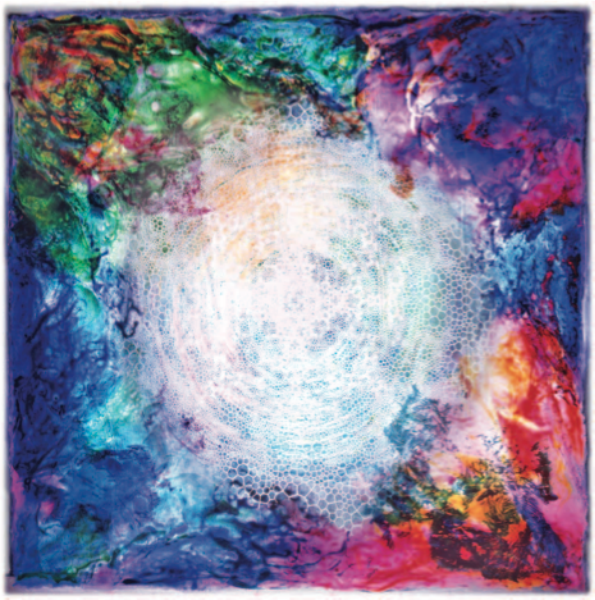

Fig. 10. *Emergence,* 119.4-cm-x-122-cm painting on Plexiglas, engraved lines with Dremel tool, 2004. (© Trudy Myrrh Reagan)

Fig. 5. *An Essential Mystery: Energy Becomes Matter,* 114.3-cm-diameter painting on Plexiglas, 1997. (© Trudy Myrrh Reagan. Photo: Richard Johns.)

Fig. 9. *An Essential Mystery: Synchrony Prevails,* 114.3-cm-diameter painting on Plexiglas, painted on both sides, 2008. (© Trudy Myrrh Reagan. Photo: Richard Johns.)

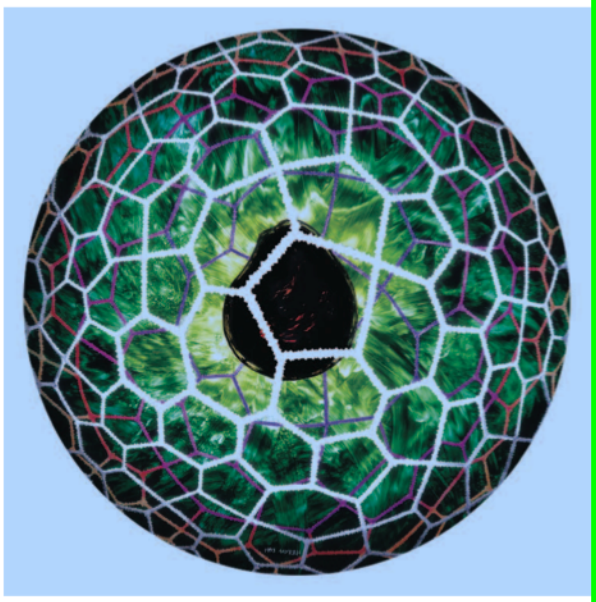

Fig. 4. *An Essential Mystery: Life Creates,* 114.3-cm-diameter painting on Plexiglas, crystals engraved with Dremel tool, 1994. (© Trudy Myrrh Reagan. Photo: Richard Johns.)

Fig. 6. *An Essential Mystery: Minds Have Wanderlust,* 114.3-cm-diameter painting on Plexiglas, "stars" incised through the paint, 2007. (© Trudy Myrrh Reagan. Photo: Richard Johns.)

Fig. 7. *An Essential Mystery: Intertwingled,* 114.3-cm-diameter painting on Plexiglas, 1997. (© Trudy Myrrh Reagan. Photo: Richard Johns.)

Can Personal Meaning Be Derived from Science?

Trudy Myrrh Reagan

ABSTRACT

The artist has derived deep personal meaning from the vast and intricate world revealed by science. Beyond unearthing facts and inspiring alluring images, this intricate world contributes to an overall context for one's life. She also acknowledges its ethic of concern for the integrity of research results.

In 1970, when I began using science material in my art, I had been married to a physicist for a decade. It became clear that he saw the world differently. He saw research as refining an overall picture of the world—investigation by continual imaginative probing. This large context extended from nanometers to millions of light years. It revealed a tantalizing space existing beyond the human ego (Fig. 1).

When my children were small, I gave a talk to my child's nursery school titled "What Is Education?" My gut feeling was that a major reference point for everything else we teach is a sense of where we are in space and time. My means were crude and inexpensive: scrapbooks in loose-leaf notebooks that we perused together. The boys became men, but I continued to pursue this vision of Where We Are, wonderfully presented in the movie *Powers of Ten* [1], illustrating the progression from subatomic particles to galactic space, and also in Robert Hone's *Seeing Time*, an interactive museum exhibit with time-lapse movies [2]. This exhibit cleverly used the analogy of a descending elevator to represent travel back in time, speeding up changes in Cape Cod's geologic features that in real time took eons. On the "top floor," the present moment, one could view slow-motion videos of instantaneous events.

In 1996 it was my privilege to arrange for Joel Primack and Nancy Abrams to speak to a forum for YLEM: Artists Using Science and Technology at the Exploratorium. Primack, a researcher in cosmology, and Abrams, who introduced cosmology into her songs, related how they and others were putting together a new creation myth for our civilization. Most human societies have them, but this one was to be based on research. According to Primack, the function of these myths is to teach each of us that we are part of a great, unfolding saga much larger than ourselves. Without this awareness, people become adrift in trivia, he averred, noting that the West has been without a generally accepted creation myth since Galileo and his dispute with the Church 500 years ago [3].

Primack and Abrams's 2006 book, *The View from the Center of the Universe,* describes cosmology in layman's language but is still rather complex for someone of my knowledge level to grasp. Moreover, since new data will continually modify the narrative, it will never be as easily learned as a Bible story.

The benefit of knowing comes not from the details, but from the wider view itself. I am distressed that education seems to neglect the overarching theme of where we are. In particular, the existence of discrete levels of matter has fascinated me for years. I first explored it in a July 1990 *Leonardo* article, "An Artist Considers Levels in Matter" [4]. In 1994, I felt it would be useful for me to paint a rough diagram of where we are in space.

The World of Small and Large

Every human should be given such a breadth of perspective from an early age. I feel fortunate to have lived in a century of scientific images and to be able to see them in my mind's eye. Most of the images I used in *The World of Small and Large* (Fig. 2) were not available until the mid-20th century, but the innovative educator Maria Montessori was teaching such a world view in 1935. She put the need more eloquently than have I:

> In school they want children to learn dry facts of reality, while their imagination is cultivated by fairy tales, concerned with a world that is certainly full of marvels, but not the world around them in which they live. On the other hand, by offering the child the story of the universe, we give him something a thousand times more infinite and mysterious to reconstruct with his imagination, a drama no fable can reveal. . . .
>
> It will create in him admiration and wonder, a feeling loftier than any interest and more satisfying. The child's mind then will no longer wander, but becomes fixed and can work. The knowledge he then acquires is organized and systematic. . . . All are linked and have their place in the universe on which his mind is centered. The stars, earth, stones, life of all kinds form a whole in relation to each other, and so close is this relation that we cannot understand a stone without some understanding of the great sun! [5]

Things we cannot readily see are more wondrous. My husband's work was with subatomic particles. I would add to Montessori's vision that cosmic rays and neutrinos are continuously penetrating our bodies and surroundings. In addition to humans' noisy broadcasts, the white noise of radio transmissions arrives from outer space. All this happens whether we have instruments to detect it or not. People call scientists materialists, yet a large part of their studies deals with invisibles, such as electromagnetic waves. Rainbows, lightning and the iridescence of birds barely hint at them.

For decades, I have endeavored to show people where they are in the universe through my art.

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See <www.mitpressjournals.org/toc/leon/47/1> for supplemental files associated with this issue.

Article Frontispiece. ***An Essential Mystery: Brains Imagine,*** **114.3-cm-diameter painting on Plexiglas, 1995. (© Trudy Myrrh Reagan. Photo: Richard Johns.)**

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Fig. 1. ***Deep Yin and Yang,*** **linoleum print, 57-cm-diameter, 1997. A knowledge of process is part of understanding the world we live in. (© Trudy Myrrh Reagan)**

METHODOLOGY

I first used the round format in a 1970 drawing, *E Pluribus Unum.* I experimented with other shapes, notably hexagons, for several years. I also used a variety of media, including the textile arts, to explore patterns in nature. But by 1991, I had returned to the round format. Sitting at my light table, moving the design around and around as I painted, was meditative, like walking a labyrinth.

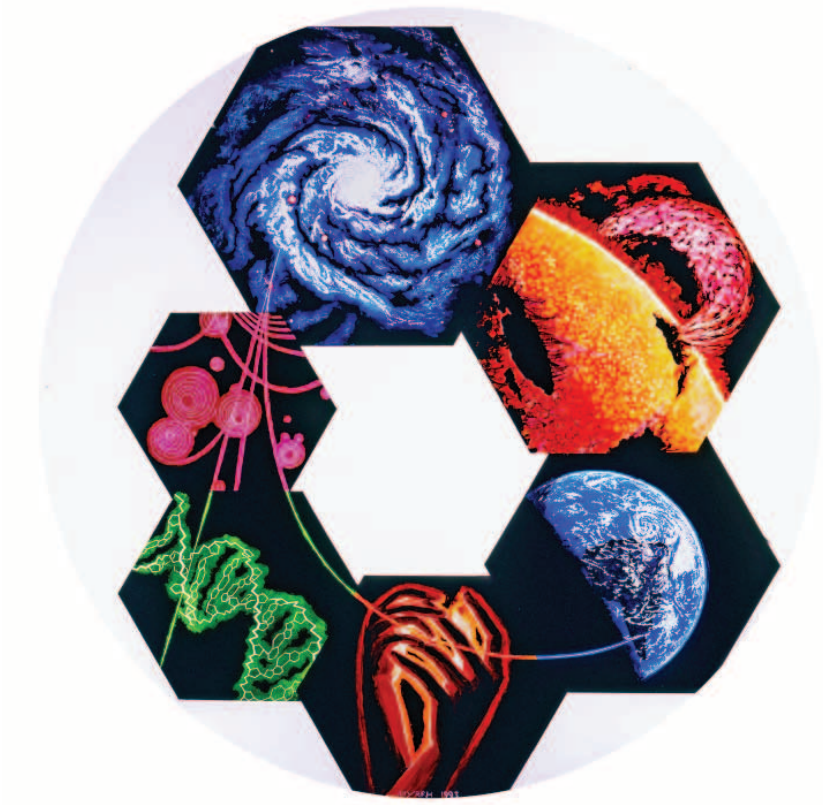
My acquaintance with digital artists made me jealous of the glowing computer screen. I found that I adored working with translucent acrylic paints on Plexiglas, because it was likewise vivid. I carved away paint to expose the "white" of Plexiglas. Carving resulted in well-defined line work hard to achieve with a brush. A further discussion of my technique is found in an earlier *Leonardo* article, "The Study of Patterns Is Profound" [6].

THE *ESSENTIAL MYSTERIES* SERIES

I spent many years enjoying all the surprising and paradoxical features of relativity and quantum mechanics. In my art, I explored patterns in nature. Under it all was a curiosity about what abides, what is always true. Traditional religious teaching purports to give us this bedrock, but I wondered whether it could be derived from the natural world. I have concluded that it can, but it is neither "stuff" nor doctrine. It is process and relationships: mathematical relationships, relations of humans one to another and our relationship with the natural world.

Additionally, I was attracted to boundary areas where not enough is known, and in some cases cannot be known, as Heisenberg decisively demonstrated in 1927 with his Uncertainty Principle. Since 1991, I have focused in my works on those questions I call "essential mysteries," those questions that eternally intrigue us and that science can never fully resolve.

Fig. 2. ***The World of Small and Large,*** **114.3-cm-diameter acrylic painting on Plexiglas (acrylic plastic sheet), 0.29 cm thick, 1993. Lines inscribed with Dremel (hand-held rotary power) tool. (In the hex on the bottom are hands of a child and its mother). This and other works in the same medium described here are lit from behind and hang in a window or are suspended in front of a brightly lit wall. (© Trudy Myrrh Reagan. Photo: Richard Johns.)**



An Essential Mystery: Number Governs Form

Beginning in 1970, I sought inspiration for my art in science images, which soon led me into an appreciation of natural patterns (Fig. 3). In 1974, Peter Stevens in *Patterns in Nature* revealed to me the mathematical underpinnings of patterns, owing to the nature of space and the process of growth. This guided my studies ("The Study of Patterns is Profound" [7]). Just as the success of an aircraft is governed as much by fluid dynamics calculations as it is by the stuff of its constituent parts, so the material world as a whole is defined by mathematical relations and probabilities. This was a revelation and a mystery to me. I learned from my husband that the correlation between abstract mental calculation and the behavior of material in the real world is often startling. Antimatter, neutrinos and black holes first turned up in mathematical calculations, later to be confirmed by experiment and observation.

By 1977, the ability to quickly model and graph mathematical ideas by computer was having an impact on what would be studied and how non-mathematical people like myself could know about it. The advent of fractals, or "the mathematics of wiggles," as Benoit Mandelbrot put it, enchanted me [8]. Complexity theory, which included fractal geometry, soon followed.

My painting *Number Governs Form* makes the point that mathematics is evident even in very common objects: amethyst crystals, the flower of a thistle. In this painting and in *Life Creates* (Fig. 4), I carved crystalline shapes into the Plexiglas. They caught the light wonderfully.

An Essential Mystery: Energy Becomes Matter

"Why is there something rather than nothing?" is one of the great questions. The mathematics of theoretical physics describes most of what we know about particles and forces that interact to make the stuff of our existence. This is the "standard model" description, which has been fabulously successful. But there is a hitch: It works only if it assumes an elusive particle, the Higgs boson, which imbues other particles with mass. It took a 27.4-km accelerator [9] to create particular, powerful energy levels required to search for it, and in 2012 researchers declared success.

Ever since Einstein published his theory of relativity, we have known that energy can become matter; this in fact created our universe. Contemplating the Big Bang (or the great Flaring Forth), I conceived *Energy Becomes Matter* (Fig. 5). I based the breaking-apart image on mud cracks. In each of my paintings, I developed a new technique. Here, I experimented with airbrush.

Fig. 3. ***An Essential Mystery: Number Governs Form,*** **114.3-cm-diameter painting on Plexiglas, crystals engraved with a Dremel tool, 1994. (© Trudy Myrrh Reagan. Photo: Richard Johns.)**

An Essential Mystery: Life Creates

Life Creates was my first painting in what I poetically named the *Essential Mysteries* series. *Life Creates* was inspired by a microscopic, single-celled animal called a radiolarian. I used a black center to suggest the living protoplasm. Around it, white lines represent the glassy exoskeleton it creates. It was spurred by a 1977 *Scientific American* article [10] on how these creatures processed silica molecules from seawater to grow their shells. "Aha!" I thought, "The creature and its lacy inorganic exoskeleton are a visual boundary between the living and the nonliving." Over the extended period in which I worked on it, I realized that there were other boundaries to explore. I made a partial list, forming the nexus of what became this series. I generally produced one or two paintings a year.

Among the mysteries in *Life Creates* are: What molecules does the organism make that attract the silica atoms dissolved in sea water? Why do they form like the lines between bubbles in a froth, a minimal surface structure? Why does only silica attach, and not calcium carbonate, from which other creatures form their shells?

A much larger question is: How did life emerge from inert matter at all? Is it a rare freak accident? Much current research explores this subject. In my stud-

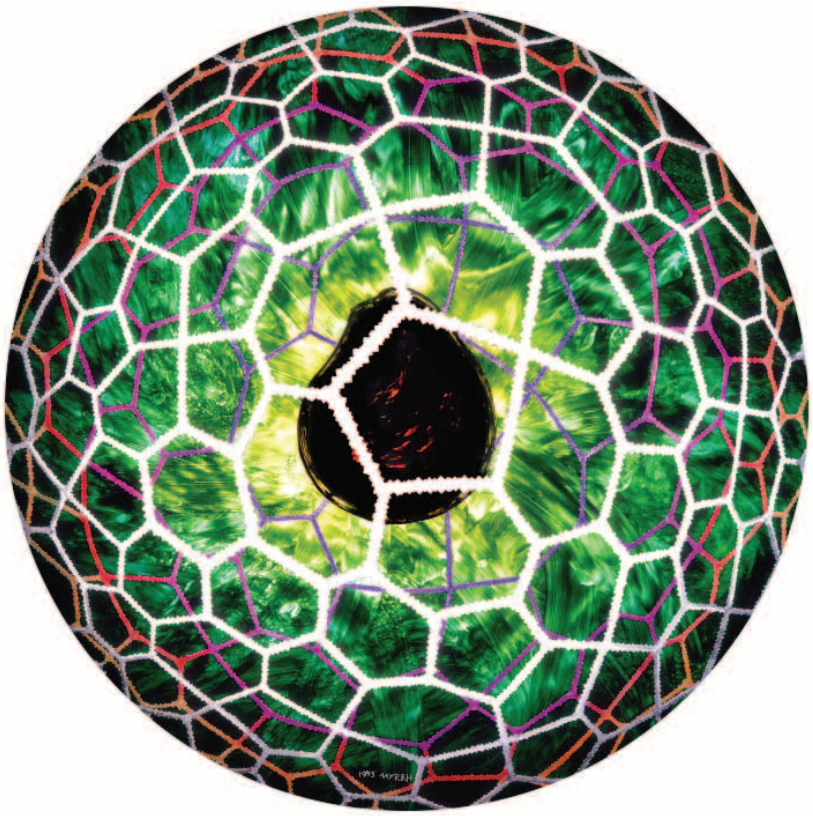


Fig. 4. ***An Essential Mystery: Life Creates,*** **114.3-cm-diameter painting on Plexiglas, crystals engraved with Dremel tool, 1994. (© Trudy Myrrh Reagan. Photo: Richard Johns.)**

Fig. 5. ***An Essential Mystery: Energy Becomes Matter,*** **114.3-cm-diameter painting on Plexiglas, 1997. (© Trudy Myrrh Reagan. Photo: Richard Johns.)**

ies I found that Stuart Kauffman, one of the architects of complexity theory, has done extensive computer modeling on the origin of life. He has executed models with a variety of organic chemical constructs (not actual chemicals) that demonstrate the ease with which novel compounds helpful to life, such as chlorophyll, could, in theory, spontaneously come together. Chlorophyll enabled photosynthesis, and this single new molecular compound changed Earth forever. There are so many more examples, Kauffman avers, that, given a large enough variety of beginning units, it is statistically inevitable that a never-before-encountered useful combination will appear. This makes evolution by natural selection much less improbable. He declares, "If life in its abundance were bound to arise, not as an incalculably improbable accident, but as an unexpected fulfillment of the natural order, then we are truly at home in the universe" [11].

An Essential Mystery: Brains Imagine

How does the assemblage of molecules and neurons result in thought and combine different ideas to make a "Eureka!" moment?

What is thinking? Even the single-celled *Dictyostelium* forms a group, which when stressed forms a slimy aggregate called a pseudoplasmodium that can slither toward new food sources. You could say that it has rudimentary volition [12]. Even colonies of the much smaller bacteria *Paenibacillus vortex* can process information, solve problems and make decisions [13].

How many steps are there from an organism that is merely motile to one that imagines? We have thinking capacity in abundance, enough to delight in thinking for its own sake. Art, storytelling, science, philosophy and mathematics are all imaginings. Where in the brain does the imagining take place?

In 1983, when I enrolled in a basic neuropsychology course, Professor Will Gordon said, "Get ready to fundamentally change how you see yourselves!" We learned a new geography, one that mapped specific locations for our many brain functions. Its discoveries were all made by inference, studying the cognitive deficits of people with brain injuries and their autopsied brains. In 1984, the first brain-imaging capability, PET scans, became available and confirmed these results. Now we use MRI scans; computer chips can even be precisely placed in the motor cortex to help the disabled.

In *Brains Imagine* (Article Frontispiece) I placed Rodin's *Thinker* in the prefrontal lobe. This is the area of the brain noted for planning and ordering activities, and for imposing values and restraint. Many functions were enumerated, but imagination was not one of them!

Yet, when I am caught in the grip of a wonderful idea such as this, imagination seems a palpable entity. Finding the classical figures that make up this image, making them equivalent in size and working this jigsaw puzzle was a protracted effort, as was painting it. Again, I invented a technique. I covered the Plexiglas with a medium tone and painted in the blacks. To obtain the highlights, I rubbed on them with toothpaste to gently erase some of the medium tone.

A rewarding aspect of *Brains Imagine* is its interaction with the imagination of the viewers. As they do double-takes, they also observe their own brains imagining.

An Essential Mystery: Minds Have Wanderlust

Humans have needed only imagination to love distant worlds. Ancient Hindus thought up ways to think about immensely large numbers [14]. With our minds and limited perception, we can encompass the world to the very edges of the extremely large and the very small.

What is different today? The Hubble telescope shows us misshapen blobs; one proto-galaxy dated 13.2 billion years ago, almost from the beginning of the universe (13.7 billion years ago) [15]. Only recently have we inferred from new data that the number of galaxies exceeds 100 billion [16].

At the other end of the scale, was it a fool's errand for researchers to look for the astoundingly numerous neutrinos, invisible particles with no charge and scarcely any mass, given off by the sun? Physicists with sophisticated detectors lodged themselves deep in mine shafts to detect them—and they succeeded! [17]

Illuminated dust around Supergiant Star V838 Monocerotis, shown as this appeared in 1990, provided the basis for *Minds Have Wanderlust* (Fig. 6). I had to follow the Hubble photograph rather exactly to capture the wonderful sweep of the fluid dynamics. However, the glowing center, the colors and the arrangement of stars are my own.

An Essential Mystery: Intertwingled

In this painting, I used the beautiful colors of alloys seen under the microscope with polarized light. When two metals, say zinc and copper, are melted

Fig. 6. *An Essential Mystery: Minds Have Wanderlust,* **114.3-cm-diameter painting on Plexiglas, "stars" incised through the paint, 2007. (© Trudy Myrrh Reagan. Photo: Richard Johns.)**

Fig. 7. *An Essential Mystery: Intertwingled,* **114.3-cm-diameter painting on Plexiglas, 1997. (© Trudy Myrrh Reagan. Photo: Richard Johns.)**

together to make an alloy, they harden, but not in an amorphous mass like dried soup. The interleaving of the metals prevents atoms from sliding easily past one another, which explains why brass is stronger than both copper and zinc separately. This can be seen through the microscope. Some alloys crystallize in a "maze" pattern, which inspired this maze of my own invention.

While developing *Intertwingled* [18] (Fig. 7) in the early 1990s, I thought about why it was speaking to me. For years, I had been helping refugees, which led me to realize how many people no longer live in the country where they were born. This leads to a fantastic mixing of many cultures. The Gaia hypothesis, developed by James Lovelock and Lynn Margulis in the 1970s, was gaining credence. This states that creatures have co-evolved with each other in ecological groups so that the waste of one becomes the food for the next [19]. Moreover, photosynthesizing microorganisms too numerous to count help create the oxygen in the global atmosphere. In this way, the smallest scale is intertwined with a very large one: that of Earth itself [20].

An Essential Mystery: Death Teems with Life

Margulis and Dorion Sagan tell us, "This is a difficult lesson: the matter of our bodies, our possession, our wealth is not ours. It belongs to Earth, the biosphere and, whether we like it or not, that is where it is headed, again and again" [21].

This is true of the brain, residence of the mind. "Apparition" is the term new media scholar Roy Ascott ascribed to his Internet art events. Even before the World Wide Web in 1991, his improvised art pieces were created by artists around the world joining together online. When all signed off, the apparition evaporated [22]. Using this as a metaphor (Fig. 8), I wonder: are the activities of our neurons a mere apparition (human cultures have resisted this notion with all their hearts), or does some residual, other than the dead coral reef of our accomplishments, persist?

An Essential Mystery: Synchrony Prevails

Interdependent processes that function almost perfectly, second by second, regulate cellular activity. In ecosystems, flora and fauna are not only attuned to each other but are engaged in a process that plays out though time, kept in harmony by feedback systems. Synchrony! (Fig. 9) [23]

Odd, but communities of gut microbes are with us from birth until death. They are tolerated by our immune system and essential for digestion and elimination [24]. This selection of flora is unique to each individual [25].

Synchrony Prevails, based on enlargements of two paper marblings I once executed, had to be carefully painted with boundaries of masking tape to make well-defined edges. To keep the two designs separated in my mind, I painted one on the top side of the Plexiglas and the other on the reverse side. Once again, I learned a new technique.

An Essential Mystery: Catastrophe!

Catastrophe! (Color Plate A) had a near-death experience. The previous painting on the plastic repelled me, and I vowed to start over. It would not be the first time I had laid a cloth over the Plexiglas, soaking it with rubbing alcohol to soften the bonds of acrylic paint in order to scrape it off. But this time, I stretched the wetted cloth out from a single point, creating ridges in it. Then, I scraped off paint selectively in the affected areas. The result suggested an explosion, upon which I elaborated.

Catastrophes such as avalanches often start with a small disturbance. As the logistics of finance, commerce and war grow ever more complex, how robust is the feedback in human systems? It is an essential mystery that catastrophes happen. Ironically, the more finely tuned and efficient, the more susceptible a system becomes to catastrophic disruption. Many of our systems are composed of a vast number of interlinked parts that may interact in totally unforeseen ways, as the 2011 tsunami damage to the nuclear reactor at Fukushima showed. This new kind of accident falls under what Yale professor Charles Perrow calls "normal accidents," in which no one person is to blame [26].

Fig. 8. ***An Essential Mystery: Death Teems with Life,*** **114.3-cm-diameter painting on Plexiglas, 2003. (© Trudy Myrrh Reagan. Photo: Richard Johns.)**

EMERGENCE

When a large variety of chemicals, genes or co-evolving species (or even human inventions!) is available, Stuart Kauffman and others declare, some will combine in a novel way, resulting in an effect that has an emergent property like that of photosynthesis. Although living organisms obey the laws of physics, they cannot be fully explained by them. Qualitatively, they constitute a new form of existence in their own right [27].

With the piece *Emergence* I discovered something new about my paints (Fig. 10). When I tried to combine colors

Fig. 9. ***An Essential Mystery: Synchrony Prevails,*** **114.3-cm-diameter painting on Plexiglas, painted on both sides, 2008. (© Trudy Myrrh Reagan. Photo: Richard Johns.)**

(say, purple on top of yellow), the paint crawled into biomorphic shapes. This painting discovery set me to contemplate emergence (I later used the technique in *Death Teems with Life)*. I developed the emergence concept by adding a lattice design, using a diagram from group theory [28].

These paintings show that I have been attracted to "emergent phenomena" at certain boundaries. When I began painting the *Essential Mysteries* series in 1992, names for these ideas were unknown to me. In fact, chaos and complexity theory were flowering just then.

So many more mysteries remain to be painted and explored. It is humbling. At this stage of my life, this is best left to others. What has drawn me onward is what Einstein observed: "The most beautiful experience we can have is the mysterious—the fundamental emotion which stands at the cradle of true art and true science" [29].

Conclusion

Research has immeasurably enlarged the grand stage upon which we spend our lives. It puts our personal stories in perspective. When we understand natural processes and why catastrophes generally happen, the world seems less inexplicable. Unsettling change surrounds us, yet knowing the universe is deeply ordered offers comfort. And it is cheering to know that within the bounds of physical laws, even organic molecules can create novelty. All of this has added meaning to my life.

I cannot end here without celebrating science—as a centuries-long group endeavor to build an honest, useful and comprehensive picture of our world—and scientists, for the humility to admit when "we just don't know." At its best, it counterbalances the dogmatism, the arrogance of power and the outright mendacity that too often rules and corrodes societies.

Appendix

The *Essential Mysteries* series was originally painted on circles of 114.3-cm-diameter Plexiglas (acrylic plastic sheet) 0.29 cm thick. Lines or crystals were inscribed through the paint, sometimes with a Dremel (small rotary power) tool. When displayed, they are lit from behind, either hung in a window or in front of a brightly lit wall. However, since backlighting posed such problems, a limited edition of smaller archival prints has been made. These are also circular but hang on the wall in the conventional manner.

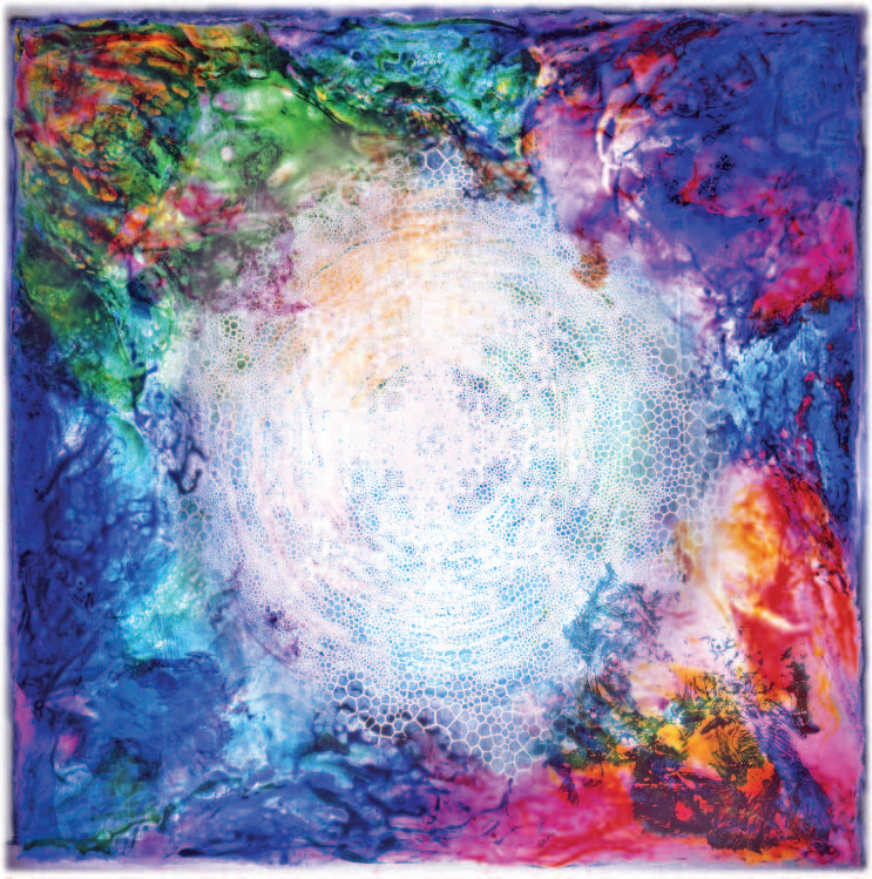


Fig. 10. ***Emergence,*** **119.4-cm-×-122-cm painting on Plexiglas, engraved lines with Dremel tool, 2004. (© Trudy Myrrh Reagan)**

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2. Robert Hone, Red Hill Studios, San Anselmo, CA. Most recently, Hone has designed two interactive iPhone apps, *Painting with Time* and *Painting with Time: Climate Change.*

3. Joel R. Primack and Nancy Ellen Abrams, *The View from the Center of the Universe: Discovering our extraordinary place in the cosmos* (New York: Riverhead Books, a division of Penguin Books, 2006). "Ours is probably the first major culture in history with no shared picture of reality" (p. 4); "The ancients took the cosmos—as they understood it—as the model for their lives and their religions" (p. 7); "We need, collectively, to become the kind of people capable of using science to uphold a globally inclusive, long-lived civilization. . . . [Otherwise we will be] reviled as ignorant, selfish and hugely destructive if we do not" (pp. 296–297).

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14. During the Vedic period (1200–900 BCE), recitations of rites invoked numbers as high as 10 to the 12th power (Wikipedia).

15. Hubble image, <www.nasa.gov/mission_pages/hubble/science/farthest-galaxy.htmlprotogalaxies>.

16. "Ask an Astrophysicist," NASA, <nasa.gov>. In 1999 the Hubble Space Telescope estimated that there were 125 billion galaxies in the universe. As instruments improve, the number grows.

17. The first experimental confirmation of neutrinos was in 1959. In 1998, the Super-Kamiokande detector in Japan was the largest to give results.

18. "Everything is Deeply Intertwingled"—computer visionary Ted Nelson. I was privileged to hear Nelson give an informal talk at The Graphics Gathering in Palo Alto in about 1983, where I heard his coinage.

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21. Margulis and Sagan [20] p. 84.

22. Roy Ascott, lecture for YLEM: Artists Using Science and Technology, 1989.

23. Fritjof Capra, *The Web of Life* (New York: Anchor Books, 1996) p. 37.

24. "Tending the Body's Microbial Garden," by Carl Zimmer, *New York Times,* 18 June 2012.

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27. Kauffman [11].

28. The diagram was sent to me by mathematics professor James Cannon of Brigham Young University.

29. From "The World As I See It," an essay included in *The World As I See It,* a collection of short pieces written by Einstein between 1922 and 1934 (NY: Citadel, 1949).

Glossary

cosmic rays—Radiation from outer space that consists of subatomic particles. We also receive solar radiation.

emergence—As Fritjof Capra explains it, "At each level, the observed phenomena exhibit properties that do not exist at lower levels. The properties of the parts can be understood only from the organization of the whole."

neutrinos—Similar to the more familiar electron, neutrinos differ crucially in that they do not carry electric charge, making them able to pass through matter with almost no interactions. This makes them excruciatingly difficult to detect. Yet they are ubiquitous.

Uncertainty Principle—The more one strives to determine an electron's position, the more one spoils possible knowledge of its velocity, and vice versa. Not simply a matter of a lack of detection apparatus, these are unknowable even in principle.

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