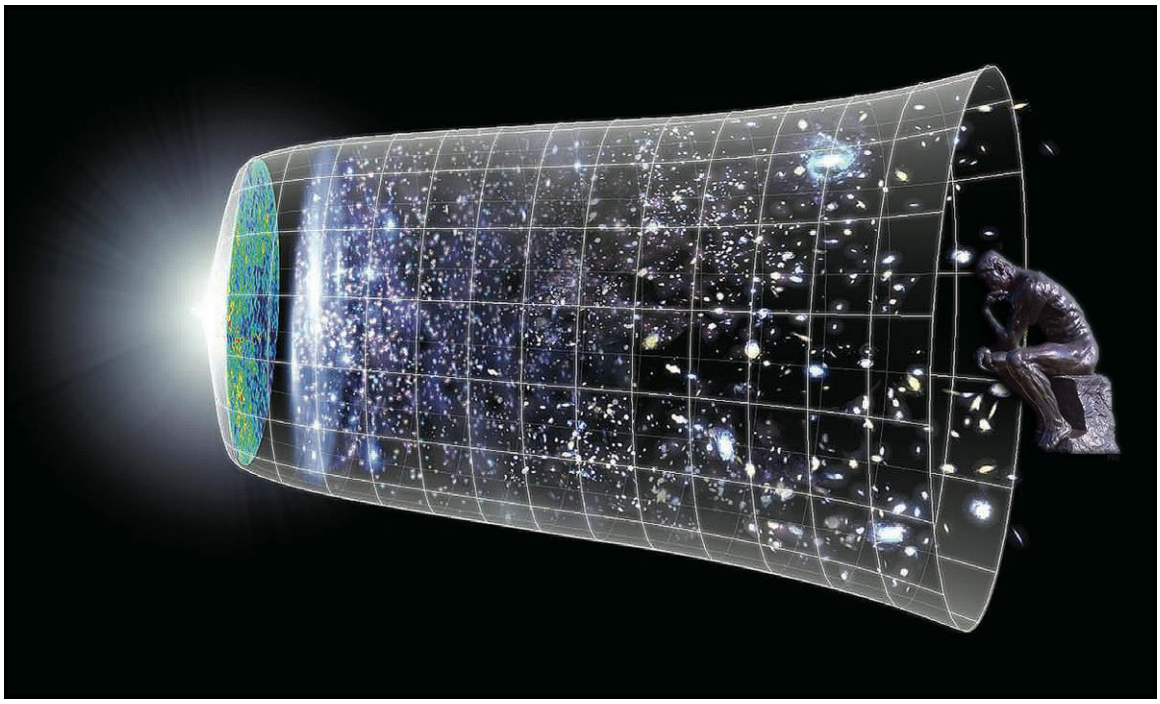

COSMIC REFLECTION

Pierre R. Schwob & Lawrence M. Krauss

Hush. A child is asking: "Where did I come from? How did it all begin?"

These questions echo the wonder expressed by hundreds of generations of shepherds and savants, of sibyls and scholars who used their senses and their imagination to tell stories, to test theories, and now at last, to apprehend many of the answers.

Listen. Hear the chorus of ancestral musings from Babylon and Greece, of powerful ideas from Galileo, from Newton, and from Einstein. Listen to the music of time…

I. *Creation, from the Big Bang to First Light*

In the beginning, there is no space. There is no time. There are no atoms, planets or stars…

13 billion 800 million years ago, the precursor of everything that now exists in our Universe emerges from a single point, formless and infinitely dense, in a titanic explosion of energy we call the Big Bang.

As this energy erupts into its self-created space, the Universe experiences an extraordinary spasm. It swells instantly at a phenomenal rate, doubling in size more than 100 times in far less than the blink of an eye.

Then, as quickly as it began, this rapid inflation slackens and energy can now begin its conversion into matter, all within a region which is, by then, not much larger than your cupped hands.

This small volume of space will eventually expand to hold the entire visible Universe of today.

A subtle asymmetry pervades this primal process: Equal amounts of matter and antimatter are initially produced. Almost instantaneously, pairs of matter and antimatter particles meet and annihilate in flashes of pure energy. Yet, for each billion such destructions, one particle of matter is left over. This humble remainder will ultimately produce all the galaxies, stars, planets… and us.

The fireball expands and cools, and in another fraction of a second, protons and neutrons are formed. Most of these protons are the nuclei of hydrogen atoms that still exist today. Indeed they are the most abundant constituents of our own bodies.

During the first second, neutrons and protons collide incessantly and sometimes combine. But in the blistering temperature of the emergent Universe these fleeting unions are almost invariably destroyed. Eventually, as the cosmos continues to expand and cool, some fusions do survive and the neutrons and some of the protons combine as nuclei of helium.

The raw materials of the stars now exist, and the Universe is just five minutes old.

Yet the Universe is still so hot that it is opaque. At a billion degrees, matter exists as a charged plasma – a dense fog through which light cannot advance.

But time passes. The Universe continues to expand and cool.

380 thousand years after the Big Bang, the temperature has eased enough to allow nuclei to capture errant electrons, forming neutral atoms. The Universe becomes transparent. The fog dissipates. Light from the edge of creation can now begin its journey toward the future, and to us.

II. ***First Light to First Stars***

The Big Bang has settled into a gentle expansion. Tiny ripples in the density of matter dating back to the dawn of time are amplified. A tenuous web of dark matter slowly condenses to create the framework upon which visible galaxies will ultimately form and evolve.

Over the course of hundreds of millions of years, primordial gas is drawn by gravity towards these folds of dark matter. Small proto-galaxies emerge. As they fragment, smaller regions coalesce yet further. Volumes of gas, containing perhaps 100 times the mass of our Sun, contract and heat up. As these swirling clouds continue to collapse, their surface temperature rises, and they begin to glow, first in the dull warmth of infrared, then in visible light, heralding our Universe's earliest dawns.

The first stars are born.

Soon, however, another – immensely more powerful – energy source takes over. Deep within the core of these nascent stars, crushing pressure and searing temperature trigger the onset of nuclear fusion.

Protons become neutrons. And in a replay of the Big Bang's earliest moment, these neutrons bind to other protons. But while the rapid cooling of the early Universe quickly prevented further spontaneous fusions, stars have all the time in the world.

Hydrogen fuses into helium, causing each single reaction to release ten million time as much energy as when a match is lit. In turn, helium becomes carbon, and further, inexorably, lighter elements fuse into heavier ones. This prodigious energy source can power stars for millions or billions of years, as it balances the relentless inward pull of gravity with the intense outward pressure of radiation and heat.

The Universe begins to resemble the one we see today, offering its familiar tableau of glorious galaxies, illuminated from within by the effusive brilliance of their stars.

III. ***Starlight to Enlightenment***

With the emergence of starlight, our Universe teems with incandescent activity. In an endless cosmic ballet, massive galaxies collide and merge, fostering rippling stellar nurseries in which countless new stars ignite.

But stars are not only born, they also die, often in terrible violence.

Stars much more massive than our Sun burn with a colossal fury and exhaust their nuclear fuel within only a few million years.

At the end of their lives, in a single day, nuclear reactions rise to a roaring frenzy, converting the entire core of the star to sweltering iron. But this marks the end of the fusion process as iron cannot burn to liberate energy. The core loses its long-standing fight against gravity and it collapses suddenly. This ignites a cataclysmic explosion. This extraordinarily violent detonation expels the outer shell of the star into space, carrying with it all the elements created during the star's lifetime, together with those forged within the explosion itself.

At least once every second, somewhere in our Universe, a star dies in such paroxysms. Over the 12 billion years that our Galaxy has existed, hundreds of millions of stars have exploded in apocalyptic supernovae, seeding the interstellar medium with their enriched exhalations, so that we might be.

Nearly all atoms, other than hydrogen and helium, making up the organic material expressing life on earth were forged within stars. Indeed, we are all children of the stars and grandchildren of the Big Bang, connected to the cosmos by our very substance.

Yet, there is more to the Universe than just what we can see. As we study the Universe and learn more of its history and composition, we find that its dominant ingredient may not be visible ordinary matter, or even phantom dark matter. The bulk of creation seems to be an exotic form of energy permeating empty space itself which drives everything apart. And starting a few billion years ago, on a cosmic scale, this energy began to quietly overwhelm gravity, causing the Universe to expand, once again, at an ever-accelerating pace.

In the far future, all the galaxies we now see will have disappeared, as they recede beyond our visible horizon. Our own Milky Way and its nearest neighbor Andromeda will have merged into one massively large galaxy that will exist alone, an island of fading embers in an otherwise cold, dark, and unknowably vast space.

We must wonder why we were destined to live at a time when we can still witness the splendid effervescence of our dynamic Universe and ask: "How did a self-aware life-form evolve on our planet, in a galaxy in the middle of nowhere in particular? Are we alone?"

We should celebrate the long chain of marvelous cosmic events that allowed us to be here, compelling us to ask these transcendent questions now.

We salute our brief, remarkable moment in the Sun, during which rational thoughts and our hearts must inform our curiosity, our creativity and our compassion.

For now, we watch, we think, we learn and we share, aware of the minuscule but nonetheless sentient part we play in this cosmic drama – within, indeed, a Universe whose center is everywhere, and boundary nowhere.

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