

The Causal Membrane as a Shifted Horizon: Predictions from the Original UAT Equation

Miguel Ángel Percudani

Independent Researcher, Puan, Buenos Aires, Argentina

miguel_percudani@yahoo.com.ar

ORCID: 0009-0007-1748-3212

August 15, 2026

Abstract

We study the original Unified Applicable Time (UAT) equation in the local, non-cosmological limit appropriate for a black hole. The equation naturally combines a relativistic gravitational term, a Planck-scale regularisation, and a Loop Quantum Gravity correction through the Barbero–Immirzi parameter. We impose the condition that the applicable time factor equals the 8-phase geometric residue $R_{\text{geom}} = 0.279182$. This defines an effective causal membrane radius r_{mem} . For astrophysical black holes we obtain the exact relation $r_{\text{mem}}/r_s = 1/(1 - R_{\text{geom}}^2) \approx 1.0845$, where r_s is the Schwarzschild radius. The causal membrane therefore lies approximately 8.45% outside the classical horizon. The same condition applied at $r = r_s$ gives a minimum black hole mass $M_{\text{min}} \approx 1.79 M_{\text{Planck}}$. No additional hypotheses are introduced.

1 Introduction

The UAT/UCP framework [1, 2] describes the flow of time as an emergent phenomenon regulated by a causal membrane. Its original defining equation integrates cosmological, relativistic and quantum gravitational effects:

$$t_{\text{UAT}} = t_{\text{event}} \frac{1}{a(t)} \sqrt{\frac{\max\left(1 - \frac{2GM(t)}{c^2 r}, \left(\frac{l_P}{r}\right)^2\right)}{1 + \gamma \frac{l_P^2 c}{4\pi r_s^2}}} + \frac{d_L}{c}. \quad (1)$$

Here $l_P = \sqrt{\hbar G/c^3}$ is the Planck length, $\gamma = 0.2375$ is the Barbero–Immirzi parameter of Loop Quantum Gravity, and $r_s = 2GM/c^2$ is the Schwarzschild radius.

In this note we evaluate Eq. (1) in the local black hole limit, where cosmological expansion is negligible ($a(t) \approx 1$) and the luminosity distance offset d_L/c is removed. The result is a simple dimensionless applicable time factor that reveals the causal membrane as a horizon shifted with respect to the classical Schwarzschild surface.

2 Local Reduction of the UAT Equation

For a non-expanding local spacetime, the applicable time factor becomes

$$F(r; M) = \sqrt{\frac{\max\left(1 - \frac{r_s}{r}, \left(\frac{l_P}{r}\right)^2\right)}{1 + \gamma \frac{l_P^2}{4\pi r_s^2}}}. \quad (2)$$

For macroscopic black holes, $r_s \gg l_P$, the quantum denominator is approximately unity. Outside the horizon, the relativistic term dominates and

$$F(r; M) \approx \sqrt{1 - \frac{r_s}{r}}. \quad (3)$$

At the classical horizon, $r = r_s$, the relativistic term vanishes and the Planck-scale regularisation takes over:

$$F(r_s; M) \approx \frac{l_P}{r_s}. \quad (4)$$

Thus the original UAT equation automatically replaces the classical divergence at the horizon by a finite, mass-dependent residue.

3 The Causal Membrane Radius

The geometric residue $R_{\text{geom}} = 0.279182$ is the unnormalised amplitude of the 8-phase interference structure of the causal membrane [3]. In the UAT/UCP framework it quantifies the fraction of coherence that survives at the membrane.

We define the effective membrane radius r_{mem} by the condition

$$F(r_{\text{mem}}; M) = R_{\text{geom}}. \quad (5)$$

For astrophysical masses, the LQG denominator is negligible and Eq. (5) reduces to

$$\sqrt{1 - \frac{r_s}{r_{\text{mem}}}} = R_{\text{geom}}. \quad (6)$$

Solving,

$$1 - \frac{r_s}{r_{\text{mem}}} = R_{\text{geom}}^2, \quad (7)$$

$$\boxed{\frac{r_{\text{mem}}}{r_s} = \frac{1}{1 - R_{\text{geom}}^2} \approx 1.0845}. \quad (8)$$

The causal membrane is therefore located approximately 8.45% outside the Schwarzschild radius. This result is universal: it depends only on R_{geom} , not on the black hole mass.

4 Minimum Black Hole Mass

At the classical horizon itself, the time factor is given by the Planck-scale residue:

$$F(r_s; M)^2 = \frac{(l_P/r_s)^2}{1 + \gamma l_P^2/(4\pi r_s^2)}. \quad (9)$$

Let $x \equiv r_s/l_P$. Then

$$F(r_s; M)^2 = \frac{1}{x^2 + \gamma/(4\pi)}. \quad (10)$$

Imposing the same condition $F(r_s; M) = R_{\text{geom}}$ gives

$$R_{\text{geom}}^2 = \frac{1}{x^2 + \gamma/(4\pi)}. \quad (11)$$

Solving for x ,

$$x = \sqrt{\frac{1}{R_{\text{geom}}^2} - \frac{\gamma}{4\pi}}. \quad (12)$$

With $R_{\text{geom}} = 0.279182$ and $\gamma = 0.2375$,

$$x \approx 3.579. \quad (13)$$

Therefore,

$$r_s(M_{\text{min}}) \approx 3.58 l_P, \quad (14)$$

and, since $r_s/l_P = 2M/M_{\text{Planck}}$,

$$\boxed{M_{\text{min}} \approx 1.79 M_{\text{Planck}}}. \quad (15)$$

This is the minimum black hole mass for which the classical horizon can still be meaningfully replaced by the causal membrane.

5 Numerical Results

Table 1 shows the effective membrane radius obtained from the exact numerical evaluation of Eq. (2) for a range of black hole masses.

Table 1: Causal membrane radius from the original UAT equation.

Mass	r_s (m)	r_{mem}/r_s	$F(r_s; M)$
Planck mass	3.23×10^{-35}	—	0.4988
10^{12} kg	1.49×10^{-15}	1.0001	1.09×10^{-20}
10^{20} kg	1.49×10^{-7}	1.0845	1.09×10^{-28}
$10^{-6} M_{\odot}$	2.95×10^{-3}	1.0845	5.47×10^{-33}
$1 M_{\odot}$	2.95×10^3	1.0845	5.47×10^{-39}
$10^6 M_{\odot}$	2.95×10^9	1.0845	5.47×10^{-45}
$10^9 M_{\odot}$	2.95×10^{12}	1.0845	5.47×10^{-48}

For all astrophysical masses the membrane radius converges to

$$r_{\text{mem}} \approx 1.0845 r_s. \quad (16)$$

6 Physical Interpretation

The result that the causal membrane lies slightly outside the classical horizon is consistent with the central UAT/UCP idea that the event horizon is not a passive geometric surface but an active causal interface. The displacement from r_s is fixed by the 8-phase geometric residue R_{geom} , the same constant that appears in the Causal Mass Gap equation and in the laboratory-measured interferometric residue.

This provides a direct, falsifiable link between laboratory phase measurements and black hole physics.

7 Observational Prospects

The predicted shift of the effective horizon by 8.45% could, in principle, be tested with:

1. Black hole shadow measurements by the Event Horizon Telescope, once systematic uncertainties are reduced below the percent level.
2. Quasi-normal mode spectra of compact objects, which are sensitive to the location of the effective reflecting surface.
3. Accretion disk inner edges, if the causal membrane modifies the effective innermost stable orbit by a similar amount.

At present, the uncertainties are too large to confirm or exclude an 8.45% displacement. The prediction therefore remains falsifiable but not yet testable.

8 Informal Observational Comparison with EHT Shadow Measurements

As a first, informal consistency check, we compare the predicted membrane shift with the Event Horizon Telescope (EHT) measurements of the black hole shadows in M87* and Sgr A*. We stress that this is not a validation of the UAT/UCP metric. The EHT shadow is determined by the photon orbit, not by the horizon, and we have not yet derived the full membrane metric. We simply assume, as a working approximation, that the fractional shift of the effective membrane radius also scales the observed shadow diameter by the same factor.

For a Schwarzschild black hole, the classical angular shadow diameter is

$$d_{\text{class}} = \frac{2 \times (3\sqrt{3}/2)r_s}{D}, \quad (17)$$

where D is the angular diameter distance. Under the membrane shift assumption, the UAT prediction is

$$d_{\text{UAT}} = d_{\text{class}} \times \frac{1}{1 - R_{\text{geom}}^2} \approx 1.0845 d_{\text{class}}. \quad (18)$$

Using the published EHT masses and distances

- M87*: $M = 6.5 \times 10^9 M_\odot$, $D = 16.8 \text{ Mpc}$, $d_{\text{obs}} = 42.0 \pm 3.0 \mu\text{as}$,
- Sgr A*: $M = 4.15 \times 10^6 M_\odot$, $D = 8.15 \text{ kpc}$, $d_{\text{obs}} = 48.7 \pm 7.0 \mu\text{as}$,

we obtain the values shown in Table 2.

Table 2: Informal comparison between the membrane-shifted shadow diameter and EHT observations. The pull is defined as $(d_{\text{UAT}} - d_{\text{obs}})/\sigma_{\text{obs}}$.

Object	$d_{\text{class}} (\mu\text{as})$	$d_{\text{UAT}} (\mu\text{as})$	$d_{\text{obs}} (\mu\text{as})$	Pull
M87*	39.69	43.04	42.0 ± 3.0	+0.35
Sgr A*	52.23	56.65	48.7 ± 7.0	+1.14

Both values are consistent with the observations within 2σ . Therefore, the membrane-shift prediction does not contradict current EHT data. At the same time, the observational uncertainties are still too large to distinguish an 8.45% shift from the classical Schwarzschild shadow. This check should be interpreted only as a first approximation and not as a confirmation of the UAT/UCP framework.

9 Conclusion

We have shown that the original UAT equation, when applied locally to a black hole, defines a causal membrane radius

$$r_{\text{mem}} \approx 1.0845 r_s, \quad (19)$$

and a minimum black hole mass

$$M_{\text{min}} \approx 1.79 M_{\text{Planck}}. \quad (20)$$

These results follow entirely from the constants already present in the UAT/UCP framework: R_{geom} , l_P , and γ . No new parameters or hypotheses are required.

Code Availability

The Python script `u_at_black_hole_membrane.py` reproduces all numerical values in this note. It uses only NumPy, SciPy, and CODATA 2018 constants.

References

- [1] M. A. Percudani, *Universal Applied Time (UAT/UCP): A Fundamental Theory of Cosmology from First Principles*, Zenodo, 2024. DOI: [10.5281/zenodo.17729221](https://doi.org/10.5281/zenodo.17729221).
- [2] M. A. Percudani, *The Causal Coherence Constant κ_{crit} : A Fundamental Limit on Retrocausal Influence*, Zenodo, 2024. DOI: [10.5281/zenodo.18210808](https://doi.org/10.5281/zenodo.18210808).
- [3] M. A. Percudani, *Experimental Verification of the Geometric Invariant R_{geom}* , Zenodo, 2026.

- [4] M. A. Percudani, *The UAT Lagrangian: Derivation of the Quantum Braking Action*, Zenodo, 2025. DOI: 10.5281/zenodo.20500431.
- [5] M. A. Percudani, *Unified Action for the UAT/UCP Framework*, Zenodo, 2026. DOI: 10.5281/zenodo.21433360.