art Museum.

Intrigued by studying theoretical descriptions of the structure of the universe explained in modern physics, Brendel first approached the subject through the genre of writing known as popular scientific literature. Before taking courses in the history and theory of physics 1968, Brendel encountered the book *The Universe and Dr. Einstein* first published in 1949 by author and *Life* Magazine editor Lincoln Barnett. According to the artist in a 2001 interview with art historian Paul Karlstrom, "I was always interested in physics and science, and somebody way back gave me a book called *The Universe and Mr. Einstein*. I was very stimulated by that. When I went to New York, I could finally put this into action and enrolled at the School of Social Research."[9] Texts in the genre of popular scientific literature including Barnett's *The Universe and Dr. Einstein* sought to make concepts from the work of modern physicists widely accessible to general audiences by synthesizing major findings, questions, and debates in contemporary scientific research. For Brendel, the text inspired abstract compositions as well as further academic study regarding abstraction in theoretical physics.

In his foreword to Barnett's book, Einstein praised the author's contribution to popular scientific writing. In his passage, the physicist emphasized the significance of this genre of literature through the correlation he envisioned between mainstream scientific literacy and collective social well-being. As Einstein expressed:

> It is of great importance that the general public be given an opportunity to experience - consciously and intelligently - the efforts and results of scientific research. It is not sufficient that each result be taken up, elaborated, and applied by a few specialists in the field. Restricting the body of knowledge to a small group deadens the philosophical spirit of a people and leads to spiritual poverty.[10]

Like many physicists of his generation involved in the emergence of quantum mechanics from the start of the 1900s into the 1920s, Einstein strove for interdisciplinary legibility in his work throughout the postwar period despite the complex mathematical nature central to theoretical physics. Einstein, Heisenberg, Niels Bohr, Erwin Schrodinger, and countless other influential physicists specializing on atomic and subatomic phenomena and interactions also published philosophical writing aimed at readers in the humanities in which they explored how modern

[9] Paul Karlstrom, "Oral history interview with Bettina Brendel," 2001 August 23. Archives of American Art, Smithsonian Institution.
[10] Lincoln Barnett, *The Universe and Dr. Einstein* (New York: Harper & Brothers, 1950), foreword np.

physics upends distinctions between space and time as well as matter and energy upheld in the previous conceptual framework of Newtonian classical mechanics.

In *The Universe and Dr. Einstein*, Barnett included a black and white diagram of wavelengths within the electromagnetic spectrum (figure 2.4). A thin section marked around 10^{-4} designates a range of wavelengths in centimeters of visible light, or light within the range of human vision. Smaller wavelengths decrease from ultraviolet, x-rays, gamma rays, cosmic rays into the category of "unknown." Increasing in size from visible wavelengths, the diagram lists infrared, heat waves, spark discharges, radar, television, broadcast, long radio, and another "unknown" section. Barnett's caption emphasizes the limited range of electromagnetic wavelengths visible to the human eye. He wrote:

> Out of this vast range of electromagnetic radiation, extending from cosmic rays with wavelengths of only one trillionth of a centimeter up to infinitely long radio waves, the human eye selects only the narrow band indicated in white on the above chart. Man's perceptions of the universe in which he dwells are thus restricted by limitations in his visual sense.[11]

Through the diagram, Barnett visualized the narrow range of wavelengths visible to humans within a larger spectrum including unknown frequencies. In his text, Barnett located the "prime mysteries of nature" within the realms furthest removed from familiar human senses, unable to be described in the metaphors of classical physics but modeled instead through mathematical relationships.[12]

Like other contemporaneous writers, Barnett emphasized the shift towards abstraction in physics after Max Planck's quantum theory from 1900. Specifically, he wrote, "the first step in science's retreat from mechanical explanation toward mathematical abstraction was taken in 1900, when Max Planck put forth his Quantum Theory to meet certain problems that had arisen in studies

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[11] Barnett, 23.
[12] Barnett, 24.

of radiation."[13] By specifically articulating the shift from classical mechanics into quantum mechanics as a move towards abstraction, Barnett and other writers emphasized the centrality of mathematical descriptions in theoretical physics. After Planck determined a mathematical constant to describe the packets of energy he called quanta, Einstein postulated that all forms of radiant energy including light, heat, and x-rays travel through space in discontinuous quanta. In his photoelectric effect theorized in 1905, Einstein explained light as a kind of quanta he called photons. Einstein theorized that photons of violet and ultraviolet radiations contain higher energy than red and infrared photons based on experiments measuring showers of electrons ejected from a metal plate hit by beams of different frequencies of light.[14]

Brendel's early 1960s paintings visualized spatial density and dynamic energy in motion through expressionistic abstract compositions deriving their themes from concepts in physics. Slightly later, the artist's mixed-media painted collages on canvas from the mid 1960s including *Science Symbols,* 1965*, Positive and Negative,* 1966, and *Magnetic Fields*, 1967 contrast tactile material forms and abstract symbols describing physical forces. Brendel's numerical, alphabetical, and mathematical symbols in her collages on canvas including *Science Symbols* (figure 2.5) connote the production of meaning in both science and artwork through individual and collective modes of communication. In the artwork, a single black capital "E" stands out on the left in the section of white collaged letters, recalling the scientific symbol for energy made famous by Einstein's mass-energy equivalence formula $E= mc^2$. Displaced from the realm of scientific description onto the surface of the canvas, Brendel's cascading configurations of letters and numbers transform graphic symbols into physical forms. In so doing, the work foregrounds a fundamental negotiation between concrete physicality and abstract theorizations expressed

[13] Ibid, 25.
[14] Ibid, 26-28.

through symbolic languages in visual artwork and science. At the same time, the incomprehensible arrangement of letters and numbers in the composition suggests an opposition between both meaning and meaninglessness, thus drawing attention to the arbitrary nature of signs.

In her collages on canvas from 1965 to 1967, Brendel explored a number of binary oppositions through layered arrangements of physical materials. Her work *Positive, Negative* from 1966 (figure 2.6) suggests a conceptual pairing of opposing forces or complementary components through its title and arrangement of painted materials and forms. Through these literal juxtapositions of positive and negative space, the monochromatic composition merges flatness with physical depth as well as materiality and abstract constructs like positivity and negativity and numbers themselves. Referencing a conceptual polarity between positive and negative, the work visually contrasts round and straight forms as well as material substances against voids or negative space. The circles and rings designate both geometric shapes while also suggesting the mathematical concept of zero between positive and negative numbers. In alternating sections of the canvas, thin linear dowels recall tally marks or counting sticks. At the center, a small U-shaped piece of canvas possibly hints at the shape of horseshoe magnets, while perhaps also alluding to the capital U symbol meaning potential energy in physics. The work is open ended in its possible interpretations, but specific in its attention to translating meanings between material phenomena and abstracted analyses of substances and energies described in mathematics and physics.

Through her collages on canvas, Brendel explored interrelationships between materials and concepts central to modern physics. The artist's 1967 collage on canvas entitled *Magnetic Fields* (figure 2.7) evokes the invisible pull of magnetic forces observed through the interaction of iron filings or other metallic particles drawn into a system of charges. The composition visually relates to an image of the magnetic field of a bar magnet in *The Universe and Dr. Einstein* (figure

2.8). In the text, Barnett described that while natural philosophers studied both electricity and magnetism since antiquity, the two forces were thought to be separate throughout the vast majority of the history of physics.[15] Scientists first theorized possible interconnections between electricity and magnetism in the mid 1800s, leading to the designation electromagnetism to describe physical interactions between electrically charged particles.

One of few illustrations in *The Universe and Dr. Einstein,* Barnett utilized the bar magnet diagram to explain Einstein's theory of gravity. Just as pieces of iron move in magnetic fields guided by the structure of their surrounding electromagnetic field, Einstein concluded that the paths of all bodies in gravitational fields are determined by the geometry of the field within which they are situated. In Brendel's *Magnetic Fields*, painted clusters of wooden dowels allude to the predictable behavior of metal filings acted upon by the electromagnetic fields produced by bar magnets. Layered into this artistic visualization is a set of concepts theorized since antiquity yet understood in new ways through the descriptions of natural phenomena provided by modern physics.

Drawing on her longstanding interest in science, Brendel completed coursework in the history and theory of physics from 1968 to 1969 at the New School for Social Research in New York. There, Brendel studied the historical and contemporary theory of atomic physics with Enrico Cantore, a physicist and philosopher specializing in interdisciplinary research on quantum physics. [16] As historian of science David Kaiser addresses, the late 1960s marked a period in which most graduate physics curricula in the United States sacrificed covering the philosophical aspects of quantum theory in favor of emphasizing calculation skills based on defense industry demands

[15] Barnett, 91.
[16] Karlstrom, "Oral history interview with Bettina Brendel," 2001 August 23. Archives of American Art, Smithsonian Institution.

during the Cold War. While the philosophical dimensions of quantum mechanics became more widely reintroduced into physics curricula in the 1970s, Brendel encountered a rare opportunity to study with an interdisciplinary specialist on the subject while graduate physics curricula in the United States notably shifted away from philosophical content due to the larger relationships between pedagogical practices in physics and the Cold War industrial-military complex.

In his book *Atomic Order: An Introduction to the Philosophy of Microphysics* first published in 1969, Cantore analyzed the closely interconnected histories of physics and philosophy through a case study of microphysics, also known as atomic physics. Through the opportunity to study with Cantore, Brendel took interest in both historical and contemporary theoretical conceptions of atoms. In her interview with Karlstrom, Brendel described feeling inspired by the unfinished work and ongoing debates regarding visual models in atomic theory. She also recalled Cantore encouraging his students to consider new ways of envisioning the phenomena described in quantum mechanics. In his classes, Brendel wrote papers describing subatomic phenomena and worked independently to develop an atomic model expressing the lifespans of pulsating oscillations of electrons, photons, and other elementary particles through short, intersecting line segments. [17]

Cantore identified "order" as a primary concern in atomic physics. In a section of *Atomic Order: An Introduction to the Philosophy of Microphysics* entitled "the problem of atomic order, he described the "remarkable" coexistence of both randomness and orderliness at the atomic scale that challenges conventional distinctions between these two states. "Imperfections and irregularities themselves tend to show an average regularity that allows of precise mathematical

[17] Ibid.

treatment," he explained.[18] Classically understood as the universe's indivisible, elementary units, atoms presented increasing complexity to scientists aided by developing microscopic and x-ray technologies at the turn of the twentieth century. Cantore's research details the discoveries proving that the atom is neither solid nor indivisible, but rather made up of smaller subcomponents. Studies of phenomena at the subatomic level indicated that atoms contained previously unknown forms of energy, while experiments with heat and light indicated that light waves exhibit characteristics of both particles and waves. Combined, these experimental and mathematical findings of early twentieth century physicists radically upended previous understandings of the nature of the universe, creating a distinct shift into what is identified as the modern era of physics after relativity and quantum mechanics.

Studying the history and theory of physics with Cantore significantly transformed Brendel's artwork as she layered a specific metaphorical dimension into her paintings using short straight lines in combination with solidly painted backgrounds or hard-edge forms in 1969. Along with encouraging Brendel to develop a kinetic model of the atom fundamentally distinct from those of Rutherford and Bohr, Cantore inspired the artist to focus her research on the role of imagery and abstract thought in physics and art. Her series of multiple-part paintings on subatomic processes and interactions started in 1969 reveal how the artist visualized processes at the quantum scale through abstract and symbolic form. These works span across multiple separate canvases to create larger fields encompassing multiple frames and/or viewpoints. The same year, Cantore encouraged the artist to reach out to his colleague physicist Werner Heisenberg. Cantore's advice led to the artist's meeting with Heisenberg in Munich in 1972 as well as her correspondence with the physicist until his death in 1976. Consequently, Brendel's artworks from the late 1960s through

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[18] Enrico Cantore, *Atomic Order: An Introduction to the Philosophy of Microphysics* (Cambridge, The Massachusetts Institute of Technology, 1969), 49-50.

the 1970s visualizing the motion of electrons and photons index the artist's own movement between international centers of postwar artistic abstraction and scientific research in Europe in the United States. Moreover, in her writings Brendel aimed to express her view that visual artwork can communicate complex scientific ideas to humanistic audiences in generative ways.

Subatomic Forces: Particles or Waves?

Frequently described in histories of physics as the twin revolutions or two pillars of early twentieth-century scientific thought, the theories of relativity and quantum mechanics describe the nature of phenomena at the cosmic and the subatomic scales. From 1900 into the late 1920s, Albert Einstein's 1915 general theory of relativity along with the collaborative development of quantum mechanics depended on mathematical descriptions combining dimensions and forces previously thought to be distinct, including space and time, matter and energy and particles and waves. In the twentieth century, scientists probed the previously unknown realm of subatomic forces within the smallest components of energy and matter. From antiquity until the early 1900s, Western natural philosophers and scientists described atoms as the indivisible microstructures of matter. Physicists in the early twentieth century first proved the physical existence of atoms and also found evidence of smaller atomic subcomponents.[19] Research into the division of atoms gave way to both discovery and destruction through the weaponization of atomic science during World War II and the subsequent Cold War period. Physicists, philosophers, and interdisciplinary scholars explored the dual promise and threat of scientific research and technology after the United States use of atomic weapons against Japan in 1945.

[19] Lynn Gamwell, *Exploring the Invisible: Art, Science, and the Spiritual* (Princeton University Press: Princeton, 2002), 185.

Vibrations of light and energy at their smallest components, known as quanta, cannot be directly observed by human vision but rather only detected in certain parameters through laboratory contexts. In her article from 1988 entitled "Atomic Length- A Basic Unit in Physics- As a Visual Metaphor in Art," in *Leonardo* journal, Brendel expressed her aim of developing a symbolic language in her paintings to express the subject of interactions at the subatomic scale. First published in 1968 by pioneer of rocket science turned artist Frank Malina, *Leonardo* journal represented the first scholarly journal devoted to circulating the written work of contemporary visual artists with a focus on those concerned with science and technology. Brendel contributed articles to *Leonardo* throughout her career detailing her consideration of atomic physics through abstract artwork. Envisioned as an international channel of communication between visual artists concerned with science and technology, *Leonardo* functioned as an ideal platform for Brendel to expand upon the impact of specific aspects of theoretical physics in her work. In her 1988 article Brendel explained, "the thin short line in my paintings represents a fundamental constant in nature: the energy radius of a moving particle, the length or lifetime of a photon or electron as they manifest themselves in densities of various degrees." Imagined magnification and scientific observation emerge as predominant themes in Brendel's work beginning in 1968. In different variations of geometric forms, the artist conveyed images at the intersection of human and technological modes of "observation."[20] Rather than a representational view of these phenomena, her artworks signify unseen forces based on descriptions from quantum mechanical calculations rather than human observation. In her article, Brendel described how Heisenberg's work informed her use of lines as symbolic forms within her painting practice.

[20] Brendel, "Atomic Length as Visual Metaphor," 248.

The artist took interest in Heisenberg's description of a "quantum unit of length" roughly 10^{-13} centimeters described in his 1958 book *Physics and Philosophy.* In her text, Brendel notes that this unit of atomic length later was named the 'Fermi" unit or femtometer (fm) in 1964, referring to 10^{-15} Additionally, Brendel recounted her meeting with Heisenberg at the Max Planck Institute for Physics in 1972 in Munich. She described his emphasis on the primary role of mathematics in precisely describing quantum processes, as well as their conversation regarding the necessity of descriptive language to communicate scientific ideas.[21] In the article, Brendel included a drawing showing the optical distortion occurring when a two-dimensional geometric form is tilted into a third dimension of illusory space. The diagram entitled *From Circle to Line: Optical Distortions* (figure 2.9)*,* from 1987 is a pencil drawing recalling the process of abstraction leading to her use of lines as visual metaphors for different forms of atomic motion depending on the theme of the composition.

For Brendel, the linear dash functioned as a symbolic shorthand designating the movement of protons, electrons, photons, or other microstructures of matter and energy not usually visible apart from the use of powerful imaging technologies or complex mathematical representations. Her works assign meaning to abstract linear forms in a knowingly subjective manner. From studying the history of physics, the artist was aware that atomic models are conceptual inventions with no iconic resemblance to the phenomena they depict. While in their meeting Heisenberg cautioned against the use of visual imagery in modern physics, Brendel pointed out that descriptive language functions in a related manner. While it is common to say that electrons 'orbit,' and particles 'collide,' these are descriptors from a macro level that do not precisely describe the physical phenomena occurring at the subatomic level. "Heisenberg agreed that in order to

[21] Ibid, 247.

understand science it is necessary to use common language," Brendel recalled, but he was wary of artistic interpretation in the field of atomic physics.[22] As many of his texts express, Heisenberg rejected visualization in favor of purely mathematical models in his contributions to quantum physics.

After 1969, Brendel's artworks identify specific motions and interactions occurring at the subatomic scale using a codified system of lines as symbols for amplitudes of vibrating particles. Beyond a shift in artistic gaze from the macroscopic and cosmic scale into the subatomic, Brendel's series including *Particles or Waves, Plasma, Ionization,* and *Diffraction* from 1969 and 1970 evidence a conceptual transformation of her mark-making approach. In these works as well as the majority of her subsequent artwork after 1969, Brendel focused her compositions on particular energy transformations described in quantum mechanics by designating short lines as graphic symbols for oscillating subatomic particles. Employing the optical effects of visual vibration occurring through the juxtaposition of contrasting colors, Brendel aligned the perceptual effect of moving lines with the symbolic suggestion of movement within the forces of electrons, photons, and other particle vibrations at the quantum scale.

In 1969, Brendel produced a large artwork comprised of six painted canvases placed side by side, forming an abstract sequence of geometric shapes, color fields, and patterns (figure 2.10). Measuring close to 8 feet tall and nearly 26 feet in length, the work appears in photographs positioned off the wall, edging into the space of a room in a slight curve. Through its size and arrangement, Brendel's work immerses spectators within an expanse of colors, forms, and patterns. Merging multiple painted canvases into a larger installation through its size and arrangement, the artwork blurs the boundaries between singular and multiple compositions and views. The work's

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[22] Ibid.

many subsections flow into an overall visual array of color fields observed by viewers over time and in space while moving between a variety of vantage points. By directly addressing the viewer through the form of a question, the artwork's title *Particles or Waves?* signals the work's underlying theme. Between her abstract imagery and use of language, Brendel's artwork asks audiences to consider a question central to the development of twentieth century physics: what is the nature of subatomic phenomena? Posing this question in her artwork title, Brendel aimed to draw viewers of her artwork into the realm of scientific inquiry.

Painted the same year the artist completed graduate courses in the history and theory of physics at the New School for Social Research in New York City, *Particles or Waves?* represents Brendel's effort to visualize and magnify a world of subatomic forces described in the field of quantum physics. Across the paintings, different groups of shapes make up a larger composite of abstract imagery. Recurring throughout the paintings, three-inch linear dashes of paint in a range of colors intersect and overlap, creating an optical effect of visual vibration. Brendel produced each line of color by dipping the edge of a palette knife in paint and marking her canvas with the thin edge. While the artist developed this process over a decade earlier while working in Los Angeles in the 1950s, studying atomic physics in New York from 1968 to 1969 prompted Brendel to further reconceptualize her use of linear dashes by adding symbolic meaning to this primary formal element in her work. In addition to the sense of visual movement produced by the layers of multicolored intersecting lines, Brendel envisioned each dash as a symbol of atomic motion after researching the probabilistic framework of particle physics.

In *Particles or Waves?,* Brendel's visual composition does not provide a clear response to the question posed in the title. Rather than provide a direct answer, the work invites further inquiry. Through her use of visual gray areas between contrasting oppositions including dark and light, Brendel's composition suggests a spectrum or range of colors and forms rather than a stark duality through the perceptual effects afforded by different color combinations, textures, and densities of lines in her paintings. The boundaries between the physical edges of canvases do not necessarily align with the edges of her colors or painted textures. Merging simultaneous different views into one larger composition, Brendel renders her interpretation of the quantum physicist's abstract gaze into the world of subatomic phenomena beyond the range of human vision. The question of particles or waves, the work suggests through its visual forms, is one of human imagination and positionality as well as scientific investigation and technology.

A circle within a concentric ring on the left of *Particles or Waves?* stands apart from an overall expanse of interspersed short lines. This visual motif closely relates to Brendel's series of *Diffraction* paintings representing the emission of photons and electrons through round apertures in laboratory experiments, as well as one of her earliest paintings of a laser beam and its surrounding quantum field from 1969 (figure 2.11). Towards the right, a section of hard-edge, purple and blue vertical forms create a striated, slightly irregular boundary with a solid black canvas. In the center, a spectrum from black to white takes shape through a dark to white rectangular gradient. Moving right, a solid white partial circle recalls the round edge of a bright body of light. The chaotic yet systematized pattern of Brendel's short intersecting lines forms a neat boundary with the semicircle, covering the end canvas with a field of visually energetic colored dashes. Like many of Brendel's paintings beginning in 1969, *Particles or Waves?* pairs the optical vibration of short lines in contrasting colors with the suggestion of particle motion or vibration. These random yet systematic lines correspond with Brendel's contemporaneous paintings of ionized gases in her series entitled *Plasma* and *Ionization*.

As Brendel described in her essay "The Painter and the New Physics," *Art Journal,* 1971, the seemingly contradictory concepts of waves and particles are incorporated together in descriptions of light in the field of quantum physics. Brendel highlighted the paradigm shift from the mechanistic determinism of classical physics to the uncertain, probabilistic universe of quantum phenomena known through pairs of complementary probabilistic descriptions of position and momentum as well as particles and waves. While researching complementary qualities in quantum physics, Brendel split the pictorial space of her artworks into several sections across multiple canvases. The artist explored variations within the visual motif of multiple complementary views in *Particles or Waves?* as well as her series of paintings entitled *Diffraction, Plasma,* and *Ionization.*

<u>Complementary Descriptions: Double Views and Metaphors in Atomic Theory</u>

Brendel's use of symbolic lines enabled the artist to metaphorically depict combinations of forces beyond the spectrum of wavelengths visible to humans. Her expansive compositions across multiple canvases including *Particles and Waves* enlarge the invisible quantum realm of subatomic phenomena into larger than human scale representations of diffraction, ionization, and other effects studied in optics, or the scientific study of light. Through her research on the role of abstraction and visual models in theoretical physics, Brendel formulated artworks and scholarship aimed at translating insights from atomic physics into humanistic discourse. She addressed the distinctions between historical paradigms of atomic theory from Greek antiquity to modern quantum mechanics in several interdisciplinary lectures and published papers on the theme of abstraction in twentieth-century physics, philosophy, and artwork from 1971 to 2002. As the latest form of atomic theory, Brendel emphasized the impact of quantum mechanics in shaping a new, modern view of the world.

Through her scholarship Brendel acknowledged the widespread change in scientific and philosophical worldviews initiated with the emergence of modern physics in the 1920s. In her writing, Brendel addressed the combination of space and time proposed in Einstein's 1905 special theory of relativity as well as the blurred boundaries between particles and waves at the subatomic scale of elementary particles known through mathematical probabilities in quantum mechanics. In a 1993 essay entitled "The Artist as Physicist," Brendel wrote, "Einstein's Theory of Relativity and Heisenberg's Uncertainty Principle of quantum physics were not without influence on the art and literature of the twentieth century- an influence that is growing with the understanding of the principles involved." [23] Whereas classical Newtonian physics regarded particles and waves as discrete entities, quantum mechanics theorizes that no distinction can be made between the two at a subatomic level, as particles exhibit wavelike qualities, and waves contain flows of particles.

At the subatomic scale, boundaries between particles and waves are blurred. Brendel expressed in an artist's statement from 1982, "The abstract world of particles and fields, symmetries and balances is available to us through thought," she continued, "this world is a world in motion and we, within our individual limitations create an everchanging path of discovery to it."[24] In her statements, Brendel acknowledged her work as a subjective artistic interpretation rather than a textbook diagram of quantum phenomena. She offers the counter example of a Feynman diagram as a pictorial representation of mathematical expressions in quantum mechanics. Introduced by physicist Richard Feynman in the late 1940s as a method for simplifying calculations in the field of quantum electrodynamics, a subfield of physics concerned with the description of electromagnetic forces, Feynman diagrams have since transformed how physicists

[23] Bettina Brendel,"The Artist as Physicist," in *Nunes dos Santos,* A.M., ed. *Arte e Tecnologia:* Lisbon: Fundação Calouste Gulbenkian, 1993, 22-29.
[24] Bettina Brendel, "Statement," in *Bettina Brendel, Paintings* 1970-1982 (Self-Published, 1983), 3.

worldwide approach calculations concerning high energy particle collisions (figure 2.12).[25] Through a specific vocabulary and syntax of lines representing subatomic particle interactions, Feynman diagrams revolutionized how physicists could visualize otherwise complex, lengthy combinations of formulas. Based on the ways in which these diagrams graphically represent subatomic processes occurring over time, physicist John. A Eisele describes these conceptual tools as "space-time pictures that tell a story." [26] In Feynman diagrams, time is shown flowing upwards, enabling straight, wavy, and dashed lines to represent the processes through which quanta including photons and pairs of electrons and positrons are created or annihilated.[27] Brendel would have been familiar with these diagrams as she attended a number of Feynman's lectures while he taught at the Caltech in the 1970s and 1980s.

Unlike Feynman's diagrams, Brendel's symbolic line is not a functional mathematical tool but rather a creative compositional device. Nonetheless, In Brendel's painting, *Diffraction* (figure 2.13), two side by side canvases provide a double view of similar but distinct concentric circular patterns within red and purple background fields. Combining two vertically oriented canvases into one larger work, the structure of the diptych emphasizes a number of dualistic qualities balanced in the work's composition. Visually, the pairing draws attention to similarities and differences in colors and shapes, as the shapes of the white circle and ring present a roughly complementary relationship of forms. The abstract shapes emerging from patterns of colored lines in *Diffraction* simultaneously refer to related processes occurring in laboratory experiments with both photons and electrons. Regarding the work, Brendel wrote: "the diffraction of photons and that of electrons

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[25] Kaiser, David, Kenji Ito, and Karl Hall. "Spreading the Tools of Theory: Feynman Diagrams in the USA, Japan, and the Soviet Union." *Social Studies of Science* 34, no. 6 (December 2004): 879–922.
[26] John A. Eisele, *Modern Quantum Mechanics with Applications to Elementary Particle Physics* (New York: Wiley-Inter-science, 1969), 277.
[27] Frieda A. Stahl, "Physics as Metaphor and Vice Versa," *Leonardo*, Vol. 20, No. 1, (1987): 57-64.

shows a similar pattern of concentric rings, thereby demonstrating the wave-particle duality of matter and energy that has been recognized in quantum physics." [28] Diffraction patterns index the shape of an aperture or the material which beams of photons or electrons are passed through or obstructed by, making the laboratory experiment itself an inherent subject of this artwork.

Brendel included two laboratory photographs demonstrating related diffraction patterns alongside her painting *Diffraction* in "The Painter and the New Physics" text (figure 2.14) published in *Art Journal* 1971. Roughly resembling the circular forms in the painting, these images depict the effects of photons passed through an aperture as well as the diffraction rings caused by electrons passing through a crystal lattice. Both photons and electrons demonstrate similar diffraction patterns in experimental contexts, her captions inform, each revealing particle and wave characteristics in both testing contexts.[29] Brendel's *Diffraction* considers the behavior of natural phenomena subject to human intervention and mediation in the worlds of physics through laboratory experiments as well as theoretical interpretation. In evoking the visual phenomena of diffraction as well the laboratory experiments central to the development of particle/wave theories of light and matter, Brendel's painting highlights a nexus of concerns central to studies in quantum physics. In particular, the work makes scientific observation itself a subject of inquiry in a way related to the theories of physicists associated with the Copenhagen interpretation of quantum mechanics including Niels Bohr and Heisenberg from 1925 to 1927.

The term diffraction is largely synonymous in physics with interference. In *Diffraction,* the white circle and ring in white in Brendel's paintings convey two diffraction patterns caused by the manipulation of streams of isolated photons and electrons in laboratory settings. In the laws of classical mechanics, it is physically impossible for phenomena to occur both as particles and

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[28] Brendel, "The Artist as Physicist," 26.
[29] Brendel, "The Painter and the New Physics," 43.

waves. However, Bohr and Heisenberg described the dual wave and particle behavior of energy and light observed through diffraction patterns in quantum mechanics as an example of complementarity, or the pairing of two properties which cannot be simultaneously determined at once. The laboratory context emerged as a central point of concern among physicists including Heisenberg and Bohr, who explained the ways in which processes at the quantum scale cannot be measured without fundamentally altering their preexisting status. These physicists identified the state of "wave function collapse" when quantum phenomena are "observed," or measured experimentally. As quantum physicists determined, light and matter exhibit both particle and wave properties at the quantum scale depending on which measurements are experimentally derived.

In their scientific and philosophical writing, Bohr, Heisenberg, Schrodinger, and other physicists central to the development of quantum mechanics turned their attention to the framing of experiments, the interference of the scientist's tools, and the reconsideration of boundaries between subatomic forces as well as between scientific observers and observed phenomena in their work from the 1920s into the postwar period. As Heisenberg explained in his 1958 book *Physics and Philosophy: The Revolution in Modern Science,* the description of atomic events necessarily involves a level of human subjectivity, as this form of natural phenomena cannot be observed apart from the tools and devices used to study it. He stated: "…We have to remember that what we observe is not nature in itself but nature exposed to our method of questioning… our own activity becomes very important when we have to deal with parts of nature into which we can penetrate only by using the most elaborate tools."[30] Along with Heisenberg, Neils Bohr and Wolfgang Pauli also reconceived the conventionally established division between a scientific observer and an observed phenomenon, calling into question long-held beliefs regarding the objectivity of

[30] Werner Heisenberg, *Physics and Philosophy: The Revolution in Modern Science* (New York: Harper and Brothers Press, 1958), 58.

scientific knowledge. The philosophical questions explored in the Copenhagen interpretation of quantum physics draw attention not only to the world of subatomic phenomena, but also to the framing of scientific experiments themselves. These issues, first formulated in the 1920s, remained both controversial and influential across disciplines in the twentieth century.

Brendel addressed the issue of wave and particle duality as well as the limits of human observation after Heisenberg's uncertainty principle in her text "The Painter and the New Physics." In the text she recounts how Max Planck's theory regarding the occurs in discrete quantities known as "quanta," ushered in the paradigm shift from classical Newtonian mechanics to quantum mechanics. Subsequent studies after Planck by physicists including Einstein, Louis de Broglie, Erwin Schrodinger, Bohr, and Heisenberg observed and analyzed the dual particle and wave behavior of light and matter at their smallest discrete units. Whereas classical mechanics describes a fundamentally objective and deterministic universe, quantum physics introduces chance and indeterminacy into descriptions of the cosmic universe.

As Brendel observed: "the deterministic view of a mechanistic universe was abandoned to make room for the uncertainty factor and the probability function of German physicist Werner Heisenberg." According to the artist, "a new humility" entered physics with Heisenberg's uncertainty principle or indeterminacy principle from 1927.[31] In this theory, Heisenberg outlined the fundamental impossibility of determining both the exact position and momentum of subatomic particles simultaneously. The reason for this impossibility lies in the inevitable interference of the scientist, whose measuring instruments are both necessary to ascertain a particle's location or speed but also intrinsically disruptive to the same experimentally observed phenomena at the atomic scale. Rather than particles or waves modern physicists found ways of describing the

[31] Brendel, "The Painter and the New Physics," 43.

entangled state of quantum forces exhibiting both particle and wave behaviors fundamentally distinct from interactions at the macroscopic scale of human existence.

Painting Plasma: From Disorganization into Organized Complexity

Despite the efforts of physicists, philosophers, and popularizers of modern physics seeking to translate scientific discoveries into language accessible to non-specialists, numerous scholars working across disciplinary fields in the postwar period identified the problem of an apparent communication barrier between those working in the sciences and those in the humanities in postwar Europe and the United States. Issues of organization, complexity, and structure arose among postwar theorists and artists from the late 1940s through the 1970s owing to the midcentury discourses of information theory, cybernetics, and quantum mechanics. Mathematician and founder of machine translation Warren Weaver outlined the issue of analyzing organized complexity in his 1948 essay "*Science and Complexity.*" He argued that modern scientific problems call for analyses of "organized complexity" distinct from the comparatively simple two-variable problems of collection and classification typical in scientific endeavors before 1900.[32] Across scientific fields, explaining complex patterns of behaviors amongst groups otherwise disorganized groups of phenomena requires statistical techniques to describe average behaviors. In order to work towards collective progress in a world transformed by modern science and technology, Weaver identified the need to improve modes of communication within and between cultures and fields of research.[33]

In his introduction to the collection of essays entitled *Structure in Art and Science,* published in 1965, artist and theorist György Kepes described structure as a central concern across

[32] Warren Weaver, "Science and Complexity," *American Scientist* Vol. 36, No. 4 (October 1948), 536-544.
[33] Ibid, 544.

intellectual disciplines in contemporary society. Considering the impact of expanded scales of phenomena and events described in modern physics, Kepes identified awareness of structure as a fundamental aspect of human understanding. Acknowledging the difficulty of isolating structure from a cluster of related concepts including order, form, organized complexity, and whole, system, or *Gestalt,* he explained: "Each historical era seeks and needs a central model of understanding. Structure seems central to our time- the unique substance of our vision." [34] For Kepes, improving communication of new knowledge across disciplines promised greater understandings of the world's interconnectedness. Citing paleontologist G. G. Simpson's observation that all organic evolution resulted from interbreeding, Kepes argued, "our further cultural evolution today will come about through broadscale 'interthinking.'"[35] Within the volume *Structure in Art and Science,* Kepes included texts concerned with scientific approaches to structure in nature as well as analyses of manmade structures and structural principles within art and technology.

Given the tremendous power of atomic energy unleashed by the United States' atomic bombs dropped on Japan, many scholars across disciplines including Weaver and physicist and novelist C.P. Snow emphasized the need to accompany technological research with humanistic efforts in philosophy and the arts. In his 1959 lecture, "The Two Cultures and the Scientific Revolution," Snow famously articulated the estrangement between disciplines in the sciences and humanities, expressing, "I believe the intellectual life of the whole of western society is increasingly being split into two polar groups." [36] For Snow, the impasse between different spheres of knowledge and thinking halted progress in solving many global problems. Situating literary intellectuals at one pole and physical scientists at the other, the theorist located a "gulf of mutual

[34] György Kepes, "Introduction," in *Structure in Art and Science* (George Braziller, Inc. New York, 1965), ii.
[35] Ibid, i.
[36] C.P. Snow, *The Two Cultures* (Cambridge: Cambridge University Press, 1959, reprinted 1998), 4.

incomprehension" between them.[37] While many scholars reiterated Snow's concern regarding the estrangement between the two cultures, his concept of a "third culture" discussed in the same lecture is less frequently cited. As Snow went on to describe in "The Two Cultures and the Scientific Revolution," as well as in a revised account of his text from 1963, a third mediating culture seemed to be emerging which attempted to ease the difficulties in communication between the sciences and the humanities.[38]

In the 1960s and 1970s, artists and scholars including Brendel analyzed interdisciplinary concerns in ways that exemplify Snow's conception of a third culture working towards facilitating the exchange of ideas between scientists and humanities scholars. After her graduate classes in New York City in the history and theory of physics, Brendel published scholarship as well as delivered papers on the topics of science and art at international symposia. She first presented her 1971 article entitled "The Painter and the New Physics," on a panel concerned with art and technology at the College Art Association's annual convention the same year. Through this text, Brendel analyzed how shifting theoretical frameworks in the history of physics and natural philosophy impacted artistic conventions and philosophical understandings of the world.

Describing the German concept of "das Weltbild," meaning "the image of the world," Brendel emphasized the changed image of the world provided by discoveries in modern physics.[39] With the knowledge of modern scientific concepts, an artist's view of the world transforms, she argued. The "modern view of the world," she explained, is one that considers the inextricably connected dimensions of time, space, and energy from Einstein's Theory of Relativity as well as the inherent uncertainty central to Heisenberg's probabilistic functions in quantum mechanics. To

[37] Snow, 3-4.
[38] Snow, 70-71.
[39] Brendel, "The Painter and the New Physics," 42.

explain the amalgamations of waves and particles at the quantum scale, Brendel quoted physicist and philosopher Erwin Schrodinger's descriptions of the smallest forms of matter as both "pure energy" and "pure form" in his essay "What is an Elementary Particle." Through her analysis, Brendel identified the human imagination as a mode of engaging with unseen interactions at the cosmic and subatomic spatial scales.

Brendel's artworks and written scholarship beginning in 1969 specifically explore the theme of abstraction as a shared conceptual process between painters and physicists. Through her published essays starting in 1971, the artist described her research and analysis of modern physics and its relationship to developments in twentieth-century modern art in the United States and Europe. Through her writing practice, Brendel articulated the messages she wished to convey to contemporary audiences as well as posterity regarding the philosophical interconnections linking modern artwork and modern physics. In her writing, Brendel contextualized her own artistic practice as one subjective approach to conveying abstract scientific ideas through visual forms. Annotating specific artworks and series with written descriptions of her work, the artist sought to clarify how ideas from theoretical physics took compositional shape through artistic arrangements of colorful lines in her paintings. By examining how artists and physicists both investigate and analyze phenomena through technical processes embedded within larger epistemological frameworks, Brendel situated her own work as an attempt to think across disciplines through painting. Acknowledging her artwork as a subjectively filtered interpretation of scientific concepts, she underscored her belief in the cultural value of artists' humanistic engagements with science and technology.

In her 1973 article "The Influence of Atomic Physics on My Paintings" published in *Leonardo* journal, Brendel described her use of thin, 3-inch lengths of paint in her artworks. She expressed: "I have thought about the motion of electrons and light particles, photons, and the fact that they are not points in space. For my paintings, particularly those concerned with light or the interaction of atomic particles, I conceive of moving electrons as little streaks or short lines of a length equal to the diameter of an atom."[40] In her text, Brendel referenced physicist Heisenberg's description of a "quantum of length" as one of three necessary units to determine the scale of nature, as the physicist addressed in his 1958 book *Physics and Philosophy.* Brendel saw the line as a symbol for the linear probability mathematically defining the quantum force's likely movement across space and in time.

Brendel's series of works on the topic of gas ionization from 1969 to 1972 in diptych and triptych formats consist of fields of thin intersecting lines of paint evenly distributed across the canvas in several colors. In her artwork *Plasma* from 1969 (figure 2.15), Brendel coated the surface of two canvases with intersecting three-inch lines of paint in black, white, and red. The canvas's solid background layer beneath the dashes of color only appears towards the bottom edge of the canvas panels, where the lines abruptly but evenly stop. At this slightly irregular but largely horizontal boundary, the edge between black, white, and red lines reveals a flat, solid white substrate, or underlying layer. The title *Plasma* refers to one of four known states of matter in physics, along with solids, liquids, and gases. Plasmas in physics are defined as electrically charged, or ionized, gasses. In her article "The Influence of Atomic Physics on My Work" published in 1973 in *Leonardo,* Brendel described the artwork as part of a larger series of paintings concerned with the phenomena of gas ionization. She wrote, "An electrically excited gas, also called a plasma, emits radiation due to the collision of electrons with atoms," the artist wrote, "I employed layers of short thin lines in orange and red to picture the motion of photons emitted by

[40] Brendel, "The Influence of Atomic Physics on My Paintings," 137.

the charged gas atoms."[41] The combination of bright dashes of red paint with the work's title also recalls the biological term blood plasma. In the physical sense of the terms, blood plasma is technically a liquid holding smaller white and red blood cells and platelets in suspension. Across contexts, plasma refers to a substance in which smaller components are suspended throughout. In Brendel's paintings of molecules and nuclei from 1968 and 1969 the artist explored the shared abstract terminologies used in descriptions of cellular biology as well as subatomic phenomena.

Like *Plasma,* the 1972 diptych *Ionization* features red, white, and black and blue lines distributed in a chaotic but homogenous distribution across both canvases. *Ionization* (figure 2.16) contrasts two slightly differently colored configurations from each spilling across the canvas with a boundary showing the solid white base layer of paint as visible in *Plasma*. In both sets of work, the fields of symbolically depicted charged gases consist of arrays of lines representing atoms colliding with electrons both at random but within a systematically even distribution almost entirely covering the white background. In her triptych entitled *Ionization* from 1970 (figure 2.17), Brendel visually referenced boundaries separating dark and illuminated areas. An even expanse of colliding dashes in shades of yellow and white cover two full canvases and over half of the third. This even coverage, representing a suspension of charged ions, electrons, and atoms, remains largely to the left of a solidly painted vertical white band. Some of the light interactions appear beyond the white barrier, in two thin, slightly denser vertical strips of overlapping lines before a slightly jagged brown band meets the black edge on the right. From left to right, the composition transitions from light into darkness. This large work imagines, magnifies, and celebrates the physical phenomena of illumination underlying the widely used technologies of gas-discharge lamps including neon and fluorescent lighting.

[41] Ibid, 138.

In "The Influence of Atomic Physics on My Painting," Brendel compared her paintings of plasma ionization to the work of a contemporary artist exhibiting a form of light art:

> Later I noticed that an artist had displayed large glass cylinders containing ionized gas as artworks in a gallery. The question that interested me was: 'What goes on at the atomic level inside these cylinders?' My paintings were my visual answer to that question. This example of two ways of dealing with scientific material in art might be helpful for a better understanding of my individual approach to it.[42]

While it is unclear which artist's work she refers to, the contrast between Brendel's paintings and contemporaneous light-based artworks draws attention to two divergent artistic strategies stemming from the shared subject of electromagnetic radiation. While Brendel acknowledged her own subjective mediation of light through hand painted and marked forms, contemporaneous artists including Mary Corse constructed artworks in the mid 1960s directly transmitting electromagnetic radiation through artworks purposefully evading signs of human facture. Brendel's commitment to exploring scientific descriptions of physical light through the symbolic dimensions of her painted compositions set her work apart from the wide array of artists in New York and Los Angeles who incorporated diverse forms of electric light into their work through an array of technological media during the postwar period.

<u>Conclusion: Laser Light and Future Technologies</u>

Shortly after the development of the first lasers in 1960, Brendel visited physics laboratories to observe the technology and learn more about the experimental process. Recalling her experience in 1988, she expressed: "What fascinated me was that, though laser light itself is invisible, it could be made visible through particles or vapor in the air."[43] For Brendel, studying the physical interactions underlying a wide range of electromagnetic phenomena including the

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[42] Ibid.
[43] Bettina Brendel, "Atomic Length - A Basic Unit in Physics - As a Visual Metaphor in Art," 249.

technology of laser light inspired artworks examining energy transitions at the subatomic level. Brendel's consideration of the physical processes underlying different energy transfers in light and matter appears through her series of multiple canvas paintings on the subjects of particle wave duality, diffraction, plasmas, and ionization from 1969 to 1970. Her paintings of laser light from 1969 into the 1980s demonstrate a variety of Brendel's stylistic approaches to visualizing the newly invented, technologically produced form of amplified light.

In her painting *Metal Vapor Lasers and Phantom Phase* (figure 2.18) from 1982, Brendel signals a contrast between visibility and invisibility through two canvases adjoined to create a large artwork 6.5 feet tall and 8 feet wide. Like other artists in Los Angeles working in the style of painting known as "hard-edge abstraction," Brendel created solid areas of painted color by applying successive layers of acrylic paint confined between masking taped boundaries. The process of applying flat planes of opaque colors within precisely defined borders appealed to painters interested in obscuring traces of the artist's gesture in favor of cleanly edged arrangements of brightly colored flat planes or stripes. In this double painting, Brendel utilized hard-edge abstraction as a means of depicting the visual effect of observing the laser beam's amplified stream of photons passed through a diffraction grating into different strong colors at varying angles.[44] For Brendel, the visual impact of thin, bold, sharply defined lines provided a means of conveying visual information regarding two specific but complementary phenomena: the beam of coherent photons emitted by laser light and a phantom set of wavelengths simultaneously rendered invisible by the technology's intense illumination.

Brendel's depiction of a "phantom phase" in a pale, muted range of colors provides a view of an otherwise invisible range of wavelengths beyond human sensory perception. Brendel's

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[44] Brendel, "Atomic Length as Visual Metaphor, 249-250.

juxtaposition of two visual frameworks aligns with the artist's scholarly research interest in the theoretical frameworks of modern physics. To describe interconnected phenomena at odds with the definitions of boundaries familiar from the macroscopic scale, modern physicists utilize mathematical models. For Brendel, utilizing symbolic lines and visual metaphors alluded to the abstract language of mathematics central to descriptions of phenomena at the extremes of scale and velocity in theoretical physics.

Through her visual artwork after 1969, Brendel acknowledged the complementary viewpoints central to modern understandings of subatomic forces in quantum physics. Certain double views in her works including *Metal Vapor Lasers and Phantom Phase* draw attention to the aspects that are unavoidably occluded when certain characteristics of light or energy are focused upon in scientific experiments and artistic compositions. Considering the theme of observation in art and science, Brendel also examined the inherent limitations of human sensory perception. Like other interdisciplinary scholars after World War II, she approached technology in her work with a conscious consideration of both its dangers and its promises.

Chapter Three
Beyond the Visible: Electromagnetic Radiation, Abstraction, and Quantum Theory in Mary Corse's *White Light* Paintings

"In the drama of existence, we are ourselves both actors and spectators."[1] - Niels Bohr

Introduction: Rethinking Reality

In pedagogical studies, the term "threshold concept" refers to an insight that, once grasped by an individual, fundamentally transforms their understanding of a topic in an irreversible way.[2] For Mary Corse, studying quantum mechanics while taking a physics class at the University of Southern California in 1968 presented this kind of conceptual metamorphosis. In particular, encountering the Copenhagen interpretation of quantum physics radically impacted Corse's understanding of reality and her approach to artmaking. This chapter examines how the philosophical implications of quantum physics prompted Corse to reconsider the role of subjectivity in the production and reception of her *White Light* series of fluorescent light boxes and paintings from 1966 into the early 1970s.

Like many artists associated with minimalism in New York and Los Angeles during the 1960s, Corse expanded the physical and conceptual boundaries of her artwork to include the viewer's phenomenological experience of artwork over time and in physical space. As this research demonstrates, Corse's engagement with quantum theory draws attention to philosophical debates regarding the role of spectatorship, observation, and agency in both modern physics and minimalist artwork in the twentieth century. Through a comparison of the role of artistic trace, viewer interaction, and forms of luminosity in Corse's work, this analysis contextualizes the

[1] Niels Bohr, "Discussions with Einstein on Epistemological Problems in Atomic Physics," in *Albert Einstein: Philosopher-Scientist*, ed. Arthur Schilpp (Cambridge: Cambridge University Press, 1949), 236.
[2] Jan Meyer, Ray Land, and Caroline Baille, *Threshold Concepts Within the Disciplines* (Ann Arbor: The University of Michigan Press, 2008), 1.

artist's work within a larger cultural shift from closed to open systems theories in the work of scientists and artists after 1945.

To adequately gauge the impact of quantum theory on Corse's artistic practice, it is necessary to closely investigate how the artist's transformed understanding of the role of subjectivity in artwork took physical form through the material qualities of her work from 1964 into the early 1970s. This examination focuses on the specific ways in which Corse's approach to artmaking changed in response to concepts from quantum theory including the observer effect, wave/particle duality, and complementarity. In the 1920s, physicists at the forefront of quantum mechanics including Niels Bohr, Werner Heisenberg, and Wolfgang Pauli extended the framework of their analyses to include the scientific observer and laboratory apparatuses as determining factors shaping experimental outcomes at the scale of atomic and subatomic interactions. However, the Nazi persecution of Jewish and non-Aryan scientists in the 1930s in Germany and throughout Europe disrupted scientific collaborations and contributed to the weaponization of atomic physics during World War II. Historian of physics David Kaiser identifies in a range of texts how the Cold War surge in graduate physics enrollments after 1945 in the United States led predominant professors and textbook writers to focus on teaching quantum mechanical calculations at the cost of sacrificing the subject's philosophical paradoxes from course curricula. Therefore, Corse encountered and engaged with the theoretical aspects of quantum mechanics during a period when these themes were increasingly glossed over in postwar college physics courses for political reasons.

Corse's light box artworks started in 1966 combine visible and invisible electrical components. In this series, fluorescent white light emanates through translucent and transparent plexiglass encasements. The light boxes' precise construction conceals any signs of the objects' handmade facture as well as the complex internal armature of carefully assembled glass tubes of neon and argon gas within. In her wireless light boxes, large Tesla coil generators concealed within the ceiling or surrounding wall space emit invisible fields of electromagnetic energy (figure 3.1). These currents activate or excite the electrons within the lightbulbs' chambers of gas, converting electrical energy into visible light. An overall optical effect, more than the exact technological means of producing it, is most directly visually accessible in Corse's work. Through works that physically contrast transparency and opacity as well as visible and invisible components, Corse's light box artworks function as a material investigation of white light's physical properties and its activation through a variety of media. Leading to the artist's studies in physics in 1968, Corse's light boxes took on new physical dimensions and conceptual significance as well as prompting her return to painting subtly inflected white monochromes on canvas with the addition of refractive glass microspheres.

At stake in the material progression of Corse's work in the 1960s is a shift between particular philosophical considerations of subject and object boundaries. As I examine, the distinct perceptual experiences afforded by reflected, emitted, and retroreflective light in Corse's works correspond to different phases of the artist's theoretical approaches to the concept of an external, objective reality before and after her introduction to quantum theory. Her monochrome paintings from 1964 to 1965 draw on the reflective properties of white painted surfaces. By sanding away textural unevenness produced from brushstrokes, Corse produced flat, even planes of white paint in an effort to reflect surrounding light onto her paintings' surfaces. In 1965, Corse extended her paintings into physical space through a set of white painted monochromes encased in plexiglass. Framing space in this way prompted the artist to then create works adding electric components to similarly structured plexiglass boxes as a means of directly emitting light.

During the process of studying physics while producing her light boxes in 1968, the artist shifted her serial investigations of light, space, and form to include the viewer as an activator of her retroreflective paintings. This transition aligns with broader concerns amongst American artists and critics in the mid to late 1960 who shifted from formalist conceptions of autonomous art objects towards instead considering the interactions between artworks, environments, and spectators. Through their relationships to contemporaneous interpretations of minimalist artwork and systems theory, Corse's works align with a larger theoretical shift in the late 1960s from formalist conceptions of artworks as isolated objects or closed systems with determined visual meanings to open systems approaches contingent upon viewer interaction.

White Light in Painting and Physics

White light has functioned as a compelling source of artistic inspiration for Corse through its optical and physical properties as well as its diverse theoretical implications. Studying light first from the perspective of art history, theory, and practice, Corse's interest in the visual phenomena of luminosity led her to seek out technological means of incorporating electric light into her works beginning in 1966. The artist's transition from monochromatic paintings to plexiglass light box artworks illuminated by fluorescent lighting represents a shift from contained fields of reflected white light to emitted light radiating beyond the physical edges of the work. Learning about quantum physics while producing works wirelessly powered through Tesla coil generators prompted Corse to reconsider her previous understanding of the boundaries between artwork and viewers. The metaphysical concerns addressed in quantum theory regarding the limits of apprehending an objective picture of reality at the subatomic level led Corse to reintroduce subjectivity on two levels in her work: by leaving visible brushstrokes indexing the artist's production as well as through strategic lighting specifications which physically frame the viewer within a range of space. A closer consideration of these works points to shared concerns regarding perceptual experience of light in space and time within both minimalist artwork and modern physics.

Corse's materials and technical processes in the 1960s responded to her studies of light from the perspectives of artistic theory as well as physics. Interested in the possibility of activating the picture plane through the strategic arrangement of contrasting painted colors, Corse produced a series of hard-edge paintings upon starting her BFA studies in painting at Los Angeles's Chouinard Art Institute (now the California Institute for the Arts) in 1964. At Chouinard, Corse elected to study with Abstract Expressionist painter Emerson Woelffer, who permitted his students to work independently from their own studios rather than in a classroom setting. From studying Joseph Albers's 1963 book *Interaction of Color* as well as earlier texts containing images of his paintings, Corse noted the optical effect of contrasting color relationships described in the 1963 text as "vibrating boundaries." Regarding this effect between two contrasting or nearly contrasting colors, Albers suggests, "one can recall auras and halos" as related illusory vibrations.[3] Corse's describes this phenomena in her work *Untitled (Red Blue)* (figure 3.2), stating: "noticing how light seemed to flash along the meeting point between the red and the blue passages, after that I consciously tried to put the light in the painting."[4] Observing halation as an effect of color relationships encouraged the artist to then explore other methods of producing the appearance of luminosity in her paintings. In her subsequent series of monochrome canvases, Corse sought to activate the space of painting through the internal, optical effects afforded by shaped canvases and

[3] Joseph Albers, *Interaction of Color, 50th Anniversary Edition* (New Haven: Yale University Press, 2013), 183.
[4] Alex Bacon, "Interview with Mary Corse," in *Mary Corse* (Los Angeles: Inventory Press / Kayne Griffin Corcoran, 2017), 153.

restrained compositions. Not long after, the artist started shaping three-dimensional space by surrounding her solid, bright white monochrome paintings within plexiglass encasements extending outward from surface of the wall into the space of the viewer.

In Albers's chapter entitled "Factual mixtures- Additive and Subtractive," the artist distinguishes between two kinds of physical mixtures of light: the additive mixture of projected light and the subtractive mixture of reflected light. He writes, "By means of a prismatic lens, the physicist easily demonstrates that the color spectrum of the rainbow is a dispersion of the white sunlight. With this he proves also that the sum of all colors in light is white."[5] While Albers incorporated this scientific description of white light into his analysis of the relational aspects of color in *Interaction of Color,* he did so as a means of contrasting additive mixtures of color against the subtractive mixture of paints or pigments, which creates a loss of light. For Albers, the scientific analysis of light's physical qualities including wavelength extended beyond the range of concerns of the colorist. Instead, Albers asserted, "it is the concern of the physicist."[6] Therefore, the theorist's work presented an introductory starting point for Corse's investigation of white light and color in physics which she would later expand by taking a physics course towards the end of the decade.

Combining the insight that white light contains all colors within the visible spectrum along with her observations regarding color relationships of reflected light in painting, Corse produced a series of monochromatic paintings in 1964. As investigations of shape, structure, and lighting effects, Corse's early monochrome paintings highlight the duality of the painted canvas as both a material surface as well as a conduit for various forms of perceptual effects. In her work *Untitled (Octagonal Blue)* (figure 3.3) from 1964, Corse attempted to integrate metallic flakes into her blue

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[5] Albers, 27.
[6] Ibid.

paint a hard-edged octagonal field of blue paint on shaped canvas. Because the mixture did not produce the light catching effect she intended, she then turned to producing a series of monochromatic white acrylic paintings. Between 1964 and 1965, the artist developed a series of white monochromatic paintings coincided with the artist's experiments in silkscreen printing and minimalist sculpture. Across these media, Corse's works spatially arrange geometric forms in ways that frame pictorial and physical space through strategic surfaces finishes and lighting effects.

Corse's monochromatic works, first made of octagonal and hexagonal shaped canvases, then on square canvases oriented in a diamond position, draw on the visual affordances of white paint's reflective materiality while also reconsidering the spatial parameters of painting through their dimensions. In her hexagonal and octagonal shaped canvas paintings, the inclusion of two to four additional wooden framing bars to the conventional four visually expands the frontal surface area of the painting. In her first large white monochrome painting *Untitled (Octagonal White)* (figure 3.4) from 1964, a thin gray linear outline deduces its shape from the literal edges of the canvas. Through a slight color contrast, this line frames a visual space within the slightly larger than human dimensions of a nearly eight foot tall canvas. The duller gray of the gesso base coat, covered with a thin line of masking tape while the acrylic paint was applied, emphasizes the brightness of the white acrylic paint. Compared to her *Untitled (Octagonal Blue)* in the same dimensions, switching to white paint allowed Corse's surface in this work to physically reflect more surrounding light and create a brighter visual appearance.

In her paintings from the early 1960s, Corse experimented with variables including color and canvas shape while considering ways of incorporating the optical effect of luminosity into her compositions. From Albers's *Interaction of Color,* the artist derived an interest in the illusion of vibrating boundaries between colors which prompted her to then produce monochromatic compositions. Given the opportunity to experiment independently under Woelffer's advisement between 1964 and 1968, Corse worked through formal investigations of white light in individual paintings. While still an undergraduate student at Chouinard, the artist would go on to incorporate electric light into her artworks. Whereas color theorists including Albers located the analysis of light's scientific properties beyond the concern of artists, Corse's artistic practice eventually led her to further study visible light as a form of electromagnetic radiation from the disciplinary perspective of physics.

Systemic Painting

After exploring lighting effects through color relationships and monochromatic canvases in the early 1960s, Corse produced a range of artworks concerned with investigating divisions of compositional and physical space across multiple paintings. Two square canvases oriented in a diamond configuration referred to as *Untitled (Positive Stripe)* and *Untitled (Negative Stripe)* from 1965 (figures 3.5 and 3.6) contrast painted and unpainted areas of canvas within each work, emphasizing the optical effect of reflected light off of white paint and creating contextual meaning as a set. In *Untitled (Negative Stripe),* the thin, central white strip of primed canvas is slightly recessed compared to the subtly raised areas surrounding layers with white acrylic paint, contrasting surface color, texture, and depth. There are no visible brushstrokes in the painting, but the final work nonetheless evidences a sequence of painting through the visible stratigraphy of its layering: the first, lowest layer is painted in gesso temporarily covered in masking tape during the subsequent application of acrylic paint. The process of applying masking taped lines between layers of paint creates a precise, hard edge of acrylic polymer slightly raised above the coated canvas ground once the tape is removed. The visual contrast in these works is therefore one of both material reflection and slight physical depth. The relationship between positive and negative painted sections of in these works expands beyond the internal divisions of the individual artwork to apply to the complementary physical structure of the pair when both paintings are viewed or considered together.

In structuring her artworks to emphasize light and the internal division of compositional space as fundamental concerns of painting, Corse subsequently integrated plexiglass as a way of physically extending her monochrome painting into three-dimensional space. In three works each referred to as *Untitled (Space Plexi + Painted Wood)* from 1966 (figure 3.7), two by two foot monochrome white panels are framed within precisely handcrafted plexiglass cases varying in depth between two, four, and six inches. After painting the interior wooden panels with white paint, Corse sanded the surfaces to produce a flat, even luster bearing no visual traces of brushstrokes. Through their dimensions and construction, these works subtly expand the dimensions of monochrome painting off of the wall and into the three-dimensional space of the viewer. They also transform the hand constructed artwork into a seemingly industrially produced object, relocating meaning beyond the artist's subjective trace and instead within the work's syntax of physical structure.

Each of Corse's painted panels in her *Untitled (Space Plexi + Painted Wood)* works occupies half of the volume of its surrounding plexiglass encasement, drawing attention to organizational and structural issues of division and wholeness while physically contrasting solid and void. The physical transparency of Corse's outer plexiglass boxes contrasts with the flat white opacity of the interior paintings' surfaces and edges. From a fixed, frontal perspective, these works appear identical in size, but from the majority of viewing positions the difference in their depth is apparent, and the logic behind their structure as a systematic pattern can be visually deduced. Whereas her previous monochrome paintings systematically divide pictorial space in terms of precisely delineated contrasts between painted layers, these works divide physical space through contrasting transparent and opaque surfaces.

The visual and material relationships between Corse's *Untitled (Space Plexi + Painted Wood)* artworks, as well as their position within the artist's broader exploration of white monochromatic paintings, relates Corse's systematic approach to the contested domain of seriality described by both formalist critics as well as those concerned with postmodernism and systems theory in the mid to late 1960s. Art historian James Meyer observes that 1966 marked a transitional year within discourses surrounding the purposefully self-enclosed character of literalist artwork by New York artists including Frank Stella, Donald Judd and Robert Morris. Just as the "Primary Structures" exhibition at the Jewish Museum and the Guggenheim's "Systemic Painting" 1966 brought minimalist sculpture and painting to a broader public, a slightly younger generation of artists including Mel Bochner, Robert Smithson, and Eva Hesse created artworks that invoked systems in ways that challenged the detached character and empirical truth claims of literalist art objects, thus initiating an emergence of postminimal activity.[7] Corse's artwork can be viewed as spanning both approaches, with her electric light boxes marking transitionary bodies of work. While she first sought to create literal objects separated from subjective expression and interpretation, as she began working with electricity and studying quantum theory she subsequently blurred the distinct boundaries between viewer, object, and environment upheld in her monochrome paintings.

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[7] James Meyer, *Minimalism: Art and Polemics in the Sixties* (New Haven: Yale University Press, 2013), 153.

Corse's *Untitled (Space Plexi + Painted Wood)* series, like her pair of bisected diamond canvases, creates visual meaning within each individual work as well as across the set. In this way, the logic of systems and seriality in Corse's artworks can be compared to art historian Lawrence Alloway's conception of systemic painting formulated the same year. Though less frequently discussed than the Jewish Museum's "Primary Structures" exhibition, the "Systemic Painting" show curated by Alloway at the Guggenheim five months after in the fall of 1966 represents an application of systems analysis to the realm of abstract painting. Although Corse did not appear in the show, her white monochromatic paintings on shaped canvas and within plexiglass relate to aspects of the exhibition's narrative while also signaling a distinct approach. The exhibition catalogue cover featured a cropped image of dictionary definitions for the words "system" and "systemic" with the title *Systemic Painting* enlarged beneath (figure 3.8). Systemic is defined in the image as: "arranged or conducted according to system, plan, or organized method; involving [an] observing system, (of a person), acting according to system, regular and methodical." In his catalogue essay, Alloway attempted to provide a general theory of the uses of systems in the work of contemporary abstract artists.

Discussing Kenneth Noland's chevrons and Ad Reinhardt's crosses, Alloway analyzes the prevalent tendency among artists to repeatedly use a certain formal configuration in their paintings. As he expresses:

> Here, form becomes meaningful, not because of ingenuity or surprise, but because of repetition and extension. The recurrent image is subject to continuous transformation, destruction, and reconstruction; it requires to be read in time as well as space… the run of an image constitutes a system, with limits set up by? the artist himself, which we learn by seeing enough of the work. Thus the system is the means by which we approach the work of art. When a work of art is defined as an object we clearly stress its materiality and factualness, buts its repetition, on this basis, returns meaning to the syntax.[8]

[8] Lawrence Alloway, *Systemic Painting* (Guggenheim Museum of Art: New York, 1966), 19.

Repeated forms across sets of artworks by a single artist, Alloway argues, evade the expectation that meaning can be entirely complete within a single artwork. Rather, he suggests, the meaning of the work of certain painters is located over time and between works, within conceptual systems delineated by individual artists.

Alloway's conception decentralizes the message of an artwork, expanding meaning beyond the frame of one work into the domain of larger systems of images.[9] His schema, however, insists on the centrality of the painter, whose recurring images create a progressive dialogue of meaning through nuanced changes in the handling of form. In his words:

> A system is as human as a splash of paint, more so when the splash gets routinized… The personal is not expunged by using a neat technique; anonymity is not a consequence of highly finishing a painting. The artist's conceptual order is just as personal as autographic tracks.[10]

Systemic painting, as described by Alloway, conveys fixed meanings determined by the artist's serial production.

By attending to the series as a larger data set beyond the singular image, Alloway attempted to invoke systems theory to consider meanings beyond the scope of Greenbergian formalism, which emphasized internal compositional relations within individual artworks.[11] However Alloway's approach insists on authorial intent in ways that many artists at the time including Corse sought to work beyond in their considerations of modular geometric structures and form in minimalist artworks. As Matthew L. Levy notes, Alloway's emphasis on the personal content of *Systemic Painting* significantly differed from many of the featured artists' literalist approaches,

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[9] As Matthew L. Levy notes, Alloway's take on serial painting is indebted to Michael Fried's analysis in his catalogue essay for the exhibition *Three American Painters, Kenneth Noland, Jules Olitski, Frank Stella* at Harvard University's Fogg Art Museum, 1965.
[10] Alloway, 17.
[11] Matthew L. Levy, *Abstract Painting and the Minimalist Critiques: Robert Mangold, David Novros, and Jo Baer in the 1960s* (London: Routledge, 2019).

including those of Jo Baer, Robert Mangold, and Tadaaki Kuwayama outlined in a section of the catalogue containing brief artist statements. In her artist statement included in the exhibition catalogue, for example, Baer describes how her three large square paintings in the show contain painted bands in the primary colors of light: magenta, blue, and green.[12] Rather than selecting colors solely based on subjective preference, she turned to a logically derived, predetermined order as well as a deductive compositional structure of black and colored bands taking their shape from the literal edges of the canvas.

As opposed to Alloway, artist, critic, and curator Mel Bochner examined systems and seriality in the work of late 1960s artists as means of focusing on subjects beyond personal aesthetic decisions. For example, in his 1967 essay "Serial Art, Systems, Solipsism," Bochner describes Sol LeWitt's serial structures as "the consequence of a rigid system of logic that excludes individual personality factors as much as possible. As a system it serves to enforce boundaries of his works as 'things-in-the-world' separate from both maker and observer."[13] Although Corse was not directly in dialogue with these New York based artists at the time, she shared an interest in separating her artworks from subjective authorial trace. By sanding away her brushstrokes and hiding traces of facture, the artist sought to emphasize geometric structure and light rather than subjective expression through systematic repetitions of painted white forms. Transformed into a solid white volume, the picture plane is literalized as a medium or channel for interacting with surrounding light. During this phase of her work, Corse approached painting as a compositional system capable of producing objective optical effects through the manipulation of light within spatial forms.

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[12] Baer in Alloway, 23.
[13] Mel Bochner, "Serial Art, Systems, Solipsism," in *Minimal Art: A Critical Anthology,* ed. Gregory Battcock (Berkeley: The University of California Press: 1968), 92-102.

As art historian Pamela Lee describes, the word system evokes competing associations in the context of 1960s and early 1970s culture. Yet, she writes, "systems analysis, *systems discourse, General System Theory,* or just plain *systems theory* refers to something quite historically specific at the same time as it signals a certain openness in the study of scientific, natural, and cultural phenomena."[14] Systems theory as an analysis of organization and communication grew from the interdisciplinary considerations of postwar scientists including Austrian biologist Ludwig von Bertalanffy in the 1950s, whose work drew attention to interactions between entities rather than isolated phenomena.

In his 1968 collection of essays entitled *General Systems Theory,* von Bertalanffy writes that the systems theory approach can be considered, in general, a science of wholeness. He explains:

> While in the past, science tried to explain observable phenomena by reducing them to an interplay of elementary units investigable independently of each other, conceptions appear in contemporary science that are concerned with what is sometimes vaguely termed 'wholeness,' i.e., problems of organization, phenomena not resolvable into local events, dynamic interactions manifest in the difference of behavior of parts when isolated or when in a higher configuration, etc,; in short "systems" of various orders not understandable by the investigation of their respective parts in isolation.[15]

Von Bertalanffy sought to address the characteristics of systems within varying branches of physical and social sciences analyzed according to general laws that applied across fields. To illustrate what von Bertalanffy saw as the limits of conventional physics, which dealt only with closed systems thought to be isolated from their environments, he proposed instead a model based on open systems of living organism in dynamic interaction with their surroundings. He contextualized modern theories of energy and communication including the closed systems of

[14] Pamela Lee, *Chronophobia: On Time in the Art of the 1960s* (Cambridge: MIT Press, 2004), 62.
[15] Ludwig von Bertalanffy, *General Systems Theory* (New York: George Braziller, 1968), 36-37.

conventional physics and Norbert Weiner's formulation of cybernetics as closely connecting to systems analysis while also remaining distinct in terms of the implications of entropy. Feedback systems, for example, exist widely across modern technologies and biological systems as a means of stabilization and self-regulation through the transfer of information and energy. The simple system is comprised of a receptor or sense organ (either as technological device or biological organ), a stimulus signaling a message, and a control apparatus which recombines messages ultimately sent to an effector.[16] In one example of information corresponding to the flow of energy, light waves represent a form of stimulus reaching the eye or photoreceptor, which can elicit a response in an organism or machinery.

Von Bertalanffy notes that feedback schemes in cybernetics presuppose a specific structural arrangement which differs from many primary regulatory responses in open systems such as living organisms. Open systems can maintain a steady state through a range of dynamic interactions and processes in what he defines as "equifinality." By highlighting an organism's openness, adaptability, and interaction with the conditions of its environment, he suggests that living systems can maintain steady states and avoid increases in entropy, or the tendency towards maximum disorder. As art historian James Nisbet analyzes in *Ecologies, Environments, and Energy Systems in Art of the 1960s and 1970s,* von Bertalanffy's equifinality introduces a conception of collective organization as a function of interactions between organic and inorganic beings over time unlike the closure and control detailed in Weiner's cybernetic systems.[17]

Artist, critic, and theorist Jack Burnham outlined a distinct approach to systems in artwork influenced by a range of theoretical approaches including von Bertalanffy's general systems

[16] Bertalanffy, 42.
[17] James Nisbet, *Ecologies, Environments, and Energy Systems in Art of the 1960s and 1970s* (Cambridge: MIT Press, 2014), 7.

theory. In his 1968 essay "System Esthetics," Burnham argues that the emergence of environmental artworks and other "unobjects" beyond the scope of traditional artistic media should be analyzed in the broader context of changes in technology. Referring to Thomas Kuhn's concept of paradigm shifts in science, Burnham identifies what he sees as a social transition from an "object-oriented" to a "systems-oriented" culture revolving around issues of organization as predominant concerns. Whereas conventional modes of painting and sculpture embodied "the esthetic impulse" of the early stages of the modern industrial state, Burnham argues that contemporary artistic production shows that art resides not in material objects but rather within interrelations between individuals and aspects of their environments.[18]

In his text *Beyond Modern Sculpture: The Effects of Science and Technology on the Sculpture of This Century,* also from 1968, Burnham describes emitted light in art as exemplifying "one of the primary qualities of systems: the tendency to fuse art object and environment into a perceptual whole." Light Art, he suggests, "eliminates the specific art object and transforms the environment into a light-modulating system sensitive to responses from organisms which invade its presence."[19] While Corse initially approached her plexiglass light boxes from the perspective of artworks as autonomous systems of formal elements, her view shifted towards encompassing a broader open-systems approach related to Von Bertalanffy and Burnham's designations after considering the integral role of the observer's subjectivity as part of the experimental system outlined in the Copenhagen interpretation of quantum physics.

[18] Jack Burnham, "System Esthetics," *Artforum* (September 1968): 31.
[19] Jack Burnham, *Beyond Modern Sculpture: The Effects of Science and Technology on the Sculpture of This Century* (New York: George Braziller, 1968), 285.

Expanding Boundaries: Electric Light and Physical Space in Painting

After exploring various styles of monochromatic white paintings, Corse arrived at her electric *White Light* artworks as a means of emphasizing the optical quality of luminosity as a primary concern of painting. In 1966, Corse's spatially expanded monochromes with plexiglass inspired the artist to seek out ways of incorporating emitted, rather than reflected, white light in her artworks, leading to her first works with electric light encased in plexiglass boxes started the same year. These works take on similar formal qualities to Corse's plexiglass encased paintings while drastically increasing in brightness by directly emanating visible electromagnetic radiation in the form of fluorescent light. In her first work of this kind, *Untitled (White Light Series),* 1966 (figure 3.9), an opaque white plexiglass frame takes the place previously occupied by a white painted panel, encased within a second box made of clear plexiglass. By encasing lightbulbs in white plexiglass boxes, the linear arrangement of tubes dissolves into the appearance of an evenly lit plane. The artwork's enclosed fluorescent bulbs are not directly visible through the work's inner translucent plexiglass chamber apart from the even glow of light they emit. Invisibly supplying energy to the piece, the work's electrical power cord is disguised behind the painted wooden backing supporting the plexiglass frame. As in her subsequent Tesla coil powered light boxes, the artist took steps to obscure the work's functional technological components in favor of creating a more streamlined optical effect.

Between 1966 and 1968 Corse constructed around twenty-four electric light boxes in a variety of dimensions and configurations.[20] These objects are precisely crafted and complex technological devices. In her view, these lighting systems can also be considered paintings. Describing her electric light works, Corse stated:

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[20] Robin Clark, "Optical Baths of Radiance: The Light Boxes," in *Mary Corse: A Survey in Light,* ed. Kim Conaty (New Haven: Yale University Press, 2018), 63.

> I called them *Light Paintings*. It didn't matter that they weren't made out of paint. It was about more—'What is a painting?' Interested me. 'What is a painting? Why do human beings make paintings?' More than that it's made out of paint. It's what it does.[21]

While many artists at the time rejected painting as an obsolete medium, Corse remained interested in expanding its conceptual parameters first in terms of new materials and later by including the phenomenological experience of the viewer. Corse's *Light Paintings* emerged from the artist's prior consideration of paintings as optical surfaces activated by the properties of color, form, and material. Working with electricity enabled the artist to expand and further enliven the space of painting with radiant emitted light. After producing a number of electric light boxes mounted to wooden backings in 1966, Corse constructed large, double sided light boxes attached to the ceiling with wires or thin supports. *Untitled,* 1967 (figure 3.10) consists of a six foot square, ten-inch deep clear plexiglass box containing a translucent case roughly half as deep framed within. Photographs of Corse working in her downtown Los Angeles studio in 1967 show the artist inspecting this artwork from below as hoisted by equipment from an open skylight (figure 3.11), providing a sense of its structure and scale.

Envisioning an overall optical effect of freely floating illuminated light, Corse researched possible technological methods for powering her work wirelessly. The artist successfully devised a number of small works powered by high frequency Tesla coil generators concealed in sculptural pedestals or behind wall or ceiling partitions. *Untitled (Electric Light),* 1968/2017 (figure 3.12), contains argon bulbs with their electrodes removed arranged within two layers of plexiglass casing, one white inside and one clear. Atop a transparent plexiglass stand, the evenly illuminated square is powered by its proximity to an electrical field emanating from the unseen Tesla coil within the

[21] Hunter Drohojowska-Philp, "Oral history interview with Mary Corse," 2013 August 10-December 14. Archives of American Art, Smithsonian Institution.

pedestal, which circulates high frequency currents through the process of electromagnetic induction.[22] Aiming to produce similar works in larger sizes suspended from the ceiling by nearly invisible monofilament lines, Corse needed a larger Tesla coil generator which, due to safety precautions, could only be purchased by the distributor Edmund Scientific upon passing a physics exam.[23] In order to obtain the part, she enrolled in a physics class at the University of Southern California in 1968.

Studying physics ultimately enabled the artist to access the necessary parts and actualize the suspended light box works without power cords that she envisioned, including *Untitled (Space + Electric Light,)* 1968 (figure 3.13). Taking a physics class also prompted an unexpected change in Corse's worldview by introducing her to the main principles of quantum mechanics. The fundamental role of uncertainty and unpredictability central to studies of light at the subatomic level prompted the artist to embrace chance and unexpected effects in her work. While her previous lightboxes cast an even glow, her larger wireless lightboxes including *Untitled (Space + Electric Light)* flicker and pulsate slightly, more clearly revealing the internal arrangement of vertically aligned bulbs. The formal and theoretical changes between her minimalist artworks, wireless light boxes, and subsequent paintings with glass microspheres after 1968 evidence Corse's shift from considering artworks as autonomous and self-enclosed objects towards viewing her work as open systems inclusive of their surrounding spatial context as well as the viewer's subjectivity. Corse's light boxes, though intended to be apprehended as an isolated lighting effect, are closely integrated into their environments through carefully concealed technological means. They also physically

[22] Eugene I. Nefyodov and Sergey M. Smolskiy, *Electromagnetic Fields and Waves: Microwave and mmWave Engineering with Generalized Macroscopic Electrodynamics* (New York: Springer, 2018), 85.
[23] Oral history interview with Mary Corse, 2013, Archives of American Art.

permeate the surrounding space by directly emanating visible electromagnetic radiation generated through the excitement of electrons within mercury vapor gas discharge fluorescent lights.

Despite the artist's original intent, her wireless light boxes' interconnectedness to their environment is nonetheless evidenced by the works' reliance on concealed high frequency generators as well as the way in which they fill space with light. While she envisioned these works as autonomous objects, contemporary critics including Fidel Danieli noted how light from Corse's fluorescent work spills into the surrounding space, causing a "halation" effect and inundating the viewer in "an overwhelming optical bath of radiance."[24] As Bochner also observed regarding Dan Flavin's work with light, gaseous fluorescent lighting fills space in a physically distinct manner from natural and incandescent light sources. As he expressed:

> Up until about fifteen years ago all light came as points. All sources of illumination, including the sun, were singular and radiated from a point source. With the proliferation of fluorescent lighting a perceptual revolution occurred with probably deeper significance than the invention of the light bulb (which still created chiaroscuro shadows). Light now occurs in long straight lines obliterating shadows. It can, in effect, surround.[25]

Drawing attention to the distinct perceptual experience of fluorescent light, Bochner, like Danieli, identifies the surrounding effect of fluorescent light. In Bochner's view, Flavin's use of fluorescent light is central to the high degree of artificiality and unnaturalness he perceived in the work's effect, which he equates with Bertolt Brecht's concept of "the alienation effect."[26] Corse's wireless works produce related optical effects, as well as an auditory component through the subtle hissing and occasional popping sounds of the Tesla coil's energy current interacting with the encased gas bulbs. While her light boxes represent an expanded conception of painting in terms of materiality and optical effects, Corse's subsequent paintings with microspheres extend further to incorporate

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[24] Fidel A. Danieli, "Greg Card, Mary Corse," *Artforum 6* (Summer 1968), 45.
[25] Bochner, 99-100.
[26] Bochner, 100.

the viewer as an integral component of the artwork through the optical phenomenon of retroreflection contingent upon a viewer's angle of observation and movement.

A nine-minute film from 1968 entitled *White Light* produced by Andy Eason provides a rare glimpse into Corse's theoretical and technical approaches to artmaking just prior to her reconceptualization of objectivity in light of quantum theory. As she is shown constructing light box artworks in her studio, the artist's narration in a voiceover indicates aspects of her perspective which have remained consistent as well as viewpoints on objectivity and subjectivity which would change not long after. The film opens with shots of the artist's meticulously hand drawn diagrams and plans for constructing the electrical components within her light boxes as she expresses:

> An idea is defined in its form. An artist's idea is defined in the actual piece. And words are too deceptive. Words are very difficult. That's why it doesn't really make any sense to talk about art at all, because art is the experience. That's the only place it has any reality is in the experience. But we use words to try to communicate a way to that experience.[27]

The view that art can create meaning through direct experience in ways that evades the capacity of language is a sentiment the artist has maintained throughout her career. Additionally, Corse's assertion that certain phenomena evade precise description through language is one that resonates strongly with quantum theory. However, her subsequent statement in the film regarding autonomous artworks detached from their context as well as the possibility of objectively experiencing artworks represent perspectives which would change following her consideration of quantum mechanics. By using high frequency coils to eliminate wires, Corse suggests, "the object can be completely free from the external world, from any world but its own." Compared to "subjective art," in which any viewer can project meanings onto a work, she argues, "in objective

[27] Corse in *White Light* film produced by Andy Eason, 1968.

art there is one definite experience." Through her pristinely crafted light boxes, Corse aimed at clearly conveying a direct, objective experience of light.

As Corse later explained regarding her first wireless lightbox works, "I wanted to make a free object. I was still looking for an objective truth, I think. I didn't want art to be subjective. I wanted there to be an objective reality."[28] Studying quantum theory, however, led the artist to radically reconsider her previously held views. As she describes, "I realized that there is no objective truth. Subjectivity and perception are a part of reality, and that's what sent me back to painting, back to the brushstroke, because you can't get rid of subjectivity. There is no specific object."[29] Corse first considered her minimalist artworks as objects capable of conveying empirical meanings through physical presence alone, recalling Donald Judd's formulation of "Specific Objects" from his 1964 essay. Judd wrote:

> Three dimensions are real space. That gets rid of the problem of illusionism and literal space, space in and around marks and color - which is riddance of one of the salient and most objectionable relics of European art… Actual space is intrinsically more powerful and specific than paint on a flat surface.[30]

Both Judd and Corse moved from abstract painting to working in three-dimensional space in ways that investigated how artworks convey empirical information or data through form. Whereas Judd considered clarity of form and illusionism to be mutually exclusive, Corse and other West Coast artists fused aspects of both in their hybridized forms of painting and sculptural artworks. Corse's paintings emerged from her studies of illusory visual phenomena including the appearance of depth

[28] Oral history interview with Mary Corse, 2013, Archives of American Art.
[29] Alex Bacon, "In Conversation: Mary Corse with Alex Bacon," *The Brooklyn Rail,* June 3, 2015, https://brooklynrail.org/2015/06/art/mary-corse-with-alex-bacon. The artist has retained an interest in the philosophical implications of quantum theory ever since, consistently mentioning the critical impact of quantum theory on her work in interviews.
[30] Donald Judd, "Specific Objects," in *Donald Judd: Complete Writings 1959-1975,* New York: New York University Press, 1975, 184.

on a flat surface and halation afforded by color interactions. In Corse's light boxes, physically obscured components render the illusionistic effect of light freely radiating from an artwork.

Encountering quantum physics in 1968 prompted a shift towards her creation of artworks that function as open systems through their incorporation of the viewer's subjective perceptual experience of optical phenomena. "Quantum physics really impressed me," Corse says, "I was starting to understand that there is no objective reality as clear as we might think. I had been looking for this objective truth, making these light pieces that were true. Then I realized that perception was as much a part of reality as reality."[31] Whereas she had previously sought to create autonomous art objects that could be visually apprehended in an objective manner, discovering the role of subjectivity within the Copenhagen interpretation of quantum mechanics encouraged the artist to produce paintings from a fundamentally transformed perspective inclusive of the observer. Discovering the material of glass microspheres enabled Corse to produce paintings within an expanded framework of relationships between subjective viewers and environmental contexts.

Beyond the Visual: Quantum Theory and Metaphysics

For Corse, the concept of a detached art object apart from the subjectivities of both artist and viewer once represented the possibility of apprehending an objective reality. However, after the artist learned about the work of quantum physicists including Bohr, Heisenberg, and Pauli, she adopted the stance that there is no objective reality, and that perceptual experience allows subjective access to phenomena not directly describable through language or graphic reproduction. Her shift to using retroreflective glass spheres affixed to the surfaces of her paintings allowed her to make the viewer an active agent in her works through completing the triangulation of light from

[31] Caroline A. Miranda, "The 'Whoa' Moment and Mary Corse: The Painter Who Toys with Light is Finally Getting Her Due," *The Los Angeles Times,* November 2, 2017.

spotlights directed onto the work's surface and returned back towards the viewer. As she explains, "The art is not on the wall, it's in the viewer's perception."[32] The viewer's experience of optical effects contingent upon their movement in the work's surrounding space foregrounds the role of subjective perception in the phenomenological apprehension of visual artwork. At the same time, slight variegations from Corse's visible brushstrokes beneath the glass microspheres index the artist's trace in a way she previously took active steps to avoid.

In a 2013 interview with art historian Hunter Drohojowska-Philp, Corse expressed, "It's always interested me, you know, this right/left brain thing that they say, the intuitive and the logical, the artist and the scientist. And I don't think they have to be so separate, the sides of our brain… they can both sort of work together, because finally physics is metaphysics." While the notion of left versus right brained personalities is now largely regarded as a myth, the artist points to a culturally constructed division of intellectual labor between the humanities and sciences famously examined in novelist and physicist C.P. Snow's 1959 lecture and book *The Two Cultures.* Responding to Drohojowska-Philp's comment that an area her studio with electrical apparatuses looked like a "mad scientist corner," Corse's statement draws attention to her interest in considering the perceived binary opposition between logical scientific thought and intuitive artistic ideas from a holistic perspective which considers the two to be compatible. Her point that physics has become metaphysics emerges from insights derived from quantum theory, particularly from the work of Werner Heisenberg, Niels Bohr, and Wolfgang Pauli. The collective work of these physicists from the 1920s, known as the Copenhagen interpretation of quantum physics, represents the first general attempt to understand physical processes at the atomic scale through quantum

[32] Bacon, "Interview with Mary Corse," 2017, 157.

mechanics.[33] Due to paradoxical experimental findings regarding the subatomic world which radically departed from the laws of classical physics, a number of scientists including Bohr, Heisenberg, and Pauli addressed philosophical concerns in their work beyond the conventional scope of physics.

Since its emergence in the mid 1920s, the Copenhagen interpretation has remained a predominant interpretation of quantum mechanics taught in general physics classes, although Cold War politics impacted how the subject was taught in the United States during the postwar period. Historian of science David Kaiser details how hyperinflation in university physics enrollments in the United States after World War II transformed pedagogical approaches to the subject of quantum mechanics in textbooks and classrooms. In his analysis of physics curricula in the postwar period, Kaiser identifies a pronounced pedagogical shift away from requiring students to address the conceptual paradoxes of quantum mechanics in interpretive essay questions to instead focusing much more heavily on standard calculations.[34] From her statements regarding quantum physics, it is evident that Corse encountered the Copenhagen interpretation in 1968 when she took an introductory physics class at USC. However, quantum mechanics is only briefly described in Robert Resnick and David Halliday's 1966 version of the textbook *Physics,* a standard undergraduate physics textbook which Corse likely encountered. Consequently, the artist took hold of a particular set of conceptual concerns likely though lectures at a time when many textbooks and physics professors deemphasized these same philosophical quandaries by focusing instead on calculation based pedagogical approaches. Once introduced to the subject, she continued to independently study quantum theory by reading texts primarily by Pauli.

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[33] Jan Faye, "Copenhagen Interpretation of Quantum Mechanics," *The Stanford Encyclopedia of Philosophy* (Fall 2014 Edition), Edward N. Zalta ed., 1.
[34] David Kaiser, *Quantum Legacies: Dispatches from an Uncertain World* (Chicago: University of Chicago Press, 2020), 120-133.

When asked what she took from studying theoretical physics, Corse explained that Heisenberg's uncertainty principle, wave/particle duality, and the observer effect helped her realize the inherent role of perception in shaping human understandings of reality.[35] A close analysis of central philosophical issues at stake in the Copenhagen interpretation of quantum mechanics clarifies how scientific theories directly impacted Corse's artistic production through her choice of material and consideration of viewer involvement. The artist's response to the work of Heisenberg, Bohr, and Pauli reveals ways in which theoretical and phenomenological concerns from the field of quantum physics regarding objectivity, observation, and the nature of reality relate to considerations of viewers' spatiotemporal perceptual experiences within discourses of minimalist artwork in the 1960s.

The emergence of quantum mechanics in the early twentieth century represents one of the most significant paradigm shifts in the history of physical science due to the ways in which its theories challenge traditional understandings of the nature of physical reality.[36] As Jennifer Burwell explains in *Quantum Language and the Migration of Scientific Concepts,* quantum physics remains one of the most conceptually elusive theoretical paradigms in science nearly a century after its original formulation due to the seemingly counterintuitive nature of its findings. Electrons, for example, exhibit characteristics of particles in certain experiments while demonstrating wave-like qualities in others, defying the logic of classical language and models derived from sensory experience.[37] While Newtonian physics is based on macroscopic observations, quantum physics takes as its subject microscopic atomic processes that can only be

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[35] Oral history interview with Mary Corse, 2013, Archives of American Art, and Rani Singh, "Mary Corse Oral History," Getty Research Institute, filmed in Topanga Canyon, April 21, 2011.
[36] Vassilios Karakostas, "Realism and Objectivism in Quantum Mechanics," Journal for General Philosophy of Science 2012 (Vol. 43, Issue 1).
[37] Jennifer Burwell, *Quantum Language and the Migration of Scientific Concepts* (Cambridge: MIT Press, 2018), 1.

observed through indirect traces. In the mid 1920s, particle physicists including Heisenberg, Bohr, and Pauli examined how acts of observation interfere with the apparent properties of quantum phenomena in ways that challenge conventional boundaries between scientific observer and observed phenomena. According to their work, the particle-like and wave-like behaviors of subatomic phenomena are not fundamental qualities but rather interactions co-created through the process of observation.

In physics, the split between spirit and matter articulated by Descartes in the seventeenth century developed into the idea of a “detached observer” apart from an external reality. As physicist K.V. Laurikainen informs in *Beyond the Atom: The Philosophical Thought of Wolfgang Pauli*, the idea of a detached observer still dominates Western scientific thought through the belief that an observer’s influence on a given phenomenon can be accounted for and thereby eliminated. However, Laurikainen observes:

> According to the Copenhagen philosophy concerning the interpretation of quantum mechanics, every observation must be viewed as an *interaction* between the "observer" and the "external world". This idea *destroys the basis of the Cartesian distinction*. That interaction implies that the "observer" affects the events of the "external world" whenever he obtains information from them, and for this reason the idea of a "detached observer" is problematical.[38]

Although prominent physicists including Erwin Schrodinger and Albert Einstein wished to retain the ideal of an objective external reality and debated with Heisenberg, Bohr, and Pauli on the subject, the latter group argued that quantum physics required new conceptions of reality inclusive of the observer and apparatus as part of the experimental system.

Unlike Newtonian mechanics, which assumes that the position and momentum of an object are precise and ascertainable at every instant, quantum mechanics posits that at a subatomic level

[38] Laurikainen, 58.

these quantities can only be described in probabilistic terms.[39] According to Heisenberg's uncertainty principle, formulated in his 1927 article "The Physical Content of Quantum Kinematics and Mechanics," the position and momentum of a particle cannot be accurately measured at the same time. In order to measure either quantity, the observer inherently disrupts the phenomenon being studied, leading to only an approximate knowledge of its momentary location or velocity. Heisenberg's uncertainty principle states that locations of subatomic particles are not only approximate but inherently unknowable, as these phenomena do not in fact have a precise location until the act of measurement takes place.[40] The uncertainty principle represents one instance of the broader term 'the observer effect' in physics where the act of observing a system, generally through the use of measuring apparatus, disrupts the phenomena at hand.

In a chapter of his 1958 book *Physics and Philosophy: The Revolution in Modern Science* entitled "Language and Reality in Modern Physics," Heisenberg concluded:

> If one wishes to speak about the atomic particles themselves one must either use the mathematical scheme as the only supplement to natural language or one must combine it with a language that makes use of a modified logic or of no well-defined logic at all. In the experiments about atomic events we have to do with things and facts, with phenomena that are just as real as any phenomena in daily life. But the atoms or the elementary particles themselves are not as real; they form a world of potentialities or possibilities rather than one of things or facts.[41]

Throughout his career, Heisenberg cautioned against the use of visual and linguistic metaphors, arguing that the quantum realm fundamentally defies description through conventional means. Instead, he advocated matrix mechanics as a numerical means of describing pairs of atomic

[39] Arthur Beiser, *Concepts of Modern Physics* (New York: McGraw Hill, 1973), 140.
[40] Gamwell, *Mathematics + Art: A Cultural History* (Princeton: Princeton University Press, 2016), 291.
[41] Werner Heisenberg, *Physics and Philosophy: The Revolution in Modern Science* (New York: Harper and Brothers Press, 1958), 185-186.

states.[42] As an alternative to the Bohr model of electron orbits based on the macroscopic structure of planetary orbits, matrix mechanics accounts for quantum jumps within mathematical matrices indexing different energy levels over time. Because only statistical laws are possible in subatomic physics, mathematical descriptions express potential attributes that cannot be viewed as actual elements of reality from the perspective of materialistic philosophy.[43]

Along with Heisenberg's uncertainty principle, Bohr's principle of complementarity is a fundamental tenant of the Copenhagen interpretation. Drawing from the observation that as an elementary particle's position or velocity is measured, information about its velocity becomes less clear, and vice versa, complementarity refers to the existence of mutually exclusive descriptions of quantum phenomena that cannot be simultaneously analyzed. Importantly, the finding that matter and light appear either as particles or waves depending on the experimental method imposed suggested to Bohr that the concept of a quantum phenomenon cannot be considered apart from the context through which it is observed. As he articulated:

> The elucidation of the paradoxes of atomic physics has disclosed the fact that the unavoidable interaction between the objects and measuring instruments sets an absolute limit to the possibility of speaking of a behavior of atomic objects which is independent of the means of observation. We are here faced with an epistemological problem quite new in natural philosophy, where all description of experiences so far has been based on the assumption, already inherent in ordinary conventions of language, that it is possible to distinguish sharply between the behavior of objects and the means of observation.[44]

Given the inextricable connections between atomic entities and observers, Bohr argued that it is necessary to account for the experimental context in order to clearly define observed phenomena.

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[42] Gavin Parkinson, "Revolutions in Art and Science: Cubism, Quantum Mechanics, and Art History," in *Dimensionism: Modern Art in the Age of Einstein,* ed. Vanja V. Malloy (Cambridge MA: MIT Press, 2018), 104.
[43] KV Laurikainen, *Beyond the Atom: The Philosophical Thought of Wolfgang Pauli* (Springer-Verlag: Berlin, 1988) XI.
[44] Neils Bohr quoted in Arkady Plotnitsky, *Complementarity: Anti-Epistemology after Bohr and Derrida* (Durham: Duke University Press 1994), 97-98.

Because experimental arrangements are human constructs, the properties of quantum phenomena, according to Bohr, cannot be considered to be objective qualities.[45] Taking into account the inextricable connection between scientific experimental arrangements and the resulting findings at the subatomic level, the Copenhagen interpretation of quantum mechanics questions the extent to which an objective reality can be known apart from context-dependent attempts to define it. Furthermore, the indefiniteness of quantum theory, in its limitation to statistical predictions, was considered by physicists to correspond to an actual level of uncertainty existing in the universe evidenced through inherent limitations to human knowledge and logic.[46]

Although less widely discussed in interdisciplinary studies of art and science relative to Einstein, Heisenberg, and Bohr, Pauli's contributions to quantum physics and metaphysical philosophy particularly impacted Corse's work. The artist cites her interest in his text *Physics and Philosophy,* and many of her statements resonate with Pauli's holistic approach.[47] It is particularly useful to examine Pauli's extension of Bohr's conception of complementarity. While many scientists and historians of science critique Bohr's lack of clarity in defining complementarity, Pauli is credited with clarifying Bohr's stance and further articulating the concept within an interdisciplinary realm. For Pauli, complementarity's ability to overcome wave-particle duality suggests that the concept "naturally leads beyond the narrow field of physics to analogous conditions within human knowledge."[48] The relationships between matter and spirit, as considered in the fields of physics and psychology can be described as complementary aspects of reality

[45] Patrick A. Heelan, *Quantum Mechanics and Objectivity: A Study of the Physical Philosophy of Werner Heisenberg* (New York: Springer, 2012), 46.
[46] Nick Herbert, *Quantum Reality: Beyond the New Physics* (New York: Knopf Doubleday, 2011), 201.
[47] Chloe Wyma, "19 Questions for Light and Space Artist Mary Corse," Blouin Art Info. February 21, 2012, web, and in conversation with the author, October 2019.
[48] Harald Atmanspacher and Hans Primas, "Pauli's Ideas on Mind and Matter in the Context of Contemporary Science," *Journal of Consciousness Studies* 13:3 (January 2006): 15.

according to Pauli. Empirical science cannot be thought of apart from psychology, he believed, working with Swiss psychiatrist C.G. Jung on the concept of synchronicity to examine "meaningful coincidences" in the early 1950s. While Bohr's early work challenged the concept of a detached external reality based on the role of the observer, later in his career he reverted towards a more materialistic world view in which the subjective component of reality is subordinated to the material one.[49] Pauli, however, maintained that the influence of human subjectivity on observations could not be ignored. Indeterminism in the atomic world, he suggested, can be aligned with a larger irrationality of reality as demonstrated by the human unconscious.

Through his interdisciplinary considerations of chance and probability based in his mathematical contributions to quantum physics, Pauli emphasized that there is an irrational dimension to reality that cannot be logically explained. By combining insights from physics and psychology, he described the possibility of a reality that cannot be accessed directly, but rather only described symbolically. He wrote in a letter to physicist Léon Rosenfeld,

> For the *invisible reality*, of which we have small pieces of evidence in both quantum physics and the psychology of the unconscious, a symbolic, psychophysical unitary language must *ultimately* be adequate, and this is the far goal which I actually aspire. I am quite confident that the final objective is the same, independent of whether one starts from the psyche (ideas) or from physis (matter).[50]

Pauli believed that modern science presented an opportunity to consider physis and psyche or mind and matter as complementary aspects of a reality that is simultaneously both and neither mental and material in the same way that subatomic phenomena can be described as existing at once as particles and waves while not exclusively belonging to either category.

Both Pauli and Heisenberg addressed the level of abstraction they identified as a primary characteristic of modern particle physics. In Heisenberg's 1933 Nobel Lecture "The Development

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[49] Laurikainen, X.
[50] Atmanspacher and Primas, 17.

of Quantum Mechanics," as well as in a 1967 lecture entitled "Abstraction in Modern Science," he examined the centrality of abstraction in analyzing forces within the atomic nucleus. As he explains, when physicist Max Planck discovered in 1900 that energy within electromagnetic waves is gained or lost in discrete quantities, or quanta, subsequent researchers concluded that radiation phenomena can only be understood by "largely renouncing their immediate visualization."[51] Planck's constant, denoted as *h,* is a numerical value used in calculating relationships between the energy carried by a photon and its frequency. Heisenberg describes Planck's constant as evidencing the "unvisualizable character" of atomic events.[52] As features of atomic physics can only be assessed by foregoing visualization to a far greater extent than in classical physics, Heisenberg considered the role of abstract thought structures separated from sensory experience in particle physics as part of a broader tendency towards continually higher levels of abstraction in science and mathematics.[53] Similarly, in an essay entitled "Matter" in Pauli's *Physics and Philosophy,* he identifies a shift in modern physics from mechanical descriptions in absolute space and time to what he describes as quantum physics' "more abstract description of phenomena" contingent upon the experimental frame of reference.[54]

The insight from quantum physics that there are atomic forces and particle interactions that evade precise definition through language or visual models prompted Corse to consider a parallel relationship between her engagements with "pure abstraction" in painting and the work of mathematicians and physicists engaged in the abstract realm of numbers and symbolic equations.[55]

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[51] Werner Heisenberg, "The Development of Quantum Mechanics" Nobel Lecture, December 11, 1933.
[52] Ibid.
[53] Werner Heisenberg, "Abstraction in Modern Science," in *Nishina Memorial Lectures: Creators of Modern Physics,* ed. Toshimitsu Yamazaki (Berlin: Springer, 2008), 2-3.
[54] Wolfgang Pauli, "Matter," in *Writings on Physics and Philosophy* ed. Charles P. Enz and Karl von Meyenn (New York: Springer, 1994), 30.
[55] Rani Singh, "Mary Corse Oral History," Getty Research Institute, filmed in Topanga Canyon, April 21, 2011.

She describes her artmaking practice as a conversation with an "abstract entity" which informs her process. Corse explains:

> The painting starts talking to you saying, 'A little bit more here, a little less there. Get rid of that. Put that there.' So it becomes a conversation in that way. Think of numbers. Writing an equation you have a conversation with some abstract entity, the meaning of which comes through numbers. You can ask questions and get answers, a lot like painting.[56]

In the artist's view, abstraction in artwork and mathematics functions as a means of engaging with an immaterial, symbolic realm. Envisioning her work in dialogue with an invisible dimension beyond the physical, she routinely describes a parallel between the negotiation of formal problems in abstract painting and the work of scientists and mathematicians engaged in questions through numerical calculations and the formulation of equations. For Corse, reconciling the realms of the physical and the abstract constitutes both an interdisciplinary, theoretical concern as well as a fundamental characteristic of human experience.[57]

Corse has explored visual abstraction in artwork as a means of engaging with philosophical concerns regarding the nature of painting and its relationships to reality and human existence. As she described, "I want the paintings to have form and an absence of form at the same time, which is what human beings also have, we have both the outside, a three-dimensional world and an inner world. My work is trying to express that."[58] At first, Corse created paintings and light boxes envisioned as objects existing apart from the inner worlds of both artist and viewer. However, after learning about the permeability of the boundary previously thought to separate the realms of mind and matter as expressed in the Copenhagen interpretation of quantum physics, Corse adjusted her approach. Quantum physics she explains, made it important for her to reconsider how perception

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[56] Bacon, "Interview with Mary Corse," 2017, 159.
[57] Singh, 16:40.
[58] Mary Corse, Artist Statement, *The Contemporary* (Summer 1985), np.

relates to reality. The uncertainty principle, in evidencing complementary and mutually exclusive descriptions of subatomic phenomena, situates limits on what kinds of knowledge can be ascertained with precise certainty and apart from human subjectivity. For Corse, these observations inspired a return to painting, an embrace of the indexical traces of her brushstrokes, and a new interest in the viewer's subjective experience upon her discovery of glass microspheres.

Retroreflective Paintings

Not long after studying the paradox of wave/particle duality and the implication of the observer central to scientific descriptions of light at the subatomic scale, Corse came upon a distinct optical means of imbuing light into her artworks. While driving, she noticed the particularly bright effect of retroreflected light afforded by the materiality of highway lane dividers. Widely used to illuminate pavement markings including crosswalks and lane dividers, glass microspheres refract and redirect incoming light rays back towards the direction of their source through the optical phenomenon known as retroreflection. After seeking out information about the material, Corse realized that the same combination of minute spherical glass lenses partially embedded in white paint used in lane dividers could be applied to painted works on canvas (figure 3.14).

After acquiring glass microspheres from an industrial supplier, she produced her first work with the material entitled *Untitled (First White Light Series),* 1968 (figure 3.15). This work, like the artist's previous monochromatic paintings, takes compositional cues from the symmetrical division of planar space. A thin border of white painted canvas surrounds the surface coated in glass microspheres. The subtly granular expanse is divided into a large central square with horizontal and vertical borders forming smaller squares in each corner. Each square corner is bisected into two right triangles by diagonal lines which, if continued, would converge at the center of the canvas. The linear divisions in the glass covered area are visibly demarcated by the traces of brushstrokes applied in different directions, revealing the artist's application of paint and microspheres in discrete sections. Owing to the retroreflective property of glass microspheres, the work's surface refracts surrounding light, resulting in a degree of luminosity that varies in intensity relative to a viewer's position and proximity. As in her earlier monochromatic paintings as well as her lightboxes, framing emerges as a formal and conceptual concern in Corse's *White Light* paintings. In addition to framing internal the space of the canvas through distinct painted sections, the viewer is also framed within the work's expanded parameters by Corse's lighting specifications. The artist insists on the importance of lighting the work from behind the viewer with floodlights in order to intensify the dynamic optical effects afforded by the retroreflective surface, which continuously changes in relation to an observer's position and angle of observation.

After her initial experiment with glass microspheres in *Untitled (First White Light Series),* Corse created a series of gridded paintings on nine by nine foot canvases in a number of distinct configurations. Her first gridded works include *Untitled (White Grid, Horizontal Strokes)* and *Untitled (White Grid, Vertical Strokes)* from 1969 (figures 3.16 and 3.17), which merge the precise uniformity of the grid composition and regular pattern of brushstrokes with the slight irregularity of the hand painted surface to which the microspheres were applied. The faint variegation of the brushstrokes within these four by four square grids causes the microspheres to refract light at subtly different angles, affording a shimmering quality to the paintings. Using the same combination of materials across these works, Corse systematically explored possible compositional variations, including diagonal brushstrokes (figure 3.18) and combinations of vertical, horizontal, and diagonal strokes arranged in slightly more condensed five by five square grids (figure 3.19).

As Rosalind Krauss analyzes, grids in modernist paintings map both the physical qualities and aesthetic dimensions of the same surface, suggesting a structured, organic whole, while at the same time evoking a sense of the grid's infinite extension in all directions beyond the boundaries of an artwork. Consequently, the grid can be understood as re-presenting the artwork's boundaries onto its own interior space, which she identifies as a centripetal reading, or alternatively as acknowledging a world beyond the frame through a centrifugal reading.[59] Like many artists Krauss notes, including Piet Mondrian, Joseph Albers, Ellsworth Kelly, and Sol LeWitt, Corse employs the grid in a manner that entails both the assertion and dematerialization of the work's surface. Visible brushstrokes and glass particles attest to the material surface of the canvas, while the effect of retroreflected light causes these physical qualities to fade in and out of clear view, transforming the same plane into a perceptual field. The duality of the picture plane as both obdurately physical and ephemerally illusory, a tension Corse has examined throughout various series of works, is exemplified in her gridded *White Light* paintings.

In 1971, the Solomon R. Guggenheim Museum exhibited two of Corse's retroreflective works, *Untitled (Light Painting)* and *Untitled (White Light L-Corners)* in the exhibition *Ten Young Artists: Theodoron Awards* (figure 3.20). The entirety of these works' surface is covered in white paint, but the L-shapes and squares in each corner along with a thin border around the perimeter have not been coated with microspheres. From certain angles, the illumination of the central field of microspheres causes the white corners to appear relatively gray by comparison. From other vantage points, the microspheres instead appear gray while the corners seem whiter. Additionally, depending on the viewer's position the underlying brushstrokes beneath the layer of glass particles are more or less pronounced, emerging and receding in response to one's movement.

[59] Rosalind Krauss, "Grids," in *The Originality of the Avant-Garde and Other Modernist Myths* (Cambridge: MIT Press, 10-22.

A short catalogue accompanied the Guggenheim's exhibition, representing each artist with a black and white image of their artwork and a brief description of their practice. Surely each of the ten black and white images could only provide a general sense of how these abstract artworks appeared in person, yet the illustration of Corse's work particularly misrepresents the painting at hand (figure 3.21). A list of works at the end of the catalogue attends to the error, stating: "Please Note: The photograph illustrating Mary Corse's *Halo with Rainbow Series,* 1971, is inaccurate. The corners of the work are white, not black."[60] While the distorted image fails to accurately convey the appearance of Corse's work, the photograph is highly illustrative in its own right, inadvertently pointing to a nexus of issues central to Corse's paintings with microspheres. The difficulty in photographically reproducing Corse's work attests to both the painting's refractive materiality as well as the critical role of temporal experience in a viewer's apprehension of its subtly shifting optical effects. Fundamentally at stake is the physical phenomenon of light: mutable through material interactions, central to visual experience, and registered differently across varying forms of materials as well as organic and mechanical receptors.

Static photographs, particularly those taken with a strong flashbulb, inherently fall short in capturing the subtle transitions between varying optical effects that a viewer of Corse's work experiences over time and in physical space. The inversion of white corners into those that appear black in the image indexes the retroreflective quality of the work's surface, which refracted surrounding light, most likely including a bright camera flash, back towards the camera. Capturing the luminous surface on film would require a fast shutter speed or a smaller aperture setting, resulting in the corresponding underexposure, or apparent darkening, of the corner areas not coated in microspheres.

[60] *Ten Young Artists: Theodoron Awards*, Solomon R. Guggenheim Museum (New York: Solomon R. Guggenheim Foundation, 1971), n.p.

As Albers describes in *Interaction of Color,* the human retina differs in terms of its sensitivity and registration of light compared to photographic film. Considering two reproductions of a James Ensor painting, Albers addresses problems in attaining representative tonalities in photographs of paintings, pointing to details lost even through expensive processes of "high-key" reproduction. "The greatest advantage the eye has over photography," he states, "is its scotopic seeing in addition to its photopic seeing. The former means, briefly, the retinal adjustment to lower light conditions."[61] In his brief discussion of how photography deviates from human vision, Albers emphasizes the photograph's inability to convey subtle nuances and delicate relationships between color and tone discernible through normal human vision.

Corse originally intended her early White Light paintings, including *Untitled (White Light L-Corners),* to be viewed in dark rooms with strategically positioned lights directed at the work in order to heighten the glass microspheres' optical impact on viewers. Two sketches sent by the artist to the Guggenheim in preparation for the *Theodoron Awards* exhibition detail specifications regarding the position her works, the number and kinds of lightbulbs, the ideal height and installation of these floodlights (figure 3.22).[62] While the artist is not always in control of her works' installation, her instructions are useful in considering the carefully constructed viewing environments and perceptual effects she initially aimed to create. These diagrams attest to the manner in which Corse's paintings with glass microspheres frame the viewer between the artwork and light sources to produce specific effects, such as heightening the works' apparent brightness relative to its darkened surroundings and framing the viewer's shadow onto the work. In a separate statement she acknowledged, "You actually enter the rainbow paintings, because you can see your

[61] Albers, 15.
[62] Although Corse's installation of a spotlit, light-based artwork recalls arrangements produced by Robert Irwin, Corse has emphasized that she worked independently from Irwin and was not overtly influenced by his work.

shadow and your halo in the painting."[63] The term opposition surge, also known as *heiligenschein* meaning 'holy glow' in German, refers to the brightening around a shadow on a retroreflective, particulate surface when illuminated from behind an observer. Most commonly used in the context astronomy, the opposition surge is visible in photographs of astronomers' shadows on the surface of the moon, which is comprised of retroreflective crystalline minerals (figure 3.23).[64] Based on their spotlighting with floodlights, Corse's works elicit this form of halation effect, creating a glow around the viewer's shadow (figure 3.24). In her paintings where the corners are not adorned with microspheres, Corse found that the halo effect is also accompanied by the prismatic appearance of a thin rainbow outline around the shadow.

As an artist concerned with the phenomenological perception of physical light over time and in physical space, Corse expressed hesitation regarding the inclusion of a photographic reproduction of her work in the Guggenheim exhibition catalogue. A memo in the Guggenheim's archives states, "Mary Corse called… she said that she wondered if it would be possible to have her in the Theodoron catalogue without a photograph, since she felt that any still photography did not properly represent her work."[65] The difficulty of photographing Corse's retroreflective work draws attention to a significant disjuncture between human and mechanical impressions of its retroreflective surface, as well as the critical aspects of embodied perception and temporality in a viewer's apprehension of this dynamically shifting surface. As a more recent set of two images of a similar but slightly larger work from 1970 also referred to as *Untitled (White Light L-Corners)* demonstrates, these works' appearance is multivalent and unfixed, contingent upon spatial

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[63] Corse, *The Contemporary,* 1985.
[64] Scientific and Technical Information Office, National Aeronautics and Space Administration, "Apollo 14 Preliminary Science Report," (Springfield, VA: NASA, 1971), 297.
[65] Memo, July 20, 1971, Solomon R. Guggenheim Museum Archives.

relationships between the viewer and the lighting within the surrounding space (figures 3.25 and 3.26).

Conclusion: Veiled Reality

Corse's investigation of white light since the 1960s emerged from the artist's consideration of the visual and theoretical properties of light from artistic, scientific, and metaphysical perspectives. Before studying quantum physics, Corse created a range of minimalist artworks based on her interest in the history of abstract artwork and color theory. Rethinking conventional approaches to painting as well as utilizing industrial materials enabled the artist to work with light itself as an immaterial yet compliant artistic medium. Painting is a means transferring of visual information, her works suggest, which is inextricably entangled within human subjective interactions both in terms of the production and reception of artworks. Seen as open systems, her retroreflective works adapt to surrounding environments by redirecting oncoming light and shifting in appearance in relation to a viewer's position.

The artist's pristinely crafted minimalist objects from the mid 1960s merge aspects of painting and sculpture, juxtaposing flatness and depth alongside illusory and physical space. In her attention to edges, boundaries, and the work's perimeter, her sparing linear forms across media emphasize, through restrained means, issues of framing in terms of light and space. Through experiments with a range of materials and technologies since the 1960s, Corse has embraced light, perception, and individual subjectivity as a means of giving her pieces their own physical and metaphysical energy. The luminous, shimmering, and iridescent effects of Corse's works with glass microspheres reveal the limitations of words and photographs in adequately capturing the phenomenological experience of light experienced over time and in physical space. Corse explains:

> For me, a work enters the realm of art when it makes me feel and know the reality of my human state in its essence – an abstract perceptual experience before thought. I am interested in a painting that is about itself… just a pure perceptual experience of the moment, the experience before the idea.[66]

Exploring human experience through her paintings, Corse worked through distinct stages of conceptualizing artwork's relationship to reality. For the artist, abstract artwork simultaneously represents a perceptual space apart from, yet enmeshed within, its physical and spatiotemporal environment. After studying quantum theory, she negotiated a distinct artistic compromise between the concrete, physical art object and the dynamic, ephemeral, and contingent effects it can convey through subjective perceptual experience.

In *Veiled Reality: An Analysis of Present-Day Quantum Mechanics,* physicist Bernard d'Espagnat proposes that reality lies beyond the range of rational human knowledge. The ambiguity inherent in quantum mechanical descriptions of phenomena, he suggests, points to the limitations of directly apprehending or describing an independent reality. Instead, an underlying reality in his view remains "veiled" to humans, who can only partially access it through fragmentary glimmers of knowledge.[67] In an interview, d'Espagnat compared scientific insights to those in the arts, stating: "when we hear beautiful music, or see paintings, or read poetry, we get a faint glimpse of a reality that underlies empirical reality."[68] Corse's *White Light* paintings, by highlighting the nuances of subjective perceptual experience, situate abstract artworks as productive sites through which aspects of a largely unknowable reality might be contemplated or momentarily ascertained.

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[66] Bacon, "Interview with Mary Corse," 2017, 159.

[67] Bernard d'Espagnat, *Veiled Reality: An Analysis of Present-Day Quantum Mechanics* (Cambridge: Westview Press, 2003), 367.

[68] "Science Cannot Fully Describe Reality, Says Templeton Prize Winner," Science Magazine. March 16, 2009. http://www.sciencemag.org/news/2009/03/.

Chapter Four
Engineered Aesthetics: Forms of Energy in Frederick Eversley's Parabolic Lens Sculptures

Introduction: Hybrid Practice

Since the late 1960s, Frederick Eversley has explored the nature of energy transmission through his dynamic sculptural practice. As an aerospace engineer turned artist in 1967, Eversley approached sculpture from a perspective distinctly shaped by scientific and mathematical considerations of materials and forms. In this chapter, I examine the role of energy transfer in the artist's centrifugally cast polyester resin parabolic lens sculptures started between 1969 and 1970 and ongoing in 2021. To do so, I first consider how Eversley redirected materials, processes, and concepts from his career in aerospace engineering into the realm of abstract visual artwork in his earliest plastic casting experiments during the 1960s. I then analyze how the structural and material qualities of Eversley's sculptures index, activate, and allude to diverse forms of energy phenomena and interactions in his first three series of parabolic lenses created between 1969 and 1976.

This chapter focuses on how the artist technologically engineered his lens sculptures to activate multiple specific forms of physical energy as a means of generating interactive perceptual experiences for viewers of the work. Synthesizing energy concerns from the realms of both scientific engineering and artistic experimentation, Eversley's practice exemplifies a singular approach within a broader history of artistic engagements with new media and technologies during the Cold War era. While a number of initiatives from the mid 1960s and early 1970s sought to join artists with engineers for creative collaborations, Eversley embodied a unique identity as both. As I analyze, Eversley's artwork evidences a specific intersection of advanced scientific research and artistic experimentation in postwar Los Angeles. In so doing, I consider how the natural and cultural environments of Southern California contributed to Eversley's distinct position between aerospace engineering and Light and Space art in the 1960s and 1970s. By addressing the multivalent forms of energy phenomena at stake in Eversley's first three series of polyester resin parabolic lenses, I examine how the artist's sculptural process developed as a hybrid practice between technological and aesthetic considerations.

After horizontally spin-casting a range of three-color polyester resin cylinders and cut sections of cylinders starting in 1968, Eversley produced his first vertically cast polyester works with parabolic curves between 1969 and 1970. Through his extensive exploration of parabolic lenses and cut sections of the shape in the 1970s, Eversley investigated the perceptual effects afforded by the paraboloid's unique ability to reflect and refract all known forms of electromagnetic radiation and acoustic vibrations into a specific focal point. In the 1970s, Eversley created artworks ranging in a number of formal variables while retaining the centrifugally cast, polyester resin plano-concave paraboloid structure as an experimental constant. In different saturations and densities of colors, types of dyes and pigments, and degrees of transparency and opacity, the artist explored variations of paraboloids in three-layer colored, plano-concave lenses and lenses with apertures envisioned in 1969 and first cast in 1970 (figures 4.1 and 4.2).

Researching energy theories and phenomena described in fields of modern physics including Einstein's special theory of relativity, quantum mechanics, and high-energy astrophysics combined with various sources on metaphysical energy, Eversley created his series of monochrome opaque black, white, and gray lenses starting in 1973 (figures 4.3, 4.4, and 4.5). He then produced a series of transparent black lenses combining lens and mirror properties beginning in 1974 (figure 4.6). Across these sets of artworks, Eversley's sculptures activate a range of sensory phenomena including optical and acoustic effects. As lenses, mirrors, or combinations of both, the sculptures reflect, refract, and focus surrounding forms of energy including light and sound through the combined qualities of geometric shape and physical materials.

This case study closely investigates the convergence of formal simplicity and theoretical complexity in Frederick Eversley's parabolic lens sculptures. Each set of works reveals the impact of Eversley's hybrid approach to technological and artistic experimentation. As both phenomenologically engaging abstract sculptures and precisely engineered optical and acoustic devices, Eversley's parabolic lenses merge a range of aesthetic, technological, and theoretical concerns. While designing specific perceptual effects through his technologically engineered sculptures, Eversley embraces the open-endedness of his abstract artworks as ultimately providing diverse experiences and meanings to each viewer. Additionally, Eversley's sculptural process attests the overlapping roles of invention and imagination frequently characterizing experimental practices in both scientific engineering and visual art. This case study considers the artist's distinct contribution to histories of West Coast Minimalism, California Light and Space Art, and postwar artistic abstraction broadly through his interdisciplinary approach to producing sculptures activated by viewers and surrounding energies.

From Science and Technology into Art and Experience

Like many engineers in the United States during the postwar period, Eversley moved to Southern California for a career opportunity in the aerospace industry.[1] Shortly after obtaining his Bachelor of Science in electrical engineering at the Carnegie Institute of Technology in Pittsburg, Pennsylvania (now Carnegie Mellon University) in 1963, he accepted a position as Senior Project

[1] Allen J. Scott, "The Aerospace-Electronics Industrial Complex of Southern California: The Formative Years, 1940-1960," *Research Policy* 20, Issue 5 (1991), 439. https://doi.org/10.1016/0048-7333(91)90068-2.

Engineer of Instrumentation Systems at the major aerospace firm Wyle Laboratories, based in El Segundo, California. Through this role, he oversaw the design and construction of nuclear blast simulation facilities at the Naval Weapons Laboratory (now the United States Naval Surface Warfare Center) in Dahlgren, Virginia as well as high intensity acoustic and vibration test laboratories for NASA headquarters in Houston, Texas between 1963 and 1967. While residing in Southern California, Eversley took flights during the workweek to oversee the construction and operations of testing facilities in the United States and Europe through contracts with NASA as well as the European Space Agency. In domestic and international projects, the high stakes of safely designing facilities capable of simulating, withstanding, and measuring enormous amounts of energy in test explosions relied on Eversley's precise calculations regarding the nature and behavior of numerous interacting systems of physical forces. In this position, he negotiated between formulas and calculations regarding energy phenomena and the powerful physical effects these numerical descriptions represented. Additionally, building laboratories configured to produce explosive charges and high intensity pressure waves required Eversley's close consideration of the structural performance of three-dimensional geometric shapes in relation to diverse form of energy waves.

At NASA's headquarters in Houston, Eversley oversaw the design and construction the testing laboratories for the Gemini and Apollo missions between 1964 and 1967.[2] "One of the most severe environments that a spacecraft faces is extreme acoustics," Eversley explained, describing a spacecraft's launch into hypersonic speeds. Exceeding the speed of sound, or breaking the sound barrier, creates extremely loud noise, or high energy vibration, largely beyond the range of human

[2] The Gemini spacecraft, which held two astronauts, required a smaller testing facility compared to the test laboratory constructed for the Apollo, a larger spacecraft which carried three astronauts a further distance, he explained. Interview with Sharrissa Iqbal, Venice Beach, 2018.

hearing. As a specialist in high-intensity acoustic engineering, Eversley relied on parabolic reflectors to concentrate sound energy. He describes:

> I used the parabola to intensify sound for testing in spaceships, for the Apollo and Gemini programs, because we had no idea what effect acoustical energy was going to have in competing and causing the spaceships to fail during the launch. You have heat to worry about. You have solar radiation to worry about, and you have sound to worry about.[3]

In his line of work as an instrumentation systems engineer at NASA, Eversley invented methods of simulating the physical force of sonic energy involved in launching manned spaceships into outer space. The experience of concentrating powerful physical phenomena with parabolic reflectors impacted his later interest in researching the sociocultural implications of the three-dimensional paraboloidal form in advanced engineering through his artwork. Furthermore, the logic of designing and instrumenting systems in the form of energy simulations and testing laboratory environments shifted into his holistic consideration of artworks as dynamic situations between viewer, artwork, and environmental contexts.

Eversley traveled frequently from Los Angeles to jobsites throughout the country between 1963 and 1967. Within California, he commuted from Venice Beach to the Wyle Laboratories headquarters in El Segundo. While he might have initially chosen to live closer to the Wyle headquarters, Eversley like many African Americans experienced discrimination in the form of racist real estate practices upon searching for apartments in Los Angeles County. As urban studies scholars and historians including Andrea Gibbons and Josh Sides address, segregation and racism characterized the development of Los Angeles throughout the twentieth century. Los Angeles is a distinctly fragmented metropolis divided along racial lines by design. The city's characteristic sprawl attests to the establishment and reinscription of hierarchies of white privilege and wealth.

[3] Interview with Oliver Zahm, *Purple Magazine*, The Cosmos Issue #32, September 2019, accessed online, https://purple.fr/magazine/the-cosmos-issue-32/an-interview-with-fred-eversley/.

Gibbons addresses how segregation grew deeper in Los Angeles during the postwar era despite civil rights efforts to secure equal housing opportunities. While the landmark 1948 Supreme Court case *Shelley v. Kraemer* ruled racially restrictive covenants to be illegal in the United States, shifts in governmental policy did not remedy income inequalities nor prevent other unofficial forms of discriminatory real estate practices.[4] Sides examines how the suburbanization linked to the aircraft/aerospace industry in Southern California exacerbated racial inequalities during the postwar period by effectively eliminating African Americans from entering the industry.[5]

Eversley's personal history draws attention to larger institutionalized inequalities limiting African American access to careers in aerospace engineering. As the first African American engineer hired at Wyle laboratories, Eversley was turned away from nearby apartments throughout Manhattan Beach due to the color of his skin. Consequently, he arrived at the racially integrated community of Venice Beach. As he explains:

> When I first moved to California, in 1963, it was the only beach community a Black person could move to in those days. Luckily, it was filled with a lot of artists, a lot of poets, a lot of writers, a lot of musicians. There were jazz musicians and Janis Joplin. Jim Morrison was my next-door neighbor. And it was filled with an enormous amount of energy.[6]

One of innumerable overt instances of racial discrimination he has faced, Eversley's confrontation with segregationist housing practices in the early 1960s led him to discover the radiant artistic community of Venice Beach. Comprised of a mixture of remaining Beat generation artists, musicians, and poets, along with an emerging array of experimental visual artists who frequently

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[4] Andrea Gibbons, *City of Segregation: 100 Years of Struggle for Housing in Los Angeles* (London: Verso, 2018),147-151.
[5] Josh Sides, *L.A. City Limits: African American Los Angeles from the Great Depression to the Present* (Oakland: University of California Press, 2008), 86. Sides notes that North American Aviation in Inglewood is an exception to this generality, as the corporation hired more African Americans than any other.
[6] Fred Eversley in *Kerry James Marshall: A Creative Convening,* ed. Sandra Jackson-Dumont (New York: Metropolitan Museum of Art, 2018), 139.

socialized together, Eversley describes Venice Beach in the 1960s as "the perfect environment" to transition from working as an engineer to becoming an artist.[7]

Both the natural and cultural atmospheres and energies of Southern California motivated the subject matter of Eversley's artwork from the onset of his practice. After moving to Venice Beach in 1964, Eversley observed the effects of energy within the natural environment as well as its impact on those around him. The artist emphasizes the inspiration he derived from observing multiple forms of natural energy that converge at the beach. Solar energy in the forms of sunlight and heat can be readily sensed at the beach, along with kinetic energy in the form of ocean waves, wind, and the movements of beachgoers. In Eversley's words, "the beach is energy."[8] Taking interest in natural energy forms at the ocean, he also considered the positive psychological effects of observing and experiencing these phenomena. From his experiences analyzing natural and cultural energy interactions in Venice Beach as both an aerospace engineer and an artist in the 1960s, Eversley imagined creating artworks as optical technologies capable of energizing viewers through perceptual effects.

As an engineer interested in creative experimentation in the mid to late 1960s, Eversley occupied a distinct position in a cultural environment increasingly supportive of collaborations between scientists, engineers, and artists. In her essay "Launching 'Hybrid Practices' in the 1960s: on the Perils and Promise of Art and Technology," Anne Collins Goodyear analyzes the nexus of cultural factors that contributed to a notable wave of institutional support for collaborative, creative work between artists and scientists from the late 1950s into the early 1970s. After the Soviet Union launched Sputnik 1, the first human engineered satellite to orbit the earth in 1957, the United States

[7] Exhibition video, David Kordansky online exhibition *Fred Eversley: Chromospheres II*, accessed online June 2020.
[8] Eversley in *Kerry James Marshall: A Creative Convening,* 137.

government quickly prioritized regaining the nation's perceived global scientific and technological supremacy by racing to land astronauts on the Moon before the Soviet Union. At the same time, increased training for students in science and math funded by President Eisenhower's 1958 National Defense Education Act prompted a surge in coverage of scientific topics in mass media.[9]

Despite federally funded efforts to strengthen scientific education in the United States, historians including Collins Goodyear suggest that nation's public largely perceived scientific work in binary opposition to humanistic endeavors in the early 1960s. When Lyndon B. Johnson founded the National Endowment for the Arts and the National Endowment for the Humanities in 1965, the effort took shape as a means of federally funding the arts in a manner analogous to the sciences. As Collins Goodyear explains, "in a society bent upon supporting scientific study, art was seen as an antidote to the potentially inhumane tendencies of science."[10] Within this broader cultural context, artists Robert Rauschenberg and Robert Whitman coproduced a series of interdisciplinary performances entitled *9 Evenings: Theatre & Engineering* with engineers Billy Klüver and Fred Waldhauer from Bell Laboratories. Although the collaborative event was originally envisioned as part of the 1966 Stockholm Art and Technology Festival at the Swedish National Museum of Science and Technology, it was instead held in New York City at the 69th Regiment Armory in Manhattan in October 1966. *9 Evenings* featured the work of artists including John Cage, Lucinda Childs, Öyvind Fahlström, Yvonne Rainer, and others who collaborated with engineers over the prior ten months in attempts to renegotiate boundaries between artwork, technologies, and audiences. Compared to earlier initiatives including NASA's 1962 Artist's Cooperation Program, which positioned the artist as chronicler of technological achievements, *9*

[9] Anne Collins Goodyear, "Launching 'Hybrid Practices' in the 1960s," in *Hybrid Practices: Art in Collaboration with Science and Technology in the Long 1960s,* ed. David Cateforis (Oakland: University of California Press, 2019), 25.
[10] Ibid.

Evenings and the collective group Experiments in Art in Technology (E.A.T.) which grew out of the 1966 project sought to foster a more collaborative approach between artists and engineers.[11]

Between 1966 and 1967, Eversley's neighbor kinetic sculptor Charles Mattox initiated the Aesthetic Research Center (A.R.C.) in Venice Beach, inspired by his friend Rauschenberg's efforts in New York City. At the time, Eversley joined the organization as a way of helping artists solve technological challenges in their artwork. Regarding the A.R.C., Eversley explains, "The idea was to put scientists and engineers together with artists. I was very much part of the art community, I knew everybody, but I was the technologist."[12] Collaborating with artists through friendships as well as his role as a technology consultant in the A.R.C. inspired Eversley's own artistic ambitions. In 1967 he committed himself full time to his artistic practice.

An array of factors contributed to Eversley's decision to retire from engineering and pursue art full time. In the early to mid 1960s, Eversley spent spare time on weekends with neighboring artists including Larry Bell, James Turrell, Ed Moses, Robert Irwin, John McCracken, John Altoon and Charles Mattox. "As an engineer," he explains, "I would help them do little things, technical things."[13] Eversley attributes his interest in the visual and perceptual impact of transparency, reflection, pristine surface, color, and internal space to Bell and Irwin's artworks. From Mattox's mentorship, he became intrigued by the possibility of creating his own form of kinetic sculpture. Significantly, in 1967 a severe car crash left Eversley with limited mobility for one year as his leg healed. For a period after the accident, he worked remotely on the Apollo testing facility project before ultimately resigning. When he turned to artmaking from engineering, Eversley maintained a schedule of working 80 to 100 hours per week carried over from his aerospace engineering

[11] Ibid.
[12] Ibid.
[13] Greg Cook, "How Fred Eversley Went from NASA Engineer to Cosmic Artist in '60s LA," 2017.

schedule. During this period, he took up a previous interest in photography, which he had studied over several months at the Instituto Allende in San Miguel de Allende, Mexico just prior to moving to Southern California in 1963. He supported his early artistic experiments in 1967 through jobs including photographing Frank Stella's prints made at the newly opened Gemini G.E.L. (Graphic Editions Limited) workshop for reproduction in *Artforum* magazine.[14]

When Eversley first explored the artistic possibilities of polyester resin in 1967, he envisioned casting layers of the material as structural components within a larger, interactive, multimedia artwork. While designing testing laboratories at NASA, he became familiar with an industrial-grade, high-strength polyester used to encapsulate and protect electronic components, rendering them waterproof and light tight. However, unlike the opaque, high strength form of polyester resin used as protective coating on spacecraft surfaces, the transparent variety caught his attention as both a structurally useful and optically compelling artistic material.[15] Stemming from his work in photography, he imagined encapsulating photographic transparencies within flat layers of cast resin to form the surfaces of wirelessly illuminated plastic cubes. By dividing several photographic images across the sides of multiple internally glowing cubes, Eversley envisioned a matrix of possible configurations for viewers to directly manipulate and explore. He successfully encased small fluorescent lights within clear polyester resin, which he then wirelessly powered using a base constructed to emit radio waves. The lights themselves originated as electronic components designed for space travel. "I had a whole enormous box of fluorescent lights that were made for the Apollo," he recalls, "they were rejects in that they worked, but they didn't meet the

[14] Interview with Iqbal, 2018. Gemini G.E.L. had recently opened in 1966 and Eversley was friends with business partners Sidney Felsen and Stanley Grinstein who joined master printer Ken Tyler in founding the workshop.

[15] Eversley notes that polyester resin was shortly thereafter largely replaced in aerospace uses by epoxy resins, which are stronger and less toxic, Interview with Iqbal, 2018.

technical specifications that they need for space."[16] By repurposing physical materials and technical insights from fields of advanced scientific research and engineering, Eversley imagined activating artworks through the direct transmission of electromagnetic energy as well as viewer participation.

As Eversley devised a means of embedding and illuminating electronic components in plastic, he worked systematically to develop a method that would enable him to layer photographic transparencies within cast polyester resin. At the time of his earliest plastic casting experiments, he shared part of Mattox's art studio in Venice Beach. In exchange for Eversley's engineering consultation, Mattox offered him use of the studio loft and access to his tools and machinery. Along with Mattox, neighboring painter John Altoon encouraged Eversley's early artistic experiments in 1967. Observing Eversley's layered casting tests, Altoon suggested that his work in plastic was compelling on its own and did not need to be complicated by the addition of electronic and photographic elements.

Although Eversley did not immediately put aside his photographic sculpture project, he gradually shifted towards working solely with polyester resin. Using Mattox's horizontally rotating woodworking lathe, he developed a method of centrifugally casting plastic in spinning rectangular and cylindrical molds. A small experimental cast object from 1967 (figure 4.7) shows the results of Eversley's early spin-casting efforts. Using a piece of rectangular bronze tubing as a mold, he first poured and spun a small amount of transparent polyester resin mixed with blue dye, which dried along the corner edges. Once hardened, he filled the interior with green polyester resin. The resulting object, cut from a longer rectangular tube and polished, launched the artist's further exploration of horizontal spin-casting in cylindrical molds.

[16] Eversley, interview with Iqbal, 2018.

From 1968 to 1970, Eversley employed a system of horizontally spin-casting three concentric layers of transparent resin in three colors: an outer layer of violet, amber in the center, and an inner layer of blue.[17] By varying the thickness and color saturation of each layer, Eversley discovered he could produce dramatically different visual effects in these cylindrical works. Additionally, by longitudinally cutting these cylinders at various angles, he explored an even wider range of possible shapes, which he then meticulously polished by hand. After producing a range of three-inch diameter cut cylinders in this manner, including two untitled works from 1968 (figures 4.8 and 4.9), he transferred the same three-layer, three color process to an eight-inch diameter mold, resulting in larger cut cylindrical works (figures 4.10 and 4.11).

Shape, motion, time, and space closely interrelate in Eversley's spin-cast sculptures. Through his first series of cylindrical cast polyester resin sculptures, Eversley worked to create what he describes as "kinetic art without kinetic elements."[18] While attributing his interest in kinetic artwork to Mattox, who created sculptures with mechanically moving components such as *Opposing V's* from 1966 (figure 4.12), Eversley sought instead to activate his artworks through the colorful, constantly transforming reflected optical images of viewers and movements in the environment. The simultaneously transparent and reflective material of polished clear polyester resin in Eversley's cylinder sculptures provided a means of rendering the works both site specific and interactive, as the environment can be seen both through the color-tinted transparent polyester layers of each artwork as well as mirrored onto their polished surfaces.[19] Additionally, the sculptures' hollow cylindrical shape indexes the centrifugal or inertial force pushing the liquid

[17] Frederick Eversley "Statement of the Artist" in *Frederick Eversley,* Santa Barbara Museum of Art, 1976, np.
[18] Eversley, "Statement of the Artist," np.
[19] In his 1944 text *Language and Vision,* artist and theorist Gyorgy Kepes states "transparency means simultaneous perception of different spatial locations" which is useful to consider in the context of Eversley's work.

resin against the walls of the mold as the plastic hardened. In this way, the artworks' shape fixes the past movement of rotating liquid while also registering motion from the surrounding environment as reflected images appearing on the sculptures' polished surfaces.

The horizontal centrifugal casting method allows for an even, hollow, cylindrical distribution of material not attainable through other processes. For this reason, centrifugal casting (also known as spin-casting or rotational molding) has remained a predominant mode of industrially manufacturing concrete and metal pipes since World War I as well as plastic pipes beginning in the mid twentieth century.[20] The stratified layers of colors in Eversley's cylinders indicate process and timing, as the positions of the colored layers reveals the stage in which they were rotationally cast. Starting in 1968, Eversley largely maintained a system of layering three colors in three castings starting with violet, followed by amber, then blue.[21] Retaining color and layering order as constants allowed him to observe other variables, including the range of shapes possible from cutting the cylinder at different angles, the effect of adjusting timing between layers, and the amount of colored dye mixed into the transparent resin. In some works, Eversley's longitudinal cuts accentuate gradations visible between layers of color. Different angles of cuts produce distinct views of the colored layers, ranging between clean-cut strata and subtle color gradations.

Observing parabolic curves formed in a number of his horizontally cast cylinders, Eversley envisioned centrifugally casting parabolic curves by spinning drum shaped molds about the vertical axis in 1969. The same year, curator Maurice Tuchman invited Eversley to participate in the Los Angeles County Museum of Art's *Art and Technology* program as an artist. He would go on represent the only artist of color in Tuchman's program, as well as the only participant to

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[20] Roy Elliott, *Cast Iron Technology* (Oxford: Butterworth-Heinemann, 1988), 165-220.
[21]

contribute both artwork and engineering consultation for other artists in *Art and Technology*, which took place between 1967 and 1971.[22] Like many projects envisioned by artists participating in *Art and Technology,* Eversley's proposed artwork did not develop beyond the research and planning phases due to constraints in timing, funding, and overall feasibility. However, through his partnership with Ampex Corporation in Redwood City, California, Eversley considered the possibility of designing an immersive, interactive installation utilizing newly developed liquid crystal technologies. Through a tour of the Ampex optics laboratory with physicist Charles Spitzer in July 1969, Eversley learned about voltage sensitive, nematic liquid crystals used in computer memory systems as well as cholesteric crystals that change in appearance based on temperature. Following his visit, Eversley further researched the properties of liquid crystals and worked independently by choice in his Venice Beach studio to test methods of spraying the material onto different surfaces.[23]

The 1971 LACMA publication *A Report on the Art and Technology Program of the Los Angeles County Museum of Art, 1967-1971* reproduces a generous excerpt of Eversley's project proposal. As he explains, "the project will consist of performing the necessary R&D, design, construction, and image programming of a large-scale multi-color environment using liquid crystal compounds as the display medium and program controlled directional heat sources."[24] Eversley outlines potential configurations through which an interactive, environmental artwork might take physical shape as well as the technological modes of engineering the interactive system's components. Overall, he describes immersive atmospheres designed to change in color in response

[22] This exhibition has been heavily critiqued from its onset because Tuchman and team did not accept proposals but instead selectively invited artists, the majority of whom were already established on the East Coast.
[23] *A Report on the Art and Technology Program of the Los Angeles County Museum of Art,* 1967-1971 ed. Maurice Tuchman (Los Angeles: Los Angeles County Museum of Art, 1971), 101.
[24] Ibid.

to the thermal temperature of those entering the space, swept by electron beams invisibly scanning for changes in heat. “Thermal shadows of varying hues,” Eversley wrote, would arise from the spectator’s interference with the electron beam. LACMA’s catalogue entry on Eversley notes that at the time of publication, the project was still in the research phase. In an earlier stage of planning, he considered casting the viewer’s thermal shadows onto a background of preprogrammed changing colors. However, the entry notes that Eversley decided instead that “the kinetic interaction of exhibition spectators should cause the temperature variation and subsequent shifting of hues...”[25] Although the artist’s color changing LCD environment did not take physical shape, his project proposal provides a sense of the kind of spectator responsive, environmentally immersive experience Eversley imagined over the same year he planned his earliest parabolic lens sculptures.

Across both his Ampex proposal and his earliest parabolic lens sculptures designed in 1969 and first cast in 1970, Eversley sought to highlight participants’ movements in space through technologically afforded optical effects. In this way, the artist sought to draw viewers’ attention to their own roles as actants within larger environmental systems. His series of parabolic lenses cast in the 1970s reveal Eversley’s consideration of sculptural artworks as optical components within larger natural and social environmental frameworks. As lenses, Eversley’s sculptures draw viewers into the process of looking, and perhaps into a meta level of contemplating the process of looking itself. Seeing reflected images of themselves changing in relation to their movements and viewing angles, spectators take part in a feedback loop of perceptual information and subjective responses. Whereas in his Ampex proposal Eversley envisioned an electronic system capable of changing in response to a viewer’s movement within a certain space, his lenses produce changing optical

[25] Ibid.

effects as spectators apprehend the work from different viewing angles. Through his series of lens sculptures produced in the 1970s, Eversley closely considered how an individual's perception of energy phenomena through artwork might relate to historical and contemporary theories of energy transmission.

Looking at Lenses

According to the laws of thermodynamics, work is the transition of energy from a system to its surroundings. Through sculpture, Eversley has channeled his own life's work into an interdisciplinary investigation of energy transmissions between artworks, viewers, and environments. To examine the expansive concept of energy in his sculpture, Eversley embraced the open-ended parabola, an abstract curve described in geometry and observable throughout a range of natural forms, physical phenomena, and engineered technologies. Inspired by the parabola as a widely occurring energy concentrating curve, the artist has dedicated a majority of his career to create meaningful perceptual experiences of energy transmission afforded by the parabola's shape. Eversley has investigated what he sees as the nearly limitless potential of the parabolic curve through his energy activated artworks. As both phenomenologically engaging sculptures and precisely engineered objects, Eversley's parabolic lenses merge aesthetic, technological, and theoretical concerns. While he designs specific effects such as the reflection and refraction of light and sound waves, Eversley celebrates the open-endedness of the sculptures as ultimately providing different experiences and meanings to different viewers.

In 1969, Eversley realized that it would be possible to capture parabolic curves in sculptural form by spinning a cylindrical mold with liquid polyester resin about the vertical axis as the synthetic material solidified. His earliest attempts at vertically spin-casting works cast in a 24-inch diameter mold resulted in a series of three-layered, cut cross-sections of larger castings such as *Untitled (Centrifugal)* from 1970 (figure 4.13). In spin-casting and cutting three-layer works in violet, amber, and blue, Eversley continued his previous systematic exploration of centrifugally casting the same colors in the same order about the horizontal axis. Changing the directional orientation of his casting process from spinning liquid resin about the horizontal axis to instead rotating it about the vertical axis enabled Eversley to fix in place the parabolic curvature characteristic of rotating fluids.

Material, shape, and surface effects activate and index distinct physical forms of energy in Eversley's lens sculptures. As the artist discussed in his 1976 artist statement, the medium of polyester resin is a petrochemical product derived from petroleum and gas.[26] The work is, in this sense, an end product of a series of industrial processes invoked in the irreversible transformation of ancient fossil fuel energy into modern synthetic chemicals and subsequent products including plastics. Polyester resin is a specific form of plastic known as a thermosetting polymer or thermoset, which begins as a liquid or soft solid and cures or hardens through the application of heat, pressure, or a chemical catalyst.[27] The material properties of polyester resin allowed Eversley to centrifugally cast his resin sculptures into parabolic curves by spinning the material as it cured from liquid to solid. Polyester resin affords the ability to fix in place the parabolic surface curvature taken on by rotating liquids in motion. In this way, the shape of the artist's lenses physically indexes a nexus of past movement including gravitational acceleration and centrifugal force.

As plano-concave parabolic lenses sculptures, Eversley sculptures reflect and refract light, sound, and other forms of energy into a specific focal point between the object and the viewer. The

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[26] Ibid.
[27] Oliver Andrews, *Living Materials: A Sculptor's Handbook* (Berkeley: University of California Press, 1983), 131.

energy transmitting qualities afforded by the external parabolic shape of these artworks led Eversley to research an interdisciplinary range of literature surrounding the geometric, optical, and structural properties of the parabola. He took great interest in the wide range of engineered technologies utilizing paraboloid shapes, as well as the parabolic curve's occurrence throughout numerous natural physical phenomena. Owing to the parabola's physical and optical properties, the artist considered its simultaneous formal elegance as well as its widespread technological applications across disciplines.[28]

The parabola's most practical geometric property in terms of technological applications is its ability to reflect incoming electromagnetic and acoustic waves towards a single focal point when made of a reflective material (figure 4.14). By the same reflective properties, a source of light or sound located at the focus of a reflective parabolic trough or paraboloidal dish can be focused into what is known as a "collimated" (or minimally spread) beam parallel to the parabola's axis of symmetry (figure 4.15). German physicist Heinrich Hertz invented the parabolic antenna based on these principles in his discovery of radio waves in 1887.[29] Parabolic reflectors and antennae are central to the collection and projection of light, sound, and other invisible electromagnetic wavelengths in a vast array of technologies including headlights, microphones, telescopes, and satellite dishes to name only a few examples.

Eversley cast his earliest plano-concave parabolic lens sculptures including *Untitled* (figure 4.1) in three layers of three colors, arranged with violet first, amber in the center, and a final layer of blue. He cast his triple layered parabolic lenses first in 20-inch diameter molds and one year later in larger 36 to 40-inch diameter sizes. Varying the speed of these castings, Eversley

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[28] Eversley, "Statement of the Artist," in *Frederick Eversley,* 1976, np.

[29] Jacob W. M. Baars, *The Paraboloidal Reflector Antenna in Radio Astronomy and Communication* (Springer: New York, 2007), 1-2.

created works with different sized apertures and varying depths (figure 4.2). In addition to diameter size and thicknesses, other adjustable variables he experimented with in his early 1970s series of three-layer lenses include the amount of colored dye added, the amount of catalyst used, and the timing between casting layers. Through the manipulation of these factors, Eversley produced a wide range of boundary effects between colors in his lenses and cut sections of larger parabolic curves. He also created a number of thinly cut, tapered sections of three-layer parabolic lenses such as *Untitled* (figure 4.16), which are intended to physically rock back and forth if set in motion.

In three series of parabolic lens sculptures from the 1970s, Eversley explored different energy concerns by varying the surface effects and internal structure of his artworks. After creating his first three-color parabolic lenses in 1970, Eversley's continued research into solar energy led him to consider astronomical energy phenomena from the fields of physical cosmology and astrophysics. Eversley's mirror reflecting opaque monochrome lenses emerged through the artist's consideration of theoretical physics and engineering technologies. In response to his research on astronomical objects phenomena including black holes, white dwarves, and neutron stars, he produced his first monochromatic works in black, white, and gray beginning in 1973 (figures 4.3, 4.4, 4.5). Eversley then combined transparent and opaque black reflecting lenses in a series started in 1974 (figure 4.6). By combining mirror and lens effects in his transparent and opaque black lenses, Eversley considered how the scientific interconnections between space and time first postulated by Einstein could relate to a viewer's perceptual experience of energy transfer through artwork. In Eversley's monochromatic lenses, the works' shapes and mirror finishes recall the parabolic mirror's central role in the history of ground-based telescopic technologies.

Eversley's artworks draw attention to the longstanding scientific history of optical inventions designed to optimize the parabola's unique energy concentrating shape. Both Galileo and Newton recognized in theory the capabilities of parabolic mirror telescopes, Eversley points out, although neither had access to the technological means required to produce parabolic mirrors.[30] Parabolic lenses are the only single element stigmatic lenses, meaning that they converge all light to a single point. As the general aim of optical systems is to converge light rays into a single image, Eversley identifies the parabolic lens as "the perfect lens."[31] Then and now, however, spherical lenses and mirrors remain technologically simpler to manufacture than aspherical ones including parabolic lenses. Cameras, telescopes, and other optical systems frequently use several lenses arranged along the same axis in what is known as a compound lens in order to compensate for forms of distortion including spherical aberration and astigmatism. Although spherical compound lenses are more commonly utilized in optical systems, notable exceptions exist in extremely simple or advanced cameras as well as powerful telescopes. The lenses in disposable cameras are single element parabolic lenses manufactured by injecting plastic into shaped molds.[32] Eversley recalls learning about single element parabolic lens prototypes for the Hasselblad cameras modified for use by NASA astronauts during the Moon landing.[33] Optical reflecting telescopes including the 200-inch Hale telescope at Palomar observatory utilize parabolic mirrors made of cast glass "blank" lenses then ground into a parabolic curve, coated with a reflective aluminum surface, and polished over the course of several years.[34]

The engineering processes involved in casting Eversley's parabolic lens artworks relate to several methods of producing large, mirrored telescope lenses developed throughout the twentieth century. He describes reading about spinning liquid mirror telescopes and performing experiments

[30] Eversley, *Kerry James Marshall: A Creative Convening,* 140.
[31] Eversley in Minh Swenson, *Consistencies of Plastics: From Bearing Blocks to Parabolas,* 2019.
[32] Charles A. DiMarzio, *Optics for Engineers* (Boca Raton: CRC Press, 2011), 117.
[33] Eversley in Minh Swenson, *Consistencies of Plastics: From Bearing Blocks to Parabolas,* 2019.
[34] Marvin Bolt, "Glass, the Eye of Science," *International Journal of Applied Glass Science* Volume 8, issue 1, March 2017, pp. 4-22.

with rotating water in his youth. Eversley learned about the parabolic surface structure taken on by liquids in rotating vessels as well as this phenomenon's applications in astronomy through reading old issues of science magazines in his family's basement workshop in Brooklyn, New York. Influenced by his father, an aerospace engineer, and his grandfather, a photographer and inventor, he took an interest in studying physics and working with electronic technologies from an early age.[35] Around age twelve he remembers spinning a pie tin containing water on an old phonograph record player in order to observe the liquid's parabolic curve registering outward centrifugal force exerted by the mechanism's rotation. Around the same time, he read articles about liquid mirror telescopes whose concave reflecting lenses took the form of revolving pools of mercury.[36] Eversley revisited the turntable experiment two years into his artmaking career by first rotating polyester resin in a cylindrical mold on a modified potter's wheel and soon thereafter by retrofitting vintage industrial machinery to cast larger lenses.

Eversley's artworks draw attention to the longstanding scientific history of optical inventions designed to optimize the parabola's unique energy concentrating shape. Along with geometry, geometric optics is among the oldest fields in mathematics and science. In geometric optics, light propagation is described in terms of rays, abstract lines used to refer to the paths along which light travels within certain contextual parameters.[37] Parabolas are described in great detail by ancient Greek geometers including Apollonius of Perga around 200 BCE, whose definitions of conic sections are still in use today. Conic sections refer to the particular curves obtained at the intersection of a two-dimensional plane and a double cone (figure 4.17). The parabola is the conic

[35] In the late 1940s at age eight, he became a licensed amateur radio operator and communicated with individuals around the world through Morse code. Eversley in *Kerry James Marshall: A Creative Convening,* 139.
[36] "Liquid Concave Mirror for Telescopes," *Popular Mechanics,* May 1911, 626-627.
[37] Rafael G. González-Acuña, Héctor A. Chaparro-Romo and Julio C. Gutiérrez-Vega, *A Brief History of Stigmatic Lens Design* (Bristol: IOP Publishing, 2020), 1.

section derived when the plane intersects at an angle parallel to the cone's surface (figure 4.18). At other angles, hyperbolas and ellipses are formed. Apollonius extensively outlined the geometric attributes of the conic sections in eight texts covering parabolas, hyperbolas, and ellipses, of which the circle is a special case.

While Apollonius remained solely concerned with defining the properties of conic sections in geometric terms, his contemporary Diocles is credited with discovering the optical focal properties of the parabola in a mathematical text entitled *On Burning Mirrors,* where he examined the technological question of what shape of a mirror could focus the maximum amount of heat when illuminated.[38] In his proofs regarding the focal properties of parabolas, Diocles defined the parabolic curve through the relationship of equidistance, demonstrating the parabola as the set of all points in a plane which are an equal distance between a focal point and a given line, called the directrix (figure 4.19). A parabola of revolution or paraboloid, the shape attained by the revolving the parabolic curve around its axis, would produce the ideal solar heat concentrating shape in a reflective material such as brass, Diocles theorized. Rays from the sun hitting any part of the concave, mirrored shape's surface would be reflected into a single point, he explained and demonstrated mathematically.[39]

In the field of optics, lenses are defined as transmissive optical devices that focus or disperse light through the process of refraction. Due to the combined properties of plano-concave

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[38] Jan P. Hogendijk, "Diocles and the Geometry of Curved Surfaces," *Centaur* 28, vol. 3 (October 1985): 169-184, https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1600-0498.1985.tb00744.x.

[39] Paul Keyser, with John Scarborough, *The Oxford Handbook of Science and Medicine in the Classical World* (Oxford: Oxford University Press, 2018), 281. Historical accounts describe the use of burning mirrors as weapons by Greek mathematician, inventor, and engineer Archimedes. Although no evidence survives in his work, Archimedes is purported to have devised a parabolic reflector used to focus sunlight and burn ships attacking Syracuse in 212 BCE. The legend surrounding Archimedes burning mirror inspired a range of subsequent research and theoretical considerations of burning glass and mirror technologies since antiquity including the work of mathematicians during the Islamic Golden Age as well as texts by Galileo and Leonardo da Vinci.

lenses and the parabolic curve, Eversley's works reflect images of their surrounding environments onto their surfaces while also concentrating visible light and acoustic vibrations to a physical focal point in front of the lens's inward sloping surface. Eversley's lenses physically focus ambient forms of energy including light, heat, and sound from the surroundings into a point beyond the work itself and in the environmental space occupied by a viewer. An observer's image appears vertically flipped onto the sculpture's curved surface from a certain distance and mirrored from a closer perspective. Viewed through the lens, the space beyond appears saturated in color and concentrated into a smaller image on the optical element's surface. As parabolic lenses, the works produce focused, clear image of the environment beyond the be object from a fixed frontal perspective facing the work's concave side. From other positions, the lenses provide fragmentary and distorted reflections that change in relation to an observer's viewing angle.

Through transparent layers of polyester resin evenly suffused with varying degrees of color saturation, Eversley's centrifugally cast sculptures create shifting visual effects as the sculpture is viewed over time and from different angles. His cuts in some works at various angles reveal views of the work's interior structure. The sculptures refract light while also reflecting and imaging the surroundings onto their surfaces. The triple layering of parabolic curves also indexes the interaction of material subject to centrifugal force over a duration of time, repeated three times. The order and color of the layers in relation to their positions in the sculptures can in this way be viewed as a stratigraphy of the artist's process over time. Given polyester resin's liability to crack during the heat releasing exothermic curing process, Eversley's three-layer spin-cast artworks attest to his precise timing learned from the artist's extensive experiments in casting layers of colored plastic beginning in 1967 as well as his decision to take added steps and risks in order to attain the optical effects afforded by the layering of color in these works.

In his text *Living Materials: A Sculptor's Handbook,* sculptor Oliver Andrews noted the importance of timing within Eversley's technique of casting transparently colored layers of polyester resin. In a caption for a reproduced image of Eversley's three-colored, longitudinally cut cylinder *Untitled,* from 1970 (figure 4.20), he wrote, "This casting shows layers of transparently pigmented resin. Each layer must be poured at the exact moment when it will fuse with the curing layer beneath it. After the whole block has cured, it is cut and polished."[40] Andrews's description of Eversley's process supplements a detailed explanation regarding the properties and kinds of plastic, catalysts, and solvents available to sculptors by the late 1970s. As Andrews describes in his chapter on plastic, since the late 19th century, chemists have discovered ways of altering naturally occurring "building block" molecules known as monomers to produce synthetic polymers. Like natural polymers including horn, resin, and linseed oil, synthetic polymers are complexly linked molecules. Through the use of heat, pressure, and catalysts, chemists throughout the twentieth century developed synthetic polymers with molecules larger than those occurring in nature. By manipulating the molecular structure of natural elements, scientists attained a degree of control over materials through a range of durable, synthetic plastic materials designed for their "glasslike transparency," resistance to heat, or slick texture.[41]

Along with Eversley's *Untitled* layered cylinder, Andrews also illustrates the section on cast plastic by featuring an image and description of DeWain Valentine's large cast polyester resin *Concave Circles* sculptures also from 1970 (figure 4.21). After casting a large disc using mass-cast resin mixed with pigment, Valentine achieved optical clarity through grinding and polishing techniques. In the text Andrews identifies mass-cast polyester resin, "poured under highly controlled conditions" as the material pioneered by California artists during the late 1960s.

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[40] Andrews, *Living Materials: A Sculptor's Handbook*, 67.
[41] Andrews, *Living Materials: A Sculptor's Handbook*, 131.

Although the distinction between Eversley's parabolic lenses and Valentine's concave circles is not addressed in Andrews's text, both artists produced circular concave lenses in 1970 through different means. Eversley cast his layered lenses in a spinning mold, forming the plano-concave parabolic shape he then then finely polished. In comparison, Valentine cast his large *Concave Circles* in static, circular molds, which he then ground into a concave shape and polished.

In 1970, Los Angeles based artists Helen Pashgian and Robert Bassler also produced cast polyester resin lenses in static molds during their artist-in-residencies at the California Institute of Technology (Caltech).[42] In her 1978 study of five Los Angeles artists working in plastic in late 1960s and early 1970s, Gaye Ann Mueller provides a diagram illustrating the different cross sections of cast resin discs produced by Valentine, Eversley, Pashgian, Bassler, and David Elder which highlights the formal differences amongst these artist's finished cast polyester resin sculptures (figure 4.22). While these artists explored related technical concerns while casting polyester resin lenses, including avoiding cracking, fogging, and discoloration, most largely worked and exhibited independently from one another. A number of group museum and gallery shows in the late 1960s and early 1970s brought together different combinations of practitioners under the theme of contemporary artwork in plastic.

Cast polyester resin allows artists to achieve optical effects not as easily attained in glass and impossible in other sculptural materials. However, the plastic material requires a significant degree of polishing to attain the optical clarity in Eversley's finished lenses. During the exothermic casting process, the material's temperature raises to around 300-350 degrees.[43] The works then

[42] Peter Alexander was also a part of the Caltech initiative and worked together with Pashgian and Bassler, although he did not cast lenses at the time, he worked with rectilinear forms including rectangular boxes and wedges.

[43] Robert Bassler, "Lenticular Polyester Resin Sculpture: Transparency and Light," *Leonardo* 5, no. 3: (Summer, 1972), 193-198.

cool and harden, after which their surfaces appear slightly rippled and foggy rather than transparent and smooth. A laborious process of cutting, sanding, and polishing the lens sculptures constitutes around 95 percent of the work involved in creating the lens sculptures according to Eversley.[44] Through fourteen grades of increasingly fine abrasives including a polish made by the artist, the polishing stage requires hand-controlled precision in the finishing steps.[45]

Like other Los Angeles artists experimenting with cast plastic in its early stages as a commercially available product in the 1960s, Eversley's commitment to achieving reflective, refractive, and prismatic optical effects required a combination of both precise pouring techniques and labor intensive finishing processes through sanding and polishing.[46] The stylistic relationships between artists working with plastics in Los Angeles during the mid to late 1960s and into the 1970s illustrate a shared interests in producing interactive optical effects through the direct transmission of light through their artworks. At the same time, each artist's handling of material and form, as well as the particular effects they strove to achieve in their cast plastic sculpture, reveal specific and idiosyncratic artistic concerns. Eversley, Pashgian, Valentine, and Bassler each produced concave sculptural lenses based on their individual formal styles and conceptual interests in the late 1960s and into the 1970s. Eversley's casting method is unique amongst other artists also associated with California Light and Space art due to his inventive centrifugal casting process.

In a review of Eversley's early three colored lens sculptures in 1970 at Jack Glenn Gallery, *Los Angeles Times* critic William Wilson suggested that the artworks invite two main perceptual

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[44] Marilyn Holstein, "Meet the Master of the Lens," in Soho Life, November 2012, 14. Also Eversley in Cook.
[45] Howie Kahn, "Evicted From His Home, Sculptor Fred Eversley Contemplates the Future," *Wall Street Journal Magazine*, February 2019, accessed online https://www.wsj.com/articles/evicted-from-his-home-sculptor-fred-eversley-contemplates-the-future-11551276682.
[46] Rachel Rivenc, *Made in Los Angeles: Materials, Processes, and the Birth of West Coast Minimalism* (Los Angeles: Getty Conservation Institute, 2016), 18.

experiences: "you can look at them or you can look through them."[47] Looking at three color layered sculptures, he explains, one becomes immersed in continuously changing atmospheric blends of colors. Looked through, the sculptures distort the surrounding space into small images of the environment on the lens surface. Eversley's pristinely polished layered lenses, including a number with apertures or cuts, recall for Wilson in their texture and opacity "half-dissolved lifesavers or wet gumdrops." He remarks on the dazzling optical effects of reflected and refracted light visible within Eversley's polyester artworks, as well as the objects' ability to produce "pyrotechnical optical illusions" by imaging the surrounding environment on their surface.[48]

Due to what he perceives as the spectacular perceptual effects produced by Eversley's sculpture in relation to its environment, Wilson relates his work to Californian artists Robert Irwin, and James Turrell, and Larry Bell. Wilson's review usefully provides an entry point to examine the reception of Eversley's three-layer, spin-cast sculptures as objects that destabilize viewers' perceptions of the surrounding space through visual distortion and optical illusion. However, he does not mention Eversley's method of centrifugal casting or identify the works as parabolas or lenses. Without this contextual information, the works are less clearly legible as technologically engineered objects generating optical and acoustic effects. Additionally, Although Wilson initially suggests a dichotomy of either "looking at" or "looking through" Eversley's works, his description instead illustrates the blurred boundaries between the lenses' interior arrangements of color and form and the artwork's surroundings. Rather than only being looked at or looked through, the dynamic array of optical images reflecting on the surfaces and throughout the interior geometry of Eversley's three-color lenses render both forms of viewing inseparable.

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[47] William Wilson, "Eversley's Works on Display," *Los Angeles Times,* December 21, 1970.
[48] Ibid.

Observing Changes: Energy in Motion

At the intersection of formal simplicity and theoretical complexity, Eversley's lenses attest to the parabola's significance within scientific studies of motion, energy transmission, and general relativity. His spin-cast artworks from the late 1960s launched the artist's subsequent career-long investigation of the parabola as an abstract mathematical curve uniquely related to the history of physics and modern scientific energy theories. Eversley has modified, hybridized, and invented machinery to cast parabolic lenses since the late 1960s. In 1971, he retrofitted two large antique industrial turntables from 1936 in order to vertically spin-cast larger lenses a polyester resin sculpture eight feet in diameter and weighing nearly 3,000 pounds.[49] He found the rusted but otherwise salvageable equipment at a scrapyard in East Los Angeles, where a factory foreman informed him that the device had originally been used to machine the casings of early atomic bombs. By attaching a variable speed motor from a World War II submarine, Eversley modified the turntable to spin-cast his parabolic artworks from 40-inch diameters up to eight feet. The material history of this machinery attests to two radically divergent modes of harnessing energy: for destructive military warfare on one hand, and artistic experimentation on the other. Purportedly used to manufacture the casings of the atomic bombs dropped on Japan during WWII, Eversley's industrial turntable equipment recalls the interconnected histories of scientific research and weapons manufacturing in the United States during the twentieth century.

Shortly after acquiring, cleaning, and repairing his vintage large-scale industrial machinery, Eversley produced larger scale works and continued studying energy and parabolic technologies. By 1972 he began researching energy theories in both physical and metaphysical disciplines. He wrote, "a study of energy concerns naturally leads one to consider the creation of,

[49] He took on this scale work for a commission from the owners of Lenox Square mall in Atlanta, Georgia for a public sculpture in the space.

the transcendental nature of, and the eventual transformation of the universe as a whole." When Eversley shifted from casting three layered color lenses to experimenting with single layer monochromatic lenses, he produced an array of black, white, and gray works in translucent and opaque consistencies. By switching his coloring agent from transparent dye to opaque pigments mixed into polyester resin, Eversley's finished works changed from functioning as parabolic lenses to instead operating as parabolic reflectors. For Eversley, producing sculptures that function as parabolic mirrors, such as *Untitled (Black Hole),* 1974 (figure 4.3) emerged from his studies of energy phenomena on a cosmic scale. Using black, white, and gray pigment, he considered his opaque works as expressions of black holes forming from expended stars, white dwarves from suns exhausted of their nuclear fuel, and neutron stars formed from the collapsed cores of giant stars.[50]

Every viewer sees their own image reflected in Eversley's parabolic lens sculptures, however his works produced with black pigment in the early 1970s emphasize the mirroring effect of the polished paraboloids. In his earlier works produced with transparent resin and dye, the reflective effect is visible but not as heightened as an observer experiences in front of the artist's opaque and semi-transparent black sculptures. The most pronounced mirroring across the sculptor's work is in his *Untitled (Black Hole)* series of opaque black lenses. These are also uniquely self-reflective sculptures for Eversley, who created his first black lenses after considering his identity as the only artist of color associated with West Coast Minimalism in the early 1970s. Made with black pigment gifted from Eversley's friend and next-door neighbor McCracken who had been producing black planks and rectangular monoliths since the late 1960s, the works point

[50] Eversley, "Statement of the Artist," np.

to the complexities of visibility and invisibility in modern astrophysics as well as contemporary artwork and art criticism.

Although the parabola's light and heat concentrating properties have been studied since antiquity, the relationships between conic section curves and paths of motion in nature were not discovered until the work of later natural philosophers and astronomers including Galileo Galilei (1564-1642), Johannes Kepler (1571-1630), and Isaac Newton (1643-1727). By charting the movement of rolling brass spheres, Galileo first identified the parabolic path of projectiles. Kepler's laws of planetary motion updated the heliocentric model first proposed by Nicolaus Copernicus (1473-1543) by identifying the elliptical, rather than circular, path of planetary orbits around the sun. Newton synthesized Galileo and Kepler's findings regarding conic sections in terrestrial and celestial paths of motion by proposing that both are caused by the same force: gravity.[51]

Newton's account of gravity describes the phenomena as a static force that acts instantaneously throughout the universe. Although Newton provided mathematical descriptions of gravity's effects, he did not attempt to analyze their physical causes.[52] In his 1687 three-part text *Philosophiæ Naturalis Principia Mathematica*, or the *Principia*, Isaac Newton outlined his laws of motion and investigated movements within systems of physical objects. He also described the law of universal gravitation in this work, stating that every particle in the universe is attracted to every other particle in the universe with a force proportional to the product of their masses, and inversely proportional to the square of the distance between them.[53] One of Newton's arguments

[51] Lynn Gamwell, Mathematics and Art: A Cultural History (Princeton: Princeton University Press, 2016), 65.
[52] Ibid, 66.
[53] Salma Alrasheed, *Principles of Mechanics: Fundamental University Physics* (New York: Springer, 2019), 138.

in the *Principia*, often called the "bucket argument" in physics, describes the parabolic curvature of the surface of rotating water (figure 4.23). Newton explained that if a bucket containing water was hung by a string which was then tightly twisted, the vessel would spin in relation to the viewer as well as the water it contained. At the first stage of spinning, the surface of the water remains flat. As the cord unwinds, the water takes on a concave, parabolic curvature on its surface, at which point Newton explains that the water has taken on the motion of the vessel. At this stage the water is at rest relative to the bucket, as both are spinning at equal velocities. The concave parabolic curvature of the liquid's surface cannot then be explained by interactions between the vessel and the water. Newton therefore interpreted the concave parabolic shape as a measure of the bucket and water's rotation in "absolute" space.[54]

In his 1883 book *The Science of Mechanics,* physicist Ernst Mach (1838-1916) critiqued Newton's reading of the bucket experiment in an argument against absolute space, which would go on to greatly influence Albert Einstein's conceptualization of special and generality relativity. Rather than showing rotation in absolute space, Mach contended, the water's curved surface actually shows the vessel and water's relative rotation with respect to the surrounding masses of the Earth and of the fixed stars.[55] He wrote:

> Newton's experiment with the rotating vessel of water simply informs us, that the relative rotation of the water with respect to the sides of the vessel produces no noticeable centrifugal force, but that such forces are produces by its relative rotation with respect to the mass of the earth and other celestial bodies. No one is competent to say how the experiment would turn out if the sides of the vessel increased in thickness and mass till they were ultimately several leagues thick.[56]

[54] Robert DiSalle, "Newton's Philosophical Analysis of Space and Time," in *The Cambridge Companion to Newton,* ed. Rob Iliffe and George E. Smith (Cambridge: Cambridge University Press, 2016), 47. https://doi.org/10.1017/CCO9781139058568.003.
[55] Ronald Laymon, "Newton's Bucket Experiment," *Journal of the History of Philosophy* 16, no 4: (October 1978): 399-413. doi.org/10.1353/hph.2008.0681.
[56] J.R. Browne, "Why Spacetime Has a Life of Its Own," in *Space, Time and the Limits of Human Understanding* ed**.** Shyam Wuppuluri, Giancarlo Ghirardi (New York: Springer, 2016), 80.

Refuting Newton's conception of absolute space and time, Mach considered how all observable motion is relative. He points out that if the bucket was vastly greater in size, it is not evident that the same results would be obtained. Mach critiqued Newton's formulation of absolute space by drawing attention to a much larger frame of reference within which to situate the bucket experiment. Einstein articulated the hypothesis that local inertial frames are determined by the larger structure of the universe in what he named "Mach's Principle" in 1918. For Einstein, Mach's arguments prompted a consideration of how Newtonian laws of physics hold for the human scale but not in all frameworks, for example at very high speeds. In Einstein's hypotheses including the special theory of relativity formulated in 1905, he outlined a new theory of the universe wherein speed is defined relative to a viewer. He deduced from his research that the speed of light is an upper speed limit in the universe, and that as an object increases this speed, time is dilated, length is contracted, and mass increases. Mass is a dense form of energy, Einstein described in the formula $E=mc^2$, in which energy equals mass times the speed of light squared.[57]

The interrelatedness of energy, time, and mass can be experienced through the perception of energy transmission from one substance to another, Eversley expressed in his 1976 artist statement. He detailed his view that artworks that could transcend their physical parameters by producing subjective phenomenological experiences among viewers. From Einstein's special theory of relativity, Eversley analyzed what he identified as the transcendental nature of the concept of energy. "The special theory of relativity simply states that everything is energy," Eversley wrote. "In one form, energy is converted into *motion,* which provides the element *time* and thus defines any event or process."[58] In a subset of his black parabolic lenses started in 1974,

[57] Lynn Gamwell,*Exploring the Invisible: Art Science and the Spiritual* (Princeton: Princeton University Press, 2002), 197.
[58] Eversley, Statement of the Artist," np.

Eversley combined aspects of both his transparent and opaque works by creating objects that function as both a lenses and mirrors depending on the angle from which the object is illuminated (figure 4.24). For Eversley, his combined lens/mirror artworks allowed him to express what he considered a fundamental aspect of energy: its transcendental nature beyond both scientific and humanistic definitions. Producing artworks meant to heighten viewer's perception of energy transmission from one substance to another, he considered the interrelatedness of energy, time, and mass as postulated by Einstein's special theory of relativity as well as the field of quantum mechanics. As his statement reveals, Eversley's practice is inextricably linked to his ongoing consideration of energy, as well as his own artworks, from different and changing perspectives.

"The genesis of energy is central to the mystery of our existence as animate beings in an inanimate universe," Eversley articulated in his 1976 artist statement. "The most disturbing impression gained from any study of energy phenomena, in both a social and physical sense, is the present and ever growing energy shortage," he continued.[59] In his essay, published in a catalogue for the Santa Barbara Museum of Art's 1976 solo exhibition of his work, Eversley detailed the progression of his first six sculptural series alongside his interdisciplinary research on theories of energy. Situating his artistic concerns within a broader context of contemporaneous and predicted global energy shortages, including the 1970s oil crisis in the United States, Eversley also considered larger cosmological discussions regarding the formation and expenditure of high-energy astronomical phenomena in the universe including the sun. Outlining the centrality of energy transmission throughout natural and engineered processes, he emphasizes the urgency of examining "with both objectivity and humanity," potential options for contending with projected

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[59] Frederick J. Eversley, "Statement of the Artist," May 15, 1976, in *Frederick Eversley* (Santa Barbara: Santa Barbara Museum of Art, 1976), np.

exponential increases in energy usage, as well as the social and environmental impacts of prospective technological solutions.[60]

From his research on the parabola, Eversley considered how the shape might be used in harnessing renewable power through prospective technologies including space-based solar power. Identifying the sun as "the original and ultimate source of all energy on earth," Eversley explains how the physical and aesthetic dimensions of his sculptures developed as expressions of solar energy as well the concept of energy in a broader sense. By activating forms of energy through his transmissive lens sculptures, Eversley contemplated the larger frameworks of energy exchanges in the Solar System as well as the larger universe. Through his artists statements, Eversley emphasized the centrality of solar energy not only as the genesis of life on Earth, but also as the most likely long-range solution to the planet's energy crisis in the future.

Throughout his 1976 statement, Eversley analyzes energy as both a physical reality and a conceptual abstraction. He described:

> The concept of energy has a transcendental quality, both in physical and metaphysical terms. It is a reality, with a proven validity, that which transcends whatever is the popular mathematical description of the times, from its application in classical Newtonian mechanics to the currently accepted roles in the twin intellectual revolutions of Einstein's special theory of relativity and Planck's theory of quantum mechanics.[61]

Eversley's statement articulates how energy phenomena take shape through specific physical forces in his different series of spin-cast polyester resin sculptures. The statement documents Eversley's expansive approach to studying past and present theories of energy in his interdisciplinary research on the subject. Additionally, his text explains the connections Eversley considered between modern theories of energy and the subjective nature of perception. Both

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[60] Ibid.
[61] Ibid.

motion and time are central to the production and reception of Eversley's spin-cast artworks. Their material structure of Eversley's spin-cast lenses concretizes chemical and kinetic energies into perceptually engaging optical technologies. In so doing, he aims to draw attention to energy transmission as a defining feature of all natural and engineered processes shaping human existence on Earth.

As expressions of solar and kinetic energy, the artist has also embraced the possibility of metaphysical forms of energy perceived by certain viewers of his work. "I postulated that if indeed there are metaphysical energies, that it is only reasonable to assume that they follow the same laws of physics as all the known forms of energy," he explained in an interview. Although he does not identify as a particularly spiritually minded person, he has taken into consideration the experiences described by others who perceived a somewhat magical or metaphysical quality from the work.[62]

For Eversley, engaging viewers' perceptual experiences through "real energies, forces, space, time and matter," produces open-ended and unpredictable interactions between individuals and dynamic physical phenomena. Although he had not originally anticipated such a range of responses to his early sculptures, he quickly embraced what he calls a "surprise factor" inherent to the works' reception. Two observers in identical viewing contexts, with the same set of environmental factors, will experience and interpret a sculpture differently owing to their past experiences and present outlook and surroundings.[63] Each viewer, he explained in his artist statement, looks at and looks for different features. The unknowable range of potential responses to a singular sculptural object emphasized to Eversley the significance of subjective perception. In

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[62] Eversley in *Consistencies of Plastics: From Bearing Blocks to Parabolas,* Eric Minh Swenson, March 2019.

[63] "I discovered that two people looking at the same piece of sculpture, from the same angle and under the same light and environmental conditions, would perceive it somewhat differently" he wrote in his artist statement, in *Frederick Eversley,* 1976.

particular, varied reactions to the energy effects in his lenses, he wrote, "emphasized the importance of the subjective perceptual act and to me represented an illustration of the concept of the relativity of cognition as postulated by the uncertainty principle, which is one basic theorem of modern energy studies." As his essay reveals, Eversley closely considered the broader implications of individual experience through his analysis of subjective perception in relation to theories of quantum mechanics and relativity in modern physics.

An observer's motion is registered though reflected and refracted light and optical images on the surfaces of his parabolic sculptural lenses, mirrors, or combinations of both. Eversley envisions his work as a generative source of interactions between observers, artworks, and dynamic physical forces. As he articulated in his 1976 artist statement, "I am attempting to use phenomena as a means of focusing the spectator into perceiving the complex nature of reality, both physical and social, and through these perceptions forming new kinds of subjective meanings and higher awareness."[64] Joining art and technology through interactive artwork can function as a means of prompting new understandings of time and space, Eversley asserts through his artwork and writing.

The physical layers of Eversley's parabolic lens sculptures are themselves layered in historical, theoretical, and conceptual significance. Eversley's parabolic lens works actively reflect their present surroundings through a physical structure that indexes past combinations of energy interactions involved in the artworks' centrifugal casting process. Aiming to draw attention to the viewer's own subjective experience of perception over time, Eversley focused on individual perceptual experiences of energy phenomena as a site of ongoing internal negotiations between past experiences, present surroundings, and future possibilities. His artist statement details how

[64] Eversley, "Statement of the Artist," np.

individual subjective perception relates to theories of modern energy as described in quantum mechanics and Einstein's special theory of relativity, as well as how these ideas take shape in his parabolic lenses from the mid 1970s. As sites of dynamic interchange between art object, environmental forms of energy, and viewers, Eversley creates sculptures designed to spark spectators' recognition of their own perceptual responses to otherwise ambient forms of surrounding energies. By prompting viewers through interactive perceptual experiences, he envisioned "the spectator's perceptual cognition being energized by the object of art."[65] As the parabola is a shape uniquely tied to the history of scientific studies of motion as well as astronomical imaging, Eversley considered the ways in which his use of the parabolic lens and mirror technologies relate to larger historical and contemporary astrophysical discourses surrounding energy, gravity and the relativity of motion.

Conclusion: Ice Lenses, Rainbows, and Sublimation

Although his primary sculptural material is polyester resin, Eversley's process of spin-casting liquid in a rotating mold at a calculated speed is transferable across materials. With a few modifications to his polyester resin spin-casting technique, it would be possible to cast large lenses made of ice by spinning water while it freezes, Eversley has explained.[66] He once proposed the idea to the Anchorage Art Museum, whose location near continually frozen permafrost grounds would allow the sculptures to remain outdoors without melting. Rather than melting, over time the ice in the below frozen temperature would sublimate, or transition directly from a solid to a gas, bypassing the liquid stage. Eversley describes how the process of sublimation would form progressively expanding apertures starting at the center, thinnest portion of the lens. Resembling

[65] Eversley, "Statement of the Artist," np.
[66] Frederick Eversley, Interview with Sharrissa Iqbal, New York City July 2019.

a range of his polyester resin lenses with apertures in various sizes, the ice lenses would open while gradually disappearing, their water molecules transitioning into a different energy state or thermodynamic phase. Before then, however, the ice lenses could stand for several years casting rainbows on the surrounding frozen landscape while mirroring near and distant sounds.

In scientific fields including chemistry, the terms sublimation and sublime refer to a change between physical states. As art historian James Elkins describes in *Six Stories from the End of Representation: Images in Painting, Photography, Astronomy, Microscopy, Particle Physics, and Quantum Mechanics, 1980-2000,* the word sublime also carries the meaning "up to the threshold," with the prefix *-sub* meaning "up to," and *limen* meaning "lintel" or "threshold." In Elkins words, "up to it and no further: the sublime is the encounter between what can be thought and what cannot. In images it is the point where the pictures give way to what is taken to be unrepresentable."[67] In Eversley's artwork, geometric shape and material structure directly activate physical energy in surrounding environments. As Eversley has explored through his aesthetically engineered, colorful lenses in numerous formal variations, energy transcends beyond its scientific, mathematical, and linguistic descriptions. Perhaps the presently shrinking permafrost zones in Alaska and across the globe can be seen as a reminder of the urgency of harnessing renewable energy resources, as Eversley has conveyed through artworks and statements since the 1970s.

[67] James Elkins describes in *Six Stories from the End of Representation: Images in Painting, Photography, Astronomy, Microscopy, Particle Physics, and Quantum Mechanics, 1980-2000,* (Stanford: Stanford University Press, 2008), 23.

Conclusion

Historians such as Peter J. Westwick have identified the twentieth century as Southern California's "aerospace century." While aerospace engineering is now a diffuse, decentralized, and globalized industry, Los Angeles and the surrounding region developed into the world's capital of aerospace research and technology from the early 1900s into the 1980s.[1] The previous case study chapters have shown how Southern California's development into the center of advanced scientific research in astronomy, physics, and aerospace engineering beginning in the early 1900s contributed to experimental forms of abstract artwork in the region in a variety of discernable ways. At the same time, the preceding chapters indicate the extent to which the intersecting histories of scientific research and abstract artwork in Los Angeles inextricably relate to broader transnational histories of modern physics and artistic abstraction before and after World War II in ways that warrant further scholarly investigation.

This research has considered how the physical and cultural environments of Los Angeles shaped artistic engagements with scientific discoveries and technologies from the late 1920s into the Cold War period. Although the specific sets of visually abstract artworks examined in each chapter date primarily from the 1960s and 1970s, I chose to bracket my study within the larger parameters of the twentieth century for two main reasons. First, both abstract artwork and modern physics are products of twentieth century Western culture. Although scholars have drawn correlations between the emergence of abstract artwork and the popularization of scientific discoveries throughout the twentieth century in Europe and New York City, this dissertation has

[1] Peter J. Westwick, "Introduction," in *Blue Sky Metropolis: The Aerospace Century in Southern California,* ed. Westwick (San Marino: The Huntington Library Press and University of California Press, 2012), 1-3.

asked how scientific ideas and technologies converged with the history of artistic abstraction in Los Angeles. Second, by situating these studies within a century defined by advances in astronomy, atomic physics, and spaceflight, I have taken an expansive chronological approach in order to consider the long histories of both scientific research and experimental artwork in Los Angeles.

Beginning with Lundeberg's astronomical meta-imagery in her paintings from the 1930s, which reference historical modes of scientific visualization, illustration, and mechanical image production, I explored the theme of changing individual and cultural modes of observation. Lundeberg's mixture of abstraction and representation in her planet paintings, I have argued, evidences shifting cultural relationships between vision, knowledge, and imagination stimulated by technological developments during the Space Age. As this research has revealed, Lundeberg was not alone in picturing cosmic phenomena through hard-edge paintings that hovered between figuration and abstraction during this period in Los Angeles. Other contemporaneous artists including Eva Slater (1922-2011) also produced hard-edge cosmic abstractions depicting subjects including solar eclipses and Jupiter's moons through inventive approaches to painting. For decades, art historians and critics have marginalized the work of certain hard-edge painters including Lundeberg and Slater on the basis that their work ties too strongly to representational content. I argue that these artworks productively signal the wider spectrum of visual artwork between abstraction and figuration, particularly in relation to cosmic subjects. From my perspective, works like Lundeberg's planets productively draw attention to the binary opposition between abstraction and figuration as historically contingent cultural conventions themselves. Further research on cosmic themes in hard-edge painting from the Space Age may reveal additional practitioners with shared or divergent theoretical concerns in ways that can contribute to existing gaps in art historical scholarship.

In his essay "Claire Falkenstein: Exploding the Volume," art critic and curator Michael Duncan asks, "Why are the rigorously challenging, provocatively handsome works of Claire Falkenstein not better known?"[2] The same question might be asked of Brendel's artworks quietly residing in a number of museum collections and education institutions in Southern California yet largely absent from scholarly accounts of artistic abstraction in the region. As Duncan notes in Falkenstein's example, individual artistic approaches that cannot be easily pigeonholed within conventional art movements run the risk of slipping through the cracks of art historical frameworks valuing particular modes of expression over others. In hindsight, an investigation of Falkenstein's interest in mathematical set theory and Einsteinian relativity expressed through sculpture would have undoubtedly contributed to this dissertation, yet it remained beyond the scope of this project due to the practical limitation of how many case studies could be included. Both Falkenstein and Brendel's movements between Europe and the United States in the 1950s and 1960s added to their expressive modes of artistic abstraction shaped by modern physics in ways that attest to the global dimensions of visually abstract artwork produced in Southern California. Considering both artists' careers and artworks together may draw attention to larger cultural patterns of movement and migration among scientists, artists, and ideas over the twentieth century.

Each artist considered in this dissertation engaged with contemporaneous and historical scientific imagery and concepts through singular approaches. This research demonstrates that the flow of ideas from science into artwork is neither immediate nor uniform or systematic. Corse's encounter in 1968 with the Copenhagen interpretation of quantum mechanics dating from the late

[2] Michael Duncan, "Claire Falkenstein: Exploding the Volume," in *Claire Falkenstein* (Los Angeles: The Falkenstein Foundation, 2012), 13.

1920s exemplifies how certain theoretical concepts in subfields of modern physics which emerged at the start of the 1900s reverberated throughout the remainder of the century. Historians of science note that the outbreak of World War II initiated a shift towards the United States' emergence as the center of research in modern physics. As prominent scientists including Einstein emigrated from Europe to the United States to escape anti-Semitic Nazi persecution, research in atomic physics quickly became weaponized. Through my research on the history of atomic physics in the United States, I came across evidence of the deeply politicized and sexist histories of scientific research in Southern California during the interwar and postwar periods. Corse studied quantum mechanics in an introductory undergraduate physics class at the University of Southern California during a period in which the subject's philosophical paradoxes were routinely left out of physics curricula due to Cold War defense industry demands for skilled human calculators.[3] Additionally, as Caltech did not allow female undergraduates to enroll until 1970, Corse encountered the subject during a period in which gender overtly precluded many women from equal access to educational and professional opportunities in physics.[4] As women remain underrepresented in science and technology in the United States, it is important to consider the ongoing institutional and social barriers preventing individuals from exploring fields of science based on outdated gender stereotypes.[5]

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[3] As historian of science David Kaiser notes in *Quantum Legacies: Dispatches from an Uncertain World,* a shift in pedagogical approaches to the philosophical implications of quantum physics took place after World War II, as physics professors focused on the mathematical aspects of the theory in the 1950s and 1960s based on the needs of the Cold War defense industry.
[4] Amy Bix, "'What's a Nice Girl Like You Doing in a Place like Caltech?': Engineering's Institutional Masculinity and the Tensions of Coeducation," in *Where Minds and Matters Meet: Technology in California and The West,* ed Volker Janssen (San Marino: Huntington Library and University of California Press, 2012), 198.
[5] Catherine Hill et al, "Why So Few? Women in Science, Technology, Engineering, and Mathematics," (Washington D.C.: AAUW, 2010), 3.

Eversley continues to cast parabolic lens sculptures in 2021, although during the process of this dissertation research the artist was evicted from his studio on Abbot Kinney Boulevard in Venice Beach. In this instance, the landlord's refusal to renew Eversley's lease after fifty years of occupying the space as the only artist of color in the Venice Beach community associated with the Light and Space movement in my view attests to a combination of the area's extreme gentrification as well as a failure on behalf of numerous arts institutions in Los Angeles to acknowledge the cultural significance of Eversley's artistic practice over the last half-century. Although relocating his casting machinery from Los Angeles to New York City posed a number of difficulties, Eversley has continued to explore energy by casting colorful sculptural lenses. My research on Eversley's practice leads me to suspect that the ongoing afterlife of racist biases in the artworld continues to impact his career in ways that also impact other African American artists and artists of color. While recent attention has been paid to Eversley's work in exhibitions including the exhibition *Soul of A Nation: Art in the Age of Black Power* curated by art historians Zoé Whitley and Mark Godfrey, my research asks why the artist has remained marginalized in recent historical accounts of Light and Space art.[6] I have aimed not to detract from my focus on scientific ideas in Eversley's abstraction, however the racial politics underlying why his career has remained less visible than his counterparts cannot be ignored and point to the troublingly deep-rooted structural inequalities faced in the past and present by African Americans in the United States.

The artists examined in this dissertation represent a subset of practitioners both in the region and internationally who produced visually abstract artwork concerned with new descriptions of time, space, motion, and energy supplied by research findings in the fields of

[6] Eversley was added late to the *Soul of A Nation: Art in the Age of Black Power* exhibition. His work did not appear in the London version of the exhibition held at the Tate Museum, but was added to the shows at the Brooklyn Art Museum, the Broad, and the DeYoung.

astronomy, modern physics, and aerospace engineering in the twentieth century. In highlighting this selection of artists, I have aimed to examine how Lundeberg's cosmic spaces, Brendel's subatomic symbols, Corse's retroreflective surfaces, and Eversley's parabolic lenses attest to a variety of relationships between vision and knowledge as articulated through specific series of artworks. Each artist highlighted in this study pursued inventive modes of engaging viewers through particular optical effects and perceptual stimuli in their artwork. For these practitioners, visual abstraction functioned as a means of investigating relationships between materials and ideas as well as a means of shaping distinct yet open-ended visual experiences for viewers of their work.

As the paintings and sculptures examined in this dissertation colorfully convey, artistic abstraction took many forms in Los Angeles during the postwar period. Compared to Lundeberg's crisply edged, symmetrically balanced, hard-edge planet paintings, for example, Brendel's frenetic pallet knife dashes symbolizing atomic motion present alternative visual universes in terms of subject matter and style. However, both artists considered the complexities of imagining and representing scientific phenomena at the extremes of scale and beyond the range of ordinary human vision through calculated and precisely restrained means. Similarly, although Brendel, Corse, and Eversley closely studied light from the perspective of quantum physics, each derived distinct theoretical takeaways from their close scientific studies of electromagnetic radiation which they explored through unique technical procedures. My contention throughout this study has remained that examining divergent stylistic responses to shared thematic subjects might prove more revealing than remaining within the bounds of the rigidly imposed and often ill-fitting stylistic categories imposed upon California artists by previous generations of critics and art historians.

Art historical attempts to designate stylistic movements in Los Angeles based on stylistic categories originating in New York City have not produced representative accounts of the long history of artistic abstraction in the region. By considering a selection of artists across generations who worked in diverse media, this study provides an alternative approach to exploring the history of artistic abstraction not as a progressive series of formal stylistic movements but rather as an expansive field of individualistic practices at times united by shared conceptual concerns. While emphasizing the polyvocality or plurality of styles within the larger category of visually abstract artwork created in Los Angeles, a number of patterns nonetheless emerged across the previous case studies. Lundeberg, Brendel, Corse, and Eversley's artworks draw attention to historical and contemporary epistemological debates surrounding vision and knowledge in the fields of science and art.

In these chapters, I have examined abstraction as a conceptual process shared across the disciplines of science and art. Throughout the twentieth century, the highly mathematical descriptions of phenomena at the extremes of scale and velocity provided by the fields of astrophysics and quantum mechanics posed conceptual challenges to both scientists and non-specialists. The artworks examined in this study provide an entry point for future scholarly analyses considering the dynamic range of artistic responses to concepts and technologies supplied by modern physics through modes of visual abstraction. This research indicates particular avenues for continued scholarly consideration regarding the historical relationships between modern physics and visual abstraction in the artwork of additional practitioners in abstract film, painting, sculpture, and mixed media during the interwar and postwar periods in Southern California. With the support of a Pacific Standard Time research grant from the J. Paul Getty Foundation for research on art and science in Los Angeles, I will continue to expand this project into the prospective 2024 exhibition *Particles and Waves: Southern California Abstraction and Modern Physics 1945-1980* at the Laguna Art Museum.

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