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Black hole merger as an event converting two qubits into one

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A black hole represents a quantum state that saturates three bounds of the quantum orthogonalization interval. It is a qubit in an equal superposition of its two energy eigenstates, with a vanishing ground state and a nonvanishing one equal to the black hole's energy, where the product of the black hole's entropy and temperature amounts to half of its energy. As two black holes frequently merge into one, it is natural to ask what happens with the qubits they carry. I 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, which correspond to the Bell states of this two-qubit system.

KEYWORDS

quantum orthogonalization intervals, quantum foundations and information, black hole merger, black hole information paradox, emergent dimensionality

1 Introduction

I have previously (Łukaszyk, 2023) shown that a black hole (BH) can be considered a patternless (Chaitin, 1966) bitstring of $[N_{\text{BH}}]$ fluctuating Planck triangles (FPT) carrying a binary potential $\delta\phi_k = -c^2 \cdot \{0, 1\}$ —where c is the speed of light in a vacuum—and having the Hamming weight of $N_1 = [N_{\text{BH}}/2]$ active Planck triangles, where “ $[x]$ ” is the floor function yielding 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 (Bekenstein, 1973) (four FPTs) but also maximize Shannon entropy (Shannon, 1948). I have also previously (Łukaszyk, 2024) demonstrated that a BH can be modeled as a qubit in an equal superposition of its energy eigenstates, uniquely achieving three known bounds for the quantum orthogonalization interval (Mandelstam and Tamm, 1945; Margolus and Levitin, 1998; Levitin and Toffoli, 2009). A BH is thus a fundamental quantum system.

The consideration of qubits and BHs within a single conceptual framework is known from the state of the art (see, for example, Borsten et al., 2009; Lévy, 2010; Duff, 2013; Giddings and Shi, 2013; Verlinde and Verlinde, 2013; Prudêncio et al., 2015; Belhaj et al., 2016; Osuga and Page, 2018; Broda, 2021).

Interferometric data¹ on collisions of celestial objects (called “mergers”) indicate that the fraction of BH mergers is much higher than might be expected by chance (Gerosa and Fishbach, 2021; Abbott et al., 2021; Abbott et al., 2023b; Abbott et al., 2023a; Dall’Amico et al., 2024). While gravitational events are real, labeling them as waves may be

1 Available online at the Gravitational Wave Open Science Center (GWOSC) portal <https://www.gw-open-science.org/eventapi/html/allevnts>.

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 (Szostek et al., 2019). Furthermore, based on the gravitational event GW170817, it was experimentally confirmed that mergers are perfectly spherical (Sneppen et al., 2023). This is also an expected result as no point of impact can be considered unique on a patternless, perfectly spherical BH surface. BHs may be different from their general relativistic counterparts outside Einstein's relativity (Li et al., 2023).

In this study, I 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,

$$\mathbf{H}_{2 \times 2} = \frac{1}{2} E \sum_{k=0}^3 \omega_k \boldsymbol{\sigma}_k = \frac{1}{2} E \begin{bmatrix} \omega_0 + \omega_3 & \omega_1 - i\omega_2 \\ \omega_1 + i\omega_2 & \omega_0 - \omega_3 \end{bmatrix}, \quad (1)$$

expressed as a linear combination of the Pauli matrices $\boldsymbol{\sigma}_k$ with $\omega_k \in \mathbb{R}$, a coupling energy $E/2$, and $\boldsymbol{\sigma}_0$ being the identity matrix. The Hamiltonian (Equation 1) governs the evolution of any qubit (we omit the irrelevant global phase in this study):

$$|\psi\rangle = \alpha_0 |E_0\rangle + \alpha_1 e^{i\varphi} |E_1\rangle, \quad (2)$$

where the relative phase $\varphi \in \mathbb{R}$, $\alpha_0^2 + \alpha_1^2 = 1$, and $i^2 = -1$ by the Schrödinger equation $\mathbf{H}_{2 \times 2} |E_{0/1}\rangle = E_{0/1} |E_{0/1}\rangle$, where the eigenvalues of the Hamiltonian (Equation 1) are

$$E_{0/1} = \frac{1}{2} E (\omega_0 \mp \omega), \quad (3)$$

$$\omega^2 = \omega_1^2 + \omega_2^2 + \omega_3^2, \text{ and}$$

$$|E_{0/1}\rangle = \frac{\omega \mp \omega_3}{\sqrt{2\omega(\omega \mp \omega_3)}} \begin{bmatrix} 1 \\ \mp \frac{\omega_1 + i\omega_2}{\omega \mp \omega_3} \end{bmatrix}, \quad (4)$$

are their corresponding normalized eigenstates, which are commonly referred to as “stationary states” (Nielsen and Chuang, 2010). This is because, under the Hamiltonian's (Equation 1) evolution, they only acquire an overall numerical factor, $|E_k\rangle \rightarrow e^{-iE_k \delta t / \hbar} |E_k\rangle$, where $\hbar$ is the reduced Planck constant. The expected value of the Hamiltonian (Equation 1) for the qubit (Equation 2) and its average energy is

$$E_{avg} = \langle \psi | \mathbf{H}_{2 \times 2} | \psi \rangle = \sum_k |\alpha_k|^2 E_k = \alpha_0^2 E_0 + \alpha_1^2 E_1, \quad (5)$$

and the variance of the Hamiltonian (Equation 1) for the qubit (Equation 2) and its variance of energy is

$$\begin{aligned} (\delta E)^2 &= \langle \psi | \mathbf{H}_{2 \times 2}^2 | \psi \rangle - \langle \psi | \mathbf{H}_{2 \times 2} | \psi \rangle^2 = \frac{1}{2} \sum_{k,l} |\alpha_k|^2 |\alpha_l|^2 (E_k - E_l)^2 \\ &= \alpha_0^2 \alpha_1^2 (E_0 - E_1)^2, \end{aligned} \quad (6)$$

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 φ of the qubit (Equation 2).

According to Levitin and Toffoli (2009), the minimum time needed for any quantum state to evolve into an orthogonal state, known as the “quantum orthogonalization interval” $\delta t_{\perp}$, is achieved by a qubit (Equation 2) in an equal superposition ($\alpha_k^2 = 1/2$) of its energy eigenstates (Equation 4) with the average energy equal to the standard deviation ($E_{avg} = \delta E$), and the eigenvalues (Equation 3) equal to $E_0 = 0$ and $E_1 = \hbar\pi/\delta t_{\perp}$. In this case, the square of the expected value of the Hamiltonian (Equation 5) can be equated with its variance in Equation 6, yielding $\langle \psi | \mathbf{H}_{2 \times 2}^2 | \psi \rangle = 2 \langle \psi | \mathbf{H}_{2 \times 2} | \psi \rangle^2$.

Furthermore, $E_0 = 0$ implies the vanishing determinant of the Hamiltonian (Equation 1) $|\mathbf{H}_{2 \times 2}| = \omega_0^2 - \omega_3^2 - (\omega_1^2 + \omega_2^2) = 0$, yielding $\omega^2 = \omega_0^2 = \omega_1^2 + \omega_2^2 + \omega_3^2$. We note that the eigenstate $|E_0\rangle$ (Equation 4) would be singular for $\omega_1^2 = \omega_2^2 = 0$ as in the case $\omega^2 = \omega_0^2 = \omega_3^2$. Furthermore, $\omega_3 = \mp \omega_0$ implies $\mathbf{H}_{2 \times 2} = E|0\rangle\langle 0|$ and $\mathbf{H}_{2 \times 2} = E|1\rangle\langle 1|$. Therefore, to prevent these singularities, we set $\omega_3 = 0$. Levitin and Toffoli (2009) also showed that $\frac{E_{max}}{4} \leq E_{avg} \leq \frac{E_{max}}{2}$, where E_{max} is the maximum energy eigenvalue of any quantum system. In the case of a qubit in an equal superposition and vanishing eigenstate E_0 , this implies $E_{avg} = \frac{E_1}{2} = \frac{E_{max}}{2}$. However, such states are not considered functional qubits, at least in the context of quantum computing.

I previously found that a BH is the only quantum system having a vanishing ground-state energy, only two possible states, and average energy equal to its standard deviation and half of its total energy (Łukaszyk, 2023; 2024). Thus, a BH's average energy is its entropic work, which is the scalar product of the BH (Hawking) temperature and (Bekenstein) entropy

$$T_{BH} \cdot S_{BH} = \frac{\hbar c^3}{8\pi G M_{BH} k_B} \cdot \frac{1}{4} k_B \frac{4\pi R_{BH}^2}{\ell_P^2} = \frac{T_P}{2\pi d_{BH}} \cdot \frac{1}{4} k_B N_{BH} = \frac{1}{2} E_{BH}, \quad (7)$$

where G is the gravitational constant, k_B is the Boltzmann constant, ℓ_P is the Planck length, T_P is the Planck temperature, and M_{BH} and R_{BH} denote the BH mass and radius. Thus, $\delta E = E_{avg} = E_1/2 = E_{BH}/2$, where

$$E_{BH} = M_{BH} c^2 = \frac{\hbar \pi}{\delta t_{\perp BH}} \quad (8)$$

is the BH energy, and $\delta t_{\perp BH}$ represents the BH's orthogonalization interval—the minimal period required for the BH qubit state to evolve into an orthogonal one, which is inversely proportional to the BH's 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

$$\lim_{m \rightarrow \infty} \langle 0_1 0_2 \dots 0_m | +_1 +_2 \dots +_m \rangle = \lim_{m \rightarrow \infty} \left(\frac{1}{2^{m/2}} \right) = 0 \quad (9)$$

tend as shown in the Equation 12 to orthogonality with the increasing size of the quantum system as shown in Equation 9. Even toy examples involving just two nonorthogonal states could shed some light on the foundations of quantum theory (Fuchs, 2002).

Expressing the BH energy E_{BH} as the product of temperature and information capacity (or entropy, as in Equation 7) conceals the fact that both the quantities $T_{\text{BH}} = T_p/2\pi d_{\text{BH}}$, and $N_{\text{BH}} = \pi d_{\text{BH}}^2$ can be stated as functions of the BH's diameter $D_{\text{BH}} = d_{\text{BH}} \ell_p$, where $d_{\text{BH}} \in \mathbb{R}$. However, such notation reveals that the BH's energy $E_{\text{BH}} = N_{\text{BH}} \cdot \frac{1}{2} k_B T_{\text{BH}}$ is a product of the number of FPTs on a BH's surface and their energies, whereas these energies are given by the equipartition theorem for one degree of freedom (DOF). Hence, one DOF corresponds to one bit of information (Łukaszyk, 2024). 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 $\delta\varphi_k = -c^2 \cdot \{0, 1\}$.

With $E_1 = E_{\text{BH}}$ from Equation 3, we conclude that $\omega_0 = 1$, which bounds $\omega_1^2 + \omega_2^2 = 1$, and we define $e^{i\theta} = \omega_1 + i\omega_2$. Correspondingly, the qubit general Hamiltonian (Equation 1) in the case of a BH becomes a continuum of complex Hamiltonians, parametrized by the BH energy and the unobservable phase θ

$$\mathbf{H}_{\text{BH}} = \frac{1}{2} E_{\text{BH}} \begin{bmatrix} 1 & e^{-i\theta} \\ e^{i\theta} & 1 \end{bmatrix} = \frac{1}{4} k_B T_{\text{BH}} N_{\text{BH}} \left(\sigma_0 + \sum_{k=1}^2 \omega_k \sigma_k \right). \quad (10)$$

The stationary eigenstates of the Hamiltonian (Equation 10) are

$$|\emptyset\rangle = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -e^{i\theta} \end{bmatrix}, \quad |E_{\text{BH}}\rangle = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ e^{i\theta} \end{bmatrix}, \quad (11)$$

and the BH qubit (Equation 2) can be expressed as

$$|\psi_{\text{BH}}\rangle = \frac{1}{\sqrt{2}} (|\emptyset\rangle + e^{i\varphi} |E_{\text{BH}}\rangle), \quad (12)$$

where, in particular, $|\psi_{\text{BH}}\rangle = |\emptyset\rangle$ for $\varphi = 2k\pi$, and $|\psi_{\text{BH}}\rangle = -e^{i\theta} |1\rangle$ for $\varphi = (2k+1)\pi$. Due to the predefined coupling energy $E/2 = E_{\text{BH}}/2$, the Hamiltonian expected value (Equation 5) for the qubit (Equation 12) equals the BH entropic work (Equation 7) regardless of the relative phase φ . Furthermore, the Hamiltonian (Equation 10) has the scalar multiple idempotent property of, given by Equation 13

$$\mathbf{H}_{\text{BH}}^2 = \frac{1}{4} E_{\text{BH}}^2 \begin{bmatrix} 1 & e^{-i\theta} \\ e^{i\theta} & 1 \end{bmatrix}^2 = \frac{1}{2} E_{\text{BH}}^2 \begin{bmatrix} 1 & e^{-i\theta} \\ e^{i\theta} & 1 \end{bmatrix} = E_{\text{BH}} \mathbf{H}_{\text{BH}}, \quad (13)$$

which cannot be further reduced to $\mathbf{H}_{\text{BH}} = E_{\text{BH}} \mathbf{I}$ as it is non-invertible (but is, in fact, so reduced during a merger of two BHs described by the relation (Equation 24), as I propose in the subsequent section).

The unitary evolution operator of the Hamiltonian (Equation 10) is

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

$$\mathbf{U}_{\text{BH}}(\delta t_{\perp}) = - \begin{bmatrix} 0 & e^{-i\theta} \\ e^{i\theta} & 0 \end{bmatrix}, \quad (14)$$

where $\eta = E_{\text{BH}} \delta t / \hbar$. In particular, the operator (Equation 14) provides the following transformations (Equation 15):

$$\mathbf{U}_{\text{BH}}^{\otimes n} |\emptyset\rangle = |\emptyset\rangle \quad \forall \eta, \forall n,$$

$$\mathbf{U}_{\text{BH}}^{\otimes n} |E_{\text{BH}}\rangle = e^{-in\eta} |E_{\text{BH}}\rangle,$$

$$\mathbf{U}_{\text{BH}}^{\otimes n} (\delta t_{\perp}) |E_{\text{BH}}\rangle = (-1)^n |E_{\text{BH}}\rangle,$$

$$\mathbf{U}_{\text{BH}}^{\otimes n} |0\rangle = \frac{1}{2} \begin{bmatrix} e^{-in\eta} + 1 \\ e^{i\theta} (e^{-in\eta} - 1) \end{bmatrix},$$

$$\mathbf{U}_{\text{BH}}^{\otimes n} (\delta t_{\perp}) |0\rangle = \begin{cases} |0\rangle & \text{if } n \text{ is even} \\ -e^{i\theta} |1\rangle & \text{if } n \text{ is odd} \end{cases}.$$

$$\mathbf{U}_{\text{BH}}^{\otimes n} |1\rangle = \frac{1}{2} \begin{bmatrix} e^{-i\theta} (e^{-in\eta} - 1) \\ e^{-in\eta} + 1 \end{bmatrix},$$

$$\mathbf{U}_{\text{BH}}^{\otimes n} (\delta t_{\perp}) |1\rangle = \begin{cases} -e^{i\theta} |0\rangle & \text{if } n \text{ is odd} \\ |1\rangle & \text{if } n \text{ is even} \end{cases}.$$

$$\mathbf{U}_{\text{BH}}^{\otimes n} |-\rangle = \frac{1}{\sqrt{2}} e^{-i\frac{n\eta}{2}} \begin{bmatrix} \cos\left(\frac{n\eta}{2}\right) + i \sin\left(\frac{n\eta}{2}\right) e^{-i\theta} \\ -\cos\left(\frac{n\eta}{2}\right) - i \sin\left(\frac{n\eta}{2}\right) e^{i\theta} \end{bmatrix},$$

$$\mathbf{U}_{\text{BH}}^{\otimes n} |+\rangle = \frac{1}{\sqrt{2}} e^{-i\frac{n\eta}{2}} \begin{bmatrix} \cos\left(\frac{n\eta}{2}\right) - i \sin\left(\frac{n\eta}{2}\right) e^{-i\theta} \\ \cos\left(\frac{n\eta}{2}\right) - i \sin\left(\frac{n\eta}{2}\right) e^{i\theta} \end{bmatrix}, \quad (15)$$

if invoked n times on the states (Equation 11) or the states $|0\rangle, |1\rangle$, $|-\rangle = (|0\rangle - |1\rangle)/\sqrt{2}$, and $|+\rangle = (|0\rangle + |1\rangle)/\sqrt{2}$.

3 Merging two qubits into one

If the Hamiltonian (Equation 10) 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

$$\mathbf{H}_{AB} = \mathbf{H}_A \otimes \mathbf{I} + \mathbf{I} \otimes \mathbf{H}_B + \mathbf{H}_{\text{int}} = \mathbf{H}_A \otimes \mathbf{I} + \mathbf{I} \otimes \mathbf{H}_B =$$

$$= \frac{1}{2} \begin{bmatrix} E_A + E_B & E_B e^{-i\theta_B} & E_A e^{-i\theta_A} & 0 \\ E_B e^{i\theta_B} & E_A + E_B & 0 & E_A e^{-i\theta_A} \\ E_A e^{i\theta_A} & 0 & E_A + E_B & E_B e^{-i\theta_B} \\ 0 & E_A e^{i\theta_A} & E_B e^{i\theta_B} & E_A + E_B \end{bmatrix} \quad (16)$$

with $\mathbf{H}_A$ and $\mathbf{H}_B$ being the Hamiltonians (Equation 10) of the individual BHs having energies E_A and E_B , and $\mathbf{H}_{\text{int}}$ 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 $\delta t_{\perp B}$ (Equation 8). The continuum hypothesis ensures a unique fractional part of a BH surface $0 < N_{\text{BH}} - [N_{\text{BH}}] < 1$ (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 $[N_{\text{BH}}]$ on many BHs (Łukaszyk, 2023).

The Hamiltonian (Equation 16) has four eigenvalues (Equation 17)

$$E_0 = 0, \quad E_1 = E_B, \quad E_2 = E_A, \quad E_3 = E_A + E_B, \quad (17)$$

associated with four eigenstates given by (Equation 18)

$$[|\varnothing_A \varnothing_B\rangle |\varnothing_A E_B\rangle |E_A \varnothing_B\rangle |E_A E_B\rangle] = \frac{1}{2} \begin{bmatrix} 1 & 1 & 1 & 1 \\ -e^{i\theta_B} & e^{i\theta_B} & -e^{i\theta_B} & e^{i\theta_B} \\ -e^{i\theta_A} & -e^{i\theta_A} & e^{i\theta_A} & e^{i\theta_A} \\ e^{i(\theta_A+\theta_B)} & -e^{i(\theta_A+\theta_B)} & -e^{i(\theta_A+\theta_B)} & e^{i(\theta_A+\theta_B)} \end{bmatrix} \quad (18)$$

Hence, the BHs A and B form a quantum system (we skip the BH subscript in this section) of two separable qubits (Equation 12)

$$|\psi_{AB}\rangle = |\psi_A\rangle \otimes |\psi_B\rangle = \frac{1}{2} (|\varnothing_A \varnothing_B\rangle + e^{i\varphi_B} |\varnothing_A E_B\rangle + e^{i\varphi_A} |E_A \varnothing_B\rangle + e^{i(\varphi_A+\varphi_B)} |E_A E_B\rangle), \quad (19)$$

and the evolution operator $\mathbf{U}_{AB} = \exp(-i\mathbf{H}_{AB}\delta t/\hbar)$ of the Hamiltonian (Equation 16) is the tensor product of the individual evolution operators (Equation 14), so their evolution is independent, preserving their separability. In particular, the state (Equation 19) has a form given by (Equation 20).

$$|\psi_{AB}\rangle = |00\rangle \quad \text{for} \quad \varphi_A = 2k\pi \cap \varphi_B = 2l\pi,$$

$$|\psi_{AB}\rangle = -e^{i\theta_B} |01\rangle \quad \text{for} \quad \varphi_A = 2k\pi \cap \varphi_B = (2l+1)\pi,$$

$$|\psi_{AB}\rangle = -e^{i\theta_A} |10\rangle \quad \text{for} \quad \varphi_A = (2k+1)\pi \cap \varphi_B = 2l\pi, \text{ and}$$

$$|\psi_{AB}\rangle = e^{i(\theta_A+\theta_B)} |11\rangle \quad \text{for} \quad \varphi_A = (2k+1)\pi \cap \varphi_B = (2l+1)\pi. \quad (20)$$

The BH merger M must convert two separable BH qubits (Equation 19) into one BH qubit (Equation 12) ($|\psi_{AB}\rangle \rightarrow |\psi_M\rangle$) and the 4×4 Hamiltonian (Equation 16) into a 2×2 Hamiltonian H_M (Equation 10).

A merger cannot trace out one qubit from the two-qubit system (Equation 19), 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 BH A is “observing” BH B or *vice versa*. However, BHs are qubits, and qubits are not observers (Brukner, 2021; Pienaar, 2021). 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 (Equation 16) 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} (Equation 16) exist. For the subspaces spanned by $\{|00\rangle, |01\rangle\}$ and $\{|10\rangle, |11\rangle\}$

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

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

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

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

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

We must reject the nonorthogonal projection (Equations 21, 22) as they allow the state transitions of one qubit while fixing the state of the

other. For example, the projection (Equation 22) of the Hamiltonian (Equation 16) 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, the orthogonal projection (Equation 23) seems not to preserve the form of the BH Hamiltonian (Equation 10). However, we must not forget that we are crossing the singularity here: we merge two independently evolving, quantum systems A and B into a new quantum system M . Therefore, we should interpret a projection (Equation 23) as the real part of the BH Hamiltonian (Equation 10), that is as

$$H_M = \frac{1}{2} (E_A + E_B) \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = \text{Re} \left(\frac{1}{2} (E_A + E_B) \begin{bmatrix} 1 & e^{-i(\theta_A \pm \theta_B)} \\ e^{i(\theta_A \pm \theta_B)} & 1 \end{bmatrix} \right) \rightarrow \frac{1}{2} (E_A + E_B) \begin{bmatrix} 1 & e^{-i\theta_M} \\ e^{i\theta_M} & 1 \end{bmatrix} \quad (24)$$

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

Furthermore, the evolution operator of the Hamiltonian (Equation 16) 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 Conclusion

The qubit (Equation 12) in equal superposition of two energy eigenstates, attaining the bounds for the quantum orthogonalization interval (Mandelstam and Tamm, 1945; Margolus and Levitin, 1998; Levitin and Toffoli, 2009), introduces the Hamiltonian (Equation 10) that completely describes BH dynamics (Nielsen and Chuang, 2010) 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 (Equation 20) evolving independently under a common Hamiltonian (Equation 16), I have shown that their merger can be considered in terms of the orthogonal projection of this Hamiltonian onto a two-dimensional Hilbert subspace spanned by $\{|00\rangle, |11\rangle\}$ and/or $\{|01\rangle, |10\rangle\}$ states that correspond to the Bell states of this two qubit system (Equation 19).

The relation (Equation 24) shows that BH qubits must be orthogonal to merge. Otherwise, the merger would violate the no-deleting (Kumar Pati and Braunstein, 2000) and no-hiding (Braunstein and Pati, 2007) theorems. On the other hand, the orthogonalization interval (Equation 8) is inversely proportional to the BH's energy. This may explain why mergers of massive BHs are the most frequently registered gravitational events.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding author.

Author contributions

SŁ: Writing – review and editing, Writing – original draft.

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Conflict of interest

Author SŁ was the sole owner of Łukaszyk Patent Attorneys during the conduct of this study.

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