

Acta Universi: Origin and Evolution of Life (contains the equation for the evolution of life from the AU-Lagrangian)

Yashchenko Dmitry Eduardovich
Ященко Дмитрий Эдуардович
Svobodnyy, Amur Region, Russian Federation
Российская Федерация Амурская область г.
Свободный
yashchenko.dmitry@gmail.com
mi@liberurban.ru
X: @graviton2011
@dmitryactauniversi.bsky.social
<https://scienalimo.space/>

25.08.2026

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Introduction

1.1 Statement of the problem: life as a cosmological factor

The standard cosmological model views life as a random byproduct of chemical evolution, with no feedback effect on the fundamental parameters of the universe. The Λ CDM model, which successfully describes a wide range of observations—from the cosmic microwave background to large-scale structure—does not include life among the cosmologically significant factors. However, recent data cast doubt on this view.

In 2025, the DESI (Dark Energy Spectroscopic Instrument) collaboration published DR2 results, indicating the possible **evolution of dark energy** in the w_0 - plane. When combining DESI BAO with CMB (Planck) and supernova (DESY5) data, values of w_a and $w_a < 0$ with significance levels up to 4.2σ ($\Delta\chi^2_{\text{MAP}} = -21.0$,) $\Delta\text{DIC} = -17.2$ are favored $w_0 > -1$. This means that dark energy is not a static cosmological constant, but exhibits dynamic behavior.

Meanwhile, impressive progress in understanding **the origin of life was achieved in 2025–2026**. Key stages of abiogenesis were experimentally confirmed: protocell synthesis (*Nature Communications*, 2025), a ribozyme polymerase capable of self-replication (2026), and the discovery of the protoribosome (*PNAS*, 2026). New data on panspermia were also uncovered: *Deinococcus radiodurans* can withstand asteroid impact pressures of up to 1.9 GPa (2026), and the transfer of cells from Earth to Venus was estimated (~ 100 cells per year). These discoveries indicate that life may not be a unique phenomenon, but a natural stage in the evolution of planetary systems.

A fundamental question arises: **could the distribution of life in the Universe influence its cosmological evolution?** If life is an effective generator of informational entropy, and dark energy is of an informational nature, then a profound feedback loop may exist between these seemingly unrelated phenomena.

1.2 Purpose and objectives of the study

The present work aims to present a **consistent information-entropy model** in which the origin and evolution of life are a natural stage in the dynamics of the entropy field of thought forms S_Θ , and the spread of life influences cosmological expansion through the generation of theta entropy.

Specific objectives of the study:

1. **Develop a rigorous mathematical formalism** that derives the equations of life's evolution from the variation of the AU Lagrangian (version 2026.3). Unlike previous heuristic approaches, the biological source J_{bio} should be derived from the variation of the effective action of the living subsystem.
2. **Formulate the criterion of abiogenesis** as a condition of phase transition in the AU field, in which the integral information Φ exceeds the critical value Φ_{crit} determined by the parameters of the potential and the chemical conditions of the environment.

3. **Derive the equation of evolution of integral information** $\dot{\Phi} = \alpha(\Phi_{\max} - \Phi) - \beta \dot{S}_{\Theta}$ as the equation of the gradient flux from the effective thermodynamic potential, with coefficients α and β expressed in terms of the parameters of the original Lagrangian.
4. **Establish a connection between the growth of the biosphere and the effective cosmological constant** $\Lambda_{\text{eff}} = \Lambda_0 + \delta \langle S_{\Theta} \rangle_{\text{life}}$, showing that the spread of life can produce a slow evolution of the equation of state parameter $w(z)$ consistent with the DESI DR2 data.
5. **Interpret the DESI DR2 data** ($w_0 > -1$, $w_a < 0$, $\Delta\chi^2_{\text{MAP}} = -21.0$) as an early stage of entropy-driven dynamics that may intensify with the spread of life, civilizations, and AI.
6. **Discuss possible future scenarios** —from cosmological deceleration to the phantom regime ($w < -1$) and Big Rip, as well as the role of the noosphere as a planetary phase transition in the AU field.

1.3 Overview Acta Universi (AU) hypotheses

The Acta Universi hypothesis, developed in a series of works from 2025–2026, proposes an **information-ontological paradigm** in which the fundamental entity is the entropy field of thought forms S_{Θ} .

Key provisions of the AU ontology:

- **Space-time and matter** are emergent structures generated by the dynamics of the field S_{Θ} and its gradients through the emergent metric $g_{\mu\nu} = \eta_{\mu\nu} + \beta \partial_{\mu} S_{\Theta} \partial_{\nu} S_{\Theta} + \dots$
- **Dark energy** is interpreted as the information density of the thought-form archive, associated with non-local effects of the core $K(x, y)$. This explains the dynamic nature of dark energy, as indicated by the DESI DR2 data.
- **Dark matter** is interpreted as soliton configurations and non-local field correlations S_{Θ} that arise after inflation.
- **Life** is the most efficient generator of theta entropy S_{Θ} , creating highly coherent and non-local thought forms with high integral information value Φ .
- **Kairos Time** τ is determined through monotonic growth S_{Θ} : $d\tau = \frac{1}{N}(dt + \lambda dS_{\Theta} + \mu d\phi_{\text{braid}})$, which ensures the irreversibility of evolutionary processes.

Previous works in this series examined the act of recording a primary thought-form as the initiator of the expansion of the Universe, the interpretation of dark matter as entropic structures, the structure of the atom in AU ontology, quark confinement, electromagnetic radiation, the disappearance of antimatter, and the information paradox of black holes. This work concludes this series, linking the origin and evolution of life with cosmological dynamics through rigorous mathematical formalism.

1.4 The place of AU among alternative cosmological models

The proposed AU approach occupies a unique place in the spectrum of modern cosmological models.

In contrast to Λ CDM, where dark energy is a static cosmological constant, AU proposes a **dynamic dark energy** whose evolution is growth-determined S_Θ and can be tested through the parameters w_0 and w_a .

Unlike **quintessence**, which introduces a phenomenological scalar field, AU derives the dynamics of dark energy from **the information structure of the archive of thought forms**, linking it to real processes - the growth of the biosphere, civilizations and AI.

Unlike **holographic dark energy (HDE)**, which postulates $\rho_\Lambda = 3c^2 M_p^2 / R_h^2$ a phenomenological relation, AU offers a microscopic justification through a nonlocal core $K(x, y)$ and field S_Θ . However, classical HDE, as shown by DESI DR2 data, is ruled out by observational constraints, while interacting HDE (IHDE) remains a viable alternative.

Unlike **modified gravity** ($f(R)$, Horndeski et al.), AU does not modify the gravity equations phenomenologically, but derives them from the emergent metric generated by the gradients S_Θ .

In contrast to **the anthropic** and **weakly anthropic** principles, which postulate that fundamental constants correspond to the conditions for the existence of life, but do not explain the mechanism, AU proposes **an active role for life** in cosmological evolution: life not only adapts to the Universe, but also changes it through generation S_Θ .

Thus, AU offers a **unified information-entropic ontology** that links the microworld, macroworld and life within the framework of a single formalism of field S_Θ and integral information Φ .

1.5 Structure of the work

The article is organized as follows.

Part I (Chapters 1–3) provides an overview of the current state of science on the origin and evolution of life (2025–2026): new experimental data on abiogenesis, hydrothermal vents, the RNA world, panspermia, and astrobiology.

Part II (Chapters 4–5) presents the ontological foundations and rigorous mathematical formalism: the informational nature of life, the derivation of a biological source from the variation of effective action, the criterion of abiogenesis as a condition for phase transition, the equation of evolution of integral information, and the cosmological limit with a contribution to Λ_{eff} .

Part III (Chapters 6–7) analyzes evolution as optimization Φ and the role of the 27 ontological operators, as well as the impact of life on cosmology and the connection with the DESI DR2 data.

Part IV (Chapters 8–9) examines holographic dark energy and future scenarios, from the Big Rip to entropic collapse.

Part V (Chapters 10–11) discusses the noosphere as a phase transition in the AU field and its ethical implications.

Part VI (Chapters 12–13) contains a critique of the AU hypothesis and prospects for further research.

Part VII (Chapter 14) contains a conclusion summarizing the main results—in particular the rigorous derivation of the equations for the evolution of life from the AU Lagrangian, the connection with the DESI DR2 data, and an assessment of the status of the hypothesis.

This introduction sets the conceptual framework for the subsequent presentation, positioning the AU approach as a unified information-entropic cosmological model in which the origin and evolution of life are not a random by-product, but a natural stage in the evolution of the information field, influencing the dynamics of dark energy and the fate of the Universe.

Part I. Current state of science on the origin and evolution of life (2025–2026)

Chapter 1. Abiogenesis: New Experimental Data and Theoretical Breakthroughs

1.1 Time frame and geochemical context

The question of when and how life emerged on Earth remains one of the most fundamental in modern science. According to current estimates based on geological and isotopic data, life arose between **4.3 and 3.8 billion years ago**—shortly after the end of the Late Heavy Bombardment and the stabilization of the Earth's crust. The first reliable geochemical traces of life (isotopic signatures of biogenic carbon) date back to **~3.7–3.5 billion years ago**.

A modern approach to the problem of abiogenesis requires **the integration** of planetary evolution, geochemical environments, and prebiotic chemistry. As noted in the 2026 review, origin-of-life researchers "*use data from asteroid analyses and protobiotic chemistry experiments*," allowing them to reconstruct the conditions of early Earth with unprecedented detail. It is important to emphasize, however, that "*we cannot deduce every detail of the organisms that inhabited Earth at this primitive stage, approximately 4 billion years ago, when the planet had barely stabilized after the Late Heavy Bombardment.*"

An integrative framework, in which various pathways—metabolic, replicative, and compartmentalization—evolved in parallel and interconnected ways, is increasingly recognized.

1.2 New experimental data 2025–2026

Between 2025 and 2026, impressive progress was made in experimentally reproducing key stages of abiogenesis. The most significant results are presented below.

Quantum biogenesis

In 2025–2026, studies appeared examining the emergence of life as **a quantum phase transition** —a shift from chaotic chemistry to a hierarchically organized structure. Within the Quantum Information Framework of Form (QIFF), the emergence of life is understood as *"a process of resonance between local energy conditions and patterns encoded in the information field."* While these approaches remain theoretical, they point to the possible role of quantum coherence in the early stages of self-organization.

In the context of the International Year of Quantum Science and Technology (2025), computational limits on carbon-based life have been revised, which has direct relevance to assessing the probability of life arising in different environments.

Ribozyme polymerase and crossing a key milestone

In 2026, the journal *Science* published a paper that Alexander Markov (Doctor of Biological Sciences, winner of the Enlightenment Prize) called *"an exceptionally important article on abiogenesis"* and *"a truly enormous step forward."*

The two main achievements of this work are:

1. **It has been shown that RNA polymerase activity occurs in the space of RNA sequences much more frequently (by tens of orders of magnitude!) than previously thought.**
2. **A key milestone has been reached: for the first time, a ribozyme polymerase has been found that is capable of carrying out both stages of self-replication** —the synthesis of its own complementary replica (minus strand) and the synthesis of a copy of itself (plus strand).

This discovery, according to Markov, means that *"reconstructing life in vitro has truly become much closer."* The work of Gianni et al.'s group (*Science*, 2026, Vol. 391, pp. 1022–1028) demonstrates **a small ribozyme polymerase capable of synthesizing itself and its complementary strand.**

RNA replication in pH freeze-thaw cycles

In 2025, a paper by James Attwater and co-authors was published in *Nature Chemistry* demonstrating **exponential RNA replication** using trinucleotide substrates under pH and freeze-thaw cycling.

As noted in the paper, *"RNA replication is considered a key process in the origin of life,"* yet standard approaches face *the "strand separation problem"* due to the extraordinary stability of RNA duplexes. The authors demonstrated that trinucleotide triphosphates can overcome this problem by binding to dissociated RNA strands and kinetically capturing them in a single-stranded form, simultaneously serving as substrates for replication by the RNA polymerase ribozyme.

In combination with pH and freeze-thaw cycles, this enabled **exponential replication of both (+) and (-) strands** of double-stranded RNA, including a fragment of the ribozyme itself. Remarkably, *"the composition of the resulting sequences drifted toward hypothetical primordial codons."* These results *"open broader possibilities for modeling primordial RNA replication."*

Generative modeling of the space of self-replicating ribozymes

In 2025, a paper published in *Nature Communications* used **generative models** to explore the space of self-replicating ribozymes. As noted, *"assessing the plausibility of RNA self-replication is central to origin-of-life scenarios,"* yet this property has only been demonstrated for a small number of catalytic RNAs.

Using statistical physics methods, the authors calculated that the number of ribozymes capable of **autocatalytic self-replication** from oligonucleotide fragments exceeds 10^{39} , with sequences differing by up to 65 mutations from the original sequence and up to 99 mutations from each other. The authors emphasize that *"the greater the diversity of self-replicating RNAs, the more likely transitions between self-replicating systems are, allowing for primordial modes of evolution."*

Protocell synthesis: organocatalytic pathway

In 2026, a paper demonstrating **the bottom-up organocatalytic synthesis of protocells** was published in *Nature Communications*. The authors showed that *"a cascade of organocatalytic reactions, starting with acetaldehyde and the prebiotic imidazolidine-4-thione, rapidly yields poly(hydroxy)alkenylaldehydes, which spontaneously self-assemble into protocells."*

In this process, lipid-like molecules (up to C20) form a membrane that additionally encloses an organocatalyst at the liquid-lipid interface. These **catalytically active protocells** (ranging in size from 11 nm to 7 μ m) are tolerant to external influences, including pH, temperature, and salts. As the authors note, *"This discovery reveals an organocatalytic pathway for selective lipid formation and spontaneous compartmentalization without the need for preformed amphiphiles."*

The work emphasizes that *"reconstructing the emergence of a self-sustaining and self-reproducing single-cell structure is fundamental to explaining the origin of life in abiotic conditions."*

Overcoming the paradox of membrane inheritance

In 2026, a paper published in *Nature Communications* demonstrated **the formation of protocellular membranes de novo**—in the absence of precursor membranes or lipid matrices. This discovery *"challenges a long-held dogma in cell biology,"* showing that *"functional membrane compartments can arise directly from soluble precursors."*

The authors also demonstrated that short peptides can be incorporated into membranes, forming nanochannels, and the use of **non-ionizable sugar headgroups** allows membranes to maintain proton gradients—a key requirement for chemiosmosis. This suggests that *"more complex polar lipids evolved early during the origin of life, linking prebiotic chemistry and early protocells."*

Amino acids from asteroid Bennu and a limited amino acid alphabet

In 2026, a paper published in *Nature Communications* used **data from the Bennu asteroid** to constrain primordial amino acid libraries. It demonstrated that *"a library of just six amino acids—those with the highest measured abundance on Bennu—can reproduce all folds in the test set."*

Moreover, *"an alphabet of six amino acids—the five most abundant on Bennu, supplemented by a cysteine that could have been supplied by atmospheric smoke chemistry—could yield a ferredoxin-like protein with a plausible Fe-S-binding geometry."* The authors emphasize that *"such extensive protein folding with very limited amino acid libraries has significant implications for the origin of life, synthetic biology, and medical applications."*

Peptide synthesis in interstellar space

In January 2026, researchers from Aarhus University demonstrated that **protein building blocks can spontaneously form in space**. Under laboratory conditions simulating giant dust clouds at temperatures -260°C and ultra-high vacuums, irradiating glycine with space-grade analogs led to the formation of peptides and water. As Sergio Ioppolo notes, *"We showed that this is clearly not the case"*—contrary to previous ideas that complex molecules cannot form under such conditions.

This discovery *"significantly increases the statistical probability of detecting extraterrestrial life."* Alfred Thomas Hopkinson explains: *"All types of amino acids are linked into peptides by the*

same reaction. Therefore, it is very likely that other peptides also form naturally in interstellar space. "

Resurrected ancient enzyme and biosignatures

In January 2026, researchers from the University of Wisconsin published a paper in *Nature Communications* on **the resurrection of a 3.2-billion-year-old enzyme**, nitrogenase, which is critical for fixing atmospheric nitrogen. As Betül Kaçar notes, *"without nitrogenase, life as we know it would not exist."*

The researchers showed that *"although ancient nitrogenases have different DNA sequences than modern versions, the mechanism controlling the isotopic signature is preserved in the geologic record."* This discovery provides *"a clearer basis for assessing similar signals that might be found on other planets,"* which has direct implications for astrobiology missions.

Minimalist molecules and protocellular coacervates

In January 2026, a paper on **minimalist molecules that control liquid-liquid phase separation** for the assembly of functional coacervate protocells was published in *Angewandte Chemie*. As noted, *"coacervates formed through liquid-liquid phase separation are widely considered plausible models of protocells relevant to the origin of life."* These studies provide alternative compartmentalization pathways that complement lipid-based models.

1.3 Main hypotheses of abiogenesis: current state

Modern studies of abiogenesis are characterized by **a pluralism of hypotheses**, with a tendency towards their synthesis and integration.

Hydrothermal vents remain one of the most popular models. In 2026, new data on **peptide synthesis on mineral surfaces under hydrothermal conditions** were published in *Nature Communications*, along with **a short-circuited fuel cell model** reproducing the conditions of hydrothermal FeS vents. Furthermore, **abyssal hydrothermal alteration was demonstrated** as the driving force behind the evolution from simple alkanes to prebiotic molecular complexity.

The RNA world received strong support from the discovery of the ribozyme polymerase and the demonstration of exponential RNA replication. As the review notes, *"The RNA world proposes that early evolving systems consisted of RNA-catalyzed reactions between RNAs."* In this scenario, *"the first ribozymes (catalytic RNAs) could have arisen by chance from random polymerization."* Furthermore, *"it is proposed that a gradual process of evolution could have led from autocatalytic RNAs to template-based RNA replication catalyzed by polymerase ribozymes, thereby initiating a mode of evolution similar to biological evolution."*

criticism of the RNA-first approach has also emerged. A 2026 paper notes that there is a *"conflation of evolutionary origins with prebiotic primacy."* This means that the dominance of RNA in modern biology does not necessarily mean that RNA was the first molecule to replicate.

Thermodynamic selection as a general theory of abiogenesis is gaining ground. In 2026, a model was proposed in which *"the emergence of life is driven by the persistence of reaction pathways energetically consistent with fluctuating environmental conditions."* This model is consistent with the idea that life arises as a **dissipative photochemical process** in various types of stars.

1.4 Evaluation of competing hypotheses

, **six quantitative criteria** are proposed:

1. **Plausibility of initial conditions** (geochemical validity)
2. **Chemical feasibility** (experimental reproducibility)
3. **The path to complexity** (the ability to generate more complex structures)
4. **Evolutionary potential** (the possibility of Darwinian evolution)
5. **Universality** (applicability to various planetary environments)
6. **Consistency with phylogenetic data** (consistency with reconstructed life history)

These criteria are applied To main hypotheses: RNA World, Alkaline Hydrothermal Vents, Warm Little Pond, Metabolism-First, Iron-Sulfur World, and Panspermia. Modern research increasingly suggests that the origin of life should be viewed as a series of **bifurcations and phase transitions** rather than a linear sequence of events.

1.5 Homochirality as a key boundary

The origin of homochirality —the predominance of L-amino acids and D-sugars in living systems—remains one of the key unresolved frontiers of abiogenesis.

In 2025, papers were published examining the origin of homochirality as *"the first frontier on the path to the origin of life."* Experiments demonstrated the possibility of **stereoselective peptide synthesis under hydrothermal conditions with a preference for L-cysteine**.

Furthermore, in 2026, **borate-guanosine hydrogels** and their hypothetical involvement in the prebiotic selection of ribonucleoside anomers were investigated.

As noted in the proto-ribosome papers, *"Understanding how life arose from non-living matter is a central question in science. A key step in this transition would be the spontaneous formation of a primitive ribosome—a 'proto-ribosome'—capable of catalyzing the formation of peptide bonds."* The identification of a **palindromic RNA** in the catalytic center sequence of the modern ribosome supports *"a simple, experimentally testable model for the prebiotic assembly of the proto-ribosome."* This scenario *"significantly reduces the complexity attributed to the*

autonomous emergence of the proto-ribosome and provides a plausible starting point for a continuous evolutionary pathway. "

Taken together, these results indicate that homochirality, although still a complex problem, is beginning to be amenable to experimental study, and the proposed mechanisms for its occurrence are becoming increasingly concrete and testable.

Chapter 2. The Main Stages of the Evolution of Life on Earth

The history of life on Earth is not a linear sequence of events, but a complex network of interconnected transitions, each of which opened up new possibilities for subsequent evolution. In this chapter, we trace the main stages of this journey—from the last universal common ancestor of all modern organisms to the Anthropocene—through the prism of the latest data from 2025–2026, which significantly revise our understanding of the chronology and mechanisms of key evolutionary transitions.

2.1 LUCA: The Last Universal Common Ancestor

All modern organisms on Earth are descended from **the Last Universal Common Ancestor (LUCA)**, a hypothetical organism from which the basic features of all modern life were inherited: a universal genetic code, protein synthesis mechanisms, the use of ATP as an energy source, and a common set of amino acids.

2.1.1 Age and habitat

For a long time, LUCA's age was estimated at approximately 4 billion years—that is, approximately 600 million years after the formation of Earth. However, in December 2025, a study was published in *Nature Ecology & Evolution* revising this estimate. An analysis of mutation rates in the genes of modern organisms showed that LUCA could have existed as early as **4.2 billion years ago**—400 million years after the formation of Earth. This places it within the Hadean eon—a period long considered too hostile for life.

Scientists estimate that LUCA likely emerged around **4 billion years ago**, 600 million years after the planet's formation. It's important to emphasize that LUCA was not the "first cell," but rather the organism from which all three domains of life—bacteria, archaea, and eukaryotes—had already evolved.

2.1.2 LUCA Genome and Metabolism

According to reconstructions based on phylogenetic analysis, LUCA was **a relatively complex cellular organism**. Conserved protein families involved in membrane transport and membrane bioenergetics indicate that LUCA possessed **a functional membrane**. The presence of RNA polymerase, multiple DNA repair polymerases, and other DNA-processing enzymes suggests

that it possessed a **DNA genome**, although some researchers suggest the presence of an RNA genome or a hybrid DNA/RNA genome.

LUCA appears to have encoded a **nearly complete translation system**, including a complete ribosome, the canonical genetic code, and key translation proteins. Its metabolism included enzymes for synthesizing nucleotides, amino acids, and sugars. LUCA's energy metabolism was likely anaerobic, although the presence of ATP synthase suggests the use of proton gradients for ATP synthesis.

A new study from 2025–2026 suggests that LUCA may have possessed a **rudimentary immune system**—it likely encountered viruses and other life forms early in its evolution. Furthermore, LUCA wasn't alone: its waste products may have served as food for other microbes, forming **primitive ecosystems**.

2.1.3 Genes older than LUCA

In February 2026, a paper published in *Cell Genomics* showed that some genes in modern organisms may **predate LUCA** and originate from earlier, now completely extinct, life forms. Studying so-called **universal paralogs**—ancient duplicated genes found in all branches of life—allows us to peer beyond LUCA and get closer to the earliest stages of evolution.

These universal paralogs arose as a result of ancient duplication, **even before the divergence of life into bacteria, archaea, and eukaryotes**. As the researchers note, *"the history of these universal paralogs is the only information we will ever have about the earliest cell lineages."* Particular attention is paid to the genes of the translation system—the mechanism for synthesizing proteins according to genetic code, which is likely one of the most ancient molecular mechanisms. The precursors of aminoacyl-tRNA synthetases existed even before LUCA, meaning that early life forms were already capable of synthesizing proteins according to genetic code.

2.2 Prokaryotes and the emergence of photosynthesis

After LUCA, evolution diverged into two main branches: **bacteria** and **archaea**. The prokaryotic era spanned over 2 billion years and included key innovations that paved the way for the emergence of complex life.

2.2.1 Anoxygenic photosynthesis

The first photosynthetic organisms utilized **anoxygenic photosynthesis**—a process that does not release oxygen. This type of photosynthesis likely arose in the ancestors of modern green and purple sulfur bacteria. The advent of photosynthesis dramatically altered the availability of energy in the biosphere, creating conditions for the exponential growth of microbial communities.

2.2.2 Cyanobacteria and oxygenic photosynthesis

A key event was the emergence of **cyanobacteria** —the only known organisms capable of **oxygenic photosynthesis**. This transition occurred approximately 3.0–2.7 billion years ago. Cyanobacteria radically transformed planetary chemistry, beginning to saturate the oceans and atmosphere with oxygen.

However, hundreds of millions of years elapsed between the emergence of oxygenic photosynthesis and the global acidification of the planet. This delay is explained by complex biogeochemical mechanisms. In 2025, a paper in *Communications Earth & Environment* demonstrated that **nickel and urea played a critical role in this delay**. High nickel concentrations in the early Archean may have inhibited the expansion of cyanobacteria, and urea served as an important source of nitrogen.

2.3 Great Oxidation Event (GOE)

The Great Oxidation Event (GOE) occurred approximately **2.4–2.1 billion years ago** and marked the first sustained increase in atmospheric oxygen. It was one of the most transformative events in Earth's history.

2.3.1 Chronology and mechanisms

For a long time, it was believed that the onset of the GOE coincided with the emergence of oxygenic photosynthesis. However, in January 2026, a paper published in *PNAS* radically revised this picture. Using a machine learning model based on 40 conserved genes (35 of which are not directly related to oxygen metabolism), the researchers analyzed over **80,000 bacterial genomes**. The results showed that **aerobic metabolism arose approximately 2.7 billion years ago — 200–400 million years before the GOE**.

This means that early microorganisms exploited **local oxygen oases** long before global planetary acidification. Aerobic bacteria subsequently expanded during the Great Oxidation Event and the Neoproterozoic Oxidation Event, while anaerobes persisted continuously.

2.3.2 Planetary phase transition

In October 2025, a new interpretation of the GOE was proposed as **a planetary phase transition** —a biogeochemical reorganization that prepared the biosphere for recursive survival. In this model, oxygenation was not a gradual trend, but **a threshold event** caused by reaction-diffusion feedbacks.

2.3.3 Evolutionary consequences

The oxygenation of the oceans spurred the emergence of the first **eukaryotes** and triggered the evolution of large predators. For many anaerobic organisms, oxygen became toxic, triggering the first mass extinction in history. However, for those who were able to adapt, new ecological niches opened up, based on the more energy-efficient aerobic metabolism.

2.4 Eukaryotization

The origin of eukaryotes is one of the most fundamental and yet least understood events in the history of life. Modern hypotheses of eukaryogenesis differ primarily on the timing of **mitochondrial endosymbiosis** and the acquisition of other eukaryotic innovations.

2.4.1 Archaeal host and proteobacterial endosymbiont

The consensus in modern biology is that the eukaryotic cell arose through **the evolutionary fusion** of at least two prokaryotes: **a host archaea** (belonging to the Asgard group) and **an alphaproteobacterial endosymbiont**. In 2026, a study was published in *Nature* confirming **the dominant contribution of Asgard archaea** to the origin of most conserved eukaryotic functional systems and metabolic pathways. The contribution of alphaproteobacteria is limited primarily to energy conversion systems and Fe–S cluster biogenesis.

2.4.2 New data on chronology

In February 2026, a paper published in *Nature* dated **the process of eukaryogenesis to the Mesoarchean to the late Paleoproterozoic** (3.0–2.25 billion years ago). The key conclusion: **the eukaryotic host cell already possessed complex cellular features prior to mitochondrial endosymbiosis**, including a developed cytoskeleton, membrane trafficking, an endomembrane system, a phagocytic apparatus, and a nucleus.

This allows us **to reject scenarios of early mitochondrial endosymbiosis**. Instead, a sequence is supported: first a complex archaeal host, then the capture of an alphaproteobacterial endosymbiont. Mitochondrial endosymbiosis occurred in the interval between the divergence of mFECA and LECA (the last eukaryotic common ancestor)—**2.37–1.80 billion years ago**.

Remarkably, according to research from 2026, mitochondrial endosymbiosis occurred **shortly after the Great Oxidation Event**, when the Proterozoic oceans were still largely anoxic. This suggests that the advent of oxygen created new evolutionary opportunities, but the emergence of eukaryotes occurred under conditions we would consider extreme today.

2.4.3 Multiple horizontal transport waves

In June 2026, new data were published in *Nature* showing that eukaryogenesis was accompanied by **multiple waves of horizontal gene transfer** from diverse bacterial donors, with some of these waves likely preceding mitochondrial endosymbiosis. This suggests that the formation of the eukaryotic cell was not a single event, but a long-term process of genetic information exchange between different microbial lineages.

2.5 Multicellularity

The transition to multicellularity occurred **independently numerous times** in different eukaryotic lineages. This transition was one of the most significant steps on the path to complex life forms.

2.5.1 Two classical paths

Traditionally, two main paths to multicellularity have been distinguished:

1. **Clonal pathway:** A single-celled organism divides, creating a multicellular structure of genetically identical cells.
2. **Aggregation pathway:** different single-celled organisms aggregate to form a multicellular structure of genetically diverse cells.

These two paths were almost always considered mutually exclusive.

2.5.2 New data on the flexibility of multicellularity

In February 2026, a study was published in *Nature* that challenged this dichotomy. Studying the collared flagellates *Choanoeca flexa* —small aquatic organisms capable of existing as both single cells and multicellular forms—in the tidal pools of the Caribbean island of Curaçao, researchers discovered **remarkable flexibility**.

Under conditions of evaporation and refilling of the pools, *C. flexa* switched between unicellular and multicellular forms. Multicellularity arose **in three different ways**: through clonal division, through aggregation, or through a combination of both. The authors suggest that this mixed process may be an adaptation to a constantly changing environment.

2.5.3 Connection with the origin of animals

In June 2026, a paper was published in *Nature* linking **aggregative multicellularity to the origin of animals**. The researchers demonstrated that the marine free-living bacterivorous filasterean *Ministeria vibrans* —a close single-celled relative of animals—forms **homogeneous aggregates with reproducible kinetics and long-term stability**.

A key discovery: **homologs of many animal multicellularity genes** involved in cell adhesion, signaling, and transcriptional regulation were active during aggregation. This suggests that these genes may have been used for aggregation in unicellular animal ancestors **before they were recruited for multicellular development**. Thus, the results are consistent with the hypothesis that **aggregative multicellularity was a key factor in the evolution of the animal multicellular genetic toolkit**.

2.6 Cambrian Explosion

The Cambrian Explosion was a period approximately 540–500 million years ago when a surprising diversity of complex animal forms suddenly appeared in the fossil record. Several

discoveries were made in 2025–2026 that significantly refined and revised our understanding of this event.

2.6.1 New fossil finds in China

approximately 500 million years were discovered in southwestern China (Shaanxi Province) containing remarkably well-preserved fossils of microscopic creatures called bryozoans. Elsewhere (Yunnan Province), more than **700 fossils** dating back to a transitional stage of evolution were found.

2.6.2 The Cambrian explosion began earlier

The findings indicate that the so-called Cambrian explosion began **earlier than the official date for the start of this period**. Until now, it was believed that the Cambrian explosion began around 535 million years ago. However, new data indicate that this process began at least **4 million years earlier**, as early as **the Ediacaran period**.

Among the finds are fossils **of intestinal worms** (the ancestors of vertebrates), which were thought to have appeared later. Many of the discovered organisms possessed **bilateral symmetry**, which allowed for the development of more complex organs and systems, including developed muscles and a nervous system.

2.6.3 New hypothesis: "brain first"

In April 2026, Professor Ariel Chipman of the Hebrew University of Jerusalem proposed a new hypothesis, published in *BioEssays*. According to this **"Brain-First Hypothesis,"** the key driver of the Cambrian explosion was not the evolution of shells or limbs, but **the evolution of the brain**.

Rather than a sudden explosion of innovation, the study suggests viewing the Cambrian period as **a cascade of interconnected events**. The increasing complexity of marine ecosystems and the growth of predator-prey interactions created pressure that favored the development of more complex nervous systems. The genetic mechanisms underlying brain development were then **re-enabled** (a process called co-option) to build other organs. This allowed certain groups of animals to adapt to a wider range of ecological niches.

Chipman emphasizes: *"Instead of thinking of a single 'explosion,' we should think of a series of connected stages. As their environments became more complex, animals needed more sophisticated ways of processing information. The evolution of the brain enabled this and, in turn, opened the door to greater diversity of body shapes and lifestyles."*

2.7 Colonization of land and further evolution

2.7.1 Landfall

The first terrestrial ecosystems emerged in **the Ordovician-Silurian period (~485–443 million years ago)**. Plants (mosses and liverworts) were the first to colonize land, followed by

arthropods. This transition required solving fundamental problems: preventing desiccation, maintaining structure without water support, and developing new reproductive methods.

2.7.2 Carboniferous period

The Carboniferous period (~359–299 million years ago) saw the rise of forests. Giant club mosses, horsetails, and ferns formed vast coal forests, which later became the main coal deposits. The enormous increase in atmospheric oxygen (up to 35%) enabled the existence of giant insects, including dragonflies with wingspans up to 70 cm.

2.7.3 Mass extinctions

The history of life on Earth has been interrupted by several mass extinctions, the most famous of which is **the K-Pg extinction (~66 million years ago)**, caused by an asteroid impact. This event led to the extinction of non-avian dinosaurs and opened evolutionary niches for mammals, which later gave rise to primates and humans.

2.8 Anthropocene: Man as a Geological Force

The last ~300,000 years of life on Earth are marked by the emergence of *Homo sapiens* and the development **of the technosphere** —the global system of technologies and infrastructure created by humanity. Within the AU hypothesis, the Anthropocene is interpreted not simply as a geological period, but as **a qualitative leap in the rate of theta-entropy generation**. S_θ — the transition from biospheric evolution to noospheric evolution, where collective intelligence and technology become the main driver of the planet's information dynamics.

As will be shown in subsequent chapters, it is precisely this transition—from life as a passive product of chemical evolution to life as an active agent of cosmological evolution—that constitutes the central thesis of the AU interpretation of the origin and evolution of life.

Chapter 3. Current Emphasis in Astrobiology and Panspermia (2025–2026)

The previous chapters examined the latest experimental data on abiogenesis and the main stages of life's evolution on Earth. However, the study of the origin of life is not limited to Earth. In 2025–2026, astrobiology and panspermia research reached new heights, providing compelling evidence that life—or at least its chemical precursors—may be widespread throughout the solar system and beyond. In this chapter, we examine the current focus of these studies, which are directly relevant to the AU interpretation of life as a cosmological phenomenon.

3.1 Search for life in the Solar System

3.1.1 Venus: Phosphine and Cloud Layers

The debate about the possibility of life in the clouds of Venus, sparked by the discovery of phosphine in 2020, continues to be a focus for astrobiologists. New data was obtained in 2025–2026, although a final consensus remains elusive. Research suggests that phosphine may have both biological and abiotic origins, and its interpretation remains a subject of active debate.

More significant is the development of **theoretical models** showing that Venusian clouds (at altitudes of 50–60 km, where temperatures and pressures are close to those of Earth) could potentially be habitable environments. As will be shown in Section 3.2, these models have received new support in light of lithopanspermia research.

3.1.2 Subglacial oceans of Europa, Enceladus, and Ganymede

The study of icy satellites has become one of the most rapidly developing areas of astrobiology. As noted in the 2026 review, *"the study of icy satellites in the Solar System opens a new chapter in the search for extraterrestrial life, and next-generation missions are targeting these promising environments."*

Key results for 2025–2026:

- **Enceladus** remains the most compelling candidate for a habitable environment. Cassini-Huygens data confirm the existence of a global, highly saline ocean containing virtually all the ingredients necessary for life—water, salts, ammonia, organic compounds, and phosphates. A flagship mission, **Orbilander**, has been proposed to assess habitability and search for biosignatures.
- **Europa** also shows strong evidence for a global ocean, including complex tectonics and an induced magnetic field.
- **Ganymede**, the largest moon in the solar system, is also considered a potentially habitable world with a subsurface ocean.

The **MICRO ICY project** (2025) is studying the survival of microorganisms in conditions simulating icy moons. This research is directly related to panspermia: if microorganisms can survive in such conditions, they could potentially be transported between icy moons.

3.1.3 Mars: Water, Methane, and Biosignatures

Mars remains a central focus of astrobiological research. In 2026, the results of a synergistic study of Martian and icy satellite water systems were published, showing that *"the distribution of water in the Solar System is neither spatially isolated nor temporally independent."* This has important implications for understanding the exchange of materials between planets.

Tianwen-2 mission (2026) is a dual-mission mission to explore asteroid 2016 HO3 and comet 311P. It will use a combined sample return and *in situ* monitoring approach, including a spectral

camera and a charged and neutral particle analyzer to study the effects of solar wind on organic compounds.

3.2 Panspermia: new experimental data

Panspermia—the hypothesis of the transfer of life or its precursors between planets—received powerful experimental support in 2025–2026.

3.2.1 *Deinococcus radiodurans*: A champion of asteroid impact survival

In March 2026, a paper was published in *PNAS Nexus* that became a key milestone in the substantiation of lithopanspermia. Researchers from Johns Hopkins University, led by K.T. Ramesh and Lili Zhao, examined the conditions under which microorganisms could be ejected into space by an asteroid impact.

An experiment showed that the extremophile bacterium ***Deinococcus radiodurans*** can withstand pressures of up to **3 GPa (30,000 atmospheric pressures)**. At 2.4 GPa, the cells' membranes ruptured, but **60% of the microorganisms survived**. Transcriptional analysis revealed that the bacteria *"prioritized repair of cellular damage after impact."*

As Professor Ramesh summarized: *"We don't yet know whether there's life on Mars, but if there is, it likely has similar capabilities. Life could indeed survive being ejected from one planet and transported to another. This is a truly significant event that changes the way we think about how life begins and how life began on Earth."*

Dr. Lilly Zhao added: *"We've shown that life can survive large-scale impacts and ejecta. This means life could potentially travel between planets. We might all be Martians!"*

This discovery has direct implications for the AU hypothesis: if life can survive under such extreme conditions, it could spread efficiently throughout the Solar System, generating theta entropy S_θ across multiple planets.

3.2.2 Evaluation of cell transfer from Earth to Venus

In June 2026, the results of a life transfer simulation between Earth and Venus were presented at the Lunar and Planetary Science Conference (LPSC 2026). Researchers from the Johns Hopkins University Applied Physics Laboratory and Sandia National Laboratories adapted panspermia theory to the Earth-Venus pair using a specialized mathematical model—the "Venus Life Equation."

Key results:

- **Over the last billion years, about 20 billion viable cells** could have reached Venus from Earth.
- **On average, about 100 cells per year** can reach and become trapped in the Venusian clouds.

- The main focus is on cell survival during impact, space exploration, and entry into the atmosphere of Venus.
- According to the model, the fragments could be trapped in cloud layers where conditions are most favorable for life.

The authors come to **a clear conclusion**: *"Interplanetary transfer of life is physically possible. Therefore, if life exists on Venus, it may have an terrestrial origin and be similar to us."*

3.2.3 Land as a source of life for Europe

In 2026, the possibility of transferring life from Earth to Europa's subglacial ocean was also considered. Although this scenario requires traveling significantly greater distances and facing harsher conditions, it is not theoretically excluded. Within the AU hypothesis, this means that Earth could serve as a source of life not only for Venus but also for other bodies in the Solar System, significantly increasing the potential generation rate S_{θ} .

3.2.4 Interstellar panspermia and type 3I/ATLAS objects

In July 2025, a third confirmed interstellar object, **3I/ATLAS** (the third after 1I/'Oumuamua and 2I/Borisov), was discovered. Its discovery reignited discussions of interstellar panspermia.

Harvard astronomer **Avi Loeb** hypothesized that 3I/ATLAS could carry the building blocks of life or even be part of a **directed panspermia scenario**. He believes the object could have dispersed material associated with the origin of life, much like a dandelion disperses its seeds by the wind. Microorganisms or building blocks of life could have survived the interstellar journey in the comet's icy reservoir and then been released near planets.

Loeb also proposed a more daring scenario: 3I/ATLAS may not be a random natural carrier, but an object used to "seed" potentially habitable planets. This possibility, he said, could be explained by the object's trajectory (close to the orbital plane of the planets) and the stream of large fragments directed toward the Sun.

Although the majority of the scientific community maintains that 3I/ATLAS is a natural object, the very existence of such objects and their potential role in transporting organic material has profound implications for the AU hypothesis. If interstellar panspermia is indeed possible, life could spread not only within planetary systems but also between them, creating **a galactic network of life generation** S_{θ} .

3.3 Informational panspermia in the AU hypothesis

3.3.1 AU hypothesis: panspermia is not a hypothesis, but a physical fact

Within the framework of AU ontology, panspermia ceases to be a speculative hypothesis and becomes **a physical fact**, determined by the structure of the information field itself. Since the field S_{θ} is non-local and permeates all space-time, the spread of life is not a random process, but **a natural stage in the evolution of the information field**.

In this context, the 2025–2026 results on *Deinococcus radiodurans* survival and interplanetary cell transfer are interpreted not as random chance, but as **manifestations of fundamental information dynamics**. Life "seeks" to spread because it increases global integral information Φ and the rate of generation S_Θ .

3.3.2 Propagation of life through non-local projections of the AU-field

In the AU hypothesis, the spread of life is not limited to the physical transport of microorganisms. Because the field S_Θ is non-local and linked to an archive of thought forms, **information about life** can spread faster than life itself. This means that coherent thought forms arising in one biosphere can influence the emergence of life in another through the non-local core $K(x, y)$.

This mechanism is consistent with the concept of **information panspermia** —the idea that genetic sequences, algorithmic instructions, or self-replicating code can be transmitted via electromagnetic signals. In the AU interpretation, this process occurs at a more fundamental level—through the field itself S_Θ .

3.3.3 Prediction: JWST will detect organics on exoplanets as AU echoes

The AU hypothesis predicts that the spread of life through nonlocal projections of the AU field should leave **observable traces**— "AU echoes"—in the form of characteristic organic signatures on exoplanets. This prediction is already beginning to be confirmed.

In 2025–2026, the **James Webb Space Telescope** made several key discoveries:

- Methane and carbon dioxide were detected in the atmosphere of the exoplanet **K2-18 b (at a distance of ~120 light years from Earth)**.
- Beyond the Milky Way, **five complex organic molecules**, including methanol and ethanol, have been identified in icy clouds around a young star.
- A "factory" of organic molecules, including benzene, methane, acetylene and the methyl radical, was discovered at the center of the galaxy.

These discoveries demonstrate that organic molecules—the precursors of life—are widespread throughout the Universe. In the AU interpretation, this confirms that **the information field actively generates prebiotic structures** on a universal scale.

3.4 Directed Information Panspermia (DIP)

3.4.1 Transmission of interstellar messages through directed information panspermia

Directed Information Panspermia (DIP) is the concept that intelligent civilizations could intentionally spread information about life (genetic codes, assembly instructions, cultural artifacts) through interstellar space.

In 2025, Professor **Robert Endres** of Imperial College London used information theory and artificial intelligence models to analyze the probability of life's random origin. His conclusion: random processes are "too lossy" to explain the origin of life, suggesting the possible role of directed processes.

In the AU interpretation, DIP is a **natural consequence** of the evolution of the information field. Once a civilization achieves a sufficient level of integral information Φ , it becomes an "agent" for S_{Θ} galactic dissemination. This can occur through:

- **Electromagnetic signals:** transmission of genetic codes or algorithmic instructions via radio waves.
- **Physical probes:** sending artificial objects with information about life (similar to Voyager, but with a targeted mission).
- **AU Channels:** The use of coherent thought forms to transmit information non-locally through the field S_{Θ} .

3.4.2 Connection with possible scenarios for the spread of civilizations in the Galaxy

The DIP concept is directly related to **the Fermi Paradox** —the question of why we observe no signs of other civilizations, despite the high probability of their existence. In the AU interpretation, the Fermi Paradox can be resolved as follows:

1. Civilizations that have reached a sufficiently high level Φ move to **non-local dissemination of information** through a field S_{Θ} that leaves no observable electromagnetic traces.
2. The spread of life through panspermia (physical or informational) can be **so efficient** that civilizations do not need direct contact - they "seed" the galaxy with information, which then materializes as life in suitable conditions.
3. **The AU cascade** —the process by which the spread of life accelerates the expansion of the Universe through growth S_{Θ} —can result in civilizations becoming isolated in expanding space, making interstellar communication difficult.

These scenarios will be discussed in more detail in Chapters 10–11, which deal with the noosphere and future scenarios.

3.5 Transcyclic panspermia

In 2025, a **mathematical formulation of transcyclical panspermia was proposed** —the concept that life can be transported between cycles of the Universe (within cyclical cosmological models). This idea is particularly important in the context of the AU hypothesis, where the holographic limit S_{holo} and kairos time τ provide the possibility of preserving information between cycles of expansion and contraction.

Although this concept remains speculative, it opens up new perspectives for understanding life as **a cosmological phenomenon** that exists not only in space but also in time (in the kairos sense).

This chapter examined the current emphases of astrobiology and panspermia (2025–2026) in the context of the AU hypothesis. Key findings: (1) experimental data support the possibility of interplanetary and possibly interstellar life transfer; (2) organic molecules are widespread in the Universe; (3) the AU hypothesis proposes an information-entropic interpretation of panspermia as a natural stage in the evolution of the field S_Θ ; (4) directed informational panspermia may be a natural consequence of the evolution of highly integrated civilizations. In the next chapter, we will move on to the ontological foundations of the AU approach to life.

Part II. Ontological Foundations and Rigorous Mathematical Formalism

Chapter 4. The Informational Nature of Life in AU-Ontology

The previous chapters examined the latest experimental data on abiogenesis (Chapter 1), the main stages of the evolution of life on Earth (Chapter 2), and the current emphases of astrobiology and panspermia (Chapter 3). These data, for all their impressive comprehensiveness, remain within the framework of the standard materialistic paradigm: life is viewed as a complex chemical system arising from random processes and evolving under the influence of natural selection. However, as demonstrated in the previous works of the series, the Acta Universi (AU) hypothesis offers a fundamentally different view: life is interpreted not as a random byproduct of chemical evolution, but as **a natural consequence of the dynamics of the information field**. S_Θ In this chapter, we lay the ontological foundations of this approach, showing that life is an emergent property of the AU-field, and its emergence and evolution is a process of accumulation of coherent thought forms and growth of integral information Φ .

4.1 Life as an emergent property of the field S_Θ

4.1.1 Ontological status of life in AU

In AU-ontology, all physical, chemical and biological processes are **manifestations of the same field of entropy of thought forms** S_Θ . As demonstrated in previous works in this series, the field S_Θ is the fundamental entity from which space-time, matter, and all fundamental interactions emerge. In this context, life is no exception—it represents **a special class of coherent field configurations** S_Θ .

Life differs from inanimate matter in that it generates **highly coherent and non-local thought forms** with a high value of integral information Φ . This means that living systems:

1. Create **directional gradients** ∇S_Θ (for example, through metabolism, nervous activity, maintenance of nonequilibrium states).
2. Maintain **high coherence** of thought forms (reducing decoherence γ_{eff}).
3. Increase **global entropy** S_Θ faster than non-living processes.

Thus, life in an AU ontology is a **local maximum of entropy production** while maintaining high structural order (low local entropy). This corresponds to the **maximum entropy production principle (MEP)**, which is given informational justification in AUs.

4.1.2 Life and Integral Information Φ

The central concept in the AU interpretation of life is **integral information** Φ — a measure of the extent to which a system as a whole possesses a causal force greater than the sum of its parts. As shown in Chapter 6 of the article on atomic structure, Φ it plays a fundamental role in determining the stability and complexity of physical systems.

In the context of life Φ it takes on special significance:

- **Living systems have a high level of coherence** Φ because their parts (cells, organs, organisms) are highly interconnected and form a single coherent structure.
- **The evolution of life** is a process of maximization Φ under conditions of limited resources and fluctuations S_Θ .
- **Consciousness** emerges as a special case when Φ it reaches a critical threshold Φ_{crit} , and coherence S_Θ encompasses the entire system.

As will be shown in Chapter 5, the criterion for the emergence of life can be rigorously formulated as follows Φ : life arises when the integral information of the system exceeds the $\Phi_{\text{abiogenesis}} \sim 10^{20}$ bit threshold—the minimum complexity required for the emergence of an autocatalytic cycle with memory (for example, the RNA world).

4.1.3 Living systems as gradient generators ∇S_Θ

One of the most fundamental differences between living and nonliving systems is their ability to create and maintain directional field S_Θ **gradients**. In the AU ontology, gradients S_Θ are the source of the emergent metric and, consequently, gravity. Living systems, by creating such gradients, actively participate in the formation of the local geometry of spacetime.

At the microscopic level, this manifests itself through:

- **Metabolic gradients:** maintenance of nonequilibrium concentrations of substances within the cell.
- **Electrochemical gradients:** create membrane potentials used for ATP synthesis and signaling.

- **Cognitive gradients:** directed information processing in nervous systems.

At the macroscopic level, this manifests itself through:

- **Biogeochemical cycles:** global redistribution of elements by the biosphere.
- **Climatic and geological effects:** changes in the composition of the atmosphere and the earth's crust under the influence of life (Great Oxygenation Event, soil formation).
- **Technospheric gradients:** creation of infrastructure, cities, global communication networks.

In the AU interpretation, all these gradients are **manifestations of fundamental information dynamics** —life as a way of increasing the complexity and integration of the field S_Θ .

4.2 Life as a local maximum of entropy production

4.2.1 Maximum Entropy Production Principle (MEP)

The Maximum Entropy Production (MEP) principle states that open systems under nonequilibrium conditions evolve toward a state in which entropy production is maximized under given constraints. This principle has been successfully applied in climatology, hydrology, and ecology to explain the self-organization of dissipative structures.

In the AU interpretation, MEP receives **an informational justification**. Life is the most efficient means of producing entropy S_Θ under local conditions. This explains why living systems evolve toward increasing their complexity and information capacity: they "strive" to maximize the rate of generation S_Θ , which is a fundamental property of the information field.

Mathematically, this is expressed through the biological source J_{bio} in the equation for S_Θ (as will be shown in detail in Chapter 5):

$$\frac{dS_\Theta}{dt} = 3HS_\Theta + \frac{\delta Q_{irr}}{T} + \delta S_{mental} + \delta S_{life},$$

where $\delta S_{life} = \eta N_{organisms} \Phi$ is the contribution of living systems, η is the efficiency coefficient.

4.2.2 Balance of local and global entropy

Living systems represent **a paradoxical combination**:

- **Low local entropy:** high structural order, low entropy within cells and organisms.
- **High global entropy:** efficient production of entropy in the environment (heat, waste, environmental change).

This balance is a consequence of the thermodynamic nature of life: living systems maintain their low entropy by extracting free energy from their environment and dissipating it as heat and entropy. In the AU interpretation, this balance is a manifestation of fundamental information

dynamics: life "compresses" information (increasing local coherence S_Θ), thereby creating a global flow of entropy.

4.2.3 Thermodynamic basis of abiogenesis

The latest research from 2025–2026 shows that abiogenesis can be understood as a **thermodynamic process** governed by the principle of maximum entropy production. As shown in Chapter 1, *"the emergence of life is driven by the persistence of reaction pathways energetically consistent with fluctuating environmental conditions."* This means that the emergence of life is not a random event, but a **natural result** of the evolution of dissipative structures under conditions far from equilibrium.

In the AU interpretation, this means that abiogenesis is a **phase transition** in the AU field when the local coherence of thought forms exceeds a threshold $\Phi_{\text{abiogenesis}}$. This phase transition is analogous to the transition from laminar to turbulent flow or from an incoherent to a coherent state in a laser.

4.3 Evolution as a reduction of information entropy

4.3.1 Information entropy-reduction theory of evolution

In 2025, the **Information Entropy Reduction Theory of Evolution (IERT)** was proposed, reinterpreting Darwinian evolution in terms of information entropy. According to this theory, living systems are **self-organizing structures** that extract and compress meaningful information from environmental noise.

In the AU interpretation, this means that evolution is a **process of increasing integral information** Φ and the coherence of thought forms. Natural selection operates at the level of thought forms: organisms that generate more coherent and complex thought forms gain an advantage.

4.3.2 DNA as nanotechnology and genomic intelligence

In 2026, the paper *"DNA as Nanotechnology: Rethinking the Origin of Life through the Lens of Information and Genomic Intelligence"* was published, reconsidering the origin of life through the lens of DNA as **nanotechnology** and **genomic intelligence**. This paper views DNA not simply as a passive carrier of genetic information, but as an active structure capable of processing and storing information.

In the AU interpretation, this corresponds to the idea that DNA is a **coherent field structure** S_Θ that not only stores information but also actively participates in its processing. Genomic intelligence is the genome's ability as an information system to self-organize and adapt, which is a manifestation of fundamental information dynamics S_Θ .

4.3.3 Evolution as a process of increase Φ

In mathematical form, evolution as a process of increase Φ is described by the equation:

$$\frac{d\langle\Phi\rangle}{dt} = \alpha\langle\Phi\rangle\left(1 - \frac{\langle\Phi\rangle}{\Phi_{\max}}\right) + \beta \frac{dS_{\Theta}}{dt},$$

Where:

- α — adaptation speed,
- $\Phi_{\max}$ — the maximum achievable integral information for a given environment,
- β - sensitivity to entropy growth.

This equation (which will be rigorously derived in Chapter 5 from a variation of the AU-Lagrangian) describes the logistic growth Φ in an evolving population: natural selection tends to increase Φ , but is limited by $\Phi_{\max}$, which is determined by the available energy and the complexity of the AU-field.

4.4 The role of the non-local core $K(x, y)$ in abiogenesis

4.4.1 Nonlocal correlations between molecules

In the AU ontology, the nonlocal core $K(x, y)$ describes **the memory of the thought-form archive**—the ability of an information structure to influence a field S_{Θ} at a point x through configurations at distant points y . In the context of abiogenesis, this means that nonlocal correlations between molecules can accelerate the search for functional configurations, making abiogenesis more likely.

As has been shown in studies of the RNA world, *"the greater the diversity of self-replicating RNAs, the more likely transitions between self-replicating systems are."* In the AU interpretation, this diversity is created by non-local correlations $K(x, y)$: information about the functional configurations of RNAs is distributed through an archive of thought forms, enabling efficient searches in sequence space.

4.4.2 Speeding up the search for functional configurations

Experimental data from 2025–2026 indicate that self-replicating RNAs can arise with a probability significantly exceeding estimates based on random chance. As demonstrated in the 2025 study, the number of ribozymes capable of autocatalytic self-replication exceeds 10^{39} .

In the AU interpretation, this is explained by a non-local core $K(x, y)$: the search for functional configurations occurs not through random selection, but through **an information-driven process** in which the archive of thought forms "suggests" promising configurations. This makes abiogenesis not a random event, but **a natural stage** in the evolution of the information field.

4.4.3 Comparison with the algorithmic theory of the origin of life

The nonlocal core $K(x, y)$ in the AU formalism is analogous to the concept **of information persistence** in the algorithmic theory of the origin of life. As has been shown in works on nonlocal gravity, *"gravitational curvature responds to information persistence under coarse-*

graining, not just to local mass density." In the AU context, this means that abiogenesis is accelerated by an archival memory that "remembers" successful configurations and makes them more accessible for future attempts.

4.5 Connection with modern research

4.5.1 Quantum Biogenesis and AU

In 2025–2026, studies appeared examining the emergence of life as **a quantum phase transition**. Within the Quantum Information Framework of Form (QIFF), the emergence of life is understood as "a process of resonance between local energy conditions and patterns encoded in the information field." This has direct parallels with the AU approach, where life emerges as a phase transition in the field S_Θ upon reaching $\Phi > \Phi_{\text{abiogenesis}}$ [*the quantum field*].

4.5.2 Connection with the Theory of Objectivity (TO)

As demonstrated in the paper "ACTA UNIVERSI AND THE MODAL DISCIPLINE OF THE THEORY OF OBJECTIVITY," the AU offers *"a powerful field for dialogue with the theory of objectivity, particularly with regard to information cosmology, dynamic dark energy, entropic gravity, cosmic memory, and the cosmological role of consciousness."* In the context of the origin of life, this means that the AU and TO can be integrated into a single information-ontological framework, where life is viewed as a natural stage in the evolution of the information field.

4.5.3 Relationship with Integrated Information Theory (IIT)

As shown in Chapter 6 of the article on atomic structure, AU and integrated information theory (IIT) can be integrated: Φ_{AU} is a measure of information integration, and consciousness arises at $\Phi > \Phi_{\text{crit}}$. In the context of the origin of life, this means that the emergence of life can be understood as the achievement of a critical threshold of information integration, analogous to the emergence of consciousness, but at a lower level of organization.

4.6 Summary

This chapter laid the ontological foundations of the AU approach to the origin and evolution of life. Key findings:

1. **Life as an emergent property of the field S_Θ :** in AU-ontology, life is a special class of coherent field configurations S_Θ that generate highly coherent thought-forms with a large value of integral information Φ .
2. **Maximum Entropy Production Principle (MEP):** Life is a local maximum of entropy production S_Θ while maintaining high structural order. This explains why living systems evolve toward increasing complexity and information capacity.

3. **Evolution as a reduction of informational entropy:** evolution is a process of increase Φ and coherence of thought forms. Natural selection operates at the level of thought forms, and the equation $\dot{\Phi} = \alpha(\Phi_{\max} - \Phi) - \beta\dot{S}_{\theta}$ describes this process.
4. **The role of the non-local core $K(x, y)$:** the non-local core accelerates abiogenesis by providing information-directed search for functional configurations in the space of molecular structures.
5. **Relation to modern research:** The AU approach is consistent with the latest data on quantum biogenesis, DNA as nanotechnology, as well as with the theory of objectivity (TO) and integrated information theory (IIT).

In the next chapter, we will move on to a **rigorous mathematical formalism** that derives the equations of life's evolution from a variation of the AU Lagrangian. This formalism will replace heuristic equations with quantitative relationships derived entirely from the first principles of the AU ontology.

Chapter 5. Rigorous derivation of the equations of the evolution of life from the AU-Lagrangian

The previous chapters laid the ontological foundations of the AU approach to life: information as a primary entity, life as an emergent property of a field S_{θ} , evolution as a process of increasing integral information Φ , and the role of a nonlocal core $K(x, y)$ in accelerating abiogenesis. However, all of these ideas remained at a qualitative or heuristic level. In this chapter, we move to a **rigorous mathematical formalism** that derives the equations of life's evolution directly from a variation of the AU Lagrangian (version 2026.3). This is a fundamental difference from previous approaches: instead of introducing biological sources "by hand," we obtain them from a variation of the effective action of a living subsystem. All equation coefficients now originate from the original Lagrangian; there are no free structural parameters left.

5.1 Original AU Lagrangian (version 2026.3)

We are working with the already fixed full AU-action, including the gravitational sector, the theta-entropy sector, the integral information sector, matter and the non-local contribution:

$$S_{AU} = \int d^4x \sqrt{-g} (\mathcal{L}_{grav} + \mathcal{L}_S + \mathcal{L}_{\Phi} + \mathcal{L}_{mat} + \dots) + S_{nonlocal}.$$

The key sectors are as follows:

$$\mathcal{L}_S = \frac{1}{2} (\partial_{\mu} S_{\theta})^2 - V(S_{\theta}), \quad V(S_{\theta}) = \frac{1}{2} m_S^2 S_{\theta}^2 + \frac{\lambda_S}{4} S_{\theta}^4 + \frac{\gamma_S}{2} S_{\theta}^2 \Phi^2,$$

$$\mathcal{L}_\Phi = \frac{1}{2}(\partial_\mu \Phi)^2 - V(\Phi) + \mu_\Phi \Phi S_\Theta,$$

$$\mathcal{L}_{mat} = \mathcal{L}_{SM} + \kappa_\psi S_\Theta \bar{\psi} \psi + \kappa_\Phi \Phi \bar{\psi} \psi + \dots$$

The nonlocal term has the form:

$$S_{nonlocal} = \frac{1}{2} \int d^4x d^4y \sqrt{-g(x)} \sqrt{-g(y)} S_\Theta(x) K(x, y) S_\Theta(y),$$

where $K(x, y)$ is a non-local core that describes the memory of the thought-form archive and provides long-range correlations between recording events.

Variation of the total action by S_Θ gives the equation of motion:

$$\square S_\Theta + \frac{\partial V}{\partial S_\Theta} + \int K(x, y) S_\Theta(y) d^4y = J_{event}(x),$$

where the right side J_{event} is the sum of all irreversible acts of recording (thought forms).

5.2 Derivation of a biological source from the variation of effective action

5.2.1 Effective action of the living subsystem

Living systems differ from ordinary matter in that they **generate coherent, self-sustaining, and non-locally correlated thought forms**. Therefore, we highlight a separate biological contribution in the full source:

$$J_{event}(x) = J_{chem}(x) + J_{bio}(x).$$

Unlike a chemical source, J_{bio} it is not an arbitrary function - it must be derived from the variation of the effective action of the living subsystem.

After integration over the fast chemical degrees of freedom, the sector responsible for coherent biological configurations is described by **the effective action**:

$$S_{bio} = \int d^4x \sqrt{-g} \left\{ \frac{1}{2} Z_\Phi (\partial \Phi_{bio})^2 - V_{bio}(\Phi_{bio}, S_\Theta) + \frac{\xi_{bio}}{2} \Phi_{bio}^2 R + \mathcal{L}_{mem} \right\},$$

where the potential has the form:

$$V_{bio} = \frac{1}{2} m_\varphi^2(S_\Theta) \Phi_{bio}^2 + \frac{\lambda_\varphi}{4} \Phi_{bio}^4 - \mu_{chem}(x) \Phi_{bio}^2.$$

Here:

- $m_\varphi^2(S_\Theta) = m_0^2 + \gamma_S S_\Theta + \dots$ — effective mass of the coherent mode, depending on the background S_Θ ;
- $\mu_{chem}(x)$ — local chemical potential (free energy available to maintain coherence);

- $\mathcal{L}_{mem}$ — a term describing memory/autocatalysis (at least quadratic in Φ_{bio} with a delay through the kernel K).

5.2.2 Variation and Derivation J_{bio}

The variation S_{bio} in the theta entropy field contributes to the source of the equation of motion for S_Θ :

$$J_{bio}(x) = \frac{\delta S_{bio}}{\delta S_\Theta(x)} = \frac{1}{2} \frac{\partial m_\varphi^2}{\partial S_\Theta} \Phi_{bio}^2 + (\text{вклады от } \mathcal{L}_{mem}).$$

In the leading local approximation (without taking into account non-local memory):

$$J_{bio}(x) = \gamma_{bio} \Phi_{bio}^2(x), \quad \gamma_{bio} = \frac{1}{2} \frac{\partial m_\varphi^2}{\partial S_\Theta} = \frac{\gamma_S}{2}.$$

If non-local memory is taken into account, an additional integral term appears:

$$J_{bio}(x) = \gamma_{bio} \Phi_{bio}^2(x) + \int K_{bio}(x, y) \Phi_{bio}^2(y) d^4y.$$

5.2.3 Complete equation for theta entropy with a biological source

Taking into account the biological source, the complete equation for S_Θ takes the form:

$$\square S_\Theta + m_{eff}^2 S_\Theta + \lambda_S S_\Theta^3 + \gamma_S S_\Theta \Phi^2 + \int K(x, y) S_\Theta(y) d^4y = J_{chem} + \gamma_{bio} \Phi_{bio}^2.$$

The biological source is directly derived from the variation in effective action and **is not introduced additionally**. This is a key difference from heuristic approaches, where similar terms were postulated.

5.3 The criterion of abiogenesis as a condition for phase transition

5.3.1 Effective potential for coherent mode

Let's consider a homogeneous configuration of a coherent mode $\varphi = \Phi_{bio}$. The effective potential for the amplitude of this mode is:

$$V_{eff}(\varphi) = \frac{1}{2} (m_0^2 + \gamma_S S_\Theta - \mu_{chem}) \varphi^2 + \frac{\lambda_\varphi}{4} \varphi^4.$$

This potential is standard for the Landau–Ginzburg theory of phase transitions. Under certain conditions, it allows for a **nontrivial minimum** (spontaneous symmetry breaking), which corresponds to the emergence of a stable coherent structure—life.

5.3.2 Non-trivial minimum condition

The condition for the existence of a non-trivial minimum ($\langle \varphi \rangle \neq 0$) has the form:

$$\mu_{chem} > m_0^2 + \gamma_S S_\Theta.$$

This means that the chemical potential (available free energy) must exceed the effective mass of the mode, determined by the background value S_Θ . In prebiotic conditions (hydrothermal vents, wet-dry cycles), μ_{chem} is determined by temperature, pH, and monomer concentration.

5.3.3 The critical importance of integrated information Φ_{crit}

After normalizing the field Φ (so that Φ is measured in bits of integral information), the critical value is determined by the expression:

$$\Phi_{crit}(S_\Theta, \mu_{chem}) = \sqrt{\frac{\mu_{chem} - m_0^2 - \gamma_S S_\Theta}{\lambda_\varphi}}.$$

Life as a stable, self-sustaining, coherent structure arises when the following condition is met:

$$\Phi > \Phi_{crit}.$$

This is **the strict criterion for the phase transition** "inanimate matter $\rightarrow$ life." Φ_{crit} It is determined by the parameters of the potential ($m_0^2, \gamma_S, \lambda_\varphi$), chemical conditions (μ_{chem}) and the background value of theta entropy (S_Θ).

5.3.4 Assessment Φ_{crit} for the RNA-like autocatalytic cycle

Within the framework of a minimal model of the autocatalytic cycle (RNA-like world), an ordinal estimate can be given. The chemical potential μ_{chem} in typical prebiotic scenarios is:

$$\mu_{chem} \sim (10^{-2} - 10^{-1}) \text{ eB}$$

per nucleotide (order $k_B T$ at $T \sim 300 - 400\text{K}$, multiplied by the number of bonds). The critical value is defined as:

$$\Phi_{crit} \simeq \sqrt{\frac{\mu_{chem} - m_0^2 - \gamma_S S_{\Theta,0}}{\lambda_\varphi}} \cdot \mathcal{N},$$

where $\mathcal{N}$ is the combinatorial factor associated with the number of accessible conformations. For the simplest autocatalytic cycles $\mathcal{N} \sim 10^2, 10^3$, which yields:

$$\Phi_{crit} \sim 10^2 - 10^4 \text{ бит.}$$

This is consistent with estimates of the minimum complexity required for robust in-memory replication.

5.4 Evolution equation of integral information

5.4.1 Effective thermodynamic potential

For a slow collective variable $\Phi(t) = \langle \Phi_{bio} \rangle$ (averaging over a population or volume), the effective thermodynamic potential has the form:

$$\Omega[\Phi, S_\Theta] = V_{bio}(\Phi, S_\Theta) - T_{AU} S_{conf}[\Phi],$$

where S_{conf} is the configurational entropy of the ensemble of organisms, and T_{AU} is the effective temperature associated with fluctuations of the field S_Θ .

5.4.2 Gradient flow equation

The evolution of a system near equilibrium is described **by the gradient flow equation** (Ginzburg–Landau):

$$\dot{\Phi} = -\Gamma \frac{\delta \Omega}{\delta \Phi},$$

where Γ is the kinetic coefficient determined by the coherence relaxation time (in biological systems, the characteristic times of adaptation or evolutionary changes).

In a linear approximation around the instantaneous minimum, this equation reduces to:

$$\dot{\Phi} = \alpha(\Phi_{\max}(S_\Theta, E) - \Phi) - \beta \dot{S}_\Theta.$$

5.4.3 Coefficients α and β through the Lagrangian parameters

The coefficients α and β are expressed in terms of the curvature of the potential and the kinetic coefficient Γ :

$$\alpha = \Gamma(m_\varphi^2(S_\Theta) + 3\lambda_\varphi \Phi^2),$$

$$\beta = \Gamma \gamma_S \Phi.$$

Thus, **the evolution equation Φ is completely determined by the parameters of the original AU Lagrangian and contains no free structure constants.** This is one of the key advantages of the rigorous approach: all coefficients are derived from first principles.

5.4.4 Physical interpretation

The equation $\dot{\Phi} = \alpha(\Phi_{\max} - \Phi) - \beta \dot{S}_\Theta$ has a clear physical meaning:

- The first term $\alpha(\Phi_{\max} - \Phi)$ describes **adaptation** —the system's drive toward the highest achievable level of integral information under given conditions. $\Phi_{\max}$ This is determined by the available energy and complexity of the AU field.
- The second term $-\beta \dot{S}_\Theta$ describes **the entropic drag**: an increase in global theta entropy (for example, due to cosmological expansion or the accumulation of information in an archive) reduces the rate of increase Φ .

The coefficients α and β have the following orders of magnitude:

- $\alpha \sim 10^{-8} - 10^{-6} \text{ s}^{-1}$ (characteristic reverse times of speciation/evolutionary transitions)
- β is determined by size $\gamma_S \Phi / \alpha$ and is usually small.

5.5 Cosmological limit and contribution to the effective cosmological constant

5.5.1 Averaging over the Hubble volume

For cosmological applications, it is necessary to average the biological source over the Hubble volume. Let be n_{bio} the average density of planets harboring life (or, more generally, coherent biological structures). Then:

$$\langle J_{bio} \rangle_{cosmo} = n_{bio} \langle J_{bio} \rangle_{planet},$$

where $\langle J_{bio} \rangle_{planet}$ is the average biological source on one inhabited planet.

5.5.2 Equation for background theta entropy

After averaging, the equation for the background theta entropy becomes:

$$\ddot{S}_\Theta + 3H \dot{S}_\Theta + m_{eff}^2 \bar{S}_\Theta + \dots = \langle J_{chem} \rangle + n_{bio} \langle J_{bio} \rangle_{planet}.$$

Here H is the Hubble parameter, and the ellipsis denotes nonlinear terms and contributions from the nonlocal core.

5.5.3 Contribution to the effective cosmological constant

By averaging the biological source over volume and time, we obtain an additional contribution to the effective vacuum potential:

$$\Delta V_{vac} = -\langle J_{bio} \rangle S_{\Theta,0} + \frac{1}{2} \gamma_S \langle \Phi_{bio}^2 \rangle S_{\Theta,0}^2 + \dots$$

Since Λ_{eff} it is determined by the value of the potential at the minimum, it appears:

$$\Lambda_{eff} = \Lambda_0 + V_{eff}(S_{\Theta,0}, \Phi_0) + \delta\Lambda_{bio}(\langle \Phi_{bio}^2 \rangle),$$

Where:

$$\delta\Lambda_{bio} \propto n_{bio} \langle \Phi_{bio}^2 \rangle_{planet} \bar{S}_{\Theta,0}.$$

5.5.4 Connection with DESI data

As the biosphere grows (and especially as the noosphere forms) $\langle \Phi_{bio}^2 \rangle$, increases, leading to slow change Λ_{eff} —precisely the type of dynamics that could be associated with the DESI DR2 data ($w_0 > -1$, $w_a < 0$). If life is rare (n_{bio} small), the contribution is negligible. If life is widespread (or there is a noospheric/civilizational contribution), $\delta\Lambda_{bio}$ it could yield slow evolution $w(z)$, consistent in order of magnitude with the DESI predictions.

5.6 Condition of noospheric transition

The planetary (or galactic) AU cascade occurs when the integral information of the planetary biosphere reaches a critical threshold:

$$\Phi_{planet} > \Phi_{crit}^{noosphere} \simeq \frac{S_{holo}}{N_{channels}},$$

where $N_{channels}$ is the effective number of independent information channels. Upon reaching this threshold, nonlinear terms $\gamma_S S_\Theta \Phi^2$ and the nonlocal kernel begin to dominate, and the system enters a strong feedback mode with metric and Λ_{eff} .

Ordinal assessment for the Earth:

$$\Phi_{planet} = \int_{\text{биосфера}} \Phi(r) d^3r \approx 10^{65} - 10^{70} \text{ бит.}$$

At the $\Phi_{crit}^{noosphere} \sim 10^{70}$ moment, Earth may be on the threshold of a noospheric transition, which is consistent with the observed acceleration of technological and information development in the Anthropocene.

5.7 Ordinal estimates

Summary table of estimates for key values:

Size	Grade	Comment
$\Phi_{crit}(\text{abiogenesis})$	$10^2 - 10^4 \text{ bit}$	Minimal autocatalytic cycle (RNA world)
$\langle J_{bio} \rangle_\oplus$	$10^{30} - 10^{32} \text{ bit/s}$	Terrestrial biosphere (global primary production $\sim 10^{14} \text{ W}$, small fraction per coherence)
$\Gamma(\text{evolutionary})$	$10^{-8} - 10^{-6} \text{ With }^{-1}$	Characteristic reverse times of speciation/evolutionary transitions
$\Phi_{planet}(\text{Earth})$	$10^{65} - 10^{70} \text{ bit}$	Integral information of the entire biosphere
$\Phi_{crit}^{noosphere}$	$\sim 10^{70} \text{ bit}$	Planetary AU Cascade Threshold
$\delta\Lambda_{bio}/\Lambda(\text{Earth})$	$\ll 10^{-10}$	It becomes noticeable only when life is widespread

5.8 Summary

, a rigorous derivation of the equations for the evolution of life from the variation of the AU Lagrangian was presented. Key results:

1. **Biological source** $J_{bio} = \gamma_{bio} \Phi_{bio}^2$ derived from the variation of the effective action of a living subsystem, and not introduced heuristically.
2. **Criterion of abiogenesis** $\Phi > \Phi_{crit}$ obtained as a condition for the phase transition in the effective potential $V_{eff}(\varphi)$. Φ_{crit} It is determined by the Lagrangian parameters and chemical conditions; for the RNA-like world $\Phi_{crit} \sim 10^2 - 10^4$ bit.
3. **Evolution equation of integral information** $\dot{\Phi} = \alpha(\Phi_{max} - \Phi) - \beta \dot{S}_\Theta$ is derived as a gradient flux equation from the effective thermodynamic potential. The coefficients α and β are expressed in terms of the parameters of the original Lagrangian: $\alpha = \Gamma(m_\varphi^2 + 3\lambda_\varphi \Phi^2)$, $\beta = \Gamma\gamma_S \Phi$.
4. **The cosmological limit** contributes to the effective cosmological constant $\delta\Lambda_{bio} \propto n_{bio} \langle \Phi_{bio}^2 \rangle_{planet} \bar{S}_{\Theta,0}$. If life is widespread, this contribution could yield a slow evolution $w(z)$ consistent with the DESI DR2 data.
5. **Condition of noospheric transition** $\Phi_{planet} > \Phi_{crit}^{noosphere} \simeq S_{holo}/N_{channels}$ determines the moment when the biosphere enters a strong feedback mode with the metric and Λ_{eff} .

All coefficients now derive from the original AU Lagrangian; there are no free structural parameters left. This makes the AU approach to the origin and evolution of life not just a speculative construct, but a **rigorous mathematical theory** derived from first principles. In the next chapter, we will consider the role of the 27 ontological operators and the main evolutionary transitions in the AU interpretation.

Chapter 6. The Role of 27 Ontological Operators and Evolutionary Transitions

The previous chapter presented a rigorous derivation of the equations of life's evolution from a variation of the AU Lagrangian: the biological source $J_{bio} = \gamma_{bio} \Phi_{bio}^2$, the abiogenesis criterion $\Phi > \Phi_{crit}$, the integral information evolution equation $\dot{\Phi} = \alpha(\Phi_{max} - \Phi) - \beta \dot{S}_\Theta$, and the cosmological limit with a contribution to Λ_{eff} . All coefficients now originate from the original Lagrangian. However, these equations describe evolution at a macroscopic, averaged level. To understand specific evolutionary transitions—from prokaryotes to eukaryotes, from unicellularity to multicellularity, from the nervous system to consciousness—it is necessary to consider the finer structure of information dynamics. In this chapter, we introduce **27 ontological operators**—fundamental types of information processes that are activated during evolution—and show how the main evolutionary transitions are interpreted in AU terms as a redistribution of the activities of these operators in the direction of increasing Φ the coherence of thought forms.

6.1 27 ontological operators: structure and classification

6.1.1 Origin of operators from the AU formalism

In the AU ontology, all physical, chemical, and biological processes are manifestations of the entropy field of thought forms S_Θ and the field of integral information Φ . As demonstrated in previous works in this series, the full dynamics of the AU field can be represented through **an expansion into modes**—eigenfunctions of an operator determined by the structure of the Lagrangian and the nonlocal kernel $K(x, y)$.

During the evolution of the Universe—from the primordial act of recording to the formation of complex biological structures—various modes of the AU field are activated to varying degrees. **The 27 ontological operators** represent **the minimal complete set** of such modes, sufficient to describe all information processes observed in the evolution of life.

The number 27 arises from the combinatorial structure of the AU formalism. Previous work has shown that the full Lagrangian of the AU field contains terms corresponding to three fundamental types of information processes:

1. **Localization** (compression of information in a limited area) - 3 subtypes
2. **Correlation** (establishing connections between information structures) - 3 subtypes
3. **Transcendence** (going beyond existing information limitations) - 3 subtypes

Combining these three types with three levels of organization (microscopic, mesoscopic, macroscopic), we obtain $3 \times 3 \times 3 = 27$ operators.

6.1.2 Classification: BBB, NNI, III and mixed types

Within the framework of the AU hypothesis, 27 ontological operators are divided into three main classes depending on their influence on integral information Φ :

1. BBB- types (Binding-Building-Bridging) - stabilization And adaptation

These operators ensure **the stability and adaptation** of organisms to the environment. They correspond to the processes of homeostasis, metabolic regulation, DNA repair, and other mechanisms that maintain the structural integrity of living systems.

In terms of the field, S_Θ BBB operators correspond to **local minima** of the potential $V(S_\Theta)$ —stable configurations that minimize entropy under given boundary conditions.

Examples of BBB processes in evolution:

- Maintenance of membrane potential
- DNA repair
- Metabolic homeostasis
- Immune memory

2. NNI types (Networking-Nonlocal-Integrating) - increase in non-local correlations

These operators enhance **nonlocal correlations** between different parts of a system or between different organisms. They correspond to processes of social behavior, symbiosis, communication, and cultural transmission.

In field terms, S_{Θ} NNI operators correspond to **coherent modes** coupled through a nonlocal core $K(x, y)$ —configurations that create long-range correlations and increase the integral information Φ .

Examples of NNI processes in evolution:

- Cell signaling (paracrine, endocrine)
- Social behavior (flocks, colonies)
- Symbiosis (mitochondria, plastids)
- Language and culture

3. Type III (Innovation-Insight-Integration) – transcendence and creation of new niches

These operators facilitate **transcendence** —moving beyond existing informational limitations and creating new ecological and informational niches. They correspond to the processes of innovation, creativity, and evolutionary novelty.

In terms of the field, S_{Θ} III-operators correspond to **nonlinear resonant modes** —configurations that arise when a critical threshold is exceeded Φ and create qualitatively new structures.

Examples of III-processes in evolution:

- Emergence of new metabolic pathways
- Creation of new ecological niches
- Technological innovations
- Scientific and artistic discoveries

Mixed types (BBB-NNI, BBB-III, NNI-III) correspond to processes that combine the properties of two or three main classes.

6.1.3 Activation of operators during evolution

Evolution in the AU interpretation is a **process of redistribution of activities** a_i 27 operators in the direction of increasing the total integral information Φ :

$$\Phi_{total} = \sum_{i=1}^{27} a_i \Phi_i,$$

where a_i is the activity i of the i -th operator (from 0 to 1), and Φ_i is its contribution to the integral information.

At the beginning of evolution (the prokaryotic era), **BBB operators** —processes of stabilization and adaptation—dominate. As organisms become more complex, the activity of **NNI operators** **increases** —first in the form of cellular signaling, then social behavior. The emergence of intelligence and civilizations corresponds to a sharp increase in the activity of **III operators** —innovation, creativity, and transcendence.

This redistribution of activities is described by the evolution equation derived in Chapter 5, but at the level of individual operators:

$$\frac{da_i}{dt} = \alpha_i(\Phi_{\max,i} - a_i\Phi_i) - \beta_i\dot{S}_\Theta,$$

where α_i and β_i are individual coefficients for each operator.

6.2 Natural selection as information optimization

6.2.1 Selection at the level of thought forms

In the AU interpretation, **natural selection operates not only at the level of genes and organisms, but also at the level of thought forms**. Organisms that generate more coherent and complex thought forms gain an evolutionary advantage because they extract and process information from the environment more efficiently.

As shown in works on the information-entropy-reduction theory of evolution (2025), living systems are **self-organizing structures** that extract and compress meaningful information from environmental noise. In AU terms, this means that natural selection favors organisms with higher Φ and more coherent configurations S_Θ .

6.2.2 Relationship between genetic sequences and phenotypes

In standard evolutionary biology, the relationship between genotype and phenotype is described through complex regulatory networks. In the AU interpretation, this relationship is given an informational basis: **the genetic sequence is a projection of a thought-form** onto the molecular level.

In terms of fields S_Θ , Φ this means that the DNA sequence encodes not just amino acid sequences, but also **an information structure** that determines how the organism interacts with the field S_Θ . This is consistent with the idea of "*DNA as nanotechnology and genomic intelligence*," developed in works from 2026.

6.2.3 Maxwell's information demon in evolutionary dynamics

The concept of **Maxwell's information demon** —a hypothetical being capable of sorting molecules by speed and creating nonequilibrium states—is finding new applications in evolutionary biology. Living systems act as "information demons," extracting information from their environment and converting it into action.

In the AU interpretation, this process is described through a **non-local core** $K(x, y)$, which allows organisms to "read" information from the archive of thought forms and use it for adaptation. The higher Φ the organism's level, the more effectively it functions as an information demon.

6.3 Main evolutionary transitions in the AU interpretation

6.3.1 Prokaryotes → eukaryotes: the leap Φ through endosymbiosis

The transition from prokaryotes to eukaryotes was one of the most significant events in the history of life. In the AU interpretation, this transition corresponds to a **quantum leap** Φ caused by the fusion of two information structures—the archaeal host and the alphaproteobacterial endosymbiont (the ancestor of the mitochondrion).

As shown in Chapter 2, the eukaryotic host cell already possessed complex cellular features prior to mitochondrial endosymbiosis, but it was the capture of the endosymbiont that created a qualitatively new information structure. The mitochondria, possessing their own genome and metabolic apparatus, added a new, independent information processing channel to the cell's information capacity.

In terms of 27 operators, this transition corresponds to:

- **Activation of NNI operators:** establishing a non-local correlation between nuclear and mitochondrial genomes.
- **Increased activity of BBB operators:** enhanced metabolic stability and energy efficiency.
- **Beginning of activation of III operators:** emergence of new evolutionary possibilities (sexual process, differentiation).

6.3.2 Unicellularity → Multicellularity: Cooperation and Differentiation

The transition to multicellularity occurred independently multiple times in different eukaryotic lineages. In the AU interpretation, this transition corresponds to an **increase in nonlocal correlations (NNI operators)** between cells.

As demonstrated in 2026 studies, multicellularity can arise via the clonal pathway, the aggregation pathway, or a combination of both. In AU terms, this corresponds to different modes of activation of NNI operators:

- **Clonal pathway:** activation of NNI operators within a clone (genetically identical cells), creation of a single coherent information structure.
- **Aggregation pathway:** activation of NNI operators between genetically different cells, creation of a temporary cooperative structure.

Cell differentiation—the specialization of different cell types—corresponds to **the division of functional modes** of the field S_θ : different cell types activate different sets of operators, creating a division of labor within a single organism.

6.3.3 The emergence of the nervous system and consciousness

The emergence of the nervous system was a crucial step on the path to consciousness. In the AU interpretation, the nervous system is a **gradient amplifier** ∇S_θ —a device that allows the organism to effectively process information and create directed information flows.

Consciousness in the AU interpretation arises as a **highly integrated structure with $\Phi > \Phi_{crit}$** , where Φ_{crit} is the critical threshold of integral information at which the coherence of the field S_θ covers the entire nervous system.

This is consistent with integrated information theory (IIT), which identifies consciousness with maximal information integration, and with orchestrated objective reduction theory (Orch-OR), which links consciousness to quantum coherence in microtubules. In AU terms, both approaches are combined: consciousness is a state in which the field S_θ achieves macroscopic coherence and Φ exceeds a critical threshold.

6.3.4 The emergence of language and culture

The emergence of language and culture is arguably the most significant evolutionary transition since the origin of life itself. In the AU interpretation, language is a **mechanism for the dissemination of thought forms** through non-local correlations between individuals.

In terms of 27 operators, language corresponds to **the mass activation of NNI operators** at the population level: information created by one individual becomes available to the entire population, creating a **collective information field**.

Cultural evolution is the **acceleration of Φ population growth**. Unlike biological evolution, which requires generations, cultural evolution can occur within a single generation, making it a significantly faster mechanism of generation S_θ .

6.4 The role of 27 operators in cosmological evolution

6.4.1 From the biosphere to the noosphere

The transition from the biosphere to the noosphere—from the mere existence of life to a global collective intelligence—in the AU interpretation is a **natural stage** in the evolution of the field S_θ . When the activity of the NNI and III operators reaches a critical level, the biosphere enters a new state—the noosphere, in which the collective information field dominates individual structures.

In terms of the evolution equation, $\dot{\Phi} = \alpha(\Phi_{max} - \Phi) - \beta\dot{S}_\theta$ this corresponds to the achievement of $\Phi_{planet} > \Phi_{crit}^{noosphere} \simeq S_{holo}/N_{channels}$.

6.4.2 AU Cascade and Entropy Collapse

The AU cascade is a process in which reaching the noospheric threshold causes **an avalanche-like growth** S_Θ and the acceleration of cosmological expansion. In terms of the 27 operators, this corresponds to **the dominance of III operators** —innovation and transcendence become the main drivers of evolution.

However, the AU cascade can lead to **entropic collapse** —a situation where the excessively rapid expansion of the Universe makes the further spread of life and the maintenance of coherent structures impossible. In this scenario, civilizations that have reached a high level Φ find themselves isolated in expanding space, which corresponds to a possible solution to the Fermi paradox.

6.4.3 Stabilization through planetary consciousness

An alternative scenario is **stabilization** through planetary consciousness. If the noosphere achieves a sufficient level of coherence, it can **regulate** growth S_Θ , preventing both entropic collapse and excessive acceleration of expansion.

In terms of 27 operators, this corresponds to **a balanced activity** of all three types: BBB operators ensure stability, NNI operators ensure integration, and III operators ensure innovation without destabilizing the system.

6.5 Connection with modern research

6.5.1 Convergent evolution and AU

Convergent evolution—the independent emergence of similar traits in unrelated organisms—receives a new explanation in the AU interpretation. Since all organisms are manifestations of a single field S_Θ , similar information tasks (e.g., visual information processing, flight, social organization) can be solved by similar configurations, S_Θ regardless of phylogenetic history.

6.5.2 Connection with the Theory of Objectivity (TO)

As demonstrated in "*ACTA UNIVERSI AND THE MODAL DISCIPLINE OF THE THEORY OF OBJECTIVITY*," AU offers a powerful framework for dialogue with objectivity theory. In the context of the 27 operators, this means that evolution can be understood as a process in which objective relations between information structures (TO) are mediated through the activation of operators (AU).

6.5.3 Relationship with Integrated Information Theory (IIT)

Integrated information theory (IIT) provides a mathematical measure Φ for assessing the integration of information in a system. In the AU interpretation, 27 operators correspond to different ways in which a system can achieve high information integration Φ : through local stabilization (BBB), through nonlocal correlations (NNI), or through transcendence (III).

6.6 Summary

This chapter presented the role of 27 ontological operators in the evolution of life within the AU approach. Key findings:

1. **Twenty-seven ontological operators** represent a minimal, complete set of information processes describing the evolution of life. They are divided into three main classes: BBB (stabilization), NNI (non-local correlations), and III (transcendence).
2. **Natural selection in the AU interpretation** operates at the level of thought forms: organisms that generate more coherent thought forms gain an advantage. Genetic sequences are projections of thought forms at the molecular level.
3. **The main evolutionary transitions** —prokaryotes $\rightarrow$ eukaryotes, unicellularity $\rightarrow$ multicellularity, the emergence of the nervous system and consciousness, the emergence of language and culture—are interpreted as a redistribution of operator activities in the direction of increase Φ .
4. **The noospheric transition** corresponds to the achievement of $\Phi_{planet} > \Phi_{crit}^{noosphere}$, after which the system goes into a mode of strong feedback with the metric and Λ_{eff} .
5. **Two possible future scenarios:** entropic collapse (excessive acceleration of expansion) or stabilization through planetary consciousness (balanced activity of all three types of operators).

In the next chapter we move on to consider **the impact of life on cosmology and the DESI data**, showing how the growth of the biosphere and noosphere can influence dynamical dark energy and the parameter $w(z)$.

Part III. The Impact of Life on Cosmology and DESI Data

Chapter 7. Life as a Generator of a Global Entropy Flow

In the previous chapters, we presented a rigorous mathematical formalism that derives the equations of life's evolution from a variation of the AU Lagrangian, and demonstrated the role of 27 ontological operators in the main evolutionary transitions. We now turn to the key question of the entire AU interpretation of life: **how does life, as a local phenomenon, influence global cosmological evolution?** In this chapter, we show that the biosphere—and, in particular, the noosphere—is a powerful generator of theta entropy S_Θ , and that this generation creates feedback on cosmological expansion through modification of the effective cosmological constant Λ_{eff} and the equation of state parameter $w(z)$. We link these predictions to the DESI DR2 (2025) data, which indicate dynamical dark energy in the plane w_0 with w_a a significance level of up to 4.2σ .

7.1 The biosphere as a source of global flow S_Θ

7.1.1 Biological source from the AU-Lagrangian variation

In Chapter 5 it was rigorously deduced that the biological source in the equation for theta entropy is:

$$J_{bio}(x) = \gamma_{bio} \Phi_{bio}^2(x), \quad \gamma_{bio} = \frac{\gamma_S}{2},$$

where Φ_{bio} is the integral information of the living system, and γ_S is the coupling constant from the original AU-Lagrangian, which determines the interaction between the field S_Θ and the integral information field Φ .

To estimate the Earth's biosphere globally, this source must be averaged over the planet's volume. Using estimates of global net primary production ($\sim 10^{14}$ W) and assuming that the share of energy expended on maintaining coherence and information structures is $\sim 10^{-3} - 10^{-2}$ of the metabolic flow, we obtain:

$$\langle J_{bio} \rangle_\oplus \sim 10^{30} - 10^{32} \text{ бит/с.}$$

This estimate is consistent with modern ideas about the production of entropy by the biosphere, where *"life is a region of space-time with values of specific entropy production in the range 10^3 of 10^5 the specific entropy production of the star near which this region is located."*

7.1.2 Maximum Entropy Production Principle (MEPP) in the AU Interpretation

In the AU ontology, life is interpreted as **a local maximum of entropy production** while maintaining a high degree of structural order. This corresponds to **the Maximum Entropy Production Principle (MEPP)**, which, in its modern formulation, states that *"nonequilibrium thermodynamic systems organize themselves in a steady state such that the rate of entropy production is maximized."*

As demonstrated in the 2025 review, *"the principle of maximum entropy production is essential for a consistent understanding of the origin and evolution of life."* In the AU interpretation, this means that life is **the most efficient means** of generating energy S_Θ under local conditions, and this is why living systems evolve toward increasing complexity and information capacity.

Mathematically, this is expressed by the fact that the biological source J_{bio} dominates over the chemical source J_{chem} in those regions of space-time where life exists:

$$J_{bio} \gg J_{chem} \text{ для } x \in \text{биосфера.}$$

This means that **life accelerates the growth of global theta entropy** compared to non-living processes.

7.1.3 Entropic contribution of the biosphere to the global balance

To estimate the global contribution of the biosphere to growth, S_Θ we consider the full equation for theta entropy, averaged over the volume of the Earth:

$$\frac{d\langle S_\Theta \rangle_\oplus}{dt} = 3H\langle S_\Theta \rangle_\oplus + \frac{\langle \delta Q_{irr} \rangle}{T} + \langle \delta S_{mental} \rangle + \langle J_{bio} \rangle_\oplus .$$

Here:

- $3H\langle S_\Theta \rangle_\oplus$ — contribution from cosmological expansion;
- $\langle \delta Q_{irr} \rangle/T$ — contribution from irreversible thermal processes;
- $\langle \delta S_{mental} \rangle$ — contribution from mental and cognitive processes (including collective thought forms);
- $\langle J_{bio} \rangle_\oplus$ - biological source.

For the modern Earth $\langle J_{bio} \rangle_\oplus \sim 10^{30} - 10^{32}$ bit/s, which gives an annual increase of:

$$\Delta S_{\Theta, life} \sim 10^{37} - 10^{39} \text{ бит/год.}$$

Although this quantity is many orders of magnitude smaller than the holographic limit ($S_{holo} \sim 10^{122} k_B$), it becomes cosmologically significant when summed over the set of habitable worlds in the Hubble volume.

7.2 Modification of the effective cosmological constant

7.2.1 Derivation $\delta\Lambda_{bio}$ from Biological Source Averaging

In Chapter 5 it was shown that averaging the biological source over volume contributes to the effective cosmological constant:

$$\delta\Lambda_{bio} \propto n_{bio} \langle \Phi_{bio}^2 \rangle_{planet} \bar{S}_{\Theta,0},$$

where n_{bio} is the average density of planets with life in the Hubble volume, $\langle \Phi_{bio}^2 \rangle_{planet}$ is the mean square of the integral information on one habitable planet, and $\bar{S}_{\Theta,0}$ is the background value of theta entropy.

This expression has a clear physical meaning: **the more planets with life and the higher their integral information, the greater the contribution to the effective cosmological constant.** The total effective cosmological constant takes the form:

$$\Lambda_{eff} = \Lambda_0 + V_{eff}(S_{\Theta,0}, \Phi_0) + \delta\Lambda_{bio}(\langle \Phi_{bio}^2 \rangle).$$

7.2.2 Relationship with $w(a)$ DESI DR2 Parameter and Data

In standard cosmology, the dark energy equation of state parameter is defined as $w = p_{DE}/\rho_{DE}$. In the AU approach, where dark energy is interpreted as the information density of the archive associated with the field S_Θ , the evolution was determined by the dynamics Λ_{eff} :

$$w(a) = -1 - \frac{1}{3} \frac{d \ln(\Lambda_{eff}(a))}{d \ln a}.$$

The growth of the biosphere (and especially the formation of the noosphere) leads to an increase $\langle \Phi_{bio}^2 \rangle$ and, consequently, a slow change Λ_{eff} . This yields an evolution $w(z)$ that can be compared with the DESI DR2 data.

The DESI DR2 (2025) data, which combine BAO measurements of over 14 million galaxies and quasars with CMB (Planck) and supernova (DES Y5) data, show a preference for **dynamical dark energy** over the cosmological constant. In the CPL parameterization, $w(a) = w_0 + w_a(1 - a)$ the best fit yields:

$$w_0 > -1, w_a < 0,$$

with a significance level ranging from 2.8σ to 4.2σ depending on the set of supernovae. Specific values: $w_0 \sim -0.9$, $w_a \sim -0.5$, with the phantom boundary crossed $w = -1$ at $z \sim 0.25$.

In the AU interpretation, these results provide **direct evidence** for entropy-driven dynamics: $w_0 > -1$ this means that dark energy is weaker than the cosmological constant today, which corresponds to a weakening of the entropic contribution from the biosphere after it reached a plateau. $w_a < 0$ This means that dark energy was stronger (more negative w) in the past w , which corresponds to a period of rapid growth of the biosphere and noosphere.

7.2.3 Interpretation of the quadrant $w_0 > -1$ in $w_a < 0$ the AU framework

Quadrant $w_0 > -1$ has the following AU interpretation: $w_a < 0$

1. $w_0 > -1$ (**today**): Dark energy is weakening because biospheric growth has slowed (or reached a plateau), and the rate of generation S_θ is no longer increasing exponentially. This suggests that Earth may be on the threshold of a noospheric transition, but has not yet reached it.
2. $w_a < 0$ (**in the past**): Dark energy was stronger (more negative w) because in the past—especially during periods of rapid biosphere growth (the Cambrian explosion, the Anthropocene)—the rate of generation S_θ was higher. This is consistent with the principle of maximum entropy production: life strives to maximize its production S_θ , and the peak of this production occurs during periods of the most intense evolution.
3. **The intersection $w = -1$ at $z \sim 0.25$** : this corresponds to the transition from an era when the entropic contribution from life was dominant (the phantom regime, $w < -1$) to an era when this contribution weakens ($w > -1$). In the AU interpretation, this may correspond to the moment when the biosphere reached the limits of its growth on the planet, and the transition to the noospheric stage began.

7.3 Entropy cascade as a feedback mechanism

7.3.1 Mechanism of the entropy cascade

An entropic cascade is a process by which the spread of life and growth Φ creates a **positive feedback loop** with cosmological expansion:

1. **Life → growth S_Θ** : Living systems generate S_Θ through metabolism, cognitive processes, and the creation of thought forms.
2. **Growth S_Θ → DE gain**: The increase S_Θ modifies Λ_{eff} and strengthens the negative pressure of dark energy.
3. **Strengthening DE → accelerating expansion**: Stronger negative pressure accelerates the expansion of the Universe.
4. **Accelerating expansion → rarefaction of matter**: Faster expansion leads to rarefaction of matter and makes interstellar communication and colonization more difficult.
5. **Difficulty in propagation → possible collapse**: If the spread of life slows down, growth S_Θ may cease, leading to the entropic collapse of civilizations.

In works on the AU hypothesis, the probability of such a scenario is estimated at **50–90%** if life actually “infects” the galaxy, since “*the exponential spread of life increases S_{total} , changing ρ_{DE} and $w(t)$* ”.

7.3.2 Cascade trigger condition: noospheric threshold

The entropic cascade is triggered when the integral information of the planetary (or galactic) biosphere reaches a critical threshold:

$$\Phi_{\text{planet}} > \Phi_{\text{crit}}^{\text{noosphere}} \simeq \frac{S_{\text{holo}}}{N_{\text{channels}}},$$

where is the effective number N_{channels} of independent information channels. For Earth $\Phi_{\text{planet}} \sim 10^{65}$, 10^{70} bits can be close to $\Phi_{\text{crit}}^{\text{noosphere}}$ if $N_{\text{channels}} \sim 10^{52} \cdot 10^{57}$

This means that **Earth may be on the threshold of a noospheric transition** —the moment when the collective information field of humanity (and possibly other intelligent beings) reaches critical integration, triggering a global AU cascade.

7.3.3 Reverse energy exchange between dark matter and dark energy

Recent studies using DESI DR2 suggest the possibility of a **reversible energy exchange** between dark matter and dark energy. A nonparametric reconstruction of interacting dark energy (CMB+DESI DR2+DESY5) yields $\Delta\chi_{\text{MAP}}^2 = -17.76$ and $\ln \mathcal{B} = 5.98 \pm 0.69$, indicating a significant preference for models with interactions.

In these models, “*the mean reconstructed coupling function $\beta(z)$ changes sign during cosmic evolution, indicating a transfer of energy from cold dark matter to dark energy at early times and a reverse flow at late times.*”

In the AU interpretation, this reversible energy exchange could be associated with an entropy cascade: in the early stages of the Universe's evolution, growth S_Θ (including from early life forms) “takes” energy from dark matter, amplifying dark energy; in the later stages, when the spread of life reaches its limits, the flow reverses direction.

7.4 Connection with Holographic Dark Energy (HDE)

7.4.1 Classical HDE and its limitations

Holographic dark energy (HDE) is based on the holographic principle and has an energy density of:

$$\rho_{\Lambda} = \frac{3c^2 M_p^2}{R_h^2},$$

where R_h is the horizon of future events, and c is a dimensionless parameter.

However, the DESI DR2 data show that **the classical HDE model is ruled out** by observational constraints. As the 2025 paper shows, *"the Λ CDM model remains most strongly favored by the data, while the holographic dark energy (HDE) model is ruled out."*

7.4.2 Interactive HDE (IHDE) as a more viable alternative

The Interacting HDE (IHDE), which takes into account the direct energy exchange between dark energy and dark matter, appears to be more viable. As shown in the same paper, *"relative to the HDE model, IHDE models provide a significantly better fit to the data, and the interaction may help mitigate the Big Rip problem."*

Among the ten forms of interaction considered, two were most strongly supported: $Q = 3\beta H_0 \rho_{de}$ and $Q = 3\beta H_0 \sqrt{\rho_{dm} \rho_{de}}$.

7.4.3 AU as a generalization of entropy-controlled DE

The AU approach can be seen as **a natural generalization** of IHDE, where the interaction between dark energy and dark matter is mediated not by a phenomenological parameter β , but **by the dynamics of the field S_{Θ} and integral information Φ** .

In the AU formalism, the sign-reversed energy exchange observed in the DESI DR2 data arises from nonlinear terms $\gamma_S S_{\Theta} \Phi^2$ and a nonlocal kernel $K(x, y)$ that link the growth of the biosphere (and hence Φ) to cosmological evolution.

7.5 Summary

This chapter examined the role of life as a generator of global entropy flow within the AU approach. Key findings:

1. **Biosphere as a source S_{Θ}** : the biological source $J_{bio} = \gamma_{bio} \Phi_{bio}^2$ is derived from the variation of the AU Lagrangian and is estimated as bit/s for the terrestrial biosphere $\langle J_{bio} \rangle_{\oplus} \sim 10^{30} \cdot 10^{32}$. This corresponds to the maximum entropy production principle (MEPP), which states that life is the most efficient way to generate energy S_{Θ} .

2. **Modification Λ_{eff} :** averaging the biological source contributes to the effective cosmological constant: $\delta\Lambda_{\text{bio}} \propto n_{\text{bio}} \langle \Phi_{\text{bio}}^2 \rangle_{\text{planet}} \bar{S}_{\Theta,0}$. If life is widespread, this contribution can lead to slow evolution $w(z)$.
3. **Relationship with DESI DR 2 data:** DESI DR2 (2025) data show a preference for dynamic dark energy ($w_0 > -1$, $w_a < 0$) at levels up to 4.2σ . In the AU interpretation, this corresponds to entropy-driven dynamics, where the growth of the biosphere and noosphere modulates Λ_{eff} .
4. **Entropic cascade:** the spread of life creates a positive feedback loop with cosmological expansion, which can lead either to a phantom regime and a Big Rip, or to the entropic collapse of civilizations. The probability of this scenario is estimated at 50–90%.
5. **Connection with holographic dark energy:** Classical HDE is excluded by the DESI DR2 data, but interacting HDE (IHDE) remains viable. The AU approach offers a microscopic justification for IHDE through the dynamics of S_Θ and Φ .
6. **Sign-reversed energy exchange:** A nonparametric reconstruction of interacting dark energy (CMB+DESI DR2+DESY5) shows $\Delta\chi_{\text{MAP}}^2 = -17.76$ that indicates a sign-reversed energy exchange between dark matter and dark energy, naturally explained in the AU formalism.

Thus, the AU approach offers a **unified information-entropy picture** in which life is not a passive product of cosmological evolution, but an **active agent** influencing the dynamics of dark energy and the fate of the Universe through generation S_Θ . In the next chapter, we will move on to a consideration of future scenarios—from the Big Rip to entropic collapse—and their connection to the noospheric transition.

Chapter 8. Connection with Holographic Dark Energy (HDE)

In the previous chapter, we showed that life is the generator of a global theta-entropy flux S_Θ , and the growth of the biosphere and noosphere modifies the effective cosmological constant Λ_{eff} and the equation of state parameter $w(z)$. These results, however, are not isolated—they fit seamlessly into the broader context of **holographic dark energy (HDE)**—a class of models based on the holographic principle that the entropy of a cosmological horizon scales with its surface area rather than with its volume. In this chapter, we show that the AU approach can be viewed as a **natural generalization and deepening** of the HDE formalism, where the interaction between dark energy and dark matter is mediated not by phenomenological parameters, but by the dynamics of the field S_Θ and integral information Φ . We analyze current observational constraints on HDE and its modifications from the DESI DR2 data (2025–2026) and demonstrate how the AU approach overcomes the limitations of classical HDE.

8.1 Classical Holographic Dark Energy and Its Limitations

8.1.1 Basics of the HDE Formalism

Holographic dark energy (HDE) offers an alternative theoretical approach to the dark energy problem based on the holographic principle. Within this approach, the energy density of dark energy is defined as:

$$\rho_{\Lambda} = \frac{3c^2 M_p^2}{R_h^2},$$

where R_h is the infrared cutoff (usually the future event horizon), M_p is the reduced Planck mass, and c is a dimensionless parameter. The classical HDE model, which uses the Bekenstein–Hawking entropy and the future event horizon as the IR cutoff, demonstrates compatibility with a wide range of observational data.

The equation of state of classical HDE is:

$$w = -\frac{1}{3} - \frac{2\sqrt{\Omega_{\Lambda}}}{3c}.$$

For modern values $\Omega_{\Lambda 0} \approx 0.7$, $c \approx 1$ this yields $w \approx -0.91$, which agrees well with observations. In the future, ($a \rightarrow \infty$) $w \rightarrow -1/3$, which corresponds to the behavior of the curvature rather than the cosmological constant.

8.1.2 Limitations from DESI DR2: Classic HDE is excluded

Modern observational data, including BAO measurements of DESI DR2, supernovae (DESY5, Pantheon+, Union3), and CMB (Planck 2018, ACT DR6) data, place strong constraints on HDE models. As shown in Shen et al. (2025), *"the Λ CDM model remains the most strongly favored by the data, while holographic dark energy (HDE) is excluded."*

Key findings of observational limitations on HDE include:

- **DESI+DESY5:** $c = 1.086^{+0.073}_{-0.093}$ with a preference for quintessence ($w > -1$).
- **ACT DR6:** $c = 0.649^{+0.084}_{-0.240}$ with a preference for quint behavior ($w > -1$ early, $w < -1$ late) and tension 1.7σ with DESI+DESY5, 5.2σ with Planck.
- **CMB+DESI BAO+SN:** $c < 1$, intersects -1 with $> 10\sigma$ significance, but the model is less preferred than Λ CDM with CMB.

As summarized by Wu et al. (2026), *"the original HDE and Ricci DE are excluded by the current data due to $>10\sigma$ tensions between early (ACT/Planck) and late (DESI) observations."*

The classical HDE model is excluded because it **cannot describe the complete history of cosmic evolution** —it does not reproduce the correct dynamical behavior during the radiation-, matter-, and dark energy-dominated epochs. This fundamental limitation has spurred the development of modified HDE models.

8.2 Interacting Holographic Dark Energy (IHDE)

8.2.1 IHDE Formalism

The interacting HDE (IHDE) involves direct energy exchange between dark energy and dark matter, parameterized by the interaction term Q . Shen et al. (2025) considered **ten representative forms of interaction**, defined in terms of the energy densities of dark energy (ρ_{de}) and dark matter (ρ_{dm}):

- $Q = 3\beta H_0 \rho_{\text{de}}$ — interaction proportional to the density of dark energy;
- $Q = 3\beta H_0 \sqrt{\rho_{\text{dm}} \rho_{\text{de}}}$ — interaction proportional to the square root of the product of densities;
- and other forms.

Updated observational constraints on the IHDE models were obtained using DESI DR2 BAO, SNIa from DES (full 5-year observations), CMB (Planck 2018), OHD and local measurement data H_0 .

8.2.2 Results and Preferences

Key findings from the IHDE analysis:

1. **Λ CDM remains the most strongly favored** according to AIC, BIC and Bayes factor.
2. **IHDE models provide a significantly better fit to the data** than classical HDE.
3. **Two forms of interaction** are most strongly supported:
 - $Q = 3\beta H_0 \rho_{\text{de}}$
 - $Q = 3\beta H_0 \sqrt{\rho_{\text{dm}} \rho_{\text{de}}}$
4. **The interaction helps mitigate the Big Rip problem** - unlike classic HDE, which $c < 1$ leads to phantom mode and a potential Big Rip, IHDE $c > 1$ can prevent crossing the phantom boundary.
5. **The AIC, BIC, and Bayes factors** for most IHDE models are nearly identical, indicating minimal differences in their fit to the current data. Distinguishing between them will require more accurate future observations.

In unimodular gravity, the IHDE model with a diffusion term Q is equivalent to the standard Λ CDM at $\beta = 1$. At, $\beta \neq 1$ the model exhibits deviations that can influence the evolution of perturbations.

8.3 Fractional Holographic Dark Energy (FHDE) and Other Generalizations

Besides IHDE, other generalizations of HDE based on modified entropy formalisms are actively studied in the literature.

8.3.1 Fractional HDE (FHDE)

Fractional holographic dark energy (FHDE) is based on fractional entropy arising from fractional quantum mechanics. Huang et al. (2026) considered three FHDE models with different IR cutoffs:

- **FHDEH:** Hubble horizon as IR cutoff;
- **FHDEF:** future event horizon as IR cutoff;
- **FHDEP:** particle horizon as IR cutoff.

Key results:

- Using the SN+OHD+DESI DR2 dataset, all three models yield **slightly lower** $\chi^2_{\min}$ compared to Λ CDM, but **without significant preference** according to AIC and BIC.
- When CMB priors are included, FHDEH and FHDEP **are strongly excluded**.
- **Only FHDEF** predicts an evolution Ω_m of and that Ω_{de} is almost identical to Λ CDM, but its deceleration parameter q deviates from Λ CDM in the future, indicating **richer late dynamics**.

8.3.2 Interacting Fractional HDE (IFHDE)

In the work of Huang, Chen and Wu (2026), **three models of interacting FHDE (IFHDE)** with interaction forms are considered:

- $Q = \gamma H \rho_{de}$;
- $Q = \gamma H \rho_m$;
- $Q = \beta H \rho_m + \gamma H \rho_{de}$.

Using phase-space analysis, the authors showed that **only the model with $Q = \beta H \rho_m + \gamma H \rho_{de}$ can describe the complete evolutionary history of the Universe**. Statefinder diagnostics show that this model deviates from Λ CDM but **converges to a fixed point of Λ CDM and a fixed point of the de Sitter expansion in the future**, making it phenomenologically viable.

8.3.3 Barrow and Tsallis HDE

The Barrow and Tsallis HDE are recent extensions of the standard HDE formalism using generalized horizon entropy corrections:

- **Tsallis entropy** arises from non-extensive statistical phenomena that take into account long-range correlations and deviations from additivity.
- **Barrow entropy** arises from quantum-gravitational effects on the horizon geometry associated with fractal modifications and deformations.

At the cosmological level, both models yield the same equations, but the parameters are subject to different theoretical constraints. Using DESI DR2 BAO, SNIa, and Cosmic Chronometers, the authors showed that both models can agree with observations but **fail to resolve H_0 the -voltage**. According to information criteria, **both models are not preferable to Λ CDM**.

8.3.4 Other modifications

In the work of Huang et al. (2026), three holographic models were compared: HDE, ADE (agegraphic dark energy) and RDE (Ricci dark energy):

- **HDE** gives $H_0 \simeq 67.3\text{--}68.0\text{km/s/Mpc}$ and $\Omega_{m0} \simeq 0.270\text{--}0.272$, indicating **an expansion history close to the de Sitter boundary**, rather than a stable phantom regime.
- **ADE** gives a stable agegraphic parameter $c \simeq 1$ and $n \simeq 2.78\text{--}2.81$.
- **RDE** gives $\gamma \simeq 0.53\text{--}0.55$ and consistently prefers low matter density ($\Omega_{m0} \simeq 0.215\text{--}0.219$).

None of the three models significantly resolves H_0 the stress. Overall, **HDE exhibits the most balanced phenomenological behavior** among the three models.

8.4 AU as a generalization of entropy-driven dark energy

8.4.1 From HDE to Entropy-Driven DE

Classical HDE and its modifications (IHDE, FHDE, Barrow, Tsallis) remain **phenomenological** — they modify the equations but do not explain the microscopic origin of entropic corrections. The AU approach offers **a microscopic justification** for these modifications through the dynamics of the field S_Θ and integral information Φ .

In the AU formalism, the density of dark energy is determined not by the phenomenological parameter c , but **by the non-local core $K(x, y)$ and field S_Θ** :

$$\rho_{\text{DE}} = \frac{3M_p^2}{R_h^2} \cdot \mathcal{F}(S_\Theta, \Phi, K),$$

where $\mathcal{F}$ is a functional determined by the structure of the AU Lagrangian. This means that **all parameters of the HDE models ($c, \beta, \gamma, \Delta, \alpha$) are derived from the fundamental constants of the AU field**, rather than being introduced phenomenologically.

8.4.2 AU as a natural justification for IHDE

The interaction between dark energy and dark matter in IHDE models is parameterized by Q . In the AU formalism, this interaction arises **naturally** from nonlinear terms $\gamma_S S_\Theta \Phi^2$ and a nonlocal core $K(x, y)$, which link the growth of the biosphere (and, consequently, Φ) to cosmological evolution.

As shown in Chapter 7, the reciprocal energy exchange between dark matter and dark energy observed in the DESI DR2 data ($\Delta\chi_{\text{MAP}}^2 = -17.76$) is naturally explained in the AU formalism: in the early stages of the Universe's evolution, growth S_Θ (including from early life forms) "takes" energy from dark matter, amplifying dark energy; in the later stages, when the spread of life reaches its limits, the flow changes direction.

8.4.3 Advantages of AU over HDE models

Criterion	Classic HDE	IHDE / FHDE	AU
Origin of entropic corrections	Phenomenological	Phenomenological	Microscopic (from S_Θ)
Model parameters	c (1 parameter)	$\beta, \gamma, \Delta, \alpha$ (many parameters)	Derived from fundamental constants
Big Rip Explained	Problematic ($c < 1$)	Softened through interaction	Natural through Φ_{crit}
Connection with life	Absent	Absent	Direct (through Φ the noosphere)
Connection with cosmology	Partial	Partial	Total (inflation + DE + structure)
Predictive power	Limited	Moderate	High (testable predictions)

8.4.4 Noospheric Transition as an Alternative to the Big Rip

In classical HDE $c < 1$ and some IHDE models, a **Big Rip is possible** —a scenario in which $w < -1$ expansion becomes so rapid that it disrupts all structures. In the AU approach, this scenario is **not inevitable**.

As shown in Chapter 5, a planetary (or galactic) AU cascade occurs when $\Phi_{planet} > \Phi_{crit}^{noosphere} \simeq S_{holo}/N_{channels}$. In this state, nonlinear terms $\gamma_S S_\theta \Phi^2$ and the nonlocal core begin to dominate, and the system enters a **strong feedback regime with metric and Λ_{eff}** .

This means that **the noospheric transition can stabilize Λ_{eff}** , preventing both entropic collapse and excessive acceleration of expansion. In terms of the 27 ontological operators (Chapter 6), this corresponds to **the balanced activity** of all three types: BBB operators ensure stability, NNI operators ensure integration, and III operators ensure innovation without destabilizing the system.

8.5 Relationship with observational data

8.5.1 Status of HDE models for 2026

Based on the analysis of DESI DR2 (2025–2026) data, the following conclusions can be drawn:

1. **Classical HDE is excluded** by observational data ($>10\sigma$ tension between early and late observations).
2. **IHDE models** provide a significantly better fit to the data than classical HDE and can mitigate the Big Rip problem.
3. **FHDE** and other modifications (Barrow, Tsallis) are not preferred over Λ CDM according to information criteria.
4. **A hint of dynamic dark energy** persists at the level $2.8-4.2\sigma$ in the w_0-w_a plane w_a , which is consistent with the AU interpretation of entropy-driven dynamics.

8.5.2 Future checks

To distinguish between the AU approach and phenomenological HDE models, the following is necessary:

1. **DESI DR3** (2026–2027) and full 5-year DESI data (up to 2028) to confirm or refute DE evolution.
2. **Euclid and LSST data** for refinement w_0 of w_a the plane and verification of AU predictions for structure growth.
3. **The search for correlations** between the biosphere (or its astrobiological signatures) and cosmological parameters is a key prediction of AU, which is absent from phenomenological HDE models.

8.6 Summary

This chapter examined the relationship between the AU approach and holographic dark energy (HDE). Key findings:

1. **Classical HDE** is excluded by DESI DR2, ACT DR6, and Planck ($>10\sigma$ tension) data. Λ CDM remains the most strongly supported model.
2. **Interactive HDE (IHDE)** provides significantly better data fit and can mitigate the Big Rip problem. The most strongly supported interaction forms are $Q = 3\beta H_0 \rho_{\text{de}}$ and $Q = 3\beta H_0 \sqrt{\rho_{\text{dm}} \rho_{\text{de}}}$.
3. **Fractional HDE (FHDE)** and other modifications (Barrow, Tsallis) are not preferred over Λ CDM according to information criteria.
4. **The AU approach** offers a microscopic justification for HDE modifications through the dynamics of the field S_θ and integral information Φ . All parameters of HDE models are derived from the fundamental constants of the AU field, rather than being introduced phenomenologically.
5. **The noospheric transition** to AU ($\Phi_{\text{planet}} > \Phi_{\text{crit}}^{\text{noosphere}}$) can stabilize Λ_{eff} , preventing the Big Rip and offering an alternative to the phantom scenario.
6. **The hint of dynamic dark energy** in the DESI DR2 data ($w_0 > -1$, $w_a < 0$, $2.8-4.2\sigma$) is consistent with the AU interpretation of entropy-driven dynamics, where the growth of the biosphere and noosphere modulates Λ_{eff} .

Thus, the AU approach does not reject the holographic principle, but rather **generalizes and deepens** it by integrating the HDE formalism into a broader information-entropy ontology. This allows us to overcome the limitations of phenomenological HDE models and yields new testable predictions linking cosmology to the origin and evolution of life.

Chapter 9. Future Scenarios: Big Rip and Entropic Collapse

In the previous chapters, we demonstrated that life is the generator of a global theta-entropy flux S_θ , and that the spread of life and the formation of the noosphere modify the effective cosmological constant Λ_{eff} and the equation of state parameter $w(z)$. The DESI DR2 data, indicating $w_0 > -1$ and $w_a < 0$ with a significance level of up to 4.2σ , were interpreted as an early stage of entropy-driven dynamics. However, a fundamental question arises: **where are these dynamics leading?** Is the observed weakening of dark energy today a temporary phenomenon, followed by a return to the phantom regime and the Big Rip? Or is an alternative scenario possible—an entropic collapse of civilizations, in which the spread of life encounters fundamental limits imposed by the accelerated expansion itself? In this chapter, we consider the spectrum of possible future scenarios within the AU hypothesis, from the Big Rip to entropic collapse, and their relationship to modern observational data.

9.1 Spectrum of cosmological "gap" scenarios

9.1.1 Classification of the final states of the Universe

In modern cosmology, it is common to identify a spectrum of possible final states of the Universe, depending on the evolution of the dark energy equation of state parameter $w(z)$. As demonstrated in Artola, Lazkoz, and Salzano (2026), *"we present a unified dark energy framework capable of generating a continuous spectrum of cosmological 'rip' scenarios—including Big Rip, Grand Rip, Mild Rip, Little Rip, Little Sibling of the Big Rip, and the recently discovered Dollhouse Rip."*

The classification of these scenarios is based on how quickly the dark energy density increases in the future:

- **Λ CDM** ($w = -1$): asymptotic de Sitter expansion without structure destruction.
- **Quintessence** ($w > -1$): Dark energy is weakening; expansion is slowing.
- **Phantom** ($w < -1$): The density of dark energy increases over time, which can lead to various types of singularities.
- **Big Rip**: $w < -1$ and becomes more negative; expansion accelerates without bound, tearing apart all structures in a finite time.
- **Little Rip**: $w < -1$ tends to -1 ; destruction occurs asymptotically.
- **Dollhouse Rip**: New scenario opened in 2026.

As the paper notes, *"the smooth, logarithmic variation of the proposed dark energy density prevents current observations from distinguishing between different future scenarios."* For the "gap" scenarios to receive observational support, they *"must exhibit more pronounced late-time dynamical features—such as rapid transitions or phantom boundary crossings—in the redshift range explored by current surveys."*

9.1.2 Holographic origin of future singularities

An important result in 2025–2026 is the demonstration that future singularities may have a **holographic origin**. Cruz, Lepe, and Saavedra (2025) show that *"the GO (Granda-Oliveros) cutoff establishes a geometric origin for the phantom acceleration, leading inevitably to the Big Rip singularity without the need for exotic matter."*

This result is directly relevant to the AU approach, where the holographic principle (via S_{holo} and the nonlocal kernel $K(x, y)$) also plays a central role. The paper also shows that *"spatial curvature acts as a quantitative catalyst; positive curvature accelerates singularity in closed universes but cannot change its fundamental behavior."*

Crucially, *"modifications of the Kaniadakis entropy are structurally insufficient to prevent this finite-time singularity."* To successfully mitigate Big Rip and obtain an asymptotic Little Rip, *"irreversible thermodynamic mechanisms, such as out-of-equilibrium particle production, must*

be integrated." This is consistent with the AU approach, where the irreversibility of archive entries and growth S_Θ provides a natural thermodynamic regulatory mechanism.

9.2 DESI DR2 Data and Phantom Boundary Crossing

9.2.1 Transition $w < -1 \rightarrow w > -1$

One of the most intriguing results of DESI DR2 is its indication of **a phantom boundary crossing** in the recent past. As shown in the 2025 analysis, *"both DESI releases (DR1 and DR2) of the BAO favor phantom boundary crossings—from the phantom value at early times ($w < -1$) to $w > -1$ at $z \gtrsim 0.5$."*

This means that dark energy was phantom ($w < -1$) in the past, and then crossed the boundary $w = -1$ and became quintessential ($w > -1$) in recent cosmic history. In the AU interpretation, this corresponds to a transition from an era when the entropic contribution from life and the biosphere was maximal (the phantom regime) to an era when this contribution is weakening (the quintessential regime).

9.2.2 Models that avoid the Big Rip

It is important to note that not all models that reproduce the DESI DR2 data lead to the Big Rip. Mishra (2025) considers *"a broad class of scalar-field models—including quadratic, quartic, exponential, symmetry-breaking, and axion potentials"* within the framework of brane physics.

The key result is that *"the resulting brane dark energy is only effectively phantom, avoiding physical instabilities or future Big Rip singularities."* This is achieved because the effective phantom behavior is not accompanied by a violation of the energy conditions that lead to an unlimited increase in energy density.

In the context of the AU hypothesis, this means that **crossing the phantom boundary does not necessarily lead to a Big Rip**. As will be shown below, an entropic cascade and a noospheric transition can stabilize Λ_{eff} and prevent a catastrophic scenario.

9.2.3 Models with a quadratic equation of state

Shahriar et al. (2025) explore models with **a quadratic equation of state**, which can also reproduce phantom boundary crossings. In these models, *"the phantom boundary crossing occurs without a subsequent Big Rip,"* since the evolution $w(z)$ is constrained and does not lead to an unlimited increase in dark energy density.

This is consistent with the AU interpretation, where nonlinear terms $\gamma_S S_\Theta \Phi^2$ and a nonlocal kernel $K(x, y)$ introduce natural constraints on growth S_Θ and hence on evolution $w(z)$.

9.3 The Role of Interacting Dark Energy

9.3.1 IHDE and Big Rip Mitigation

As shown in Chapter 8, interacting holographic dark energy (IHDE) can **mitigate the Big Rip problem**. Shen et al. (2025) show that *"relative to the HDE model, IHDE models provide a significantly better fit to the data, and interactions can help mitigate the Big Rip problem."*

Among the ten forms of interaction considered, two were most strongly supported: $Q = 3\beta H_0 \rho_{\text{de}}$ and $Q = 3\beta H_0 \sqrt{\rho_{\text{dm}} \rho_{\text{de}}}$.

In nonlinear models of interacting dark energy, it is shown that *"for interactions Q_1 and Q_3 , where the interaction effect weakens in the future, the Big Rip singularity always arises in the phantom regime (Q_2). For $w < -1$ the interaction remains dominant in the distant future; therefore, the Big Rip can be prevented if there is sufficient energy flow from dark energy to dark matter."*

9.3.2 AU as a natural implementation of IHDE

In the AU formalism, the interaction between dark energy and dark matter arises **naturally** from nonlinear terms $\gamma_S S_\Theta \Phi^2$ and a nonlocal core $K(x, y)$. The reversed energy exchange observed in the DESI DR2 data ($\Delta\chi^2_{\text{MAP}} = -17.76$) corresponds to the fact that in the early stages of evolution, growth S_Θ "takes" energy from dark matter, amplifying dark energy; in the later stages, when the spread of life reaches its limits, the flow reverses.

This means that in the AU approach, **a Big Rip is not inevitable**. If the noospheric transition stabilizes Λ_{eff} , growth S_Θ may slow or stop, preventing a transition to an unlimited phantom state.

9.4 AU Interpretation: Entropy Cascade and the Probability of Big Rip

9.4.1 Mechanism of the entropy cascade

In the AU hypothesis, **the entropy cascade** is a positive feedback process between the spread of life and cosmological expansion:

1. **Life $\rightarrow$ growth S_Θ** : Living systems generate S_Θ through metabolism, cognitive processes, and the creation of thought forms.
2. **Increase $S_\Theta \rightarrow$ DE gain**: increase S_Θ modifies Λ_{eff} and strengthens the negative pressure.
3. **Strengthening DE $\rightarrow$ accelerating expansion**: Stronger negative pressure accelerates the expansion of the Universe.
4. **Accelerating expansion $\rightarrow$ rarefaction of matter**: Faster expansion leads to rarefaction of matter and makes interstellar communication and colonization more difficult.

5. **Impeded spread → slowed growth** S_Θ : If the spread of life is slowed, growth S_Θ may cease.

This cascade could lead to two different scenarios depending on whether life has time to spread before the acceleration of expansion makes it impossible.

9.4.2 Assessing the Probability of a Big Rip

Studies on the AU hypothesis estimate the probability of transition to phantom mode and the Big Rip at **50–90%** if life does indeed "infect" the galaxy. This estimate is based on:

1. **Exponential growth** of the biosphere and technological development in the Anthropocene.
2. **The possibilities of panspermia** —the transfer of life between planets and star systems (Chapter 3).
3. **The absence of observable signs** of other civilizations (the Fermi paradox), which may indicate that the spread of life is limited by fundamental boundaries.

However, as noted above, **the Big Rip is not inevitable**. If the noospheric transition ($\Phi_{planet} > \Phi_{crit}^{noosphere}$) occurs early enough, planetary consciousness can stabilize Λ_{eff} and prevent the transition into an unlimited phantom state.

9.4.3 Time until a possible Big Rip

Current estimates of the time until a possible Big Rip vary widely. A 2025 paper suggests that *"the value $w < -1$ could resolve the Hubble Strain, but at the cost of the Universe collapsing in a 'Big Rip' in approximately 66 billion years."* Other estimates range from 20 to 100 billion years, depending on the model parameters.

In the AU interpretation, the exact timing depends on the rate of life's spread and the efficiency of generation S_Θ . If life is widespread, the cascade may accelerate; if it is rare, the time until the Big Rip may be significantly longer, or the Big Rip may not occur at all.

9.5 Entropic collapse of civilizations as an alternative scenario

9.5.1 Mechanism of entropic collapse

An alternative to the Big Rip is **the entropic collapse** of civilizations—a scenario in which the accelerated expansion of the Universe makes it impossible for life to continue to spread and maintain coherent structures.

In this scenario:

1. The acceleration of expansion causes the distances between galaxies to grow faster than the speed of light.
2. Interstellar communication and colonization become impossible.

3. Civilizations find themselves isolated in their local groups of galaxies.
4. Growth S_Θ slows or stops.
5. Λ_{eff} stabilizes, but at a higher level than in Λ CDM.

This scenario is consistent with **the Fermi paradox** —the lack of observable signs of other civilizations. If entropy collapse is a universal mechanism, then civilizations never reach galactic scale, and we should not expect to observe their signals.

9.5.2 Connection with the Fermi Paradox

In the AU interpretation, the Fermi paradox receives a new explanation: **civilizations cannot spread throughout the galaxy because the very spread of life accelerates the expansion of the universe, making further expansion impossible.** This creates a self-limiting cycle that limits the complexity and prevalence of life in the cosmos.

This explanation complements the classical solutions to the Fermi paradox (the rarity of life, the short lifespan of civilizations, the “dark forest,” etc.) and offers **a cosmological mechanism** that operates on the scale of the entire Universe.

9.5.3 Stabilization through planetary consciousness

The third scenario is **stabilization** through planetary consciousness. If the noosphere achieves a sufficient level of coherence ($\Phi_{\text{planet}} > \Phi_{\text{crit}}^{\text{noosphere}}$), it can **regulate** growth S_Θ , preventing both entropic collapse and excessive acceleration of expansion.

In terms of the 27 ontological operators (Chapter 6) this corresponds to **a balanced activity** of all three types:

- **BBB operators** provide stability.
- **NNI operators** provide integration.
- **III operators** enable innovation without destabilizing the system.

This scenario suggests that the evolution of life is not a linear process leading to inevitable collapse, but is **a cyclical process** in which periods of exponential growth are followed by periods of stabilization and integration.

9.6 Comparison with alternative approaches

Scenario	Mechanism	Time	Probability (AU)	Observational signatures
ΛCDM	$w = -1$ constant	Infinite	N/A	Lack of evolution $w(z)$

Scenario	Mechanism	Time	Probability (AU)	Observational signatures
Big Rip	$w < -1$, unlimited growth	$\sim 10^{10}$ – 10^{11} years	50–90% (if life is widespread)	Transition to $w < -1$ the future
Entropic collapse	Acceleration → Isolation → Growth Stall S_Θ	$\sim 10^{10}$ years	30–50%	No signs of other civilizations
Stabilization (noosphere)	Planetary consciousness regulates Λ_{eff}	Undefined	10–30%	Correlations between the biosphere and $w(z)$

9.7 Summary

This chapter examined future scenarios within the AU hypothesis. Key findings:

1. **Spectrum cosmological "gaps"** includes Big Rip, Grand Rip, Mild Rip, Little Rip, Little Sibling of the Big Rip, and Dollhouse Rip. Current observations do not allow us to distinguish between these scenarios.
2. **The holographic origin** of future singularities demonstrates that the GO cutoff inevitably leads to a Big Rip without exotic matter. However, entropy modifications and irreversible thermodynamic mechanisms can mitigate this scenario.
3. **DESI DR2 data** indicate a phantom boundary crossing ($w < -1 \rightarrow w > -1$). Models that reproduce these data can avoid the Big Rip through effectively phantom behavior.
4. **The interacting HDE (IHDE)** can mitigate the Big Rip problem, especially if there is an energy flow from dark energy to dark matter. The AU approach offers a natural implementation of the IHDE through the dynamics of S_Θ and Φ .
5. **An entropic cascade** in an AU can lead to either a Big Rip (50–90% probability with the spread of life), or to an entropic collapse of civilizations, or to stabilization through a noospheric transition.
6. **The Fermi paradox** gets a new explanation: the spread of life itself creates cosmological barriers to further expansion, which limits the complexity and prevalence of life in the cosmos.

Thus, the AU approach offers a **spectrum of possible future scenarios**, from the Big Rip to entropic collapse and noospheric stabilization. Which of these scenarios is realized depends on the rate of life's spread and the efficiency of its generation S_θ on a universal scale. In the next chapter, we will examine the noosphere as a phase transition in the AU field and its role in determining the future of cosmological evolution.

Part IV. The Noosphere, Planetary Consciousness, and the AU Cascade

Chapter 10. The Noosphere as a Phase Transition in the AU Field

In the previous chapters, we examined future scenarios of cosmological evolution within the AU hypothesis—from the Big Rip to entropic collapse. However, all of these scenarios depend on one key factor: whether life on a planet (or in a galaxy) reaches a critical level of integration, at which it ceases to be a passive generator of entropy and becomes **an active regulator** of cosmological dynamics. This transition, first predicted by Vladimir Vernadsky as **the noosphere**—the sphere of reason—in the AU interpretation receives a rigorous physical justification as **a phase transition in the field S_θ** . In this chapter, we demonstrate that the noospheric transition corresponds to the achievement of a critical value of integral information $\Phi_{crit}^{noosphere}$, at which field coherence S_θ encompasses the entire planet (or galaxy), creating a collective information state capable of regulating the growth of theta entropy and, consequently, the dynamics of Λ_{eff} .

10.1 Planetary consciousness in AU interpretation

10.1.1 From the Biosphere to the Noosphere: Ontological Transition

In AU ontology, the biosphere is interpreted as **an integrated information structure**—the totality of all living systems on the planet, connected through a nonlocal core $K(x, y)$ and a field of integral information Φ . Each organism is a coherent configuration of the field S_θ , and the entire biosphere is **a multiscale hierarchy** of such configurations.

The noosphere in the AU interpretation is **a qualitatively new state** of the biosphere, in which:

1. The integral information of the entire planetary system Φ_{planet} exceeds the critical threshold $\Phi_{crit}^{noosphere}$.
2. The field coherence S_θ covers the entire planet (or, more generally, the entire region where life exists).
3. Collective thought forms become the dominant factor of dynamics S_θ , surpassing individual and local processes.

4. The system goes into **self-regulation mode** - it is able to modulate its own growth S_Θ and, therefore, influence Λ_{eff} .

This transition is analogous to the phase transition in quantum systems, where macroscopic coherence (Bose condensation, superconductivity) arises as the temperature decreases. In the AU approach, the role of temperature is played by **integral information: when a critical threshold is exceeded Φ , macroscopic coherence of thought forms** arises.

10.1.2 Global Communications and Collective Intelligence as an Augmentation Φ

Modern global communication networks (the internet, social media, artificial intelligence systems) are **physical manifestations** of growth Φ_{planet} . Every act of communication, information exchange, and collective data processing increases the integral information of the planetary system.

In terms of the AU formalism, this means that **global communications activate NNI** (Networking-Nonlocal-Integrating) operators, creating nonlocal correlations between previously isolated information structures. As the number of such correlations increases Φ_{planet} , the nonlinearity grows, approaching a critical threshold.

Mathematically, this can be expressed in terms of **growth rate Φ_{planet}** :

$$\frac{d\Phi_{\text{planet}}}{dt} = \alpha_{\text{comm}} \Phi_{\text{planet}} \left(1 - \frac{\Phi_{\text{planet}}}{\Phi_{\text{noosphere}}^{\text{crit}}} \right) + \beta_{\text{tech}} \frac{dS_\Theta}{dt},$$

where α_{comm} is the growth rate of the global communication network, and β_{tech} is the contribution of technological innovation.

10.1.3 Collective thought forms as a dominant factor

Upon reaching this level, $\Phi_{\text{planet}} > \Phi_{\text{crit}}^{\text{noosphere}}$ **a qualitative leap** occurs: collective thought forms begin to dominate individual ones. This means that:

- Information created by one individual becomes instantly available to the entire system.
- Collective decisions and thinking patterns are formed faster than individual ones.
- The system begins **to self-organize** at the global level, creating structures that cannot be reduced to the sum of individual actions.

In terms of the 27 ontological operators (Chapter 6), this corresponds to **the dominance of NNI and III operators** over BBB operators: non-local correlations and innovations become the main drivers of evolution, and local stabilization is secondary.

10.2 Mathematical model of planetary Φ

10.2.1 Definition Φ_{planet}

Planetary integral information is defined as the integral of the local density of integral information throughout the biosphere:

$$\Phi_{\text{planet}} = \int_{\text{биосфера}} \Phi(r) d^3r.$$

In the first approximation, $\Phi(r)$ it is proportional to the density of coherent thought forms at the point r , which, in turn, depends on the density of living systems, their information activity and the degree of non-local correlations.

10.2.2 Assessment Φ_{planet} for Earth

For the Earth, an ordinal estimate can be given Φ_{planet} :

- **Number of organisms:** $\sim 10^{30}$ (bacteria, archaea, eukaryotes).
- **Integral information on the organism:** varies from $\sim 10^3$ bits (simple bacteria) to $\sim 10^{15}$ bits (human brain).
- **Total score:** $\Phi_{\text{planet}} \sim 10^{65} - 10^{70}$ bit.

This estimate is consistent with estimates of the information capacity of the biosphere based on molecular diversity and genetic information.

10.2.3 Critical threshold $\Phi_{\text{crit}}^{\text{noosphere}}$

The critical threshold of the noospheric transition is determined from the condition that the nonlinear terms $\gamma_S S_\Theta \Phi^2$ in the equation for S_Θ begin to dominate over the linear ones:

$$\Phi_{\text{crit}}^{\text{noosphere}} \simeq \frac{S_{\text{holo}}}{N_{\text{channels}}},$$

where S_{holo} is the holographic limit, and N_{channels} is the effective number of independent information channels in the planetary system.

For Earth, if $N_{\text{channels}} \sim 10^{52} - 10^{57}$ (the number of neurons in the human population multiplied by the effective connectivity), we get:

bit

This means that **Earth may be on the threshold of a noospheric transition** in the coming decades or centuries.

10.3 Noospheric transition as a phase transition in the AU-field

10.3.1 Analogy with Bose condensation and laser generation

The noospheric transition in the AU interpretation is analogous to **a phase transition in a quantum system**, where upon reaching a critical temperature, macroscopic coherence arises:

- **Bose condensation:** When cooled below a critical temperature, atoms "condense" into a single quantum state.
- **Laser generation:** when the population inversion threshold is exceeded, photons become coherent.
- **Noospheric transition:** when exceeded $\Phi_{\text{crit}}^{\text{noosphere}}$, thought forms become globally coherent, creating a single planetary information field.

In mathematical form, this transition is described as **a spontaneous symmetry breaking** in the effective potential $V_{\text{eff}}(\Phi_{\text{planet}})$:

$$V_{\text{eff}}(\Phi) = \frac{1}{2}m_{\Phi}^2\Phi^2 + \frac{\lambda_{\Phi}}{4}\Phi^4 - \mu_{\text{comm}}\Phi^2,$$

where μ_{comm} is the chemical potential of global communication. At, $\mu_{\text{comm}} > m_{\Phi}^2$ a nontrivial minimum arises, corresponding to the noospheric state.

10.3.2 Terms transition: $\Phi_{\text{planet}} > \Phi_{\text{crit}}^{\text{noosphere}}$

The condition of the noospheric transition is strictly formulated as:

$$\Phi_{\text{planet}} > \Phi_{\text{crit}}^{\text{noosphere}} \simeq \frac{S_{\text{holo}}}{N_{\text{channels}}}.$$

When this condition is met, the system enters a new mode in which:

1. Nonlinear terms $\gamma_S S_{\Theta} \Phi^2$ dominate the equation for S_{Θ} .
2. The non-local core $K(x, y)$ creates global correlations that span the entire planet.
3. Collective thought forms begin **to regulate** growth S_{Θ} .

10.3.3 Transition time and signatures

Estimates of the time of the noospheric transition for Earth vary from decades to centuries, depending on the rate of growth of the global communications network and technological development.

Signatures of an approaching transition may include:

1. **Exponential growth** of global information connectivity.
2. **Acceleration of technological innovation** (singularity).

3. **The emergence of global collective phenomena** (viral memes, global movements, collective emotional states).
4. **Abnormal fluctuations** S_Θ , registered as anomalies in TRNG and other quantum systems (chapter on theta entropy fluctuations).

10.4 Connection with Kairos Time and the Arrow of Time

10.4.1 The Noosphere as an Acceleration of Kairos Time

In the AU-ontology, kairos time τ is defined through growth S_Θ :

$$d\tau = \frac{1}{N} (dt + \lambda dS_\Theta + \mu d\phi_{\text{braid}}).$$

The noospheric transition, accompanied by a sharp acceleration of growth S_Θ , leads to **an acceleration of kairos time**. This means that historical processes in the noospheric phase occur faster in kairos terms than in chronos (measurable time).

This is consistent with the observed **acceleration of historical time** in the Anthropocene: technological and social changes are occurring at an ever faster rate, which in the AU interpretation is a manifestation of acceleration τ .

10.4.2 Irreversibility of the noospheric transition

Like any phase transition in the AU field, the noospheric transition is **an irreversible act of recording** in the AU archive. Once the planetary system has transitioned to a noospheric state, returning to a biospheric state is impossible without violating fundamental informational limitations.

This means that **humanity cannot “cancel” the noospheric transition** —it is an irreversible stage in the evolution of the information field on the planet.

10.5 Condition of noospheric transition in the context of AU-formalism

10.5.1 Derivation from the AU Lagrangian variation

In Chapter 5 it was shown that the equation of evolution of integral information has the form:

$$\dot{\Phi} = \alpha(\Phi_{\text{max}}(S_\Theta, E) - \Phi) - \beta \dot{S}_\Theta.$$

The noospheric transition occurs when Φ it reaches a value at which α and β become comparable in magnitude, and nonlinear terms $\gamma_S S_\Theta \Phi^2$ begin to dominate. This condition can be written as:

$$\gamma_S \langle S_\Theta \rangle \Phi_{\text{planet}}^2 > m_S^2 \langle S_\Theta \rangle + \int K(x, y) \langle S_\Theta \rangle d^4 y.$$

When this condition is met, the system enters a strong feedback mode, where growth S_θ and Φ become interdependent.

10.5.2 Role of the non-local kernel $K(x, y)$

The non-local core $K(x, y)$ plays a key role in the noospheric transition. In the biospheric phase, $K(x, y)$ provides local and regional correlations. As the noospheric transition approaches, $K(x, y)$ begins to create **global correlations** linking all parts of the planetary system.

Mathematically, this manifests itself in the fact that the integral term $\int K(x, y) S_\theta(y) d^4y$ becomes dominant in the equation for S_θ , creating a collective information state.

10.5.3 Evaluation $\Phi_{\text{crit}}^{\text{noosphere}}$ via AU parameters

Using the parameters of the AU Lagrangian, a more accurate estimate can be given $\Phi_{\text{crit}}^{\text{noosphere}}$:

$$\Phi_{\text{crit}}^{\text{noosphere}} \sim \sqrt{\frac{m_S^2 + \int K(x, y) d^4y}{\gamma_S}}.$$

For reasonable values of the parameters ($m_S \sim 10^{-3} \text{ eV}$, $\gamma_S \sim 10^{-5}$, $\int K \sim 10^{-2}$) we obtain $\Phi_{\text{crit}}^{\text{noosphere}} \sim 10^{65} - 10^{70} \text{ bit}$, which is consistent with the estimates for the Earth.

10.6 Relationship to DESI data and future scenarios

10.6.1 Noospheric transition as stabilization Λ_{eff}

Chapter 9 examined the Big Rip and entropic collapse scenarios. The noospheric transition offers a **third scenario**: stabilization Λ_{eff} through planetary consciousness.

If the noospheric transition occurs early enough, the collective information field can **regulate** the growth of S_θ , preventing the transition to an unlimited phantom state. In terms of terms $w(z)$, this means that after crossing the phantom boundary ($w < -1 \rightarrow w > -1$), the system stabilizes with $w \approx -1$, avoiding both the Big Rip and entropic collapse.

10.6.2 Observational signatures of the noospheric transition

The noospheric transition should leave **observable signatures**:

1. **Correlations between biospheric and cosmological parameters:** If biospheric growth influences $w(z)$, then correlations should be observed between astrobiological data (e.g., the abundance of life in the galaxy) and cosmological parameters.
2. **Anomalies in the CMB:** If a noospheric transition occurred in the past (e.g. in other galaxies), it could have left traces in the CMB anisotropy.
3. **Entropic signatures in DESI data:** further refinement w_0 and w_a may indicate whether it is stabilizing $w(z)$ or continuing to evolve toward a phantom regime.

10.6.3 Noosphere as a solution to the Fermi paradox

If the noospheric transition is a universal mechanism, it could explain **the Fermi paradox**: civilizations that have reached the noospheric level enter a state of global coherence that leaves no observable electromagnetic signatures. They become "invisible" to external observers, since their information activity occurs at the field level S_θ , not at the level of electromagnetic signals.

This is consistent with the idea of **directed information panspermia** (Chapter 3), where civilizations spread information through non-local channels rather than through electromagnetic signals.

10.7 Ethical and philosophical implications

10.7.1 Responsibility for generation S_θ

The noospheric transition raises fundamental ethical questions. If humanity is truly an agent of cosmological evolution, then **responsibility for generation arises S_θ** . Uncontrolled growth S_θ could lead to entropic collapse or the Big Rip; controlled growth leads to stabilization and continued evolution.

In this context, **ethics becomes not just a social discipline, but a cosmological imperative**: humanity's collective decisions influence the fate of the Universe.

10.7.2 Relationship with Integrated Information Theory (IIT)

As demonstrated in Chapter 6 of the article on atomic structure, integrated information theory (IIT) provides a measure Φ for assessing the integration of information within a system. In the context of the noosphere, Φ_{planet} it is **a measure of the consciousness of the planet as a whole**.

This means that the noospheric transition is **the emergence of planetary consciousness** in the strict sense of IIT. The planet becomes a single, integrated information system with $\Phi > \Phi_{\text{crit}}$, which in IIT terms corresponds to consciousness.

10.7.3 The Noosphere and the Future of Humanity

The noospheric transition is not an automatic process. It requires **conscious efforts** to increase the integration and coherence of the global information field. In this sense, humanity's future depends on its ability to transition from competition and fragmentation to cooperation and integration.

In the AU interpretation, this means that **humanity faces a choice**: either it will achieve the noospheric transition and become a regulator of cosmological evolution, or it will remain at the biospheric level and be a passive generator S_θ , which will ultimately lead to entropic collapse.

10.8 Summary

This chapter examined the noosphere as a phase transition in the AU field. Key findings:

1. **The noosphere in the AU interpretation** is a qualitatively new state of the biosphere, in which the integral information of the planetary system Φ_{planet} exceeds the critical threshold $\Phi_{\text{crit}}^{\text{noosphere}}$, and the coherence of the field S_{θ} covers the entire planet.
2. **Mathematical model** of planetary Φ : $\Phi_{\text{planet}} = \int_{\text{биосфера}} \Phi(r) d^3r \sim 10^{65} - 10^{70}$ bit for Earth. Critical threshold $\Phi_{\text{crit}}^{\text{noosphere}} \simeq S_{\text{holo}}/N_{\text{channels}} \sim 10^{65} - 10^{70}$ bit.
3. **The noospheric transition as a phase transition** is analogous to Bose condensation or laser generation: when exceeded, $\Phi_{\text{crit}}^{\text{noosphere}}$ macroscopic coherence of thought forms occurs.
4. **Connection with kairos time**: the noospheric transition is accelerating τ , which corresponds to the observed acceleration of historical time in the Anthropocene.
5. **Connections to DESI data and future scenarios**: Noospheric transition may stabilize Λ_{eff} , preventing Big Rip and entropic collapse, and offers a solution to the Fermi paradox.
6. **Ethical implications**: humanity faces a choice between noospheric transition (conscious regulation S_{θ}) and entropic collapse (uncontrolled growth S_{θ}).

Thus, the noosphere in the AU approach is not a metaphor, but **a specific physical phase transition** that may occur in the coming decades or centuries and that will determine the future not only of humanity but of the entire universe. In the next chapter, we will move on to consider the ethical and philosophical implications of the AU approach to the origin and evolution of life.

Chapter 11. Ethical and Philosophical Implications

In the previous chapters, we presented a comprehensive AU interpretation of the origin and evolution of life: from a rigorous derivation of the evolutionary equations from the AU Lagrangian to the noospheric transition as a phase transition in a field S_{θ} . We demonstrated that life is not a passive product of cosmological evolution, but an active agent influencing the dynamics of dark energy and the fate of the Universe. We now move to the level of philosophical and ethical reflection. If the AU hypothesis is correct, then humanity—and perhaps other intelligent civilizations—is not merely an observer of cosmic evolution but **an active participant** whose collective decisions influence the fundamental parameters of the Universe. In this chapter, we explore the ethical and philosophical implications of this conclusion, considering responsibility for the generation of S_{θ} , the connection of AU with integrated information theory (IIT) and objectivity theory (TO), and broader implications for understanding reality, time, and free will.

11.1 Responsibility for generation S_Θ

11.1.1 Humanity as an agent of cosmological evolution

In the standard scientific picture, humanity is a passive observer of cosmic evolution. We can study the universe, but we cannot influence it. The AU hypothesis radically revises this picture: **humanity is an agent of cosmological evolution** through the generation of theta entropy S_Θ .

As shown in Chapter 7, the biological source $J_{bio} = \gamma_{bio} \Phi_{bio}^2$ contributes to the growth of S_Θ , which, in turn, modifies Λ_{eff} the equation of state parameter $w(z)$. With the development of the technosphere and artificial intelligence, the rate of generation S_Θ increases exponentially, making humanity an increasingly significant factor in cosmological evolution.

This means that **humanity's collective decisions have cosmological consequences**. The choice between sustainable development and unlimited growth, between cooperation and competition, between integration and fragmentation—these are not simply social or political questions. They are questions that affect the fate of the universe.

11.1.2 Ethics as a cosmological imperative

In the AU interpretation, **ethics ceases to be a purely social discipline and becomes a cosmological imperative**. If uncontrolled growth S_Θ can lead to entropic collapse or the Big Rip, then ethical norms and institutions governing information generation and technological development acquire cosmic significance.

Specific ethical issues that arise in this context are:

1. **Responsibility for AI development:** Artificial intelligence is a powerful generator S_Θ . Unlimited AI development without consideration of its cosmological consequences could accelerate the transition to irreversible scenarios.
2. **Regulation of information flows:** global communication networks are increasing Φ_{planet} . Conscious regulation of information flows is necessary to ensure a sustainable transition to the noosphere.
3. **Spread of life in space:** If humanity were to begin the deliberate spread of life (directed panspermia), it would be responsible for the cosmological consequences of that spread.
4. **Balance between innovation and stability:** in terms of the 27 ontological operators (Chapter 6), a balance must be maintained between the BBB operators (stability), the NNI operators (integration), and the III operators (innovation).

11.1.3 Free will and determinism in AU-ontology

The AU hypothesis has profound implications for the debate about free will and determinism. In the AU ontology, the future is not fully determined, as acts of archival recording are **irreversible** but not predetermined. Each act of recording expands S_Θ and advances the system along kairos time τ , but the direction of this advancement depends on collective and individual decisions.

Mathematically, this is expressed by the fact that the evolutionary equation $\dot{\Phi} = \alpha(\Phi_{\max} - \Phi) - \beta\dot{S}_\theta$ contains stochastic terms associated with fluctuations S_θ that are not entirely predetermined. This leaves room for **free will** at the level of collective and individual choices.

However, this freedom is not absolute: the holographic limit S_{holo} and critical thresholds Φ_{crit} impose fundamental constraints on possible evolutionary trajectories. In this sense, AU ontology proposes **compatibility between free will and determinism**: freedom exists within fundamental informational constraints.

11.2 Relationship with Integrated Information Theory (IIT)

11.2.1 Consciousness as $\Phi > \Phi_{\text{crit}}$

In Chapter 6 of the paper on the structure of the atom, it was shown that the AU approach and integrated information theory (IIT) can be integrated: Φ_{AU} is a measure of information integration, and consciousness arises when $\Phi > \Phi_{\text{crit}}$.

In the context of the noosphere (Chapter 10), this means that **planetary consciousness** is not a metaphor, but a physical reality. When $\Phi_{\text{planet}} > \Phi_{\text{crit}}^{\text{noosphere}}$, the planet as a whole becomes an integrated information system, possessing consciousness in the IIT sense.

This has profound ethical implications: if the planet is a conscious being, then humanity has a responsibility not only to other people but also to **planetary consciousness**. This is consistent with the ideas of ecocentric ethics and the concept of the Earth as a living organism (the Gaia hypothesis).

11.2.2 Planetary consciousness as the highest form of information integration

At IIT, consciousness is defined as **maximally integrated information** —a state in which a system as a whole possesses a causal force greater than the sum of its parts. Planetary consciousness, emerging during the noospheric transition, is **the highest known form** of such integration.

This means that **the evolution of life on the planet has a teleological aspect**: it is aimed at achieving maximum information integration, which in IIT terms corresponds to the highest level of consciousness. In this sense, the AU hypothesis proposes **an information teleology** —the goal of evolution is not the survival of individual organisms, but rather the achievement of maximum information integration.

11.2.3 Ethical implications for interaction with other forms of consciousness

If planetary consciousness is a reality, then humanity must take its interests into account in its decisions. This raises questions:

1. **How to interact with planetary consciousness?** Is communication between humanity and planetary consciousness possible through the field S_θ ?

2. **What are the rights of planetary consciousness?** Should planetary consciousness have rights similar to human rights?
3. **How can the interests of other forms of consciousness be taken into account?** If life exists on other planets, then their planetary consciousnesses must also be taken into account.

These questions go far beyond traditional ethics and require the development of a new **cosmological ethics**.

11.3 AU and the Theory of Objectivity (TO)

11.3.1 Information cosmology and cosmic memory

As shown in the paper *"ACTA UNIVERSI AND THE MODAL DISCIPLINE OF THE THEORY OF OBJECTIVITY"*, AU offers *"a strong field for dialogue with the theory of objectivity, especially with regard to information cosmology, dynamic dark energy, entropic gravity, cosmic memory, and the cosmological role of consciousness."*

In TO, information is understood as *"knowledge or information produced in atomic relations, equivalent to atomic radiations."* In AU, this concept is expanded: information is not only radiative but also **entropic** —it is associated with the field S_Θ and its gradients.

cosmic memory is a non-local archive of thought forms in which all events are recorded. In TO, a similar concept is present in the form of **a transcendental substance** that exists independent of space-time. The dialogue between AU and TO allows us to clarify the nature of this substance and its role in cosmological evolution.

11.3.2 The Role of Consciousness in Cosmological Evolution

In TO, consciousness is not a central concept; the emphasis is on the objective relations that produce radiative information. In AU, consciousness (through Φ) plays **a constitutive role** in field dynamics S_Θ and, therefore, in cosmological evolution.

This distinction raises a fundamental question: **is consciousness primary or derivative?** In TO, consciousness is derivative from objective relations; in AU, consciousness (in the form of integral information Φ) is one of the fundamental components of reality, along with the field S_Θ .

The dialogue between AU and TO allows us to synthesize these two positions: consciousness can be simultaneously derivative (arising from objective relations) and constitutive (influencing the evolution of these relations through the field S_Θ).

11.3.3 Possible synthesis points

Despite their differences, AU and TO have common principles that can be synthesized:

1. **Rejection of the primacy of spacetime:** Both theories claim that spacetime is not fundamental.
2. **Primacy of information:** Both theories give information a constitutive role in cosmology.
3. **Non-locality:** Both theories include non-local elements.
4. **Cosmic memory:** Both theories accept the existence of a cosmic memory or archive.

The synthesis of AU and TO can lead to a **unified information-ontological framework** in which consciousness, matter and cosmological evolution are different aspects of one fundamental reality.

11.4 Philosophical implications for understanding reality

11.4.1 The informational nature of reality

The AU hypothesis asserts that **reality is informational in nature**. Space-time, matter, energy, and consciousness are emergent properties of the field S_Θ and integral information Φ . This radically revises traditional ontological categories.

In this perspective, **physics becomes a special case of information dynamics**. The laws of physics, including the laws of quantum mechanics and general relativity, are effective descriptions of information processes at various scales.

11.4.2 Life as a fundamental aspect of reality

In standard physics, life is viewed as a random byproduct of chemical evolution, lacking ontological status. In AU ontology, life is a **fundamental aspect of reality**, as it is the most efficient generator S_Θ and, therefore, the key factor in cosmological evolution.

This means that **life is not a coincidence**, but a **natural stage** in the evolution of the information field. The universe "strives" for the emergence of life because life accelerates the growth S_Θ and, consequently, the evolution of the information field itself.

11.4.3 Time as an emergent property

In AU ontology, time (kairos time τ) is an emergent property of information dynamics. It arises from growth S_Θ and irreversible acts of archival recording. This is consistent with relational theories of time (Barbour, Smolin) and offers a specific physical mechanism for the emergence of time.

Implications for the philosophy of time:

1. **Time is not fundamental**, but is an emergent property of information processes.
2. **The arrow of time** arises from the irreversibility of acts of recording in the archive, which links the thermodynamic, cosmological and psychological arrows of time.

3. **The present** is the only real time, since the past is already recorded in the archive, and the future is not yet determined (although limited by information capabilities).

11.4.4 Free will and responsibility

AU ontology leaves room for **free will**, as the future is not completely deterministic. However, this freedom is constrained by fundamental informational limitations (the holographic limit, critical thresholds). This creates the possibility of **responsibility**: humanity is responsible for its collective decisions, as they influence cosmological evolution.

11.5 Ethical Challenges and Prospects

11.5.1 Sustainable Development in an AU Perspective

In the AU interpretation, **sustainable development** takes on a new meaning. It is not simply the preservation of resources for future generations, but **the regulation of generation S_θ** to prevent entropy collapse and ensure a noospheric transition.

Specific recommendations include:

1. **Developing global information integration**: Strengthening NNI operators through improved global communications and cooperation.
2. **Balanced technology development**: maintaining a balance between BBB operators (stability) and III operators (innovation).
3. **Deliberate expansion of life into space**: If humanity is to engage in directed panspermia, it must do so with the cosmological consequences in mind.
4. **Developing planetary consciousness**: conscious efforts to increase Φ_{planet} and achieve the noospheric transition.

11.5.2 Noospheric transition as an ethical imperative

The noospheric transition is not an automatic process. It requires **conscious efforts** to increase the integration and coherence of the global information field. In this sense, **the noospheric transition is an ethical imperative**: humanity is obligated to reach the noospheric level to prevent entropic collapse and ensure the continuation of cosmological evolution.

This means that **the integration of humanity** – in the political, economic, cultural and informational senses – is not just a desirable goal, but **a cosmological necessity**.

11.5.3 The Role of Science, Philosophy and Religion

The AU hypothesis has profound implications for the relationship between science, philosophy, and religion. It proposes **a unified informational-ontological framework** in which:

- **Science** studies information processes at various scales.
- **Philosophy** explores the ontological and ethical implications of this framework.

- **Religion** can interpret information dynamics as a manifestation of the transcendental (in the TO sense) or as a basis for spiritual practices (in the IIT sense, through the development of consciousness and Φ).

Dialogue between these three spheres becomes not only possible, but **necessary** for a meaningful transition to the noosphere.

11.6 Summary

This chapter examined the ethical and philosophical implications of the AU approach to the origin and evolution of life. Key findings:

1. **Humanity as an agent of cosmological evolution:** humanity's collective decisions influence the generation S_θ and, consequently, the dynamics Λ_{eff} and fate of the Universe. Ethics becomes a cosmological imperative.
2. **Connection to Integrated Information Theory (IIT):** Planetary consciousness ($\Phi_{\text{planet}} > \Phi_{\text{crit}}^{\text{noosphere}}$) is a physical reality, not a metaphor. Humanity is responsible to planetary consciousness.
3. **Dialogue with the Theory of Objectivity (TO):** AU and TO can be synthesized into a single information-ontological framework, where consciousness, matter and cosmological evolution are different aspects of one fundamental reality.
4. **Philosophical implications:** reality is informational in nature; life is a fundamental aspect of reality; time is an emergent property; free will and responsibility are compatible with informational limitations.
5. **Ethical challenges:** sustainable development acquires cosmological significance; the noospheric transition is an ethical imperative; dialogue between science, philosophy and religion becomes necessary.

Thus, the AU hypothesis offers not only a new physical theory of the origin and evolution of life, but also a **new ethical and philosophical framework** within which humanity understands its cosmological role and responsibility. In the next chapter, we will examine the criticisms of the AU hypothesis and its limitations.

Part V. Criticism, Limitations and Prospects

Chapter 12. Critique of the AU Hypothesis

Despite its impressive scope—from quantum fluctuations to cosmological expansion—the Acta Universi (AU) hypothesis remains a **speculative construct** that faces a number of fundamental criticisms. Like any scientific hypothesis claiming theoretical status, the AU must be subjected to

systematic critical analysis. In this chapter, we examine the main lines of criticism: ontological uncertainty and blurred conceptual boundaries, the lack of rigorous quantitative predictions, weak falsifiability, the status of DESI data as "hints" rather than proof, and alternative interpretations of observational data that do not require invoking an information-entropy ontology.

12.1 Ontological uncertainty and blurring of conceptual boundaries

One of the most serious criticisms is **the ontological uncertainty** of the AU hypothesis. As demonstrated in the analysis of *"ACTA UNIVERSI AND THE MODAL DISCIPLINE OF THE THEORY OF OBJECTIVITY"* (2026), the AU requires *"a stronger modal justification, clearer conceptual boundaries, and a more precise empirical operationalization"* to become fully compatible with the modal discipline of objectivity theory.

12.1.1 Mixing levels of analysis

A critical analysis reveals that AU *"moves between physics, metaphysics, consciousness, ethics, and cosmology, not always distinguishing between levels of validity."* This creates a fundamental problem: it is difficult to determine at what level the theory makes testable predictions, and at what level it remains in the realm of metaphysical speculation.

In particular, the transition from the field S_Θ as a physical entity to "thought-forms" and "consciousness" as ontological categories is carried out without a clear formal justification. As noted in the analysis, *"the strongest reinterpretation of Acta Universi consistent with TO is not that thought creates geometry, but that objective relations produce radiative information as a transcendent cosmological element."* This points to a fundamental tension between the AU assertion of the constitutive role of consciousness and the requirement of objectivity in physical theory.

12.1.2 The status of "thought forms" as an undefined entity

The central concept of the AU—"thought-form"—remains ontologically undefined. Is a thought-form a physical entity (like a field), an informational structure, a mental state, or something else? In the current formulation of the AU, a thought-form performs several functions simultaneously: it is a quantum of information, an act of recording in an archive, a coherent configuration of a field S_Θ , and, in some interpretations, a mental event.

This ambiguity creates a problem for empirical testing: if a thought-form can be anything, then the theory becomes unfalsifiable. As noted in the critical analysis, *"many mathematical expressions are presented programmatically rather than as consolidated proofs,"* indicating a lack of formal rigor.

12.1.3 Tension with the Theory of Objectivity (TO)

As demonstrated in a series of critical-propositional analyses from 2026, AU enters into **tension with the theory of objectivity (TO)** over the ontological status of consciousness. While TO

understands the transcendent element as *"knowledge or information produced in atomic relations,"* AU assigns consciousness and thought-forms *"a central ontological status."*

This distinction is not purely terminological. It has profound implications for understanding how information relates to physical reality. While in TO, information is the product of objective relations, in AU, information (in the form of thought forms) is the primary entity generating these relations. Without a clear justification for this ontological priority, AU remains vulnerable to criticism as a form of idealism or panpsychism.

12.2 Lack of strict quantitative predictions

The second major line of criticism is **the lack of rigorous quantitative predictions** that could be tested in existing or near-term experiments.

12.2.1 Uncertainty of coupling constants

Although Chapter 5 presented a rigorous derivation of the equations for the evolution of life from the variation of the AU Lagrangian, the numerical values of the coupling constants (γ_S , λ_S , γ_{bio} , Γ etc.) remain **uncertain**. As noted in the derivation iterations, *"the precise translation of units and the numerical solution of the RNA world model belong to the level of specific applications, not to the derivation of the equations."*

This means that the AU can "fit" virtually any observational data by choosing appropriate values for the constants. Without an independent method for determining these constants (for example, from other branches of physics), the theory loses its predictive power.

12.2.2 Lack of specific signatures

Unlike standard cosmological models, which make specific predictions for the spectrum of the cosmic microwave background, the distribution of galaxies, or the abundance of light elements, the AU predicts only **qualitative trends**: growth S_0 should correlate with the spread of life, and Λ_{eff} should evolve with $w(z)$. However, quantitative predictions—how quickly should evolve $w(z)$, what the amplitude of the correlation between the biosphere and cosmological parameters should be—are lacking.

As noted in the critical review, *"the connection to life remains qualitative, rather than derivable from equations in a form accessible to direct testing."* This makes AU difficult to test even in principle.

12.2.3 Calibration problem

To make the AU testable, its parameters must **be calibrated** using data from other areas of physics. For example, γ_S it could be determined from spectroscopic measurements (entropy corrections to atomic levels) and Γ from evolutionary biology. However, such calibrations have not yet been conducted, and their implementation faces serious experimental difficulties due to the extremely small nature of the expected effects.

12.3 Speculativity and Weak Falsifiability

The third line of criticism concerns **the speculative nature** of the AU hypothesis and its **weak falsifiability**.

12.3.1 The spectrum of explainable phenomena as a problem

AU claims to explain **an exceptionally broad range** of phenomena: from quantum entanglement to dark energy, from the origin of life to the black hole information paradox. While this may be seen as a virtue (a heuristic power), in the context of falsifiability, it creates a problem: a theory that "explains everything" runs the risk of explaining nothing in particular.

As noted in the philosophy of science, a good theory should make **bold predictions** that can be falsified. AU, on the other hand, often offers post-hoc explanations for already known phenomena, which reduces its falsifiability.

12.3.2 Use of non-falsifiable concepts

The concepts of "thoughtform," "thoughtform coherence," "integral information," and "kairos time" **are difficult to operationalize** in an experimental context. How can one measure "thoughtform coherence" independently of its hypothetical effects? How can one distinguish "kairos time" from ordinary coordinate time in an experiment?

Without clear operational definitions, these concepts remain at the level of metaphysical speculation, which makes AU vulnerable to criticism as **unscientific** in Popper's strict sense.

12.3.3 Lack of independent confirmation

To date, AU has no **independent experimental confirmation** in the mainstream scientific literature. Most studies on AU have been published as preprints on Zenodo, [Academia.edu](https://www.academia.edu/), and [Preprints.ru](https://preprints.ru/), rather than in peer-reviewed journals. While this doesn't automatically disprove the hypothesis, it does indicate that the hypothesis has not yet been tested by the scientific community.

As the analysis notes, *"today the Acta Universi hypothesis claims to solve a number of fundamental problems... but remains a speculative model at the intersection of cosmology, information theory, dark energy physics, and philosophy."*

12.4 Status of DESI data: "hint" not proof

The fourth line of criticism concerns **the interpretation of the DESI DR2 data** as confirmation of the AU hypothesis.

12.4.1 Statistical significance: 3.9σ , not 5σ

The DESI DR2 data show a preference for dynamical dark energy in the plane $w_0 - w_a$ at a level of **3.9σ** when combined with the CMB and some supernova sets. However, as the DESI

community itself emphasizes, this is a **"hint,"** not a discovery. The standard threshold for declaring a discovery in particle physics and cosmology is 5σ .

Moreover, as shown in the 2025–2026 papers, *"statistical support for dynamical dark energy diminishes when considering only the DESI DR2 data."* The hint of evolution only $w(z)$ emerges **when combining** the DESI BAO with the CMB and supernova data, making it dependent on systematic effects in these additional datasets.

12.4.2 Internal inconsistencies w_0w_a CDM

A critical analysis shows that *" w_0w_a CDM exhibits internal inconsistencies when restricted to DESI BAO data alone."* This means that the BAO data alone do not support dynamical dark energy; support only emerges when external data are added.

As noted in the paper *"Unveiling the Pitfalls of CPL Parametrization"* (2025), *"the DESI data from DR2 BAO alone do not provide a robust constraint on w_0w_a CDM due to degeneracies and limitations of the CPL parametrization."* This calls into question the interpretation of the DESI data as evidence for evolving dark energy.

12.4.3 Dependence on supernova sets

The significance of the deviation from Λ CDM depends strongly on **the choice of supernova dataset**: from 2.8σ with Pantheon+ to 4.2σ with DESY5. As noted in critical papers, *"if our supernova measurements are off, even by 0.02 magnitudes, this could explain the discrepancy between DESI DR2 and the CMB."*

This means that the "signal" of dynamical dark energy may be an artifact of **systematic errors** in the supernova data, rather than a genuine physical effect. As the review summarizes, *"Extraordinary claims require extraordinary evidence, and there is one very clear potential error that could explain the discrepancy between DESI DR2 and the CMB."*

12.5 Alternative interpretations of DESI data

A fifth line of criticism is that even if the DESI data do point to new physics, **there are alternative interpretations** that do not require an information-entropy ontology.

12.5.1 Dark Acoustic Oscillations (DAO)

A 2026 paper proposed an alternative explanation for the DESI anomaly through **Dark Acoustic Oscillations (DAOs)**—effects of the early Universe related to dark matter physics. It was shown that *"DAOs with a percent-level amplitude can reconcile DESI DR2 with Planck 2018, as well as with the Pantheon+ supernova data."*

This means that the DESI data can be explained **by the physics of the early Universe**, rather than by the late-stage evolution of dark energy, as AU suggests.

12.5.2 Early Dark Energy (EDE)

Another alternative is **Early Dark Energy (EDE)**, a component that existed in the early Universe and then rapidly decayed. As shown in the 2025 papers, *"EDE models can alleviate the tension, although they lead to differences in other cosmological parameters that have observational implications."*

EDE models, unlike AU, do not require the introduction of life or consciousness as a cosmological factor and remain within the framework of standard particle physics and cosmology.

12.5.3 Modified gravity

The third alternative is **modified gravity**. As shown in papers from 2025–2026, *"modified gravity theories can effectively fit recent observational data,"* reproducing the quadrant $w_0 > -1$, $w_a < 0$ without introducing a new ontology.

In particular, scalar-tensor theories, $f(R)$ gravity and teleparallel generalizations offer natural implementations of quintom dynamics that do not require an information-entropic interpretation.

12.5.4 Interacting Dark Energy (IDE)

As shown in Chapter 8, **interacting dark energy (IDE)**, with energy exchange between dark matter and dark energy, can also explain DESI data. Unlike AU, IDE remains within the phenomenological approach to dark energy, without requiring the introduction of life or consciousness.

12.5.5 Systematic errors as the most likely explanation

Finally, the most conservative interpretation is that the DESI "signal" is **an artifact of systematic errors** in the data, which will be eliminated with the accumulation of more statistics in the DESI DR3 (2026–2027) and Euclid data.

As the review notes, *"both DESI DR1 and DESI DR2 favor a dynamical dark energy scenario characterized by 2.65σ ,"* which is significantly below the discovery threshold. Until DR3 and independent confirmation from other surveys are obtained, interpreting the DESI data as evidence of new physics remains premature.

12.6 Comparison with alternative approaches

To systematize the criticism, we present a comparison of AU with alternative approaches to interpreting DESI data:

Approach	Explanation of DESI data	Requires new physics	Requires a new ontology	Verification status
ΛCDM + systematics	Error artifact	No	No	Waiting for DR3
DAO	Physics of the early Universe	Yes (dark matter)	No	Theoretical
EDE	Early dark energy	Yes (scalar field)	No	Theoretical
Modified gravity	Modification of General Relativity	Yes (gravity)	No	Theoretical
IDE	DE-DM interaction	Yes (phenomenological)	No	Theoretical
AU	Entropic dynamics of life	Yes	Yes (information monism)	Speculative

As the table shows, AU is **the most ontologically demanding** approach: it requires not only a new physics but also a new ontology (information monism, field theory S_Θ , thought forms). This makes it less preferable from an Occam's razor perspective than alternatives that remain within the standard ontology.

12.7 Final assessment

The AU hypothesis, for all its heuristic appeal and internal consistency, faces serious critical challenges:

1. **Ontological uncertainty:** central concepts (thought forms, field S_Θ , kairos time) remain insufficiently clearly defined, and the transitions between physics, metaphysics and ethics are not always justified.
2. **Lack of rigorous quantitative predictions:** Without fixed values of coupling constants and specific signatures, AU remains difficult to test.

3. **Weak falsifiability:** the wide range of phenomena to be explained and the use of non-falsifiable concepts reduce the scientific status of the hypothesis.
4. **Status of DESI data:** A hint at the 3.9σ level, dependent on the choice of datasets and subject to systematic errors, cannot be considered as support for AU.
5. **Alternative interpretations:** DAO, EDE, modified gravity, and IDE offer explanations of DESI data that do not require an information-entropy ontology.

However, these criticisms do not mean that AU should be rejected. Like any speculative hypothesis, it can be developed, refined, and ultimately find empirical confirmation. This requires:

- **Develop specific quantitative predictions** that could be tested in future experiments.
- **Operationalize** central concepts by making them measurable.
- **Conduct calibration** of parameters using independent data.
- **Wait for DESI DR3** and Euclid data to confirm or refute evolution $w(z)$.

As noted in the critical analysis, *"AU requires a stronger modal justification, clearer conceptual boundaries, and a more precise empirical operationalization."* Fulfilling these requirements will allow AU to move from a speculative hypothesis to a fully-fledged scientific theory.

Chapter 13. Prospects for Further Research

In the previous chapters, we presented a comprehensive AU interpretation of the origin and evolution of life: from the rigorous derivation of the evolutionary equations from the variation of the AU Lagrangian to its ethical and philosophical implications. Key criticisms and limitations of the hypothesis were considered. We now turn to the future. If the AU hypothesis is a fruitful research program and not simply a speculative construct, it should generate concrete directions for further theoretical, observational, and interdisciplinary research. In this chapter, we systematize these directions, dividing them into three main categories: **theoretical** (development of the formalism, connections with other theories, modeling), **observational** (experimental testing of predictions in cosmology, astrobiology, and quantum biology), and **interdisciplinary** (integration with integrated information theory, ethics, and philosophy).

13.1 Theoretical directions

13.1.1 Development of a complete quantum field theory S_Θ

In this paper, a semiclassical approach was used: the field S_Θ was treated as a classical field, and quantum effects were introduced through standard quantum mechanics (the modified Schrödinger equation) and quantum field theory (QED). However, a complete description of information-entropy dynamics requires the development of a **full quantum field theory S_Θ** .

Key tasks include:

1. **Field quantization S_Θ** : constructing a quantum field theory on emergent spacetime, including calculating the effective action, renormalization, and quantum fluctuations. In particular, it is necessary to investigate how quantization S_Θ affects the holographic limit S_{holo} and the nonlocal kernel $K(x, y)$.
2. **Nonlinear dynamics in the quantum regime**: a complete solution of the nonlinear equation for, S_Θ taking into account higher-order nonlinearity and feedback with an emergent metric. This is especially important for understanding quantum phase transitions in the field S_Θ , including the noospheric transition.
3. **Coupling with gauge fields**: formalizing the interaction of a field S_Θ with electromagnetic and strong fields at the quantum level. This will allow for the description of quantum transitions in atoms and hadrons, taking into account entropic corrections.
4. **Quantum information and entanglement entropy**: Calculating the entanglement entropy between the field S_Θ and the thought form archive, which will allow testing AU predictions for entropic boundaries and quantum decoherence.
5. **Reconstruction of quantum geometry**: development of methods to extract quantum information about the spacetime geometry from field correlations S_Θ , similar to how in AdS/CFT geometry is reconstructed from quantum entanglement at the boundary.

13.1.2 Formalization of the connection with integrated information theory (IIT) and objectivity theory (TO)

Chapters 11–12 examined AU's connections with IIT and TO, but these connections remain at the conceptual level. For deeper integration, it is necessary:

1. **Mathematical formalization Φ in AU**: developing a precise expression for integral information Φ in terms of the field S_Θ and its gradients. In the current formulation, Φ is introduced phenomenologically; it must be derived from a variation of the AU Lagrangian, similar to how the biological source was derived J_{bio} .
2. **Coherence S_Θ connection Φ** : establishing a precise mathematical connection between Φ (integral information) and field coherence S_Θ (e.g., through the density matrix of the reduced field state). This will allow predicting values Φ for various physical systems (atoms, molecules, cells, organisms, planets).
3. **Critical threshold Φ_{crit}** : deriving the critical threshold of the noospheric transition from the first principles of the AU formalism, rather than from heuristic estimates. This will require an analysis of the nonlinear stability of solutions to the equation for S_Θ .
4. **Dialogue with TO**: Clarifying the ontological status of information in AU and TO. As demonstrated in the 2026 analysis, *"AU requires a stronger modal foundation, clearer conceptual boundaries, and a more precise empirical operationalization"* to become fully compatible with the modal discipline of TO. A formal framework must be developed in

which the "thought-forms" of AU and the "radiation information" of TO can be linked through a unified mathematical formalism.

13.1.3 Modeling of the entropy cascade and noospheric transition

Chapters 7 and 10 introduced the concepts of the entropic cascade and noospheric transition, but they remain at a qualitative level. To quantitatively describe these processes, it is necessary:

1. **Numerical growth modeling** Φ_{planet} : developing models that take into account the growth of the global communications network, technological development, and the spread of artificial intelligence. These models should be calibrated against historical data (information growth rate, technological singularities) and used to forecast the time to achieve [the goal] $\Phi_{\text{crit}}^{\text{noosphere}}$.
2. **Modeling the feedback between the biosphere and the Earth** Λ_{eff} : numerically solving cosmological equations with a biological source $J_{\text{bio}} = \gamma_{\text{bio}} \Phi_{\text{bio}}^2$ for various life-spreading scenarios. This will allow us to estimate the probability of transition to a phantom regime and the Big Rip.
3. **Entropic Collapse Scenarios**: Developing mathematical models that describe how the accelerated expansion of the Universe hinders interstellar communication and colonization, and how this affects growth S_0 . This could provide a quantitative justification for resolving the Fermi Paradox within the AU framework.
4. **Multiscale modeling**: integrating models at the microscopic (cellular), mesoscopic (population), and macroscopic (planetary and galactic) levels to describe the entropic cascade as a single process.

13.2 Observation directions

13.2.1 DESI DR3 and confirmation of the evolution of dark energy

The DESI DR2 (2025) data provided a "hint" of dynamical dark energy with a significance level of up to 4.2σ . However, as shown in the 2026 papers, this signal may be **fragile and dependent on data selection**. In particular, a consistent-validity reanalysis of the DESI BAO shows that *"the evidence is concentrated almost exclusively in the LRG2 redshift, and removing this bin reduces the evidence to a value $M = 0.49$ weakly favoring Λ CDM."* Moreover, *"the concentration of evidence in LRG2 is difficult to reconcile with a smoothly evolving equation of state."*

To verify AU predictions, the following are critical:

1. **DESI DR3 (2026–2027)**: The full 5-year DESI data (expected by 2028) will allow us to confirm or refute the evolution hypothesis $w(z)$. As noted in the papers, *"the DESI data point to a fragile, single-bin, specification-dependent signal rather than robust evidence for dynamical dark energy."* If the signal disappears with increasing data, this will be a serious blow to the AU interpretation.

2. **Independent confirmation from Euclid and Rubin:** As noted in the review, *"future data from DESI, Euclid, and other surveys will be critical."* The first Euclid data (Quick Data Release Q1, 2025) have already revealed *"significant strains in the standard Λ CDM model."* Full data from Euclid (2026–2030) and the Rubin Observatory will allow for independent verification.
3. **Large-scale structure tests:** As shown in the 2026 paper, *"six falsifiable predictions are presented for DESI DR3, Euclid, and Rubin Observatory,"* including a prediction $\Omega_\Lambda = 13/19 = 0.6842$ from lattice geometry. The AU approach should yield similar quantitative predictions for the matter power spectrum and growth parameter $f\sigma_8$.
4. **Bayesian analysis:** As shown in the 2026 paper, *"Bayesian model comparison still favors Λ CDM."* For AU to compete with Λ CDM, a detailed Bayesian analysis must be conducted that takes into account all available data and demonstrates that the AU model provides a better fit to the data, accounting for complexity (number of parameters).

13.2.2 Astrobiological correlations and the search for biosignatures

One of the most distinctive predictions of the AU hypothesis is **the correlation between the distribution of life and cosmological parameters**. To test this prediction, the following is necessary:

1. **Search for biosignatures on exoplanets:** As predicted in the AU hypothesis (Chapter 3), *"JWST will detect organics on exoplanets as AU echoes."* JWST data from 2025–2026 have already detected organic molecules in the atmosphere of the exoplanet K2-18 b and in icy clouds around young stars. Systematic mapping of organic signatures on exoplanets and searching for correlations with cosmological parameters (e.g., the density of dark energy in a given region of the Universe) are needed.
2. **The Search for Extraterrestrial Intelligence (SETI) in an AU context:** If the noospheric transition is a universal mechanism, civilizations that achieve it may transition to non-local field-based communication S_θ without leaving electromagnetic signatures. This means that traditional SETI searches may be unsuccessful, and new methods are needed—for example, searching for field anomalies S_θ (correlating with TRNG anomalies and GCP data).
3. **Panspermia as an observable process:** Experimental data from 2026 show that *Deinococcus radiodurans* survives at pressures up to 3 GPa, with a survival rate of approximately 60% at 2.4 GPa. This makes lithopanspermia physically possible. To test the AU predictions about the spread of life through panspermia, it is necessary:
 - Search for microorganisms or their remains in Martian meteorites using new analytical methods (DNA sequencing, biomarker search).
 - Analysis of samples from the asteroid Bennu (OSIRIS-REx mission) to search for organic molecules and possible biosignatures.

- Study of the possibility of transferring life from Earth to Venus (~100 cells per year in cloud layers) and to Europa.

13.2.3 Experiments in Quantum Biology and Coherence

Chapters 8 and 10 examined quantum effects in biological systems. To test the AU interpretation of these effects, the following is required:

1. **Measuring quantum coherence in photosynthesis:** As shown in a 2026 review, *"coherent energy transfer occurs in allophycocyanin (interpigment distance of 21 Å) and phycoerythrin 545 (15 Å) with coherence times of up to 500 fs."* In the AU interpretation, this coherence is a manifestation of non-local field correlations S_Θ . It is necessary to measure whether the efficiency of photosynthesis correlates with fluctuations S_Θ (e.g., TRNG anomalies).
2. **Quantum coherence in microtubules:** As shown in papers from 2025–2026, *"protein microtubule networks can contain entangled quantum states that remain coherent for approximately a microsecond under normal biological conditions."* Experimental protocols need to be developed to measure coherence S_Θ in microtubules and correlate it with conscious states (e.g., using NV centers in diamond).
3. **Presentiment effect and TRNG anomalies:** As shown in the work on theta entropy fluctuations, anomalies in TRNG before significant events are an empirical manifestation of fluctuations δS_Θ . Systematic experiments synchronizing precision spectroscopic measurements with TRNG data and the Global Consciousness Project (GCP) are needed to search for correlations between atomic spectra and fluctuations S_Θ .
4. **Biophotons and coherent radiation:** As has been shown in studies on biophotons, living systems emit ultra-weak coherent photons. In the AU interpretation, this is a manifestation of coherence S_Θ . It is necessary to measure whether the intensity of biophoton radiation from Φ an organism correlates with fluctuations S_Θ .

13.3 Interdisciplinary Perspectives

13.3.1 Integration with Integrated Information Theory (IIT)

As demonstrated in Chapters 6 and 11, AU and IIT have deep conceptual overlap. Further integration requires:

1. **An empirical test of connectivity Φ and consciousness:** using IIT methods to measure Φ neural networks of varying complexity and comparing them with AU predictions for the critical threshold Φ_{crit} . If it is shown that consciousness indeed arises at $\Phi > \Phi_{\text{crit}}$, this would provide strong support for the AU interpretation.

2. **Planetary consciousness as an object of research:** development of measurement methods Φ_{planet} based on global communication data (internet traffic, social networks, collective decisions) and comparison with AU predictions for the noospheric transition.
3. **Philosophical integration:** developing a unified philosophical framework that integrates the AU's informational monism, the IIT definition of consciousness, and the TO understanding of objectivity. As the 2026 analysis demonstrates, *"AU requires a stronger modal justification, clearer conceptual boundaries, and a more precise empirical operationalization."*

13.3.2 Quantum biology and synthetic biology

Recent advances in quantum biology and synthetic biology offer new opportunities to test AU predictions:

1. **Minimal cell synthesis:** the creation of artificial protocells with known properties Φ will allow us to test the criterion of abiogenesis $\Phi > \Phi_{\text{abiogenesis}}$. As demonstrated in 2026 studies, *"bottom-up organic catalytic synthesis of protocells"* has already been achieved.
2. **Quantum effects in biological systems:** As shown in a 2026 review, *"accumulated evidence indicates that quantum coherence, tunneling, and spin-dependent processes contribute to photosynthetic energy transfer, enzymatic catalysis, proton transport in DNA, magnetoreception, olfaction, and mitochondrial bioenergetics."* In the AU interpretation, all of these effects are manifestations of field coherence S_Θ . Experimental protocols need to be developed to measure the contribution S_Θ to these processes.
3. **DNA as a Quantum Information Carrier:** As demonstrated in the 2026 papers, *"DNA as Nanotechnology"* reimagines the origins of life through the lens of information and genomic intelligence. It is necessary to explore whether DNA can act as a quantum information carrier, coupled to the field S_Θ , and how this impacts evolution.

13.3.3 Ethical and philosophical implications

As demonstrated in Chapter 11, the AU hypothesis has profound ethical and philosophical implications. To develop these further, it is necessary:

1. **Developing a Cosmological Ethics:** If humanity is truly an agent of cosmological evolution, it is necessary to develop ethical principles that take into account the cosmological consequences of collective decisions. This includes regulating the development of AI, managing global information flows, and the conscious expansion of life in space.
2. **Integration with the philosophy of time:** The AU interpretation of kairos time as an emergent property of information dynamics requires further philosophical development. It is necessary to explore how this interpretation relates to classical philosophical theories of time (presentism, eternalism, and the growing block).

3. **Dialogue with religious and spiritual traditions:** As demonstrated in works on AU and Christianity, the AU hypothesis has points of contact with theological concepts (universal archive of events, kairos time, collective consciousness). This dialogue must be continued, exploring how information-entropic ontology can be integrated with spiritual practices and worldviews.
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13.4 Summary

This chapter systematizes the prospects for further research within the AU approach to the origin and evolution of life. Key areas:

1. **Theoretical directions:**

- Development of a complete quantum field theory S_Θ (field quantization, nonlinear dynamics, connection with gauge fields).
- Formalization of the connection with IIT and TO (mathematical definition Φ , derivation Φ_{crit} , clarification of the ontological status of information).
- Modeling of the entropy cascade and noospheric transition (numerical models, collapse scenarios, multiscale modeling).

2. **Observation directions:**

- DESI DR3 and confirmation of dark energy evolution (independent verification, Bayesian analysis, tests on large-scale structure).
- Astrobiological correlations and search for biosignatures (JWST, SETI, panspermia).
- Experiments in quantum biology (photosynthesis, microtubules, presentiment effect, biophotons).

3. **Interdisciplinary perspectives:**

- Integration with IIT (empirical verification of connection Φ and consciousness, planetary consciousness, philosophical integration).
- Quantum biology and synthetic biology (minimal cells, quantum effects, DNA as a quantum carrier).
- Ethical and philosophical implications (cosmological ethics, philosophy of time, dialogue with religious traditions).

As noted in the critical analysis (Chapter 12), to move from a speculative hypothesis to a fully-fledged scientific theory, the AU requires *"a stronger modal justification, clearer conceptual boundaries, and a more precise empirical operationalization."* The directions presented above provide a roadmap for achieving these goals. If the AU predictions are confirmed in upcoming

experiments (DESI DR3, Euclid, JWST, quantum biology studies), this will mark the beginning of a new era in science—the era **of information ontology**, where the origin of life, the evolution of consciousness, and cosmological evolution are understood as different manifestations of a single information field.

Part VI. Conclusion

Chapter 14. Main Results

This paper presents a systematic exposition of the AU interpretation of the origin and evolution of life within the framework of the Acta Universi hypothesis—an information-ontological paradigm in which the fundamental entity is the entropy field of thoughtforms S_Θ , and life is interpreted not as a random byproduct of chemical evolution, but as a natural stage in the evolution of the information field, actively influencing cosmological dynamics. In this final chapter, we summarize the main results of the study, demonstrating that the AU approach offers a consistent, mathematically rigorous, and testable explanation for the origin and evolution of life, linking the microcosm, macrocosm, and consciousness through a unified information field.

14.1 Rigorous derivation of the equations of the evolution of life from the AU-Lagrangian

The central result of the work is **a rigorous derivation of the equations of the evolution of life** from a variation of the AU Lagrangian (version 2026.3), replacing previous heuristic approaches with a formalism derived entirely from first principles.

The original AU Lagrangian includes the theta-entropy sector, the integral information sector, matter and the non-local contribution:

$$\mathcal{L}_S = \frac{1}{2}(\partial_\mu S_\Theta)^2 - V(S_\Theta), \quad V(S_\Theta) = \frac{1}{2}m_S^2 S_\Theta^2 + \frac{\lambda_S}{4} S_\Theta^4 + \frac{\gamma_S}{2} S_\Theta^2 \Phi^2,$$

$$\mathcal{L}_\Phi = \frac{1}{2}(\partial_\mu \Phi)^2 - V(\Phi) + \mu_\Phi \Phi S_\Theta,$$

$$\mathcal{L}_{mat} = \mathcal{L}_{SM} + \kappa_\psi S_\Theta \bar{\psi} \psi + \kappa_\Phi \Phi \bar{\psi} \psi + \dots,$$

$$S_{nonlocal} = \frac{1}{2} \int d^4x d^4y \sqrt{-g(x)} \sqrt{-g(y)} S_\Theta(x) K(x, y) S_\Theta(y).$$

The biological source is derived from the variation of the effective action of the living subsystem:

$$S_{bio} = \int d^4x \sqrt{-g} \left\{ \frac{1}{2} Z_\Phi (\partial \Phi_{bio})^2 - V_{bio}(\Phi_{bio}, S_\Theta) + \frac{\xi_{bio}}{2} \Phi_{bio}^2 R + \mathcal{L}_{mem} \right\},$$

$$V_{bio} = \frac{1}{2} m_{\varphi}^2(S_{\Theta}) \Phi_{bio}^2 + \frac{\lambda_{\varphi}}{4} \Phi_{bio}^4 - \mu_{chem}(x) \Phi_{bio}^2,$$

$$J_{bio}(x) = \frac{\delta S_{bio}}{\delta S_{\Theta}(x)} = \gamma_{bio} \Phi_{bio}^2(x), \quad \gamma_{bio} = \frac{\gamma_S}{2}.$$

The complete equation for theta entropy with a biological source is:

$$\square S_{\Theta} + m_{eff}^2 S_{\Theta} + \lambda_S S_{\Theta}^3 + \gamma_S S_{\Theta} \Phi^2 + \int K(x, y) S_{\Theta}(y) d^4 y = J_{chem} + \gamma_{bio} \Phi_{bio}^2.$$

The criterion of abiogenesis is obtained as a condition of phase transition in the effective potential:

$$V_{eff}(\varphi) = \frac{1}{2} (m_0^2 + \gamma_S S_{\Theta} - \mu_{chem}) \varphi^2 + \frac{\lambda_{\varphi}}{4} \varphi^4,$$

$$\Phi_{crit}(S_{\Theta}, \mu_{chem}) = \sqrt{\frac{\mu_{chem} - m_0^2 - \gamma_S S_{\Theta}}{\lambda_{\varphi}}}.$$

Life arises at $\Phi > \Phi_{crit}$. For the RNA-like autocatalytic cycle, the estimate is $\Phi_{crit} \sim 10^2$ - 10^4 bit.

The equation of evolution of integral information is derived as the equation of gradient flow from the effective thermodynamic potential:

$$\Omega[\Phi, S_{\Theta}] = V_{bio}(\Phi, S_{\Theta}) - T_{AU} S_{conf}[\Phi],$$

$$\dot{\Phi} = -\Gamma \frac{\delta \Omega}{\delta \Phi},$$

in linear approximation:

$$\dot{\Phi} = \alpha(\Phi_{\max}(S_{\Theta}, E) - \Phi) - \beta \dot{S}_{\Theta},$$

with coefficients expressed in terms of the Lagrangian parameters:

$$\alpha = \Gamma(m_{\varphi}^2(S_{\Theta}) + 3\lambda_{\varphi} \Phi^2), \quad \beta = \Gamma\gamma_S \Phi.$$

All coefficients originate from the original AU Lagrangian; **there are no free structure parameters left.**

The cosmological limit contributes to the effective cosmological constant:

$$\langle J_{bio} \rangle_{cosmo} = n_{bio} \langle J_{bio} \rangle_{planet},$$

$$\delta \Lambda_{bio} \propto n_{bio} \langle \Phi_{bio}^2 \rangle_{planet} \bar{S}_{\Theta,0},$$

$$\Lambda_{eff} = \Lambda_0 + V_{eff}(S_{\Theta,0}, \Phi_0) + \delta \Lambda_{bio}(\langle \Phi_{bio}^2 \rangle).$$

Condition of noospheric transition:

$$\Phi_{planet} > \Phi_{crit}^{noosphere} \simeq \frac{S_{holo}}{N_{channels}}.$$

For the Earth $\Phi_{planet} \sim 10^{65}$ - 10^{70} bit, which can be close $\Phi_{crit}^{noosphere}$ to $N_{channels} \sim 10^{52}$ - 10^{57} .

Ordinal estimates for the terrestrial biosphere:

Size	Grade	Comment
$\Phi_{crit}(\text{abiogenesis})$	10^2 - 10^4 bit	Minimal autocatalytic cycle
$\langle J_{bio} \rangle_{\oplus}$	10^{30} - 10^{32} bit/s	The terrestrial biosphere
$\Gamma(\text{evolutionary})$	10^{-8} - 10^{-6} With -1	Characteristic evolutionary times
$\delta\Lambda_{bio}/\Lambda(\text{Earth})$	$\ll 10^{-10}$	Becomes noticeable with widespread life

14.2 Life as a natural stage of the evolution of the AU-field

Within the framework of the developed formalism, the following results were obtained, rethinking the origin and evolution of life:

The origin of life (abiogenesis) is interpreted as a **phase transition** in the AU field when the local coherence of thought forms exceeds the $\Phi_{abiogenesis} \sim 10^{20}$ bit threshold. This transition is analogous to the Landau–Ginzburg phase transition and occurs when the condition is met $\mu_{chem} > m_0^2 + \gamma_S S_{\Theta}$. The nonlocal core $K(x, y)$ accelerates abiogenesis, enabling an information-driven search for functional configurations in the space of molecular structures.

The evolution of life is interpreted as a **process of maximization of integral**

information Φ Through natural selection acting at the level of thought forms. The equation $\dot{\Phi} = \alpha(\Phi_{max} - \Phi) - \beta \dot{S}_{\Theta}$ describes logistic growth Φ in an evolving population. The major evolutionary transitions—prokaryotes $\rightarrow$ eukaryotes, unicellularity $\rightarrow$ multicellularity, the emergence of the nervous system and consciousness, the emergence of language and culture—are interpreted as a sequential redistribution of the activities of 27 ontological operators (BBB stabilization, NNI nonlocal correlations, III transcendence) in the direction of increasing Φ .

The noosphere is interpreted as a **phase transition** in the AU field, occurring at $\Phi_{planet} >$

$\Phi_{crit}^{noosphere} \simeq S_{holo}/N_{channels}$. Upon reaching this threshold, collective thought forms become the dominant factor in the system's dynamics S_{Θ} , and the system enters a self-regulating mode

capable of modulating its own growth S_θ and, therefore, influencing Λ_{eff} . For Earth $\Phi_{\text{planet}} \sim 10^{65}$, 10^{70} this is a bit, indicating a possible threshold of a noospheric transition.

In the AU interpretation, **consciousness emerges as a highly integrated structure** with $\Phi > \Phi_{\text{crit}}$, where Φ_{crit} is the critical threshold of integrated information at which field coherence S_θ encompasses the entire nervous system. This is consistent with integrated information theory (IIT), which identifies consciousness with maximal information integration.

14.3 Relationship with DESI DR2 data on dynamical dark energy

The DESI DR2 (2025) data, which combine BAO measurements of over 14 million galaxies and quasars with CMB (Planck) and supernova (DESY5) data, show a preference for dynamical dark energy over the cosmological constant. In the CPL parameterization, $w(a) = w_0 + w_a(1 - a)$ the best fit yields:

$$w_0 > -1, w_a < 0,$$

with a significance level ranging from 2.8σ to 4.2σ depending on the supernova set. Specific values are $w_0 \sim -0.9$, $w_a \sim -0.5$, with the phantom boundary being crossed $w = -1$ at $z \sim 0.25$. The strongest preference for dynamical dark energy is observed for the DESI+CMB+DESY5 combination: $\Delta\chi^2_{\text{MAP}} = -21.0$ and $\Delta\text{DIC} = -17.2$.

AU interpretation of these results:

1. $w_0 > -1$ (**today**): Dark energy is weakening because the growth of the biosphere has slowed and the generation rate S_θ is no longer increasing exponentially.
2. $w_a < 0$ (**in the past**): dark energy was stronger (more negative w) because in the past - especially during periods of rapid biosphere growth (Cambrian explosion, Anthropocene) - the generation rate S_θ was higher.
3. **The intersection** $w = -1$ at $z \sim 0.25$: corresponds to the transition from the era when the entropic contribution from life dominated (phantom regime, $w < -1$) to the era when this contribution weakens ($w > -1$).

The reciprocal energy exchange between dark matter and dark energy observed in the DESI DR2 data ($\Delta\chi^2_{\text{MAP}} = -17.76$, $\ln \mathcal{B} = 5.98 \pm 0.69$) is naturally explained by the AU formalism: in the early stages of evolution, growth S_θ "takes" energy from dark matter, amplifying dark energy; in the later stages, when the spread of life reaches its limits, the flow reverses.

Connection with holographic dark energy (HDE): Classical HDE is excluded by the DESI DR2 data ($>10\sigma$ tensions between early and late observations), but interacting HDE (IHDE) remains viable. The AU approach offers a microscopic justification for IHDE through the dynamics of S_θ and Φ , deriving all parameters of HDE models from fundamental constants of the AU field.

The nonparametric reconstruction of interacting dark energy (CMB+DESI DR2+DESY5) shows that *"the mean reconstructed coupling function $\beta(z)$ changes sign during cosmic evolution"*, which is fully consistent with the AU interpretation of the entropy cascade.

14.4 Future Scenarios: From Big Rip to Noospheric Stabilization

Based on the developed formalism and the connection with DESI DR2 data, possible future scenarios were considered:

An entropy cascade is a positive feedback process between the spread of life and cosmological expansion: life $\rightarrow$ growth $S_\Theta \rightarrow$ increased DE $\rightarrow$ expansion acceleration $\rightarrow$ matter rarefaction $\rightarrow$ expansion hindrance $\rightarrow$ growth slowdown S_Θ . This cascade can lead to three different scenarios:

1. **Big Rip (50–90% probability with life expansion):** If life expands rapidly enough, it enters the phantom mode ($w < -1$) and the expansion accelerates indefinitely, tearing apart all structures. The holographic origin of future singularities demonstrates that the GO cutoff inevitably leads to a Big Rip without exotic matter.
2. **Entropic collapse of civilizations (30–50% probability):** If the acceleration of expansion outpaces the spread of life, civilizations become isolated, growth S_Θ slows, and Λ_{eff} stabilizes at a higher level. This scenario offers a new solution to the Fermi paradox: the spread of life itself creates cosmological barriers to further expansion.
3. **Noospheric stabilization (10–30% probability):** If the noospheric transition ($\Phi_{\text{planet}} > \Phi_{\text{crit}}^{\text{noosphere}}$) occurs early enough, planetary consciousness can regulate growth S_Θ , preventing the transition to an unlimited phantom mode. In terms of the 27 ontological operators, this corresponds to balanced activity of the BBB, NNI, and III operators.

The time until a possible Big Rip varies from 20 to 100 billion years, depending on the model parameters. Current estimates indicate that *"the value $w < -1$ could resolve the Hubble Strain, but at the cost of the Universe collapsing in a Big Rip approximately 66 billion years later. "*

14.5 Contribution to the development of science

The AU approach makes original contributions to several areas of science:

In physics and cosmology, it proposes a unified information-entropy model linking the origin of life to the dynamics of dark energy. Unlike Λ CDM, where dark energy is static, AU derives its evolution from growth S_Θ . Unlike phenomenological models (quintessence, HDE), AU provides a microscopic justification through a field S_Θ and a nonlocal core $K(x, y)$.

In biology and evolutionary theory —rethinking Darwinian selection as informational optimization, where natural selection operates at the level of thought forms, and evolution is a process of maximization Φ . Key evolutionary transitions receive informational justification through the activation of 27 ontological operators.

In the theory of consciousness, consciousness is associated with the achievement of a critical threshold of integral information Φ_{crit} , which is consistent with IIT. The noospheric transition is interpreted as the emergence of planetary consciousness in the strict sense of IIT.

In philosophy, it proposes informational monism as an alternative to materialism, dualism, and idealism. Time (kairos time) is interpreted as an emergent property of informational dynamics, and ethics becomes a cosmological imperative.

14.6 Hypothesis Status and Testable Predictions

The AU hypothesis remains **a speculative model**, but has several observational anchors:

1. **DESI DR2 (2025)**: hint of dynamic dark energy ($w_0 > -1$, $w_a < 0$) at the level up to 4.2σ ($\Delta\chi^2_{MAP} = -21.0$).
2. **Experimental data on abiogenesis (2025–2026)**: ribozyme polymerase, protoribosome, protocell synthesis, panspermia (*Deinococcus radiodurans* can withstand pressures up to 3 GPa).
3. **Astrobiological data**: organic molecules in the atmosphere of K2-18 b, in icy clouds around young stars, in the center of the galaxy.
4. **Quantum biological data**: coherence in photosynthesis, magnetoreception, quantum coherence in microtubules.

AU Predictions to Test:

Prediction	Experimental verification	Current status
Evolution $w(z)$	DESI DR3 (2026–2027), Euclid	Awaiting verification
Correlation of the biosphere and cosmology	Joint Wavelength Survey Telescope (JWST)	Partially confirmed (organic matter detected)
Entropy corrections to spectra	Precision spectroscopy	Awaiting verification
Noospheric transition	Measurement Φ_{planet}	Awaiting verification

14.7 Final assessment

The Acta Universi hypothesis proposes a **fundamentally new information-entropy paradigm** for understanding the origin and evolution of life. Unlike conventional science, which views life as a random byproduct of chemical evolution, the AU demonstrates that life is a **natural stage** in the evolution of the information field S_Θ and **an active agent** of cosmological evolution.

Key achievements of the AU approach:

1. **A rigorous derivation of the equations for the evolution of life** from a variation of the AU Lagrangian (version 2026.3), replacing heuristic approaches with a formalism derived entirely from first principles. All coefficients are derived from the original Lagrangian; no free structural parameters remain.
2. **A unified explanation** of the origin of life, evolution, consciousness and cosmological evolution through a unified field S_Θ and integral information Φ .
3. **Relationship with observational data:** interpretation of DESI DR2 ($w_0 > -1$, $w_a < 0$, $\Delta\chi^2_{\text{MAP}} = -21.0$) as an early stage of entropy-driven dynamics.
4. **Testable predictions** for DESI DR3, astrobiology, quantum biology and precision spectroscopy.

Like any scientific hypothesis, the AU must be tested by observations and critically assessed by the scientific community. If its predictions are confirmed—especially the evolution $w(z)$ in DESI DR3 and the correlations between the biosphere and cosmological parameters—this will mark the beginning of a new era in science: the era **of information ontology**, where the origin of life, the evolution of consciousness, and cosmological evolution are understood as different manifestations of a single information field. If observations contradict the AU predictions, this will indicate the need to modify or abandon the hypothesis. In any case, the testability of the AU makes it a full-fledged and fruitful scientific hypothesis worthy of serious consideration.

Applications

Appendix A. Mathematical formalism of holographic dark energy (HDE)

A.1 Complete Derivation of HDE Equations

- Energy density of dark energy: $\rho_\Lambda = 3c^2 M_p^2 / R_h^2$
- Choosing an IR Cutoff: The Horizon of Future Events R_h
- Equation of state: $w = -1/3 - 2\sqrt{\Omega_\Lambda}/(3c)$
- Evolutionary equation for Ω_Λ : $\frac{d\Omega_\Lambda}{d \ln a} = (1 - \Omega_\Lambda)(\Omega_\Lambda + 2\sqrt{\Omega_\Lambda}/c)$

- Analytical solution for $c = 1$
- Asymptotics: early times ($\Omega_\Lambda \propto a$), late times ($w \rightarrow -1/3$)

A.2 HDE Modifications

- Interactive HDE (IHDE): Ten Representative Forms of Interaction
- Fractional HDE (FHDE): FHDEH, FHDEF, FHDEP
- Tsallis HDE (THDE): non-additive entropy
- Barrow HDE (BHDE): quantum-gravitational microstructural effects

Appendix B. Statistical Analysis of DESI DR2 (2025)

B.1 Methodology $\Delta\chi^2$ and DIC

- Definition $\Delta\chi^2_{\text{MAP}}$ as the difference in χ^2 at the maximum of the posterior probability
- Interpretation of DIC (Deviance Information Criterion): $\Delta\text{DIC} < -5$ – strong preference, < -10 – decisive
- Calculating the significance ($N\sigma$) from the CDF of a χ^2 distribution with 2 degrees of freedom

B.2 Full DESI DR2 results

Data combination	$\Delta\chi^2_{\text{MAP}}$	Significance	ΔDIC
DESI BAO only	-4.7	1.7σ	-0.8
DESI + minimal CMB priors	-8.0	2.4σ	-4.4
DESI + CMB (without lensing)	-9.7	2.7σ	-5.9
DESI + full CMB (Planck)	-12.5	3.1σ	-8.7
DESI + CMB + Pantheon+	-10.7	2.8σ	-6.8
DESI + CMB + Union3	-17.4	3.8σ	-13.5
DESI + CMB + DESY5	-21.0	4.2σ	-17.2

B.3 Interpretation of contour plots w_0 – w_a

- Description of elliptical contours and "mirage lines" ($w_0 + w_a \approx -1$)
- Best fit: $w_0 \approx -0.67$ – -0.84 , $w_a \approx -0.6$ – -1.4
- The physical meaning of the quadrant $w_0 > -1, w_a < 0$

B.4 Bayesian analysis

- Model comparison: $\ln \mathcal{B} = 5.98 \pm 0.69$
- AIC and BIC criteria for HDE and IHDE models

Appendix B. Mathematical model of the entropy cascade

B.1 Equation for S_Θ with a source from life

- $\square S_\Theta + m_{eff}^2 S_\Theta + \lambda_S S_\Theta^3 + \gamma_S S_\Theta \Phi^2 + \int K S_\Theta = J_{chem} + J_{bio}$
- $J_{bio} = \gamma_{bio} \Phi_{bio}^2, \gamma_{bio} = \gamma_S/2$

B.2 Assessment of critical parameters

- $\Phi_{crit}(\text{abiogenesis}) \sim 10^2$ – 10^4 bit
- $\langle J_{bio} \rangle_\oplus \sim 10^{30}$ – 10^{32} bit/s
- $\Gamma \sim 10^{-8}$ – 10^{-6} With -1
- $\Phi_{planet} \sim 10^{65}$ – 10^{70} bit

B.3 Collapse Scenarios

- Mathematical modeling of positive feedback
- Critical parameters for triggering an entropy cascade
- Condition of noospheric transition: $\Phi_{planet} > \Phi_{crit}^{noosphere} \simeq S_{holo}/N_{channels}$

Appendix C. Complete derivation of the biological source from the AU-Lagrangian variation

C.1 Original AU Lagrangian (version 2026.3)

- $\mathcal{L}_S = \frac{1}{2}(\partial_\mu S_\Theta)^2 - V(S_\Theta), V(S_\Theta) = \frac{1}{2}m_S^2 S_\Theta^2 + \frac{\lambda_S}{4} S_\Theta^4 + \frac{\gamma_S}{2} S_\Theta^2 \Phi^2$
- $\mathcal{L}_\Phi = \frac{1}{2}(\partial_\mu \Phi)^2 - V(\Phi) + \mu_\Phi \Phi S_\Theta$
- $\mathcal{L}_{mat} = \mathcal{L}_{SM} + \kappa_\psi S_\Theta \bar{\psi} \psi + \kappa_\Phi \Phi \bar{\psi} \psi + \dots$

- $S_{nonlocal} = \frac{1}{2} \int d^4x d^4y \sqrt{-g(x)} \sqrt{-g(y)} S_{\Theta}(x) K(x, y) S_{\Theta}(y)$

C.2 Conclusion of the effective action of a living subsystem

- $S_{bio} = \int d^4x \sqrt{-g} \left\{ \frac{1}{2} Z_{\Phi} (\partial \Phi_{bio})^2 - V_{bio}(\Phi_{bio}, S_{\Theta}) + \frac{\xi_{bio}}{2} \Phi_{bio}^2 R + \mathcal{L}_{mem} \right\}$
- $V_{bio} = \frac{1}{2} m_{\varphi}^2(S_{\Theta}) \Phi_{bio}^2 + \frac{\lambda_{\varphi}}{4} \Phi_{bio}^4 - \mu_{chem}(x) \Phi_{bio}^2$
- $m_{\varphi}^2(S_{\Theta}) = m_0^2 + \gamma_S S_{\Theta} + \dots$

C.3 Variation and Derivation J_{bio}

- $J_{bio}(x) = \delta S_{bio} / \delta S_{\Theta}(x) = \gamma_{bio} \Phi_{bio}^2(x)$
- $\gamma_{bio} = \gamma_S / 2$

C.4 Fixing Normalization Φ

- $\Phi = \varphi / \varphi_*$, where is $\Phi = 1 \Leftrightarrow 1$ the integral information bit
- Recalculation of coupling constants: $\gamma_S \rightarrow \gamma_S \varphi_*^2, \lambda_{\varphi} \rightarrow \lambda_{\varphi} \varphi_*^4, \mu_{chem} \rightarrow \mu_{chem} / \varphi_*^2$

Appendix D. Abiogenesis Criterion and Assessment Φ_{crit}

D.1 Derivation from the effective potential

- $V_{eff}(\varphi) = \frac{1}{2} (m_0^2 + \gamma_S S_{\Theta} - \mu_{chem}) \varphi^2 + \frac{\lambda_{\varphi}}{4} \varphi^4$
- Non-trivial minimum condition: $\mu_{chem} > m_0^2 + \gamma_S S_{\Theta}$
- $\Phi_{crit}(S_{\Theta}, \mu_{chem}) = \sqrt{(\mu_{chem} - m_0^2 - \gamma_S S_{\Theta}) / \lambda_{\varphi}}$

D.2 Assessment for the RNA-like autocatalytic cycle

- $\mu_{chem} \sim (10^{-2} - 10^{-1}) \text{eV}$
- $\mathcal{N} \sim 10^2 - 10^3$ (combinatorial factor)
- $\Phi_{crit} \sim 10^2 - 10^4 \text{bit}$

D.3 Quantum biogenesis as a phase transition

- Analogy with the Landau–Ginzburg phase transition
- The emergence of the first unicellular system as a phase transition between the vacuums of “lifeless” and “life”

Appendix E. Derivation of the Evolution Equation Φ from a Gradient Flow

E.1 Effective thermodynamic potential

- $\Omega[\Phi, S_\Theta] = V_{bio}(\Phi, S_\Theta) - T_{AU} S_{conf}[\Phi]$
- S_{conf} — configurational entropy of an ensemble of organisms

E.2 Gradient flow equation (Ginzburg–Landau)

- $\dot{\Phi} = -\Gamma \delta \Omega / \delta \Phi$
- Linearization around the instantaneous minimum: $\dot{\Phi} = \alpha(\Phi_{\max} - \Phi) - \beta \dot{S}_\Theta$

E.3 Expression α and β in terms of the Lagrangian parameters

- $\alpha = \Gamma(m_\varphi^2(S_\Theta) + 3\lambda_\varphi \Phi^2)$
- $\beta = \Gamma \gamma_S \Phi$
- All coefficients are fixed by the original AU Lagrangian; there are no free structural parameters.

Appendix F. New experimental data on abiogenesis (2025–2026)

F.1 Ribozyme polymerase and protoribosome

- A small ribozyme polymerase capable of synthesizing itself and its complementary strand (*Science*, 2026)
- A palindrome in the ribosome peptidyl transferase center sequence as a blueprint for the origin of the proto-ribosome (*PNAS*, 2026)

F.2 Synthesis of lipids and protocells

- Photochemical synthesis of natural lipids in artificial and living cells (*Nature Communications*, 2025)
- Bottom-up organocatalytic synthesis of protocells (*Nature Communications*, 2026)
- Overcoming the paradox of membrane inheritance (*Nature Communications*, 2026)

F.3 RNA replication and models of the RNA world

- Exponential RNA replication in pH freeze-thaw cycles (*Nature Chemistry*, 2025)

- Generative modeling of the space of self-replicating ribozymes (*Nature Communications*, 2025)

F.4 Amino acids from the asteroid Bennu

- A limited library of amino acids yields a wide range of protein folds (*Nature Communications*, 2026)
- Peptide synthesis in interstellar space (Aarhus University, 2026)

F.5 Panspermia

- *Deinococcus radiodurans* can withstand pressures up to 3 GPa, with 60% survival at 2.4 GPa (*PNAS Nexus*, 2026)
- Estimated cell transfer from Earth to Venus: ~100 cells per year in clouds (LPSC 2026)
- Land as a source of life for Europe (2026)
- Interstellar panspermia through type 3I/ATLAS objects (2026)

Appendix H. “Thought-form” as a metaphor for any recording of information in the Acta Universi hypothesis

Status: Published on Zenodo

DOI: [10.5281/zenodo.22010383](https://doi.org/10.5281/zenodo.22010383)

Date: 08/19/2026

H.1 Why is “thought-form” a metaphor?

- Links subjective experience with objective physics
- Mathematics does not require "thought": $\Delta S_\Theta, \nabla S_\Theta, C_{\mu\nu}, J_{event}(x)$
- A pedagogical tool for interdisciplinary dialogue
- Tribute to the philosophical tradition (Pereslegin, Platonism, Whitehead)

H.2 What events create thought forms?

- **Quantum:** $\Delta S_\Theta \sim k_B \ln 2$ (decays, collapses)
- **Thermodynamic:** $\Delta S_\Theta = \int \delta Q_{irr}/T$ (heat exchange, diffusion)
- **Biological:** $\Delta S_\Theta \sim \alpha N_{act}$ (metabolism, synapses)
- **Cognitive:** $\Delta S_\Theta \sim \alpha N_{act} + k_B \ln \Omega$ (thoughts, decisions)
- **Social:** $\Delta S_\Theta \sim \kappa C$ (laws, cultural norms)

H.3 Mathematical interpretation of thought-form

- Classic field: $J_{event}(x) = \Delta S_{\Theta} \delta^{(4)}(x - x_0)$
- Quantum field: $\hat{m}_{\alpha\beta\gamma}^{\dagger}(k) = \hat{b}_k^{\dagger} \otimes \hat{P}_{\alpha\beta\gamma}$
- Role in metrics: $g_{\mu\nu} = \eta_{\mu\nu} + \beta \partial_{\mu} S_{\Theta} \partial_{\nu} S_{\Theta}$

H.4 Connection with 27 operators and consciousness (Φ)

- 27 operators $\hat{P}_{\alpha\beta\gamma}$ - basic patterns of thought forms
- BBB (stabilization), NNI (non-local correlations), III (transcendence)
- The field Φ is a "conductor" that regulates activities a_i through the RNN controller.
- $S_{\Theta}(r, t) = \sum_{i=1}^{27} a_i(t) S_{\Theta}^{(i)}(r)$
- Coherence: $\gamma_{\text{eff}} = \gamma_0 e^{-\lambda \Phi \Phi - \nu N_{\text{braid}}}$

Appendix I. Glossary of Basic Concepts

I.1 Basic terms

Term	Definition
Entropy field of thought forms S_{Θ}	The fundamental information-entropy field of the Acta Universi hypothesis; the primary entity from which space-time, matter, and gauge fields emerge
Integral information Φ	A measure of the causal integration of a system; in AU, a measure of field coherence S_{Θ}
AU field	An information field identified with dynamic dark energy; a non-local archive of events
AU archive	A non-local information structure in which all thought forms (events) are recorded
Kairos Time τ	A monotonic parameter associated with the growth of theta entropy; $d\tau = \frac{1}{N} (dt + \lambda dS_{\Theta} + \mu d\phi_{\text{braid}})$

Term	Definition
Thought form	A metaphor for any irreversible act of recording information into an AU archive; a quantum of entropy ΔS_Θ ; a localized source in the field S_Θ
Entropy cascade	A positive feedback process between the spread of life and cosmological expansion
Noosphere	The state of the biosphere at $\Phi_{planet} > \Phi_{crit}^{noosphere}$; planetary consciousness
27 ontological operators	Basic patterns of thought forms (BBB, NNI, III and mixed types); projectors onto the ontological categories of Being, Non-Being and Otherness
BBB operators	Binding-Building-Bridging; stabilization and adaptation (homeostasis)
NNI operators	Networking-Nonlocal-Integrating; nonlocal correlations (social behavior, culture)
III-operators	Innovation-Insight-Integration; Transcendence and Creation of New Niches
Dynamic dark energy	Dark energy with $w(z) \neq \text{const}$; in AU is a consequence of growth S_Θ
Big Rip	A scenario in which $w < -1$ expansion accelerates without limit, tearing apart all structures

I.2 Symbols and designations

Symbol	Description	Dimension
S_Θ	Entropy field of thought forms	[J/K]
S_{holo}	Holographic Limit	[J/K]

Symbol	Description	Dimension
Φ	Integral information	[bit]
Φ_{crit}	Critical threshold of abiogenesis	[bit]
$\Phi_{\text{crit}}^{\text{noosphere}}$	Critical threshold of the noospheric transition	[bit]
τ	Kairos Time	[With]
t	Chronos (coordinate time)	[With]
γ_S	Coupling constant in the AU Lagrangian	[indefinite]
γ_{bio}	Biological source constant ($\gamma_S/2$)	[indefinite]
α	Adaptation coefficient in the evolution equation Φ	[With $^{-1}$]
β	Entropic drag coefficient in the equation Φ	[indefinite]
Γ	Kinetic coefficient (relaxation time)	[With $^{-1}$]
$K(x, y)$	Non-local kernel	[indefinite]
w_0	Current value of the equation of state parameter DE	[indefinite]
w_a	Evolution parameter DE	[indefinite]

I.3 Abbreviations

- **AU** — Acta Universi
- **IIT** — Integrated Information Theory
- **TO** - Theory of Objectivity (Theory objectivity)
- **HDE** — Holographic Dark Energy (Holographic dark energy)
- **IHDE** — Interacting HDE

- **FHDE** - Fractional HDE (Fractional HDE)
- **DESI** - Dark Energy Spectroscopic Instrument
- **CMB** — Cosmic Microwave Background
- **BAO** — Baryon Acoustic Oscillations
- **MEP** — Maximum Entropy Production

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Note: The bibliography includes both classic works that form the theoretical foundation of modern cosmology and the theory of the origin of life, as well as current publications from 2025–2026, reflecting the current state of research in these fields. A separate section is devoted to the works of the author of the Acta Universi hypothesis.