Quantum Sculpture: Art Inspired by the Deeper Nature of Reality

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Abstract

The author, a sculptor with a background in physics, describes sculptures he creates inspired by quantum physics. He argues that art such as the presented sculptures can indicate aspects of reality that science cannot and therefore has the potential to help liberate us from the deep impact the paradigm of classical physics continues to have on our every perception of reality.

Introduction

After receiving a physics degree in 2000 from the Free University Berlin and the University of Vienna, I moved to the U.S. and studied fine art. Science has inspired my work since my days as an art student when I began to create sculptures based on the form and function of *proteins*, the molecular building blocks of life [1]. Throughout my art studies I also retained a strong interest in the field that had most fascinated me as a scientist: quantum physics and its philosophical implications. Quantum physics is the scientific foundation of practically everything we encounter in the world, ranging from virtually every aspect of current high-technology to the miracle of life itself. Despite its overwhelming importance and its fundamental status in science, quantum theory remains philosophically extraordinarily problematic. I will begin this article by describing the challenges in attempting to create a consistent mental image of a world ruled by quantum physics. I will then briefly outline a seminal experiment at the boundary between physics and philosophy [2] and describe how this experiment, which I was fortunate to participate in as a graduate student, has had a deep influence on my art. Finally, in the main part of this article, I will present select sculptures inspired by ideas, images and experiments from quantum theory.

On Visualizing Quantum Physics

With our intuitions schooled within the paradigm of *classical physics* [3] we tend to assume that reality has definite properties, regardless of whether or not there is anyone around to observe them. This view, called "objective realism", turns out to be incompatible with quantum theory [4]. For example, there is no accurate space-time representation of, say, an electron: It is neither a particle nor a wave nor any other "thing". So when attempting to visualize concepts from quantum physics there is a danger in presenting artificially concrete representations without making sure they are correctly understood as only a facet of something more complex or as something altogether different. A well-known example of such a misunderstanding is the ubiquitous hydrogen atom model. In earlier models, now widely recognized as grossly false, electrons are displayed as particles circling the nucleus in discrete orbits. Then there are the representations of electrons as wave-functions, the orbitals pictured in physics textbooks. Even if the three-dimensional shape of the probability density is pictured correctly [5] it is still a potentially misleading abstraction because this shape merely represents *tendencies* for results of possible electron position measurements, whereas the phenomenal reality it refers to are the discrete and apparently random positions at which the electron is actually measured when an experiment is carried out. The problem is the very notion that a hydrogen atom, or any quantum "object" for that matter, is an object and has a particular appearance or properties *independent* of the means used to observe it. Consequently, it seems impossible to assign a "quantum object" any objective existence at all. And by extension, the same is true for everything material we encounter in this world.

There is always a danger of taking any image or model too literally. Using images in science or philosophy to illustrate states of affair is generally a two-edged sword because it is essential that the audience knows the limits of a picture and uses it with discrimination and intelligence. With that caution, I believe that art in general, especially after having shed the requirement to visually represent reality accurately, is uniquely capable of instilling an intuition for the deeper aspects of reality that are hidden to the naked eye. The ability of art to transcend the confines of logic and literal representation and to offer glimpses of something beyond, can help us open up to a deeper understanding of the world and to wean ourselves from the powerful grip that the world view of classical physics has had over the last centuries on our every perception of reality.

First Sculptures

For my graduate research in Anton Zeilinger's experimental physics group in Vienna [6] I participated in an experiment that successfully demonstrated quantum behavior for very large particles by sending them – as quantum mechanical matter waves – through a double-slit experiment [7]. The particles probed were C_{60} *buckminsterfullerenes*, at that time by a large margin the heaviest particles ever probed in such a setup [8]. Affectionately called *buckyballs*, these unusual molecules consist of sixty carbon atoms located at the vertices of a truncated icosahedron, the classic soccer ball. In 1999 we saw the first interference pattern, the telltale sign for quantum behavior. The only way to explain the experimental results in classical terms is to conclude that a single buckyball (or, more accurately, the entity that is later detected as a single buckyball) goes through two openings at once – two openings that are a hundred times farther apart than the diameter of one buckyball.

Buckyball sculptures (2004—2007). Inspired by Leonardo da Vinci's illustration of a truncated icosahedron for a Renaissance mathematics book [9], I created my first buckyball sculpture in 2004. I noticed that the cut-outs on each face provide the exact amount of material for another, smaller buckyball. After cutting openings into the smaller buckyball's faces, the same is true again for the next buckyball and, taking advantage of this reiterative procedure, I fabricated a succession of four buckyballs from bronze sheet. I placed the buckyballs inside each other and attached them in place by running thin rods radially through the sixty vertices (Fig. 1, left panel). It is appealing to me that the nested structure of *Quantum Buckyball* echoes the mathematical structure of the wave-function associated with the buckyball in our experiment: a spherical wave, emanating from a central source.

A sculptural object occupying a considerable volume of space while consisting of comparatively little material is an apt metaphor for the ephemeral nature of the quantum object. I started making larger buckyballs from steel consisting only of the edges, culminating in a large piece with a diameter of 30' (9 m) that was first installed in 2006. Now permanently sited in a picturesque private park in Oregon, the buckyball hovers above arm's reach over a sloped terrain with a small creek running under it. Suspended by three majestic Douglas firs that grow through the structure, the buckyball's orientation was chosen such that two opposing hexagons, one at the bottom and one on the top, are lying between the trees on horizontal planes. Color plate (d) shows a view up from below the buckyball.

The reason that such a basic shape succeeds as a piece of art is its placement within nature. Despite its considerable size, the buckyball's visual impact is quite subtle due to the relatively thin 2" (5 cm) tubing and the natural color of the corroding steel. The trees intersecting the buckyball dissolve the mathematical shape, symbolizing quantum physics' revelation that matter has no clear-cut boundary. On a more general level, the installation speaks of the dichotomy between nature and culture, symbolized by the trees and the mathematical shape respectively. Reading the sculpture and its environment this way, culture is poised between the two poles of embracing nature and caging her.

Figure 1, left panel: *Quantum Buckyball, bronze, diameter 24" (60 cm), 2004. (© Julian Voss-Andreae. Photo: Dan Kvitka.) Four buckyballs are nested inside each other, attached in place by thin rods going radially through the sixty vertices.* **Middle panel:** *Computer sketch for 'Self-Portrait on the Brink of Detection', 2009. (© Julian Voss-Andreae) The art work made after this sketch is a back-lit steel plate with 1,500 small holes. The image resembles what our retina would detect during a very short moment with only very few photons available to build up an image of what we see. At this point, the stochastic nature of reality is still visible.* **Right panel:** *Night Path (detail), painted steel and golden thread, 18" x 19" x 6" (46 cm x 48 cm x 15 cm), 2009. (© Julian Voss-Andreae. Photo: Dan Kvitka.) Held in place by a frame of dark-blue painted steel pates, golden threads fluctuate randomly around the trajectory of a falling object to meet in one point.*

Quantum Man **(2006—2007**). In quantum theory, matter is mathematically described as a wave and therefore each portion of moving matter is associated with a specific wavelength, the distance between two consecutive waves. My former group leader Anton Zeilinger once remarked jokingly that the fact that the wavelength associated with a typical walking person happens to be approximately the Planck length [10] cannot possibly be a coincidence. This comment made me think about what such a wave-function might look like and a few years later I created a series of sculptures inspired by this idea. Modeled in the shape of a stylized human walker, *Quantum Man* consists of numerous vertically oriented parallel steel slabs with constant spacing to represent the wave fronts [11] (See Color plate (a—c)). The slabs are connected with short pieces of steel. These irregularly positioned connectors between the regularly spaced slices evoke associations with stochastic events and, more concretely, with the formulation of quantum mechanics in terms of *path integrals* [12]. When approached from the front or back, the sculpture seems to consist of solid steel, but when seen from the side it visually disappears almost completely. This fascinating visual effect [13] offers a range of possible interpretations. In one such interpretation *Quantum Man* serves as a metaphor for the *wave-particle duality* – depending on the experimental question we ask, the same physical system reveals either properties of waves or of particles:

> A feeling of intangibility and the subjectivity of points of view pervades *Quantum Man*, a walking figure created from parallel slices of steel in which the particle-like concreteness seen from the front shifts to wave-like near-invisibility when the piece is viewed from the side [14].

Quantum Woman **(2008—2009).** *Quantum Man*'s slices are oriented vertically, corresponding to horizontal motion. To create a female counterpart I rotated the slices into a horizontal orientation, quantum mechanically associated with motion in the up-down direction. The initial idea was that *Quantum Woman* would symbolize a connection between earth and the heavens, as opposed to her male counterpart symbolizing involvement in the orthogonal direction, the worldly realm. I made two versions of *Quantum Woman*, both based on a traditional life-size figure I created after a live model. For the first version, later titled *Science (Quantum Woman)*, I cut 175 slices out of a virtual model of the figure and had them laser-cut from stainless steel sheet to faithfully recreate the body's shape. The relationship between the fertile, female figure and its image in the shape of a stack of cold stainless steel slabs evokes the relationship between nature and the natural sciences; a complex reality is represented as a set of simplified maps. Both versions of *Quantum Woman* have four "seams", tension elements made from bent steel rod that vertically connect all slices. Those seams divide the figure neatly into the four Cartesian quadrants, further playing off science's insistence of imposing a grid onto the world in order to make it mathematically ascertainable. For the second version I decided to lighten the materiality of the piece and to dissolve the accuracy of the outline by using fewer and thinner slabs and adding "quantum fluctuations", random oscillations to the outlines of each slice's original shape. Both versions of *Quantum Woman* are depicted in Fig. 2:

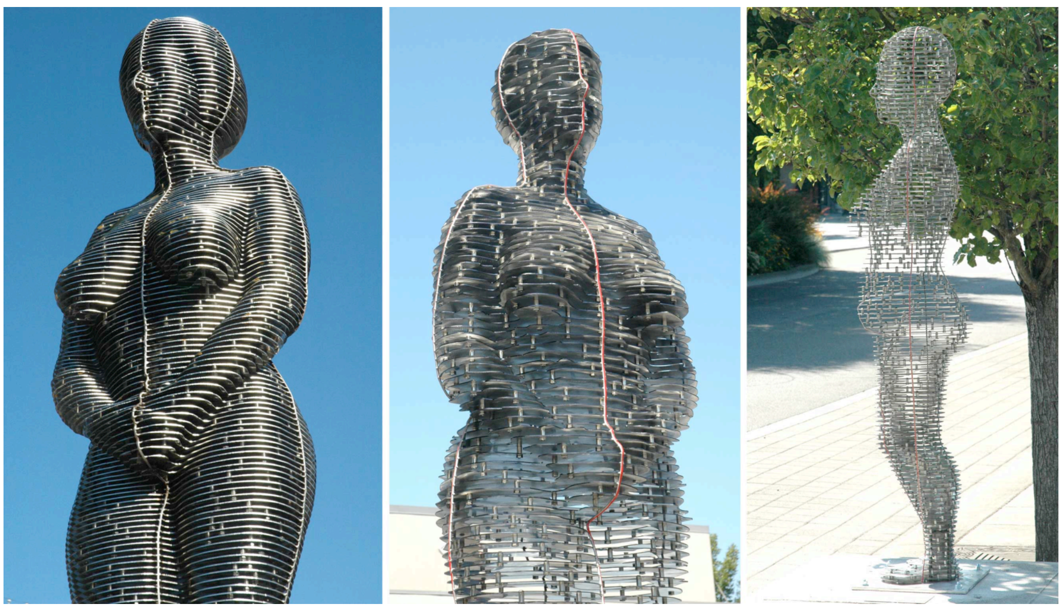


Figure 2: *left panel: Science (Quantum Woman), mirror-polished stainless steel, 69" x 19" x 16" (1.75 m x 0.50 m x 0.40 m), 2008. Middle and right panel: Quantum Woman II, stainless steel, 69" x 19" x 16" (1.75 m x 0.50 m x 0.40 m), 2009. (© Julian Voss-Andreae) The second version of Quantum Woman (middle and right panel) consists of slices that contain additional irregular fluctuations to dissolve the smooth surface that is a feature of the first version (left panel).*

The "Quantum Objects" Exhibition

When I was offered to exhibit my work at the *American Center for Physics* [15], I decided to show about thirty smaller-scale sculptures, all inspired by quantum physics. Titled "Quantum Objects" [16], the exhibition contained small versions of *Quantum Man* and *Quantum Buckyball* as well as a head study for *Quantum Woman II*. Most of the sculptures were created specifically for this exhibition, ranging from translations of quantum physical concepts that many scientists would recognize as such, to more abstracted works. Common to all pieces is a well-defined conceptual origin. The complete collection of sculptures can be viewed on my website [17].

Concerning the title of the exhibition, I should stress that the term “quantum object”, although regularly used in physics, is really an oxymoron. An “object” is something that lives completely in the paradigm of classical physics: Its reality is one that is independent of the observer, it behaves deterministically, and it has definite physical properties, such as occupying a well-defined volume in space and time. For the “quantum object” all those seemingly self-evident truths become false. As we saw in the introduction, it has a reality that is relative to the observer. In addition, the principle of causality is violated and other features of materiality, such as clear boundaries in space and time and being objectively located or even possessing identity, do not pertain.

The Well (Quantum Corral) **(2009).** One of the objects in the exhibition, *The Well*, was created by directly utilizing data from a landmark experiment performed by Mike Crommie, Chris Lutz, and Don Eigler at the IBM Almaden Research Center [18]. The researchers prepared a very clean copper surface with a few iron atoms scattered on it and used a *scanning tunneling microscope*, a device that “feels” a surface with subatomic resolution, to produce data that represent the shape of this tiny landscape. This same device was then used to push the iron atoms into a neat circle, termed “quantum corral”, after which the surface was scanned again. The single iron atoms show up as peaks and the experiment reveals the concentric circles of a standing matter wave inside the corral, analogous to the standing sound waves in musical instruments. This is a rare example of directly visualizing quantum mechanical matter waves [19].

The researchers kindly provided their experimental data which I then converted into code that was used to mill the shape out of a block of wood. In order to see the peaks and waves, the height of the contour had to be greatly exaggerated compared to its width and depth [20]. After milling, the object was traditionally gilded with gold leaf (Color plate (e)). My motivation for making such an object goes beyond showcasing the data which is fascinating in itself. I want to evoke a sense of wonder in the audience and convey the feeling of witnessing something extraordinary. Philip Ball writes about *The Well* in his review of the “Quantum Objects” exhibition in the journal *Nature*:

> The gilded surface reminds physicists that it is the mobility of surface electrons in the metal which accounts for its reflectivity (and the coloration of gold is itself a relativistic effect of the metal’s massive nuclei). But for art historians, this gilding not only invokes the crown-like haloes of medieval altarpieces but could also allude to the way gold was reserved in the Renaissance for the intangible: the other-worldly light of heaven. [21]

Night Path **(2009).** *Night Path* was inspired by Richard Feynman’s *path integral* approach to quantum mechanics. Feynman calculated quantum mechanical probabilities by adding up all possible paths between a start point and an end point. This quantum mechanical concept of a *path* only makes sense as long as it cannot be observed [22]; it is really a tendency for a path and not an actual path. Feynman handled the continuum of paths mathematically by dividing time into “slices” and filling each slice with a continuum of path points. When this approach is modeled on the computer, only some random paths in the neighborhood of the classical trajectory are calculated since they contribute most to the result [23]. Guided by this image, I started with a parabola, the classical trajectory of a falling object, and computer-generated a distribution of random paths around it. The paths get successively closer to the parabola and eventually merge into one point (Fig. 2, right panel). The image of a point expanding into a curved, fuzzy tail resembles historical depictions of comets. I wanted to connect the idea of the quantum mechanical path to the image of this celestial body that is often portrayed in art and literature as portending important events.

Spin Family (Bosons and Fermions) **(2009).** *Spin Family* playfully equates the two fundamental kinds of matter in the universe, bosons and fermions, with the two human genders, female and male. Due to their difference in a quantum physical property called *spin*, bosons tend to attract each other whereas fermions have a tendency to stay isolated. *Spin Family* is a series of five objects displaying the three-dimensional structure of the spin essentially as it follows from the rules of quantum mechanics. A continuous silk thread representing the spin is woven in and out of circular metal frames expanding the single, well-defined direction of the spin in classical physics into quantum physics' continuum of possibilities, giving a diaphanous quality to the overall forms (Color plate (g)).

Self-Portrait on the Brink of Detection **(2009).** Unable to perceive the world on the quantum level without sophisticated technology, our intuition about the nature of reality is shaped by the comparative crudeness of our unaided senses. If we, for example, observe an apple falling from a tree, we naturally assume that the apple has an identity and is one and the same thing before, during, and after the fall. Quantum physics, however, teaches us that there is no real continuity of "objects" around us. The image we perceive as "the apple" is actually the rapid accumulation of an astronomical number of single, indivisible quanta of experience, or *events*. These quanta of experience are individual little flashes of light that our brain automatically connects into familiar objects that then appear to us as constant. *Self-Portrait* imagines this process of experiencing slowed down and captures the moment where the successive accumulation of events has just lead to a first recognition of the familiar. I created an image made up of events represented by small holes in a backlit steel plate. To that end I wrote a computer program that transforms an image, in this case a photograph of my face, into a distribution of spots. The lighter a particular area of the image is, the higher the density of random spots, or "events", the algorithm generates in this area. Fig. 1 (middle panel) shows the program's output used to create the piece on display, a free-standing darkened steel sheet with 1,500 small holes. Lit from the back, the holes resemble shimmering stars on the night sky.

The Universe (The Cellular Structure of Space-Time) **(2009).** It is often believed that space-time itself is made up of smallest indivisible units, analogous to the quanta of experience or the atoms of matter that reveal themselves to us only with sufficient magnification. But how would those presumed quanta of space-time be arranged? *The Universe* portrays the cells of space-time as arranged in an organic fashion, namely as cells in a foam, the ubiquitous natural system that is comprised of irregularly shaped polyhedral bubbles with, nevertheless, well-defined properties. To make this piece, I created an artificial foam by squeezing water-filled balloons, the foam's bubbles, into a spherical mold and filling the gaps in between the balloons with hot wax. After the wax had hardened, I popped the balloons to produce an open network of polyhedral cells with rounded edges. I cast the structure in bronze, gold-plated the interior and applied a dark patina to the exterior (Color plate (f)).

Conclusion

The simultaneous advent of quantum physics in the sciences and the rise of modernism in the arts in the early twentieth century marks a profound shift in the cultural evolution of humankind. The uneasiness many of us experience when dealing with either illustrates how little we have grappled yet with the consequences of this paradigm shift. The sculptural work presented in this article aims at exploring the character of this shift by transforming ideas that emerged in the isolated intellectual realm of quantum physics into art that evokes a sensual experience. My hope is that my work will help to lift those ideas into the sphere of our collective consciousness and aid us in intuiting the unfathomable deeper nature of reality.

Acknowledgements

I would like to express my thanks to the following people: Sarah Tanguy invited me to show new sculptural works at the American Center for Physics which resulted in the “Quantum Objects” exhibition; Philip Ball asked me tough questions for his review in “Nature” which forced me to think more deeply about the topic; I had many discussions with George Weissmann about quantum physics and the implications it has on our world view and I am especially indebted to him for his central contributions to this manuscript. I am also very thankful to all the people who read the manuscript and gave me valuable feedback: Leo Gross, Jack R. Leibowitz, Michael May, Arthur I. Miller, and Kenneth Snelson as well as the six anonymous reviewers from *Leonardo* and the *Bridges 2010* conference. They all provided excellent comments which benefitted the paper greatly. And last, but by no means least, I would like to thank my wife Adriana for always inspiring me, carefully reading and editing this manuscript and, most importantly, her love.

References and Notes

[1] J. Voss-Andreae, “Protein Sculptures: Life’s Building Blocks Inspire Art,” *Leonardo* **38** 1 (2005) pp. 41–45.

[2] M. Arndt, O. Nairz, J. Voss-Andreae, C. Keller, G. van der Zouw and A. Zeilinger, “Wave-Particle Duality of C_{60} Molecules,” *Nature* **401** (1999) pp. 680–682.

[3] “Classical physics” refers to the physics before the 20th century advent of quantum physics.

[4] See A. Einstein, B. Podolsky, and N. Rosen, “Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?”, *Phys. Rev.* **47** (1935) pp. 777–780 and Bohr’s reply with the same title (but a different implied answer): N. Bohr, “Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?”, *Phys. Rev.* **48** (1935) pp. 696–702.

[5] These models often contain an additional imprecision in that they illustrate only the angular dependence of the wave-function without including the radial one. I am sure many if not most scientists would draw these spherical harmonics if asked to depict ‘what a hydrogen atom looks like’.

[6] Anton Zeilinger’s group homepage: <www.quantum.at/zeilinger>.

[7] The double-slit experiment is a beautifully simple experimental setup that consists of a beam of particles or light that is sent through two neighboring openings, the slits. The detected pattern behind the slits (“interference pattern”) reveals whether or not the beam has traveled as a wave and passed through both openings at once.

[8] Our experiment was technically not a double-slit experiment since we used a grating with more than two slits. But the difference is not significant because the wave-function of one buckyball extends coherently only over about two slits in width.

[9] Luca Pacioli. “De Divina Proportione” (Venice: 1509).

[10] A very small distance (1.6 x 10^{-35} m) that is thought to be of fundamental meaning in physics.

[11] “Dual Nature,” *Science* **313** (2006) p. 913; see <www.JulianVossAndreae.com/Artist/resume/images/2006_08_18_Science.pdf>.

[12] Richard Feynman’s path integral formalism is a tool for calculating quantum mechanical probabilities by adding up all possible paths (“sum over histories”). This is done by “slicing up time” to parameterize arbitrary paths. The slabs suggest the time slices and the irregularly placed rods the random path points. See also the description of Night Path (2009) in the last section.

[13] For footage of the sculpture displaying this effect see V. Patton, “Quantum Sculptures with Julian Voss-Andreae,” Oregon Art Beat (Oregon Public Broadcasting TV) Episode 1012 (2008); see <www.youtube.com/watch?v=LqsQYVFAgPo>.

[14] P. Ball, “Quantum objects on show,” *Nature* **462** (2009) p. 416; see <www.JulianVossAndreae.com/Artist/resume/articles/2009_11_26_Nature.pdf>.

[15] <www.acp.org>.

[16] “Quantum Objects” was part of the three-person exhibition “Worlds Within Worlds” (Fall 2009–Spring 2010).

[17] See <www.JulianVossAndreae.com> under “Work” and “Archive”.

[18] M. F. Crommie, C. Lutz and D. Eigler, “Confinement of Electrons to Quantum Corrals on a Metal Surface,” *Science* **262** (1993) pp. 218–220. This experiment is also featured in D. S. Goodsell, “Fact and Fantasy in Nanotech Imagery,” *Leonardo* **42** 1 (2009) pp. 52—57 and C. Toumey, “Truth and Beauty at the Nanoscale,” *Leonardo* **42** 2 (2009) pp. 151—155.

[19] What is imaged in this experiment is essentially the square of the surface state electrons’ wave-function.

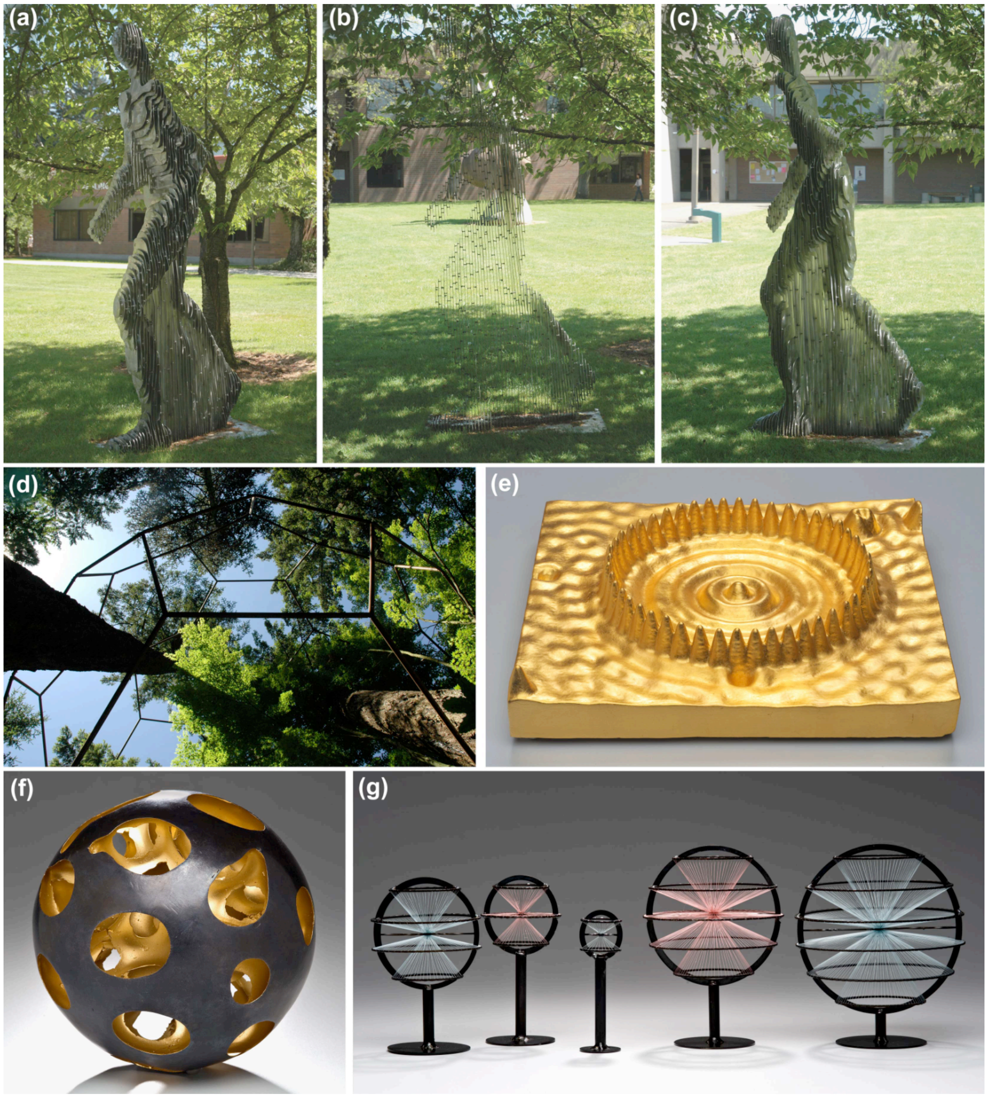
[20] The same had been done to prepare all the published images of the quantum corral including the images in the original publication M. F. Crommie et al. [18].

[21] P. Ball [14]

[22] “Cannot be observed” in this context does not mean “when nobody looks”, but rather that an observation is in principle impossible because there is no physical carrier of information (e.g. a photon that could get detected by an observer’s eye).

[23] For a more detailed discussion about the relationship between Night Path and the physics that inspired it, see [14] and the Q&A section in Philip Ball’s blog “homunculus” <www.philipball.blogspot.com/2009/11/quantum-objects.html>.

Color Plate



Color plate: *(a–c) Quantum Man, stainless steel, 100" x 44" x 20" (2.50 m x 1.10 m x 0.50 m), 2007. (© Julian Voss-Andreae) The images show three views of the same sculpture, located at the Maryhill Museum of Art in Goldendale (Wash.). (d) Quantum Reality (Large Buckyball around Trees) (view from below), steel and trees, diameter of the steel structure 30' (9 m), 2007. (© Julian Voss-Andreae) Located in a park-like setting in Portland (Ore.), a 30' (9 m) diameter buckyball is suspended in the air by large Douglas firs intersecting with the buckyball. (e) The Well (Quantum Corral), gilded wood, 3" x 13" x 12" (6 cm x 34 cm x 31 cm), 2009. (© Julian Voss-Andreae. Photo: Dan Kvitka.) Original experimental data were used to turn a man-made subatomic "quantum landscape" into an art piece. (f) The Universe (The Cellular Structure of Space-Time), bronze, diameter 8" (20 cm), 2009. (© Julian Voss-Andreae. Photo: Dan Kvitka.) An irregular network of golden cells conspires to make up a regular sphere. Could this be the way the smallest units of space-time arrange themselves to make up the universe? (g) Spin Family (Bosons and Fermions), steel and colored silk, largest object 7" x 6" x 6" (18 cm x 15 cm x 15 cm), 2009. (© Julian Voss-Andreae. Photo: Dan Kvitka.) A continuous silk thread representing quantum mechanical spin is woven in and out of circular metal frames. The 'bosons' in pink portray the 'female' members and the 'fermions' in light blue the 'male' members of a family.*