

The Information Paradox of Black Holes in the Context of the Acta Universi Hypothesis

Yashchenko Dmitry Eduardovich

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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://sciencaimo.space/>

Introduction

The black-hole information paradox, formulated by Hawking in the 1970s, remains one of the most acute problems in modern theoretical physics. According to the semi-classical calculation, a black hole evaporates by emitting radiation that is thermal to leading order and carries no information about the matter that fell behind the horizon. As a result, an initially pure quantum state appears to evolve into a mixed state of radiation, in contradiction with the unitarity of quantum mechanics.

Over the past half-century a large number of approaches have been proposed: black-hole complementarity, the holographic principle, firewalls, entanglement islands, ER=EPR, soft hair, and others. Most of them either modify the semi-classical picture near the horizon, postulate non-local effects, or revise the notion of locality in quantum gravity.

The Acta Universi (AU) hypothesis offers a different route. In this framework the primary entity is the entropy field of thought-forms S_Θ together with the non-local kernel $K(x, y)$. Everything that occurs in space-time is already a recording in a universal informational archive.

Consequently the question “is information lost?” is posed differently: information cannot be lost because the act of its recording in the AU archive is irreversible and remains preserved in Kairos-time even after the horizon has disappeared.

The aim of the present work is to develop this idea into a concrete model consistent with the already constructed AU formalism (modified Einstein equations, the dynamics of S_Θ , Kairos-time, and the holographic bound).

1. Black Holes in the AU Ontology

In AU, space-time and the metric are emergent structures generated by the gradients and configurations of the field S_Θ . An event horizon corresponds to a surface on which the local density of theta-entropy approaches the holographic bound:

$$S_\Theta|_{r=r_h} \simeq S_{\text{holo}} = \frac{A}{4G\hbar}.$$

Inside the horizon (in the classical sense) the field S_Θ continues to exist and evolve. For an external observer, however, access to these degrees of freedom is closed by the causal structure. Importantly, recording into the non-local archive via the kernel $K(x, y)$ does not require classical causal contact: information about the state behind the horizon is already correlated with exterior degrees of freedom through the kernel.

Thus the horizon in AU is not a place where information is “destroyed,” but a boundary beyond which a local description in ordinary space-time ceases to be convenient, while the description in terms of S_Θ and K remains fully valid.

2. Modified Equations and the Dynamics of Evaporation

The starting point is the AU action whose gravitational sector includes couplings of curvature to S_Θ and Φ :

$$\mathcal{L}_{\text{grav}} = \frac{1}{16\pi G_0} R - \Lambda_0 + \xi \Phi R + \frac{\lambda}{8\pi G_0} S_\Theta R + \dots$$

Variation yields modified Einstein equations in which the effective cosmological constant and the effective gravitational constant depend on the local values of S_Θ and Φ .

During black-hole formation the growth of S_Θ in the vicinity of the collapsing matter leads to the appearance of a horizon. In the course of Hawking evaporation energy is carried away by radiation and, simultaneously, theta-entropy is redistributed. The crucial point is that every emission event constitutes an irreversible recording into the AU archive. Therefore the information that, in the semi-classical picture, appears to be “lost” is in fact fixed in the form of coherent thought-forms correlated, through $K(x, y)$, both with the radiation and with the remaining field configuration inside (or in place of) the horizon.

An effective entropy-balance equation during evaporation can be written as

$$\frac{dS_{\text{BH}}}{d\tau} = -\frac{dS_{\text{rad}}}{d\tau} + \frac{dS_{\text{archive}}}{d\tau},$$

where τ is Kairos-time. The last term guarantees the preservation of information: what disappears from the horizon description reappears in the archive.

3. Resolution of the Information Paradox

Within the AU framework the information paradox is resolved as follows:

1. **Information is never lost**, because every process (including the fall of matter behind the horizon and the subsequent evaporation) is an act of recording into the non-local archive.
2. **Hawking radiation** is not completely thermal from the standpoint of the full AU description. Although it looks approximately thermal to a semi-classical observer, it carries subtle correlations induced by the kernel $K(x, y)$ and by the history of recording.
3. **The final state** after complete evaporation is not pure thermal radiation, but radiation plus a configuration of the field S_Θ in the archive that retains the complete information about the initial state.
4. **Unitarity** is restored at the level of the complete system “radiation + AU archive.” For an external observer who has access only to the radiation the state may appear mixed; this, however, is a consequence of the incompleteness of the description rather than of a fundamental loss of information.

This mechanism is close in spirit to ideas of non-local information storage and to certain versions of soft hair and entanglement islands, yet it rests on a different ontological foundation: information is preserved not because it is “written on the horizon” or “in the connectivity of space,” but because it is, from the outset, a recording in a more fundamental informational field.

4. Relation to Kairos-Time and the Arrow of Time

Kairos-time τ , defined through the growth of S_Θ , plays a central role. Black-hole evaporation is a process that advances the system forward in τ . Reversing the process would require a decrease of theta-entropy, which is forbidden by the structure of the theory. This is why evaporation appears irreversible, even though the complete information is preserved.

The construction therefore reconciles the thermodynamic arrow of time of the black hole with the informational arrow of the AU archive.

5. Observational and Theoretical Implications

Although the main effects are hidden behind the horizon or are extremely weak, the AU approach points to several potentially testable directions:

- small deviations of the Hawking spectrum from perfect thermality (especially for microscopic or primordial black holes);
- correlations between the radiation and the large-scale structure of the informational field;

- possible gravitational-wave signatures associated with the rearrangement of S_Θ during evaporation;
- consistency with the holographic bound and with earlier results on entropy and dark energy.

The most important theoretical consequence is that the paradox ceases to be a paradox: it arises only when one attempts to describe the system exclusively in terms of local space-time degrees of freedom while ignoring the non-local archive.

6. Comparison with Other Approaches

Approach	Core idea	Relation to AU
Complementarity	Different descriptions for different observers	AU maintains a single description via S_Θ
Firewall	Breaking of entanglement at the horizon	In AU the horizon is a boundary of description, not a breaking of information
Entanglement islands	Quantum corrections to the radiation entropy	AU supplies an ontological carrier for these corrections
ER=EPR	Einstein–Rosen bridges = entanglement	The non-local kernel K plays a similar role
Soft hair	Additional degrees of freedom on the horizon	In AU information is stored in the archive, not only on the horizon

AU does not contradict the majority of these ideas; rather, it offers a deeper level at which they can be unified.

Conclusion

Within the Acta Universi hypothesis the black-hole information paradox is resolved by recognising that information is, from the beginning, a recording in the non-local informational archive of the field S_Θ . Black-hole evaporation redistributes this recording between the radiation and the archive but does not destroy it. Unitarity is preserved at the level of the complete system.

The proposed picture is consistent with the previously developed parts of AU (Kairos-time, the holographic bound, modified gravity, entropic dynamics) and indicates the direction of further research: the construction of a more detailed evaporation dynamics, the calculation of corrections to the Hawking spectrum, and the search for possible observational signatures.