

A Space-to-Time Translation

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The Big Bang is an extraordinarily difficult subject for visual representation. When Josiah McElheny and I met for the first time, we began by examining his sketch for the piece that would become, over the following year, *An End to Modernity*. In this sketch, inspired by the spectacular Lohbmayer chandeliers that hang in the Metropolitan Opera House, a central sphere supports a starburst of metal rods, which in turn support clusters of glass pieces and lamps. This seemed a perfect depiction of the popular conception of the Big Bang, a tremendous explosion that flings fragments of matter in all directions from a central point. But the Big Bang is *not* an explosion of material into space; it is the origin of space and time itself, initiating an expansion that occurs everywhere and has no center. How could any static sculpture, no matter how intricate, depict *that*?

During the ensuing three-hour conversation, the solution emerged: retain the basic structure of the sketch, but change the *interpretation* of that structure by using a spatial dimension to represent time. The center of the sculpture would then become the primordial cosmos and the outer edge the present day, and the passage from one to the other would trace the 14 billion year history of the expanding Universe. With this space-to-time translation, *An End to Modernity* could incorporate many of the key features of cosmic evolution that have been revealed by astronomical observations over the last four decades, following prescriptions that Josiah and I worked out over many months of meetings, emails, and phone calls. In the finished work, each of the 230 radiating rods emerges in a random direction with a randomly selected length and terminates in a cluster of hand-formed glass disks and blown-glass globes, representing a cluster of galaxies, or in a single lamp, representing a quasar. The rules that govern the form, size, and contents of the cluster, or the brightness of the lamp, depend on the length of the rod, and thus on the cosmic epoch that corresponds to its termination point.

The central aluminum sphere that supports the cluster and lamp rods also represents one of the crucial concepts of modern cosmology: the Last Scattering Surface. The early Universe was so hot that hydrogen atoms were broken apart into their constituent protons and electrons. The free electrons scattered light much like the water molecules of a dense fog, making the Universe opaque. When the expanding cosmos cooled to a temperature of 3000°C some 500,000 years after the Big Bang, all free electrons disappeared into atoms, and the Universe became transparent. The most distant source of “light” that we can see is the opaque “surface” nearly 14 billion light years away. The 1965 discovery of the cosmic microwave background, the faded glow of this surface now cooled to a mere 3 degrees above absolute zero, provided the key piece of evidence for the hot early Universe postulated by the Big Bang theory.

In *An End to Modernity*, the Big Bang itself is a conceptual point at the center of the sculpture, time zero, hidden by the aluminum sphere just as the electron fog of the last scattering surface shields the earliest epochs of the cosmos from our direct view. From the central sphere outwards, the sculpture incorporates a logarithmic mapping between distance from the center and the size of the Universe. Every 7.2” of distance corresponds to a factor of two in cosmic expansion, and the 6-foot span from the central sphere to the

outer edge of the sculpture represents a 1000-fold growth in each spatial dimension.

At the epoch of last scattering, the Universe was filled with smoothly distributed hot gas, with no galaxies or stars or living creatures to admire them. Over time, gravity amplified small fluctuations created in the first trillionth of a second of cosmic history into the galaxies and larger structures that we observe today. In *An End to Modernity*, the first galaxies appear 3' out from the central sphere, 100 million years after the Big Bang. Like our own Milky Way, these early galaxies have the disk-like shapes that are the generic final state of a cooling, rotating cloud of gas. Moving outward towards the present, three things change. First, the galaxies get bigger, as they attract gas from their surroundings and process it into stars. Second, gravity pulls the galaxies themselves into ever larger structures, galaxy clusters and superclusters. Finally, a new type of galaxy begins to appear, rounded elliptical systems formed by chaotic collisions of the rotationally ordered disks. Elliptical galaxies, depicted by glass spheres, reside mainly in the dense clumps where collisions are most common, while the extended, filamentary superclusters are populated mainly by disks.

The lamps that illuminate *An End to Modernity* represent quasars, the brightest objects in the Universe. Quasars are powered by supermassive black holes, up to 10 billion times the mass of the Sun, which reside at the centers of galaxies. As gas falls into these black holes, it collides with itself at speeds close to the speed of light, heats up, and emits light, X-rays, and other forms of radiation. When a supermassive black hole is actively devouring gas, it can outshine the combined starlight of its host galaxy by a factor of 1000. The first quasars are faint because there has not been time to build the most massive black holes. The height of the quasar era is the period 2-4 billion years after the Big Bang. At later times, the population slowly fades because the galactic disturbances that feed gas to the black holes become less common, so that most galaxies harbor only a dark remnant of their former glory. In *An End to Modernity*, this history is encoded by the changing frequency and brightness of the quasar lamps.

Because light travels at a finite speed, astronomical telescopes function as time machines: when we observe distant objects, we see them not as they are today but as they were when they emitted their light. This fortunate feature of physics allows us to build an empirical picture of the history of the Universe from observations at the present day. *An End to Modernity* represents the principal elements of this picture — the Last Scattering Surface, the growth, transformation, and clustering of galaxies, and the rise and fall of the quasar population — in idealized but qualitatively accurate form. From our earth-bound vantage point, the history of the Universe is traced through a series of concentric shells, with the earliest epochs seen at the greatest distances. *An End to Modernity* inverts this perspective, and it invites us to view the history of the cosmos as though we stand outside of it. However, if current astronomical inferences are correct, the Universe will expand forever, at an ever accelerating rate. Thus, wherever we stand to regard *An End to Modernity*, we are implicitly enveloped by the future.

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