

The Center is Everywhere

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Abstract

The Center is Everywhere is a sculpture by Josiah McElheny, currently (through October 14, 2012) on exhibit at the Institute of Contemporary Art, Boston. The sculpture is based on data from the Sloan Digital Sky Survey (SDSS), using hundreds of glass crystals and lamps suspended from brass rods to represent the three-dimensional structure mapped by the SDSS through one of its 2000+ spectroscopic plugplates. This article describes the scientific ideas behind this sculpture, emphasizing the principle of the statistical homogeneity of cosmic structure in the presence of local complexity. The title of the sculpture is inspired by the work of the French revolutionary Louis Auguste Blanqui, whose 1872 book *L'Éternité par les astres: Hypothèse astronomique* was the first to raise the spectre of the infinite replicas expected in an infinite, statistically homogeneous universe. Puzzles of infinities, probabilities, and replicas continue to haunt modern fiction and contemporary discussions of inflationary cosmology.

1 A Principle, A Map, A Sculpture

As beings bound to a small planet orbiting an unexceptional star in the outskirts of a galaxy that is one among trillions, how can we hope to understand the universe? Astronomers approach this problem by drawing on two key ideas. The first is the Cosmological Principle, an infinite extrapolation of the Copernican discovery that displaced the earth from its special location at the center of everything. In technical terms, the Cosmological Principle states that the universe on large scales is homogeneous and isotropic: it has no preferred places and no preferred directions. If the Cosmological Principle holds, then the same laws of physics apply everywhere, and when we observe a region of the universe large enough to be statistically representative we can extrapolate its properties to the rest of the cosmos. The second idea is the finite speed of light. When we observe a distant object, we see it as it was when the light left it. This fact turns telescopes into time machines — from our vantage point in the present, we can peer back into cosmic history. Josiah McElheny's sculpture *The Center is Everywhere* is based on observations from the Sloan Digital Sky Survey (SDSS), which has created the largest ever maps of the distant universe.¹

In detail, the Cosmological Principle is manifestly wrong. It is different to look up than to look down, different to look to the center of the Milky Way galaxy than to look outward from our

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¹From this planet, anyway.

location in its stellar disk, different to look at nearby galaxies like the Magellanic Clouds or the Andromeda Nebula than to look elsewhere in the sky. But when we use telescopes to reach far beyond our local neighborhood, the Cosmological Principle holds remarkably well. While stars are collected in galaxies and galaxies themselves cluster in groups and filaments interweaved with tunnels of emptiness, the average properties of galaxies and clusters and filaments are similar in different regions of the universe. Furthermore, when we observe the most distant source of “light” that we can see, a background of microwaves that has been traveling freely since the universe became transparent 300,000 years after the Big Bang, we see that it is astonishingly smooth, implying that the distribution of matter at that time was uniform to within a tiny fraction of a percent. Gravity has since amplified primordial fluctuations, the tiny imperfections of that infant universe, into galaxies and larger structures, but the fluctuations themselves were random, so every place in the universe initially had the same chance to become “interesting” or “boring.”

Over the past decade and a half, the SDSS has used a dedicated telescope at Apache Point Observatory in New Mexico to obtain digital images over 1/4 of the sky and to map the 3-dimensional distribution of more than 2 million galaxies, 1 million stars, and 200,000 quasars. The stars are all members of the Milky Way at distances of hundreds or thousands of light years; their separation in time from us is less than a cosmic eyeblink. The galaxies, each a collection of tens or hundreds of billions of stars, span a wide range of distances, from thousands of light years to billions of light years. Quasars are the most luminous objects in the universe, powered by hot gas falling onto supermassive black holes, so they can be seen to very large distances. The most distant quasars discovered by the SDSS have lookback times of more than 13 billion years, and the light we detect left them less than a billion years after the Big Bang.

To map millions of galaxies, the SDSS observes them using “fiber plugplates,” each an aluminum disk 33” in diameter drilled with 640 holes at the locations of objects selected for observation from the digital images. Each hole is plugged with an optical fiber, and all 640 fibers are fed back into spectrographs riding on the back of the telescope, which disperse the light into its constituent colors and allow astronomers to infer the properties and distance of each object from subtle patterns of dark and bright lines, which are produced when atoms absorb and emit light at particular wavelengths. *The Center is Everywhere* utilizes a reproduction of one of the SDSS plugplates, number 1945, replacing each optical fiber with a brass suspension rod whose terminating piece represents the astronomical object that the SDSS observed through that hole on this plugplate: small glass spheres for stars in the Milky Way, lamps for the quasars, glass disks for the flattened, spinning galaxies like the Milky Way, and larger spheres for the rounded “elliptical” galaxies that form when gravity drags disk galaxies together and scrambles their stars onto disordered orbits. The length of each rod corresponds to the light-travel distance to the object, with the longest rod in the sculpture representing a light ray that has traveled 12.3 billion years to reach the earth.²

Disk galaxies are more common than ellipticals, but the ellipticals are, on average, bigger and brighter, so the SDSS telescope can see them to greater distances. Scanning downwards from the top of *The Center is Everywhere*, a dense pattern of disks gradually gives way to

²For the astronomers in the audience: the mapping from distance to rod length changes from linear at small distances to logarithmic at large distances, following $l = 72'' \times \ln(1 + t/4 \text{ Gyr}) / \ln(1 + t_0/4 \text{ Gyr})$, where t is the lookback time and t_0 is present age of the universe computed for a cosmology with $\Omega_m = 0.25$, $\Omega_\Lambda = 0.75$, and $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$.



Figure 1: Full view (left) and detail (right) of *Study for The Center is Everywhere*,” by Josiah McElheny (2012), designed in collaboration with David Weinberg. The sculpture is 32 inches in diameter and 84 inches high, made of brass, steel, three forms of cut lead crystals (representing stars, disk galaxies, and elliptical galaxies), and electric bulbs (representing quasars). The structure is based on spectroscopic plugplate 1945 from the Sloan Digital Sky Survey.

a sparser sprinkling of ellipticals. Quasars are much rarer still, for while most large galaxies contain supermassive black holes, it is only rare, short-lived events that funnel gas toward them and cause them to flare into brilliance. At the peak of its activity, a quasar can outshine its galactic host by a factor of 1000, so quasars can be detected to the farthest reaches of the universe. The volume mapped by a single plugplate expands like the cone of a lighthouse beam, so at large enough distances it begins to encompass many quasars, rare though they are. Stars enter the SDSS in many ways: some are observed as standard sources to calibrate measurements of galaxies and quasars, some are mapped in a deliberate pattern to reveal the structure of the Milky Way, and some are “contaminants,” stars with unusual colors that allow them to masquerade as quasars until an SDSS spectrum reveals their true identity.

Even a casual inspection of *The Center is Everywhere* shows that galaxies are not randomly

distributed through space. The gravity that pulls gas and dark matter into galaxies also pulls the galaxies into groups and clusters, arranged on still larger scales in a web of filaments and walls. A defining goal of the SDSS is to measure the clustering of galaxies with exquisite precision and detail, measurements that help to reveal the history of galaxy formation, pin down the geometry, matter, and energy content of the cosmos, and probe the physics of the Big Bang itself. The cosmic core sample shown in *The Center is Everywhere* is one small chunk of the SDSS map of the universe, a random but representative piece of the whole. An individual SDSS plugplate covers an area on the sky that is three degrees across, six times the diameter of the full moon, the size of a quarter held at arm's length. The circular plates must overlap so that they do not leave gaps between them, and in its original phase (see Appendix A) the SDSS used more than 2000 plates to map 1/4 of the sky, one quarter-sized patch at a time.

An astute viewer with the patience to count will notice that *The Center is Everywhere* has 306 rods, not the expected 640. The minimum separation of holes in the original SDSS plugplate is only 0.08", an uncomfortably small size to impose on the cut-glass crystals of a chandelier. *The Center is Everywhere* circumvents this problem with three compromises: it expands the central region of plate 1945 and trims its edges, it slightly nudges the positions of some holes and the lengths of some rods to create space, and it omits some objects that still can't fit.

The full title of McElheny's sculpture is *Study for The Center is Everywhere*. It is a "study" in part because this piece is the first of what may well become a series, with the multitude of SDSS plugplates providing an ample library for sculptures that follow common rules but are individually unique. But even a series of 50 such sculptures would still be "a study" for the much larger work that could be constructed in principle, with 2000+ chandeliers suspended in an arena-like vault, holding a million glass crystals and lamps to represent the celestial objects that have been mapped by the SDSS. And even this vast conceptual installation would remain "a study": the complete work should take its title seriously and include the maps constructed by astronomers and artists in other, distant galaxies, whose own Studies for *The Center is Everywhere* include the Milky Way as a glimmering disk of glass.

2 The Unsettling Infinite

"Nature is an infinite sphere, whose center is everywhere and whose circumference is nowhere." The French philosopher Blaise Pascal wrote this description (*Pensées, 1669*) centuries before the emergence of the modern cosmological model, or the gravitational theory of Einstein on which it is based. Yet it seems an apt encapsulation of the Cosmological Principle, of the centerless expansion of the Big Bang theory, and of our consequent ability to map the universe fairly from an arbitrary point within it. Because the universe has a finite age — about 14 billion years according to recent observations — the size of the *observable* universe is, in fact, finite. A galaxy or quasar more than 14 billion light years away is beyond the edge of our cosmic horizon, and it will remain so forever. But just as the slight curvature of the earthly horizon viewed from a ship bespeaks a world far larger than the sailors can see, so astronomical observations (which, despite increasingly precise measurements, have detected *no* curvature of 3-dimensional space) tell us that the universe is at least hundreds of times larger than the span of our cosmic horizon, probably much larger, and quite possibly infinite. If the Cosmological Principle holds across an infinite universe, then there are other astronomers mapping their own

observable sphere so far from us that we could never communicate, not even in principle.

Pascal's metaphor has a long history, as described by Jorge Luis Borges in his essay *The Fearful Sphere of Pascal*. One who took it up was the communist revolutionary Louis Auguste Blanqui, who devoted his imprisonment to writing a cosmological treatise, *Eternity Through The Stars: An Astronomical Hypothesis* (1872). On the first page of his book, Blanqui repeats and slightly amends Pascal's comment: "*The universe is a sphere whose center is everywhere and whose surface is nowhere.*" Blanqui becomes the first to clearly state one of the most bizarre properties of an infinite universe made of constituent atoms and molecules whose variety and possible arrangements are finite. In such a universe, every chance event, and every configuration of matter that can arise from a series of such events, must occur, and not just once, but an infinite number of times. If we take the idea of the infinite seriously, then mathematical reasoning leads us to the dizzying notion that the (very) distant universe holds replicas of ourselves, reading the same books, speaking the same words, thinking the same thoughts . . . and near replicas who do the same thing but in a different language, or with different colored eyes. Blanqui's thought experiment is like that of the Librarians in the Borges story *The Library of Babel*, who conjecture that the Library is infinite and conclude that its volumes of seemingly random letters must somewhere include all the works of great literature, and of bad literature, in all variations, over, and over, and over.

Computations of probabilities in an infinite universe present conceptual and philosophical challenges even today, forming an esoteric and sometimes controversial thread of discussion among contemporary cosmologists and string theorists. The stakes of this discussion are real, for it tells us whether an underlying fundamental theory can, with reasonable probability, explain the world as we see it. Observations do not tell us whether the universe is truly infinite, nor whether it remains statistically homogeneous far beyond our horizon, so there are avenues of escape from the replicas that Blanqui envisioned. But the mere possibility that we inhabit an infinite universe stocked with infinite replicas disturbs our already troubled senses of individuality and free will.

Closer to home, our finite observable universe is already enormous, and even the SDSS has mapped only a tiny fraction of its contents. Space is big and time is long, and these vastnesses can be intimidating. But one can choose instead to marvel at the particularities of nature, at the intricacy of its structures, at the way that gravity and electromagnetism and nuclear forces weave random fluctuations of primordial atoms into a web of galaxies, stars, and planets. On some of these planets, chemistry and biology and evolution organize those atoms into beings who can, from their own center of the universe, map the cosmos and begin to understand it.

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A About the Sloan Digital Sky Survey

The SDSS was conceived around 1990, and it began operation in 1998 after nearly a decade of design and construction. In its initial phase, the SDSS used the world’s largest digital camera and fiber-fed spectrographs, both mounted on a dedicated 2.5-meter telescope, to obtain deep multi-color images of about 20% of the sky and spectra of nearly a million stars, galaxies, and quasars. In its second phase (SDSS-II, 2005-2008), the Sloan collaboration completed the project’s original goals and carried out two additional surveys, one a map of stars in the Milky Way and one a systematic search for supernovae to measure the history of cosmic expansion. In its current phase (SDSS-III, 2008-2014), the collaboration is using the same telescope equipped with upgraded and new spectroscopic instruments to conduct four surveys, of the distant universe, the Milky Way galaxy, and extra-solar planetary systems. The team is already far along in planning for expanded surveys beyond 2014. Technical descriptions of the SDSS include York et al. (2000) for SDSS-I, Abazajian et al. (2008) for SDSS-II, and Eisenstein et al. (2011) for SDSS-III.

The “Sloan” in SDSS refers to the Alfred P. Sloan Foundation, which has provided critical funding support to all phases of the SDSS. The SDSS has also been supported by the participating institutions, by the U.S. National Science Foundation, Department of Energy Office of Science, and National Aeronautics and Space Agency, and by funding agencies of other nations. Today the SDSS collaboration has more than 500 active scientists from 40+ institutions around the globe. More information about the SDSS can be found at the web sites sdss.org and sdss3.org. The public archive of SDSS images and spectra is available through skyserver.sdss3.org.

B About Josiah McElheny and David Weinberg

Josiah McElheny is an artist who works primarily in glass, though his recent *oeuvre* includes films, books, and other media. Much of his work is created in his glass-blowing studio in Brooklyn, NY. His intellectual interests are wide ranging and include the rise and fall of modernist design and architecture, the history of glass as a material and as an artistic medium, conceptions of the infinite, and contemporary cosmology. Among other honors, he was awarded a 2006 MacArthur Foundation Fellowship.

David Weinberg is a cosmologist and a Professor of Astronomy at Ohio State University. He studies the formation and clustering of galaxies, the structure of the intergalactic medium, and the matter and energy contents of the universe. He was the Spokesperson for SDSS-II, and he is the Project Scientist of SDSS-III.

McElheny and Weinberg have collaborated since 2004 on the design of several cosmologically inspired sculptures. The article by Weinberg (2010) describes the scientific and intellectual background to the first four of these collaborative efforts: *An End to Modernity* (2005, now in the collection of London’s Tate Modern gallery), *The Last Scattering Surface* (2006, now in the Phoenix Art Museum), *The End of the Dark Ages* (2008, now in a private collection), and *Island Universe* (2008). The 2012 exhibition *Josiah McElheny: Some Pictures of the Infinite*, at the Boston Institute of Contemporary Art, includes both *Island Universe* (previously exhibited in London and Madrid) and the first exhibition of *Study for The Center is Everywhere*. Further description of this collaboration can be found in the article by Weinberg (2011).

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