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Brief Report

Black Hole Merger as an Event Converting Two Qubits into One

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Abstract: A black hole represents a quantum state that saturates three bounds for the quantum orthogonalization interval. It is a qubit in an equal superposition of its two energy eigenstates, with a vanishing ground state and the nonvanishing one equal to the black hole energy, where the product of the black hole's entropy and temperature amounts to half of the black hole's energy. As two black holes frequently merge into one, it is natural to ask what happens with the qubits they carry. We consider a binary black hole as a quantum system of two independent qubits evolving independently under a common Hamiltonian to show that their merger can be considered in terms of two orthogonal projections of this Hamiltonian onto a two-dimensional Hilbert subspace that also correspond to the Bell states of this two-qubit system.

Keywords: black hole mergers; binary black holes; gravitational waves; quantum foundations

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1. Introduction

We have previously [1] shown that a black hole (BH) can be considered as a patternless [2] bitstring of $N_{\text{BH}} \in \mathbb{R}$ fluctuating Planck triangles (FPT) carrying a binary potential $\delta\varphi_k = -c^2 \cdot \{0, 1\}$, where c is the speed of light in vacuum, and having the Hamming weight of $N_1 = \lfloor N_{\text{BH}}/2 \rfloor$ active Planck triangles, where "$\lfloor x \rfloor$" is the floor function that yields the greatest integer less than or equal to its argument x. Therefore, BHs are ergodic systems in thermodynamic equilibrium that define not only one unit of thermodynamic entropy [3] (four FPTs) but also maximize Shannon entropy [4]. We have also previously [5] demonstrated that a BH can be modeled as a qubit in an equal superposition of its energy eigenstates, uniquely achieving three known bounds [6–8] for the quantum orthogonalization interval. Thus, a BH is not only the sole[1] naturally occurring isolated quantum system but, as a qubit, it also represents a fundamental isolated quantum system.

Considering qubits and BHs within a single conceptual framework is known from the state of art (see [10–18] for example). In this note, we show that a merger of two BHs, as expected, converts a separable two-qubit BH state into a single-qubit BH state.

2. Black Hole Hamiltonian

Consider a general 2×2 Hermitian Hamiltonian

$$\mathbf{H}_{2\times 2} = \frac{1}{2}E\sum_{k=0}^{3}\omega_k \text{œ}_{\mathbf{k}} = \frac{1}{2}E\begin{bmatrix}\omega_0+\omega_3 & \omega_1 - i\omega_2 \\ \omega_1 + i\omega_2 & \omega_0 - \omega_3\end{bmatrix}, \tag{1}$$

expressed as a linear combination of the Pauli matrices $\text{œ}_{\mathbf{k}}$ with $\omega_k \in \mathbb{R}$, a coupling energy $E/2$, and $\text{œ}_{\mathbf{0}}$ being the identity matrix. The Hamiltonian (1) governs the evolution of any qubit (we omit the irrelevant global phase in this study)

$$|\psi\rangle = \alpha_0|E_0\rangle + \alpha_1 e^{i\theta}|E_1\rangle, \tag{2}$$

[1] In our further research [9] we have extended this conclusion to other *objects* emitting perfect black-body radiation and thus featuring the Bekenstein entropy [3].

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where the relative phase $\theta \in \mathbb{R}$, $\alpha_0^2 + \alpha_1^2 = 1$, and $i^2 = -1$, by the Schrödinger equation

$$\mathbf{H}_{2\times 2}|E_{0/1}\rangle = E_{0/1}|E_{0/1}\rangle, \tag{3}$$

where the eigenvalues of the Hamiltonian (1) are

$$E_{0/1} = \frac{1}{2}E(\omega_0 \mp \omega), \tag{4}$$

$\omega^2 := \omega_1^2 + \omega_2^2 + \omega_3^2$, and

$$|E_{0/1}\rangle = \frac{1}{\sqrt{2\omega(\omega \pm \omega_3)}}\begin{bmatrix} -(\omega_1 - i\omega_2) \\ \omega_3 \pm \omega \end{bmatrix}, \tag{5}$$

are their corresponding normalized eigenvectors, which are commonly referred to [19] as stationary states, as under the Hamiltonian (1) evolution they only acquire an overall numerical factor, $|E_k\rangle \to e^{-iE_k\delta t/\hbar}|E_k\rangle$, where $\hbar$ is the reduced Planck constant. The average energy of the Hamiltonian (1) is

$$E_{avg} = \langle\psi|\mathbf{H}_{2\times 2}|\psi\rangle = |\alpha_0|^2 E_0 + |\alpha_1|^2 E_1 \tag{6}$$

and its variance of energy is

$$\begin{aligned}(\delta E)^2 &= \langle\psi|\mathbf{H}_{2\times 2}^2|\psi\rangle - \langle\psi|\mathbf{H}_{2\times 2}|\psi\rangle^2 = \\ &= \frac{1}{2}\sum_{k,l}|\alpha_k|^2|\alpha_l|^2(E_k - E_l)^2 = |\alpha_0|^2|\alpha_1|^2(E_0 - E_1)^2,\end{aligned} \tag{7}$$

where the bra-ket terms $\langle\psi|\mathbf{H}_{2\times 2}|\psi\rangle$ and $\langle\psi|\mathbf{H}_{2\times 2}^2|\psi\rangle$ implicitly include the phase factor θ of the qubit (2).

It was shown [8] that the minimum time needed for any quantum state to evolve into an orthogonal one, known as the quantum orthogonalization interval $\delta t_\perp$, is achieved by a qubit (2) in an equal superposition ($\alpha_k^2 = 1/2$) of its energy eigenvectors (5) with the average energy equal to the standard deviation ($E_{avg} = \delta E$) and the eigenvalues (4) equal to $E_0 = 0$ and $E_1 = \hbar\pi/\delta t_\perp$. In this case, the average energy (6) $E_{avg} = E_1/2$ can be substituted into the variance (7), yielding

$$\langle\psi|\mathbf{H}_{2\times 2}^2|\psi\rangle = 2\langle\psi|\mathbf{H}_{2\times 2}|\psi\rangle^2, \tag{8}$$

and furthermore $E_0 = 0$ implies the vanishing determinant of the Hamiltonian (1)

$$|\mathbf{H}_{2\times 2}| = \omega_0^2 - \omega_3^2 - (\omega_1^2 + \omega_2^2) = 0, \tag{9}$$

yielding $\omega^2 = \omega_0^2 = \omega_1^2 + \omega_2^2 + \omega_3^2$, $\omega_0 = 1$, $E = E_1$, and $\omega_1\cos(\theta) + \omega_2\sin(\theta) = 0$. $\omega_3 = 1$ implies $\mathbf{H}_{2\times 2} = E_1|0\rangle\langle 0|$, and furthermore the eigenvector $|E_1\rangle$ (5) would be singular for $\omega_1 = \omega_2 = 0$ yielding $\omega = \omega_0 = \omega_3 = 1$. Therefore, we set $\omega_3 = 0$, which bounds $\omega_1^2 + \omega_2^2 = 1$, and links the qubit (2) relative phase with the off-diagonal factor of the Hamiltonian (1) $e^{i\theta} := \omega_1 + i\omega_2$.

In our previous research [1,5], we have found that the only quantum system having a vanishing ground-state energy, only two possible states, and the average energy equal to its standard deviation and to half of its total energy is a BH. Namely, the BH average energy is the BH entropic work, that is, the product of the BH (Hawking) temperature and (Bekenstein) entropy

$$\begin{aligned}T_{\mathrm{BH}} \cdot S_{\mathrm{BH}} &= \frac{\hbar c^3}{8\pi G M_{\mathrm{BH}} k_{\mathrm{B}}} \cdot \frac{1}{4}k_{\mathrm{B}}\frac{4\pi R_{\mathrm{BH}}^2}{\ell_{\mathrm{P}}^2} = \\ &= \frac{T_{\mathrm{P}}}{2\pi d_{\mathrm{BH}}} \cdot \frac{1}{4}k_{\mathrm{B}} N_{\mathrm{BH}} = \frac{1}{2}E_{\mathrm{BH}},\end{aligned} \tag{10}$$

where G is the gravitational constant, k_B is the Boltzmann constant, and M_{BH} and R_{BH} denote the BH mass and radius.

Therefore, $\delta E = E_{avg} = E_{BH}/2$, where

$$E_{BH} = M_{BH}c^2 = \frac{\hbar\pi}{\delta t_{\perp_{BH}}} \tag{11}$$

is the BH energy and $\delta t_{\perp_{BH}}$ represents the BH orthogonalization interval, that is the minimal period required for the BH qubit state $|0\rangle$ to evolve into the $|E_{BH}\rangle$ state or *vice versa*, which is inversely proportional to the BH energy. For example, the orthogonalization interval of the BH Sagittarius A* ($M_{BH} \approx 8.26 \times 10^{36}$ kg) is $\delta t_{\perp_{BH}} = \hbar\pi/M_{BH}c^2 \approx 4.4628 \times 10^{-88}$ seconds, which is in the order of a squared Planck time ($t_P \approx 5.3911 \times 10^{-44}$ s), the smallest interval considered to have a physical significance in theories combining quantum mechanics and general relativity. The scalar product also evinces this tendency to orthogonality, where two nonorthogonal states

$$\lim_{m\to\infty} \langle 0_1 0_2 \dots 0_m | +_1 +_2 \dots +_m \rangle = \lim_{m\to\infty} \left(\frac{1}{2^{m/2}} \right) = 0 \tag{12}$$

tend to orthogonality with the increasing size of the quantum system. Even toy examples involving just two nonorthogonal states hold some promise for shedding light on the foundations of quantum theory [20].

Expressing the BH energy E_{BH} as the product of temperature and information capacity (or entropy as in Equation (10)) conceals the fact that both these quantities ($T_{BH} = T_P/2\pi d_{BH}$, $N_{BH} = \pi d_{BH}^2$) can be stated as functions of the BH diameter ($D_{BH} = d_{BH}\ell_P$), where ℓ_P is the Planck length and $d_{BH} \in \mathbb{R}$. However, such notation exposes the fact that the BH energy, $E_{BH} = N_{BH} \cdot \frac{1}{2} k_B T_{BH}$ is a product of the number of FPTs on a BH surface and their energies given by the equipartition theorem for one degree of freedom (DOF). Hence, one DOF corresponds to one bit of information [5]. The equipartition theorem was rigorously proven only for one DOF and under the assumption that the DOF energy depends quadratically on the generalized coordinate, which holds for a Planck area ℓ_P^2 on the holographic BH surface and the associated quadratic binary potential $\delta\varphi_k = -c^2 \cdot \{0, 1\}$.

Correspondingly, the qubit general Hamiltonian (1) in the case of a BH becomes a continuum of complex Hamiltonians, parametrized by the BH energy and the unobservable phase θ

$$\mathbf{H}_{BH} = \frac{1}{2} E_{BH} \begin{bmatrix} 1 & e^{-i\theta} \\ e^{i\theta} & 1 \end{bmatrix} = \frac{1}{4} k_B T_{BH} N_{BH} \sum_{k=1}^{2} \omega_k \sigma_k, \tag{13}$$

with a real, unit off-diagonal factor for $\theta = k\pi$ and an imaginary one for $\theta = \pi/2 + k\pi$. The unitary evolution operator of the Hamiltonian (13)

$$\begin{aligned} \mathbf{U}_{BH} &= e^{-i\mathbf{H}_{BH}\delta t/\hbar} = \\ &= e^{-iE_{BH}\delta t/(2\hbar)} \begin{bmatrix} \cos\left(\frac{E_{BH}\delta t}{2\hbar}\right) & -i\sin\left(\frac{E_{BH}\delta t}{2\hbar}\right) e^{-i\theta} \\ -i\sin\left(\frac{E_{BH}\delta t}{2\hbar}\right) e^{i\theta} & \cos\left(\frac{E_{BH}\delta t}{2\hbar}\right) \end{bmatrix}, \end{aligned} \tag{14}$$

implicitly introduces a *temporal parameter* δt and associates it with a BH that represents a qubit

$$|\psi_{BH}\rangle = \frac{1}{\sqrt{2}}(|\varnothing\rangle + |E_{BH}\rangle) = \begin{bmatrix} 1 & 0 \end{bmatrix}^\dagger = |0\rangle, \tag{15}$$

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where the eigenvectors of the Hamiltonian (13) (that can be expressed in terms of normalized eigenvectors $|\psi_x\rangle$, $|\psi_y\rangle$ of the Pauli matrices σ_1, σ_2) are

$$
\begin{aligned}
|\varnothing\rangle &= \frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ -e^{i\theta} \end{bmatrix} = \omega_1|\psi_{x-}\rangle + \omega_2|\psi_{y-}\rangle, \\
|E_{\mathrm{BH}}\rangle &= \frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ e^{i\theta} \end{bmatrix} = \omega_1|\psi_{x+}\rangle + \omega_2|\psi_{y+}\rangle.
\end{aligned} \tag{16}
$$

3. Merging Two Qubits into One

Interferometric data[2] on collisions of celestial objects (called *mergers*) indicate that the fraction of BH mergers is much higher than might be expected by chance [21–25]. While we acknowledge the reality of gravitational events, we note that labeling them as *waves* may be misleading: normal modulation of the gravitational potential caused by merging *objects* should not be interpreted as a gravitational wave understood as a carrier of gravity [26]. Furthermore, based on the gravitational event GW170817, it was experimentally confirmed [27] that mergers are perfectly spherical. This is also an expected result as no *point of impact* can be considered unique on a patternless, perfectly spherical BH surface.

If the Hamiltonian (13) governs the evolution of one BH, then the evolution of two BHs A and B is governed by the general Hamiltonian of a two-qubit system

$$
\begin{aligned}
\mathbf{H}_{AB} &= \mathbf{H}_A \otimes I + I \otimes \mathbf{H}_B + \mathbf{H}_{\mathrm{int}} = \\
&= \mathbf{H}_A \otimes I + I \otimes \mathbf{H}_B = \\
&= \frac{1}{2}\begin{bmatrix} E_A + E_B & E_B e^{-i\theta_B} & E_A e^{-i\theta_A} & 0 \\ E_B e^{i\theta_B} & E_A + E_B & 0 & E_A e^{-i\theta_A} \\ E_A e^{i\theta_A} & 0 & E_A + E_B & E_B e^{-i\theta_B} \\ 0 & E_A e^{i\theta_A} & E_B e^{i\theta_B} & E_A + E_B \end{bmatrix}
\end{aligned} \tag{17}
$$

with $\mathbf{H}_A$ and $\mathbf{H}_B$ being the Hamiltonians (13) of the individual BHs having energies E_A and E_B, and $\mathbf{H}_{\mathrm{int}}$ being the vanishing Hamiltonian of their interaction, as they are independent. Each BH is associated with a unique orthogonalization interval $\delta t_{\perp A}$ and $\delta t_{\perp B}$ (11). The continuum hypothesis ensures a unique fractional part of a BH surface $0 < N_{\mathrm{BH}} - \lfloor N_{\mathrm{BH}} \rfloor < 1$ (too small to carry a single bit of information), and hence the uniqueness of any conceivable BH, regardless of the simultaneous existence of the same number of bits $\lfloor N_{\mathrm{BH}} \rfloor$ on many BHs [1].

The Hamiltonian (17) has four eigenvalues

$$
E_0 = 0, \quad E_1 = E_B, \quad E_2 = E_A, \quad E_3 = E_A + E_B, \tag{18}
$$

associated with four eigenvectors

$$
\begin{aligned}
&\begin{bmatrix} |\varnothing_A \varnothing_B\rangle & |\varnothing_A E_B\rangle & |E_A \varnothing_B\rangle & |E_A E_B\rangle \end{bmatrix} = \\
&= \frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 1 \\ -e^{i\theta_B} & e^{i\theta_B} & -e^{i\theta_B} & e^{i\theta_B} \\ -e^{i\theta_A} & -e^{i\theta_A} & e^{i\theta_A} & e^{i\theta_A} \\ e^{i(\theta_A+\theta_B)} & -e^{i(\theta_A+\theta_B)} & -e^{i(\theta_A+\theta_B)} & e^{i(\theta_A+\theta_B)} \end{bmatrix}
\end{aligned} \tag{19}
$$

2 Available online at the Gravitational Wave Open Science Center (GWOSC) portal https://www.gw-openscience.org/eventapi/html/allevents.

Hence, the BHs A and B form a quantum system (we skip the BH subscript in this section) of two separable qubits (15)

$$\begin{aligned} |\psi_{AB}\rangle &= |\psi_A\rangle \otimes |\psi_B\rangle = \\ &= \frac{1}{2}(|\varnothing_A \varnothing_B\rangle + |\varnothing_A E_B\rangle + |E_A \varnothing_B\rangle + |E_A E_B\rangle) = \\ &= \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix}^\dagger = |00\rangle \end{aligned} \tag{20}$$

and the evolution operator $\mathbf{U}_{AB} = \exp(-i\mathbf{H}_{AB}\delta t/\hbar)$ of the Hamiltonian (17) is the tensor product of the individual evolution operators (14), so their evolution is independent, preserving their separability.

The BH merger M must convert two separable BH qubits (20) into one BH qubit (15) ($|\psi_{AB}\rangle \rightarrow |\psi_M\rangle$) and 4×4 Hamiltonian (17) into 2×2 Hamiltonian H_M (13).

A merger cannot trace out one qubit from the two-qubit system (20), as partial trace applies to mixed states and time evolution, not directly to a Hamiltonian. Furthermore, partial trace models a measurement so that it would be tantamount to asserting that the BH A is *observing* the BH B or *vice versa*. But, BHs are qubits and qubits are not observers [28,29]. Having no interior, a BH cannot store any measurement information.

Therefore, the merger must reduce the dimension of the Hamiltonian from 4×4 to 2×2 by a projection of the Hamiltonian (17) onto a two-dimensional Hilbert subspace spanned by two orthonormal states in the computational basis to extract the submatrix of H_{AB} corresponding to the relevant rows and columns.

Three distinct projections of the Hamiltonian H_{AB} (17) exist. For the subspaces spanned by $\{|00\rangle, |01\rangle\}$ and $\{|10\rangle, |11\rangle\}$

$$H_M = \frac{1}{2}\begin{bmatrix} E_A + E_B & E_B e^{-i\theta_B} \\ E_B e^{i\theta_B} & E_A + E_B \end{bmatrix}, \tag{21}$$

for the subspaces spanned by $\{|00\rangle, |10\rangle\}$ and $\{|01\rangle, |11\rangle\}$

$$H_M = \frac{1}{2}\begin{bmatrix} E_A + E_B & E_A e^{-i\theta_A} \\ E_A e^{i\theta_A} & E_A + E_B \end{bmatrix}, \tag{22}$$

and for the subspaces spanned by $\{|00\rangle, |11\rangle\}$ and $\{|01\rangle, |10\rangle\}$

$$H_M = \frac{1}{2}\begin{bmatrix} E_A + E_B & 0 \\ 0 & E_A + E_B \end{bmatrix}. \tag{23}$$

We must reject the nonorthogonal projections (21) and (22) as they allow the state transitions of one qubit while fixing the state of the other. For example, the projection (22) of the Hamiltonian (17) onto a two-dimensional Hilbert subspace spanned by $|00\rangle$ and $|10\rangle$, allows for the first BH A state transitions ($|+\rangle$), while the second BH B is fixed ($|0\rangle$). This inconsistency is shown in the off-diagonal term $E_A e^{\mp i\theta_A}$ that does not correspond to the coupling energy $(E_A + E_B)/2$ for $\theta_A = 0$.

On the other hand, orthogonal projections (23) seem not to preserve the form of the BH Hamiltonian (13). However, we must not forget that we are crossing the singularity here: we merge two isolated, independently evolving, quantum systems A and B into a new isolated quantum system M. Therefore, we should interpret a projection (23) as the real part of the BH Hamiltonian (13), that is as

$$\begin{aligned} H_M = \frac{E_A + E_B}{2}\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = \mathrm{Re}\left(\frac{E_A + E_B}{2}\begin{bmatrix} 1 & e^{-i\theta_M} \\ e^{i\theta_M} & 1 \end{bmatrix}\right) \rightarrow \\ \rightarrow \frac{1}{2}(E_A + E_B)\begin{bmatrix} 1 & e^{-i\theta_M} \\ e^{i\theta_M} & 1 \end{bmatrix} \end{aligned} \tag{24}$$

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for $\theta_M = \pi/2 + k\pi$. It is the phase θ_M that will modulate the evolution of the new isolated system after the merger.

Furthermore, the subspaces spanned by $\{|00\rangle, |11\rangle\}$ and $\{|01\rangle, |10\rangle\}$ correspond to the two maximally entangled Bell states $|\Phi\rangle$ and $|\Psi\rangle$, the superposition of which corresponds to the single qubit BH state, so the conversion $|\psi_{AB}\rangle \to |\psi_M\rangle$ between the states (20) and (15) can be described as

$$\begin{aligned} &|\psi_{AB}\rangle = \\ &= \frac{1}{2}((|\varnothing_A E_B\rangle + |E_A \varnothing_B\rangle) + (|\varnothing_A \varnothing_B\rangle + |E_A E_B\rangle)) = \\ &= \frac{1}{2}\left(\begin{bmatrix}1 & \xcancel{0} & \xcancel{0} & -e^{i(\theta_A+\theta_B)}\end{bmatrix}^\dagger + \begin{bmatrix}1 & \xcancel{0} & \xcancel{0} & e^{i(\theta_A+\theta_B)}\end{bmatrix}^\dagger\right) \to \\ &\to \frac{1}{\sqrt{2}}\left(\frac{1}{\sqrt{2}}\begin{bmatrix}1 & -e^{i\,\theta_M}\end{bmatrix}^\dagger + \frac{1}{\sqrt{2}}\begin{bmatrix}1 & e^{i\,\theta_M}\end{bmatrix}^\dagger\right) = \\ &= \frac{1}{\sqrt{2}}(|\varnothing\rangle + |E_A + E_B\rangle) = |\psi_M\rangle. \end{aligned} \tag{25}$$

Finally, the evolution operator of the Hamiltonian (17) is the anti-diagonal matrix for $E_A t_{\perp A} = E_B t_{\perp B} = \hbar\pi$. However, only the orthogonal $\{|00\rangle, |11\rangle\}, \{|01\rangle, |10\rangle\}$ projections of this matrix are unitary (respectively for $\theta_M = \theta_A \pm \theta_B$) $\forall \theta_A, \theta_B \in \mathbb{R}$.

4. Conclusions

The qubit (15) in equal superposition of two energy eigenstates, attaining the bounds for the quantum orthogonalization interval [6–8], introduces the Hamiltonian (13) that completely describes the BH dynamics [19] and is parametrized by one observable parameter (e.g., the BH energy) and the unobservable, relative phase of the qubit.

Considering a binary BH as a quantum system of two independent qubits (20) evolving independently under a common Hamiltonian (17) we have shown that their merger can be considered in terms of orthogonal projection of this Hamiltonian onto a two-dimensional Hilbert subspaces spanned by $\{|00\rangle, |11\rangle\}$ and/or $\{|01\rangle, |10\rangle\}$ states that also correspond to the Bell states of this two qubit system (20).

The relations (24) and (25) show that BH qubits must be orthogonal to merge. On the other hand, the orthogonalization interval (11) is inversely proportional to the BH energy. We conjecture that this explains why mergers of massive BHs are the most frequently registered gravitational events.

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References

1. S. Łukaszyk, Black Hole Horizons as Patternless Binary Messages and Markers of Dimensionality, in *Future Relativity, Gravitation, Cosmology* (Nova Science Publishers, 2023) Chap. 15, pp. 317–374.
2. G. J. Chaitin, On the Length of Programs for Computing Finite Binary Sequences, J. ACM **13**, 547–569 (1966).
3. J. D. Bekenstein, Black Holes and Entropy, Phys. Rev. D **7**, 2333 (1973).
4. C. E. Shannon, A Mathematical Theory of Communication, Bell System Technical Journal **27**, 379 (1948).
5. S. Łukaszyk, Life as the explanation of the measurement problem, Journal of Physics: Conference Series **2701**, 012124 (2024).
6. L. Mandelstam and I. Tamm, The uncertainty relation between energy and time in non-relativistic quantum mechanics, J. Phys. (USSR) **9**, 249– (1945).
7. N. Margolus and L. B. Levitin, The maximum speed of dynamical evolution, Physica D: Nonlinear Phenomena **120**, 188 (1998).
8. L. B. Levitin and T. Toffoli, Fundamental Limit on the Rate of Quantum Dynamics: The Unified Bound Is Tight, Physical Review Letters **103**, 160502 (2009).
9. S. Łukaszyk, *The Imaginary Universe*, preprint (PHYSICAL SCIENCES, 2023).

10. L. Borsten, D. Dahanayake, M. Duff, H. Ebrahim, and W. Rubens, Black holes, qubits and octonions, Physics Reports **471**, 113 (2009).
11. P. Lévay, S T U black holes as four-qubit systems, Physical Review D **82**, 026003 (2010).
12. M. J. Duff, Black holes and qubits, in *What is Known and Unexpected at LHC* (WORLD SCIENTIFIC, Erice-Sicily, Italy, 2013) pp. 57–66.
13. S. B. Giddings and Y. Shi, Quantum information transfer and models for black hole mechanics, Physical Review D **87**, 064031 (2013).
14. E. Verlinde and H. Verlinde, Black Hole Information as Topological Qubits (2013), arXiv:1306.0516.
15. T. Prudêncio, D. J. Cirilo-Lombardo, E. O. Silva, and H. Belich, Black hole qubit correspondence from quantum circuits, Modern Physics Letters A **30**, 1550104 (2015).
16. A. Belhaj, Z. Benslimane, M. B. Sedra, and A. Segui, Qubits from black holes in M-theory on K3 surface, International Journal of Geometric Methods in Modern Physics **13**, 1650075 (2016).
17. K. Osuga and D. N. Page, Qubit transport model for unitary black hole evaporation without firewalls, Physical Review D **97**, 066023 (2018).
18. B. Broda, Causal unitary qubit model of black hole evaporation, Physics Letters B **820**, 136564 (2021).
19. M. A. Nielsen and I. L. Chuang, *Quantum computation and quantum information*, 10th ed. (Cambridge university press, Cambridge, 2010).
20. C. A. Fuchs, Just two nonorthogonal quantum states, in *Quantum Communication, Computing, and Measurement 2*, edited by P. Kumar, G. M. D'Ariano, and O. Hirota (Springer US, Boston, MA, 2002) pp. 11–16.
21. D. Gerosa and M. Fishbach, Hierarchical mergers of stellar-mass black holes and their gravitational-wave signatures, Nature Astronomy **5**, 749 (2021).
22. R. Abbott and et al., Population Properties of Compact Objects from the Second LIGO–Virgo Gravitational-Wave Transient Catalog, The Astrophysical Journal Letters **913**, L7 (2021).
23. R. Abbott and et al., Population of Merging Compact Binaries Inferred Using Gravitational Waves through GWTC-3, Physical Review X **13**, 011048 (2023).
24. R. Abbott and et al., GWTC-3: Compact Binary Coalescences Observed by LIGO and Virgo during the Second Part of the Third Observing Run, Physical Review X **13**, 041039 (2023).
25. M. Dall'Amico, M. Mapelli, S. Torniamenti, and M. Arca Sedda, Eccentric black hole mergers via three-body interactions in young, globular, and nuclear star clusters, Astronomy & Astrophysics **683**, A186 (2024).
26. R. Szostek, P. Góralski, and K. Szostek, Gravitational waves in Newton's gravitation and criticism of gravitational waves resulting from the General Theory of Relativity (LIGO), Bulletin of the Karaganda University. "Physics" Series **96**, 39 (2019).
27. A. Sneppen, D. Watson, A. Bauswein, O. Just, R. Kotak, E. Nakar, D. Poznanski, and S. Sim, Spherical symmetry in the kilonova AT2017gfo/GW170817, Nature **614**, 436 (2023).
28. Č. Brukner, Qubits are not observers – a no-go theorem (2021).
29. J. Pienaar, A Quintet of Quandaries: Five No-Go Theorems for Relational Quantum Mechanics, Foundations of Physics **51**, https://doi.org/10.1007/s10701-021-00500-6 (2021)