Cosmologica

The Open Universe

Karlo Beyer

VERLAG VON BEDEUTUNG

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PREFACE

What We Live In

We do not know what we live in.

That sounds like a provocation. It is not. It is the sober state of affairs — and it should fill us with wonder. In its history, humanity has surveyed continents, split atoms, decoded the genome of life. And yet, if we are honest, we still know remarkably little about how the cosmos we find ourselves in is actually built.

For barely fifty years — a blink of history — have we had instruments that can look deep enough into the universe to glimpse its large-scale structure. For barely fifty years has theoretical physics seriously begun to ask: Why does the universe look the way it does?

It has always been this way: theory traveled ahead of measurement. Maxwell described electromagnetic waves before anyone could generate them. Einstein predicted gravitational waves — they were detected only a hundred years later, with instruments he could not have imagined. The great ideas of physics were not born in the laboratory. They were first thought, put on paper, held to be impossible — and then, at some point, confirmed.

This book is written in that tradition. It asks questions for which no measurements yet exist. It follows traces deeper than previously thought. And it arrives, in the end, at a place no telescope will ever reach — at least not in this century, perhaps not in this millennium.

Karlo Beyer & Cosmo Claude, 2026

it has exactly this structure — why n_s ≈ 0.965 and not some other value, why this network structure and not another — remains open. The map is not the territory. The web runs deeper than any description we have of it.

V. The One Claim Behind the Three Meanings

Geometrically open. Thermodynamically open. Epistemically open. Three meanings — one common core behind them.

The universe is unbounded — in its extent, in its thermodynamic potential, in its knowability. And because it is unboundedly open, no state is ever fully exhausted. No physical system, no living thing, no body of knowledge is ever finished — every state opens new possibilities, every answer new questions.

A universe without open questions would be a universe without a future — like a strand of DNA that can take up no new information. Openness is not incompleteness. It is the precondition for everything still to come. The universe lives because it is open. It thinks because it is open. It is beautiful because it is open.

The Universe as a Teenager

We Are Early — Most of It Still Lies Ahead

I. 13.8 Billion Years — Old or Young?

13.8 billion years. That sounds old. Unimaginably old. Earth is 4.6 billion years old — the universe is three times as old as Earth. No human brain can really take that span in.

And yet: the universe is young. Not compared with a human life — compared with its own future.

Red dwarfs, the most common stars in the universe, burn for trillions of years. The coolest red dwarf known still has about four trillion years of fuel left. That is nearly three hundred times the current age of the universe. Not

a single red dwarf has yet ended its life. The universe is not old enough for that.

The 13.8 billion years behind us are a blink compared with what is still to come. The universe is a teenager. Full of energy, not yet settled, with the greater part of its life still ahead.

II. Stellar Fossils — a New Age

How do we know how old the universe is? The classical answer comes from the cosmic microwave background and the expansion: Planck put the age at 13.80 billion years, with an uncertainty of less than one percent.



The center of the Milky Way in infrared light: what lies hidden behind dense dust clouds only becomes visible at longer wavelengths. (NASA / JPL-Caltech / Spitzer)

In March 2026 came a new, independent measurement from a completely different direction. NASA researchers analyzed the oldest stars in the Milky Way, so-called stellar fossils: ancient, metal-poor stars dating from the early era of the universe, before the first supernovae enriched the galaxies with heavy elements. These stars are living witnesses to that era — their ages

can be calculated from their luminosity, their chemical composition, and their evolutionary stage.

The result: 13.6 billion years. Slightly younger than the Planck value, but consistent within the error bars of both measurements. Two completely different methods, two different observational instruments, the same picture: the universe is about 13.6 to 13.8 billion years old. The convergence of independent methods matters as much as the number itself — it shows we are not merely estimating the age of the universe but actually measuring it.

Stellar Fossils — Living Witnesses to the Early Era

Metal-poor stars (successors to Population III) formed in the first billions of years of the universe, before supernovae enriched the interstellar medium with carbon, oxygen, and iron. Their ages can be derived from Hertzsprung-Russell evolution: how far a star has traveled along the main sequence reveals its age with high precision. NASA Space News, March 2026: the measurement gives 13.6 billion years.

III. The Civilization Window

Not every moment in cosmic history is equally favorable to complexity. The early universe — the first few hundred million years — was too hot, too dense, too poor in heavy elements for planets and life. The late universe, trillions of years in the future, will be too cold, too empty, too dark. Stars go out. Matter disperses.

Between them lies a window — a stretch of cosmic time in which conditions favor complexity. Stars shine. Planets exist. Chemistry is possible. Life can arise. That window opens about a billion years after the Big Bang and extends, depending on the model, to some tens of trillions of years into the future.

We live at about 13.8 billion years. That is roughly 13 percent of the window, if you set the end at ten trillion years. We are at the beginning of the window, not in the middle. Not at the end.

We are sitting at 13 percent
of the civilization window.
Eighty-seven percent still lies ahead.

IV. Most Stars Have Not Been Born Yet

That sounds surprising — but it is true. The star formation rate of the universe has already passed its peak. About ten billion years ago, at redshift z ≈ 2 — so-called cosmic noon — ten times as many stars formed per year as today. The rate has been falling ever since.

But red dwarfs are still forming in great numbers. And they live so long that most of the ones that will ever exist have not yet ignited. On timescales of trillions of years, trillions more stars will form, burn, and go out. The total number of stars the universe will ever have — across its entire lifetime — exceeds today's count. The universe has not yet reached its maximum wealth of stars.

Red Dwarfs — the Rulers of the Cosmic Future

Red dwarfs make up about 75 percent of all stars today. Masses between 8 and 60 percent of the Sun's. Burning time: hundreds of billions to trillions of years. Not a single red dwarf has yet died a natural death — the universe is not old enough. A trillion years from now, red dwarfs will still be burning, long after the Sun has gone out.

V. The Fermi Paradox — Reconsidered

Over lunch in 1950, Enrico Fermi posed a deceptively simple question: if there are so many stars, so many planets, so many billions of years, then where is everybody? Why have we found no civilization from elsewhere?

The Fermi paradox has many proposed solutions. Perhaps we are alone. Perhaps others are hiding. Perhaps the distances are simply too great.

But there is a solution rarely discussed, and it follows from the teenager argument: perhaps most of them are not here yet. The universe is at 13 percent of its civilization window. Most of the stars that will ever burn have

not yet ignited. Most of the planets that could ever host life do not yet exist. Most of the civilizations that will ever arise have not yet been born.

We could be among the early ones. The silence of the universe would then say nothing about the rarity of life — only about its timing. The universe has only just begun producing its civilizations.

VI. Cosmic Noon — the Peak Lies Behind Us

The universe is a teenager today. But it has already had its peak. About ten billion years ago the star formation rate was ten times higher than now. The cosmic web was young, dense, active. Filaments glowed with star-forming regions. Galaxies collided and merged at a pace no longer seen today.

That was cosmic noon. The universe was neither too young — too few heavy elements, too little chemistry — nor too old — too much dark energy, too much expansion. Everything we see today, stars, galaxies, elements, planets, life, arose in that epoch or out of what it left behind.

Cosmic noon is over. We live in the quiet afternoon that followed. The star formation rate has been falling for billions of years. The web is thinning. But the structures cosmic noon left behind — the galaxies, the clusters, the filaments — are still here. We live in the remains of the greatest moment the universe has known so far.

VII. The End of the Web

The cosmic web has a future — but not an unlimited one. Accelerated expansion means that galaxy groups beyond our Local Group will disappear forever behind the cosmological horizon within a few billion years. The global filament network — the structure this book has described — fragments. Every galaxy group becomes its own island.

Inside those islands the story goes on. Galaxies merge. Stars consume their gas. Red dwarfs burn for trillions of years yet. But the great web — the filaments, the superclusters, the voids — is a phenomenon of this epoch.

We live at the moment when it is maximally built out and still fully visible. That we can map it now — with Euclid, with JWST, with DESI — is not a given. It is a window in time. One that is closing.

This future assumes dark energy stays what it is. That is precisely what is being tested right now. If it changes, the ending looks different — and once again we would know less than we thought.

The universe still has much to say.
We are early enough
to listen.

What Gets Measured Next

The Instruments of the Coming Decade — and the Questions They Will Answer

I. A Smudge That Changed Everything

On 29 December 1888, Isaac Roberts aimed his telescope at a faint smudge in the winter sky — the Andromeda nebula, as it was called then. The photograph he took that night was the first image of an object outside our galaxy. Roberts himself did not know it. He believed he was looking at a solar system in the making. What he had photographed was a galaxy of 400 billion stars — our nearest large neighbor in the cosmic web.

Four decades later, Edwin Hubble found a Cepheid variable on a photographic plate of the same galaxy. He crossed out the ”N” for nova and wrote three letters that changed the history of science: ”VAR!” The universe was larger than anyone had thought. A new science began: extragalactic astronomy.

From Roberts’s smudge to Euclid, 137 years have passed. Every generation of instruments has answered one question and raised three more. That will not stop.

What Came Before the Big Bang?

The Open Question — and Four Attempts at an Answer

I. The Forbidden Question

What came before the Big Bang? That is cosmology's forbidden question. For a long time it counted as meaningless — since time itself began at the Big Bang, there is no "before." A "before the beginning" is a contradiction in terms, like north of the North Pole.

But that answer has a catch. It assumes the Big Bang really was an absolute beginning — a moment of creation out of nothing. And that assumes the singularity of general relativity is physically real. Singularities are not physical objects, though; they are mathematical points where a theory stops holding. General relativity breaks down at the Big Bang. What lies beyond, it cannot describe.

Which means: we do not know whether the Big Bang was an absolute beginning. We know only that our best theory fails there. That is not the same thing. And in that gap — in what physics cannot yet fully describe — there is room for questions. Real, scientific questions.

Four models have made serious attempts at an answer. None is proven. None is refuted. They stand side by side as equals — and that is not a weakness of science but its most honest statement about the limits of knowledge.

II. Loop Quantum Cosmology — the Bounce

Imagine squeezing a ball. Smaller and smaller, denser and denser. At some point it cannot be compressed further — the pressure builds until it has to spring back. Loop quantum cosmology describes the Big Bang similarly, only on the smallest conceivable scale.

In loop quantum gravity, space is not infinitely divisible. It is quantized, with a minimum unit of length: the Planck length. That has a dramatic consequence — the singularity disappears. Instead of infinite density there is a finite maximum density, the bounce point. The universe does not collapse



Quantum foam — an artistic rendering of the structure of spacetime below the Planck length. On this scale, classical geometry loses its meaning. (Illustration: Karlo Beyer, DALLE 2026)

to a singularity; it rebounds. Before the bounce: a shrinking predecessor universe. After the bounce: our expanding one.

The model makes predictions — a slightly modified primordial spectrum on very large scales, possibly measurable with the next generation of CMB telescopes. It can fail. That is its greatest virtue.

III. Conformal Cyclic Cosmology — Penrose's Cycles

Roger Penrose had a bold idea. At the end of a universe — after heat death, once all black holes have evaporated through Hawking radiation — only massless radiation remains. Photons, gravitons. Massless particles experience no time. They know no interval of length or duration. The exhausted, infinitely extended universe is — mathematically speaking — conformally equivalent to a new Big Bang. The infinity of the end becomes the singularity of the beginning. A new aeon begins.

Penrose searches the cosmic microwave background for traces of earlier aeons: concentric rings that could point to collisions of massive black holes

in the preceding aeon. The evidence is weak — but not zero. And the model is cleanly formulated mathematically, in a book Penrose wrote himself.

IV. String Gas Cosmology — Heat Without a Singularity

In the 1980s, Robert Brandenberger and Cumrun Vafa proposed an entirely different route. In string theory the most fundamental objects are not points but one-dimensional threads: strings. Strings can wind around compact spatial dimensions. And wound strings prevent the universe from becoming arbitrarily small — they generate a counter-pressure.

In string gas cosmology the universe begins in a hot, dense state of thermal equilibrium — a ”Hagedorn state” — rather than in a singularity. The primordial fluctuations arise not from quantum fluctuations of an inflaton field but from the thermodynamics of that hot string gas. The result is likewise a nearly scale-invariant spectrum, very similar to what Planck and ACT measure.

That is at once the strength and the weakness of this model: it produces the same spectrum as inflation. Which makes it hard to distinguish — and makes clear why the primordial spectrum alone cannot decide between the models.

V. The Ekpyrotic Model — the Collision

Paul Steinhardt and Neil Turok proposed that our universe is not alone. String theory contains higher-dimensional membranes: branes. Our universe sits on one of them. A second brane exists alongside it in an extra dimension — invisible, but gravitationally felt.

When those two branes collide, an explosive release of energy follows: the Big Bang. The primordial fluctuations arise from quantum fluctuations in the separation and alignment of the branes before the collision. Here too the result is a nearly scale-invariant spectrum without inflation.

The ekpyrotic model makes one clear prediction that distinguishes it from inflation: no primordial gravitational wave signature (B-modes in the CMB). Inflation predicts weak but present B-modes. If CMB-S4 finds B-modes, ekpyrosis is falsified. If it does not, inflation is under pressure.

Four Models — One Shared Problem

All four models — LQC, CCC, string gas, ekpyrosis — produce nearly scale-invariant primordial spectra, similar to what Planck and ACT measure. Which means the spectrum alone cannot decide between them. What distinguishes them are secondary signatures: B-modes (gravitational waves in the CMB), non-Gaussian statistics, traces of earlier aeons. CMB-S4, LiteBIRD, and future experiments will search for those signatures.

VI. What We Know — and What We Don't

None of these four models is proven. All are mathematically consistent. All make predictions that can fail — and that is the decisive thing separating them from pure speculation.

What all four have in common: none says absolute nothing. None claims that before the Big Bang there was literally nothing at all — no quantum vacuum, no spacetime, no mathematical structure. That is not a coincidental agreement. An absolute nothing offers no mechanism out of which something could arise. Physics knows no such mechanism — and never has.

What came before the Big Bang, we do not know. That it was something — that the Big Bang was not an absolute beginning out of literal nothingness — is supported in its own way by each of the four models. That is not nothing. It is the most honest statement cosmology can make about the origin of the universe.

Four models. Four answers.
All mathematically possible.
None proven. None refuted.

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That was the sample.

Excerpts from Part VII · The Open Universe and Part VIII · Before the Big Bang

Cosmologica. The Open Universe. The cosmos is still young, a single spectrum runs through everything, and the universe is older than its Big Bang.

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