A Physically Grounded Model for Black Hole Interiors: Core Decay, Time Dilation, and Information Preservation

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Abstract

This paper presents a new model for black hole interiors, replacing the traditional singularity and speculative quantum emission framework with a structured decay-core composed of superheavy isotopes. Under extreme time dilation, these isotopes decay slowly, producing measurable emissions that offer an alternative explanation for Hawking radiation. This model resolves the singularity paradox, preserves information, and remains fully consistent with general relativity and nuclear physics. The paper further explores observational consistency, candidate isotopes, and the future potential of validation through quantum simulation technologies such as topological qubit processors.

1. Introduction

This paper proposes that black hole radiation originates not from quantum effects near the event horizon, but from the slow, time-dilated decay of superheavy core material trapped within the black hole. This model avoids singularities, preserves information, and better aligns with real-world observations, all while adhering strictly to known physics. It presents a grounded alternative to quantum-based speculative theories such as Hawking radiation, challenging the assumption that black holes evaporate over time.

2. Formation of Superheavy Elements

During the gravitational collapse of a massive star, core temperatures and pressures may exceed conditions achievable in particle accelerators. These extreme conditions can temporarily stabilize superheavy elements, such as those in the island of stability (e.g., Nihonium-286), through interactions involving the Higgs boson. The formation of these elements is facilitated by rapid neutron capture, nuclear compression, and boson-mediated stabilization in LHC-like reaction conditions. While such elements decay rapidly under normal conditions, the profound time dilation at the event horizon preserves their structure over cosmological timescales from an external perspective. This allows these exotic nuclei to exist and emit detectable radiation slowly and steadily, forming the active core of a black hole.

3. Time Dilation and Core Preservation

Example Calculation – Gravitational Time Dilation and Isotope Decay:

Let's consider Oganesson-294, which has a normal half-life (t_0) of 0.9 milliseconds.
Assume a gravitational time dilation factor (γ) of 10^{14} near the event horizon.

Redshifted Half-Life (t) = $\gamma \times t_0$
$\approx 10^{14} \times 0.9 \times 10^{-3}$ seconds
$\approx 9 \times 10^{10}$ seconds
$\approx \sim$2,850 years

Thus, from an external observer's perspective, Oganesson-294 would appear to persist for thousands of years, slowly decaying and emitting radiation consistent with the decay-core hypothesis.

According to general relativity, as matter collapses toward the event horizon, time dilation becomes increasingly severe. For an external observer, time near the event horizon appears to slow dramatically, approaching near-zero at the core. In this regime, processes that would normally occur in milliseconds—such as the decay of unstable nuclei—are effectively stretched over millions or even billions of years. This relativistic effect enables short-lived superheavy isotopes to persist, from our frame of reference, as slowly decaying sources of radiation. The model assumes these time-frozen particles form a compact, dense nucleus within the black hole, releasing radiation at an extremely low but constant rate. This slow emission accounts for energy leakage historically attributed to Hawking radiation, without invoking speculative quantum phenomena.

4. Core Decay and Radiation Emission

As the superheavy isotopes at the core undergo radioactive decay, they emit particles and radiation at a highly redshifted, time-dilated rate. From the perspective of an outside observer, these emissions appear as faint, continuous leakage—similar in signature to the expected effects of Hawking radiation, but originating from physical nuclear processes rather than virtual particle annihilation at the event horizon. The decay process includes alpha, beta, and gamma radiation, as well as neutrino emissions. Due to gravitational redshift, the energy of these particles is significantly reduced by the time they reach an observer, aligning with known low-energy emissions detected from black hole candidates. This steady decay-driven output ensures conservation of mass-energy and complies with thermodynamic laws, in contrast to evaporative models that imply total information loss or non-physical entropy leakage.

5. Candidate Isotopes for Core Composition

Table 1: Candidate Superheavy Isotopes for the Black Hole Core

The most plausible candidates for a decay-core model are superheavy isotopes with high atomic mass and short half-lives under normal conditions. When exposed to relativistic time dilation, these isotopes experience effectively extended decay durations. Key candidates include:

• Nihonium-286 (Nh-286): Alpha decay; normal half-life ~20 ms
• Moscovium-290 (Mc-290): Likely alpha emitter; estimated half-life ~30 ms
• Livermorium-293 (Lv-293): Alpha decay; normal half-life ~60 ms
• Oganesson-294 (Og-294): Alpha decay; ~0.9 ms half-life

Although these isotopes are unstable in laboratory settings, their stability in the intense gravitational field of a black hole would be enhanced by redshifting and time dilation effects. These elements could form dense core layers whose decay chains slowly emit radiation over cosmic timescales. Selection is based on experimental data from nuclear synthesis and isotope modeling, as well as decay energy consistency with black hole observations.

To refine the hypothesis, we now compare the candidate isotopes based on their expected behavior under extreme time dilation:

• **Evaluation Criteria**:
  - High atomic number and mass (Z/A ratio)
  - Strong alpha decay signatures with predictable chains
  - Redshifted half-life range consistent with persistent but weak radiation
  - Decay energies aligning with observed low-energy X-ray and gamma radiation from known black holes

• **Comparative Analysis**:
  - *Nihonium-286*: Promising due to intermediate mass and predictable decay, but lower energy output
  - *Moscovium-290*: Poorly characterized decay; theoretical but not observed
  - *Livermorium-293*: Longer half-life but lower decay energy; unlikely primary emitter
  - *Oganesson-294*: Exhibits high atomic mass, alpha decay pathway, and emits high-energy alpha particles

Most Probable Core Isotope:
Based on the available data, **Oganesson-294 (Og-294)** is the most probable candidate. Its decay energy is significant, and when slowed by gravitational time dilation (e.g., dilation factor of $\sim 10^{14}$), the resulting emission aligns with observed persistent radiation leaks, such as from **Sagittarius A***.

Simulation Comparison – Sagittarius A*:

Og-294 has a normal half-life of ~0.9 milliseconds. Under a dilation factor of 10^{14}, this becomes ~2,850 years. Its decay would emit alpha particles and weak gamma rays with energy levels redshifted into the soft X-ray spectrum. Sagittarius A* emits continuous faint X-ray and radio radiation—consistent with a decay-driven source. This match supports the hypothesis that Og-294 or similar isotopes form the decaying core of long-lived black holes.

6. Observational Case Studies

To assess the viability of the decay-core model, several well-documented black hole candidates are examined as case studies:

• Sagittarius A*: The supermassive black hole at the center of the Milky Way exhibits faint, continuous radiation without strong accretion activity. This emission is consistent with a midlife decay-core phase where the superheavy nucleus is steadily decaying. Time-dilated emissions align with the low energy profiles detected in X-ray and infrared observations.

• Gaia BH1: This quiescent stellar-mass black hole exhibits no observable radiation leakage. Under the decay-core hypothesis, this would represent a late-stage or cold remnant black hole whose core has largely decayed and stabilized, emitting no measurable radiation.

• Cygnus X-1: This classic black hole binary exhibits intense radiation and variability attributed to accretion. The decay-core model does not contradict this, as accretion processes dominate in this case. However, distinguishing core emission from accretion-driven radiation remains an open area for further study.

These cases demonstrate that the decay-core model can accommodate both active and quiescent black holes and provide alternative interpretations of radiation signatures that were previously attributed solely to accretion disks or hypothetical Hawking radiation.

7. Information Encoding and Preservation

One of the central advantages of the decay-core model is its ability to address the black hole information paradox. Rather than erasing information through a singularity or non-physical tunneling, this model preserves information via nuclear decay processes. Each decay event encodes data about the parent isotope, its structure, and quantum numbers. This includes properties such as spin, parity, nuclear binding energy, and decay path — all of which can be statistically retrieved from the resulting emission profile.

The radiation emitted is not purely thermal but carries weak imprints of the nuclear history of the core. This introduces a viable mechanism for information retention without invoking holography or quantum entanglement across the event horizon. It positions the decay core as a compressible, readable, and classically describable information system, in which no fundamental laws are broken and no paradox arises.

8. Comparison with the Standard Black Hole Model

Table 2: Comparison of Black Hole Models

The decay-core model and the standard singularity-based model differ fundamentally in both physical assumptions and predictive behavior. The following comparison outlines key differences:

• Core Structure:
  - Standard Model: Predicts a central singularity with infinite density and undefined physics.
  - Decay-Core Model: Proposes a dense, time-frozen nucleus of superheavy elements governed by known physics.

• Radiation Mechanism:
  - Standard Model: Relies on Hawking radiation via quantum pair production at the event horizon.
  - Decay-Core Model: Attributes radiation to relativistic nuclear decay of core isotopes.

• Information Preservation:
  - Standard Model: Encounters the information paradox with uncertain outcomes.
  - Decay-Core Model: Encodes retrievable information via nuclear decay signatures.

• Thermodynamics:
  - Standard Model: Suggests black holes evaporate over time, violating mass-energy conservation.
  - Decay-Core Model: Maintains thermodynamic consistency via physical decay and redshifted emissions.

This direct comparison highlights the decay-core model's adherence to physical laws and its capacity to offer concrete, testable mechanisms without invoking speculative constructs or infinities.

9. Model Timeline and Evolution

The decay-core model outlines a clear lifecycle for black holes that parallels stellar evolution but with quantifiable nuclear behavior:

1. **Core Collapse**: A massive star undergoes gravitational collapse. Instead of forming a singularity, extreme compression produces superheavy elements at the center.

2. **Time-Freezing Onset**: As gravitational potential increases, time dilation becomes extreme, effectively preserving the unstable isotopes at the core in a near-frozen state.

3. **Relativistic Decay Phase**: Over cosmic time, these elements decay and emit faint

radiation, observable as low-energy output from the black hole. This phase can last billions of years, explaining long-lived emissions.

4. **Core Dissipation**: As the superheavy material decays, the core gradually loses energy, entering a dormant or quiescent state.

5. **Cold Remnant**: The final state is a dense but non-radiating core with minimal active decay, indistinguishable from a classical dark remnant.

This timeline is fully grounded in nuclear decay and relativistic principles, and it offers a continuous and stable evolution without the need for exotic or unphysical transitions.

10. Resolving Core Challenges in Contemporary Black Hole Models

The decay-core model directly addresses several unresolved issues in mainstream black hole theory:

• **Singularity Paradox**: By replacing the singularity with a high-density nuclear core of finite mass and structure, the model preserves the continuity of physical law and avoids mathematical divergence.

• **Hawking Radiation Ambiguity**: Rather than rely on virtual particle dynamics and information-destroying evaporation, the model explains emissions via time-dilated nuclear decay, preserving energy and information.

• **Information Loss Paradox**: The decay process inherently carries information about the original matter through particle signatures and decay chains, resolving the paradox within standard physics.

• **Undefined Interior Conditions**: The model provides a structured description of the black hole interior based on observable nuclear behavior, rather than relegating the core to undefined physics.

• **Thermodynamic Consistency**: Emission via nuclear decay is consistent with the second law of thermodynamics, addressing one of the key conflicts in evaporative black hole models.

By addressing these core theoretical issues, the decay-core model presents a more physically grounded alternative for understanding black holes.

11. Limitations and Future Work

While the decay-core model offers a comprehensive and physically consistent alternative to singularity-based models, it also acknowledges a number of current limitations and opportunities for future development:

• **Observational Constraints**: Direct evidence of core decay remains difficult to isolate from accretion-related emissions. Distinguishing redshifted nuclear signatures from background noise or other astrophysical processes requires advanced instrumentation.

• **Formation Mechanisms**: The exact formation conditions for stable superheavy elements remain theoretical. While extreme pressures and LHC-like conditions are plausible during stellar collapse, detailed modeling of isotope formation and nucleosynthesis is still required.

• **Simulability**: Accurately simulating relativistic decay of superheavy nuclei under extreme time dilation is currently beyond classical computational capability. Future developments in quantum simulation may enable such modeling.

• **Final Remnant Composition**: The long-term fate of the decay-core—whether it stabilizes, disperses, or remains permanently quiescent—is an area of open inquiry.

Future research will involve refining decay models, developing detection methods for redshifted emissions, and advancing simulation tools that can reproduce the behavior of nuclear matter in strong gravitational fields.

12. Future Testing and Simulation Potential

Validating the decay-core model will require both theoretical advancement and technological development. Promising avenues for testing include:

• **Spectral Analysis**: Identifying specific redshifted decay emissions (e.g., gamma lines) in faint black hole output could provide direct evidence of nuclear processes.

• **Nuclear Signature Comparison**: Future telescopes and observatories may be capable of isolating subtle decay product distributions consistent with known isotope chains.

• **Quantum Simulation**: Emerging quantum processors—such as topological platforms like Majorana-based qubit systems—offer potential for simulating complex nuclear behavior under relativistic constraints. Systems with 10^4–10^6 qubits may eventually replicate the interaction environment of a black hole core, allowing experimental modeling of core decay dynamics.

• **Accretion Filtering**: Observing quiet black holes (e.g., Gaia BH1) may allow emission patterns to be studied without interference from accretion noise.

These testing approaches may ultimately allow for direct or indirect validation of the decay-core model, distinguishing it from speculative alternatives and contributing to broader efforts to unify relativity and quantum field theory.

13. Final Outlook

The decay-core model offers a novel and testable approach to black hole physics, rooted in the continuity of physical law and supported by both nuclear theory and general relativity. By reimagining the singularity not as a point of infinite density, but as a dense, decaying nuclear core governed by time dilation, the model addresses the key paradoxes that have long challenged theoretical physics.

This framework not only provides a resolution to the information paradox, but also bridges classical and quantum domains by offering a mechanism for information preservation and emission that is observable and falsifiable. In doing so, it moves beyond speculation, opening the door to a new era of black hole research that is empirical, transparent, and aligned with known science.

Future technologies such as quantum simulations and next-generation observatories may soon offer the tools required to fully test this model. If validated, the decay-core hypothesis will redefine our understanding of gravitational collapse, nuclear matter, and the boundary between relativity and quantum mechanics.