Towards Non-Singular Black Holes

Alan Oursland

February 18, 2025

Abstract

Classical general relativity predicts that black holes contain a central singularity where spacetime curvature diverges. However, quantum effects may alter this picture. We propose a self-regulating black hole core model, in which Hawking-like radiation is generated locally as a function of spacetime curvature. This radiation counteracts gravitational collapse, leading to an equilibrium core of finite curvature. The model suggests that the black hole interior is a structured region rather than a classical singularity. We discuss the mathematical framework, implications for information retention, and directions for further study.

1 Introduction

This paper presents a speculative exploration of black hole interiors. While we aim to formalize our ideas rigorously, this is not a complete theory but rather a preliminary conceptual framework for discussion. Many of the assumptions in this model remain speculative, and a full derivation from fundamental physics is not yet available. Our goal is to propose a mechanism that challenges the classical view of black hole interiors and provides a basis for future theoretical investigation.

Black holes have long been a cornerstone of theoretical physics, serving as natural laboratories for testing general relativity and quantum mechanics. The classical view, derived from Einstein's field equations, predicts that the interior of a black hole inevitably collapses into a singularity—a region of infinite curvature where known physics breaks down [1]. However, the incorporation of quantum effects into black hole physics suggests that this picture may be incomplete.

Hawking's seminal discovery of black hole radiation [2] provided the first indication that quantum effects modify black hole behavior. In the standard view, Hawking radiation originates from vacuum fluctuations near the event horizon, leading to gradual mass loss and, eventually, black hole evaporation. While this process alters the long-term evolution of black holes, it does not address the problem of singularity formation within the interior.

Several alternative proposals have attempted to resolve the singularity problem. Some models replace the singularity with a quantum gravitational "bounce" [3], while others suggest that black holes may transition into exotic compact objects at late stages of evaporation [4]. Another class of models considers the possibility of non-singular, regular black holes, such as those first proposed by Bardeen [5] and later explored in various forms [6].

In this paper, we propose a new framework that describes the black hole interior as a *self-regulating system*. We hypothesize that Hawking-like radiation is not confined to the event horizon but emerges dynamically within the black hole interior. This local radiation, dependent on the curvature of spacetime, counteracts gravitational collapse, leading to an equilibrium structure within a finite-radius core. Instead of a singularity, the black hole evolves toward a finite-curvature state, with a regulated mass-energy distribution that prevents infinite density.

This framework is intended as a heuristic model rather than a rigorously derived physical theory. The idea that local curvature-dependent radiation could significantly influence black hole interiors remains speculative. While we construct a mathematical framework that supports this hypothesis, we acknowledge that a fundamental derivation from quantum field theory or quantum gravity is necessary to establish its validity.

We will explore the theoretical foundation of this hypothesis, present a mathematical framework for its implementation, and discuss the implications for black hole stability, information retention, and late-stage evaporation. This approach suggests that black holes may be structured objects with rich internal dynamics rather than simple endpoints of gravitational collapse.

The paper is organized as follows: Section 2 outlines the core hypothesis of self-regulating black hole interiors. Section 3 presents the mathematical formalism, including proposed balance equations for radiation and collapse. Section 4 discusses stability considerations and possible observational implications. Finally, Section 5 summarizes our findings and outlines future directions for further investigation.

2 The Core Hypothesis: A Self-Regulating Black Hole Interior

The standard model of black holes, based on general relativity, predicts that matter within the event horizon undergoes unrestricted collapse, forming a singularity where spacetime curvature and energy density diverge. However, quantum effects, particularly those associated with Hawking radiation, suggest that this picture may be incomplete. We propose a speculative self-regulating mechanism within black holes that prevents singularity formation and leads to an equilibrium core of finite curvature.

This framework is exploratory in nature and should not be interpreted as a complete theory. Many of the assumptions presented here are heuristic, and a rigorous derivation from fundamental physics—whether through quantum field theory in curved spacetime or quantum gravity—is still lacking. Nonetheless, this conceptual model offers an interesting alternative to singularity formation and may provide insights into the interplay between quantum effects and gravitational collapse.

2.1 Postulate 1: Curvature-Dependent Local Radiation

Hawking radiation is typically derived as a quantum process occurring near the event horizon [2], where vacuum fluctuations generate particle-antiparticle pairs, with one escaping as radiation. In our framework, we extend this idea by proposing that a similar effect occurs *locally* within the black hole interior, with radiation emission dependent on the local curvature.

Formally, we introduce a heuristic expression for the local radiation emission rate:

$$\Gamma_H(r) = f(\mathcal{R}(r))\frac{1}{M^2}, \tag{1}$$

where:

- $\mathcal{R}(r)$ is the local spacetime curvature at radius r,

- $f(\mathcal{R})$ is a function encoding the dependence of radiation on curvature,

- M is the black hole mass.

We assume that $f(\mathcal{R})$ is a monotonic function satisfying:

$$\frac{df}{d\mathcal{R}} > 0. \tag{2}$$

This implies that regions of higher curvature experience stronger radiation effects.

At the event horizon, where $\mathcal{R}(r) \approx \mathcal{R}(r_s)$, we recover standard Hawking radiation. However, as we move deeper into the interior, the radiation rate increases due to rising curvature, eventually modifying the internal structure.

We emphasize that this **localization of Hawking-like radiation is speculative**. Standard Hawking radiation derivations rely on global horizon properties, and it is not clear whether an analogous local effect exists in a rigorous quantum gravitational treatment. Nevertheless, we use this assumption as a working hypothesis to explore the implications of quantum effects on black hole interiors.

2.2   Postulate 2: Balance Between Radiation and Collapse

Within the event horizon, classical physics dictates that matter collapses toward $r = 0$. However, in our model, the increasing radiation flux at high curvature counteracts this collapse.

We propose that an equilibrium condition is established when the local radiation flux matches the rate of gravitational collapse:

$$\Gamma_H(\mathcal{R}_c) = \Phi_{\text{collapse}}(\mathcal{R}_c), \tag{3}$$

where:

- $\mathcal{R}_c$ is the curvature at equilibrium,

- $\Phi_{\text{collapse}}(\mathcal{R})$ represents the inward flux due to gravitational collapse.

This balance prevents the curvature from diverging to infinity, stabilizing the core at a finite curvature $\mathcal{R}_c$.

It is important to note that this balance equation is an **approximate phenomenological description** rather than a rigorously derived relation. The precise formulation of Φ_{collapse}, which governs the rate at which mass-energy collapses inward, is highly nontrivial and likely requires a deeper understanding of quantum backreaction effects in strong gravity regimes.

2.3 Postulate 3: Formation of a Constant Curvature Core

If equilibrium is achieved, the black hole interior does not collapse into a singularity. Instead, for radii $r \leq r_c$, the curvature stabilizes at a constant value:

$$\mathcal{R}(r) = \mathcal{R}_c. \tag{4}$$

This implies:

- A finite energy density, satisfying Einstein's equation:

$$\mathcal{R}_c \sim 8\pi G \rho_c. \tag{5}$$

- A non-singular core that remains dynamically stable.

- The possibility that the equilibrium curvature is set by quantum gravity effects, potentially at the Planck scale:

$$\mathcal{R}_c \sim \frac{c^3}{\hbar G}. \tag{6}$$

The assumption that $\mathcal{R}_c$ approaches a fundamental quantum gravitational scale remains **speculative**. While various quantum gravity models predict modifications to singularity formation, no single accepted theory yet provides a conclusive resolution to the problem.

2.4 Physical Interpretation and Implications

This framework suggests that black holes do not have singularities but instead develop structured interiors. The self-regulating mechanism introduces a feedback loop:

1. Higher curvature generates more radiation.

2. Increased radiation counteracts gravitational collapse.

3. Equilibrium is reached when the two effects balance.

This model aligns with several non-singular black hole proposals, including regular black holes [5,6], quantum gravity-based structures [3,7], and recent proposals for Planck-scale remnants [8]. However, unlike some of these models, our framework does not impose an ad hoc energy condition or introduce a new fundamental length scale explicitly—it instead relies on a heuristic quantum backreaction effect.

Despite its appeal, this model is **not yet a complete theory**. Several key aspects remain open:

- The function $f(\mathcal{R})$ should be derived from first principles in quantum field theory or quantum gravity.

- The balance equation $\Gamma_H(\mathcal{R}_c) = \Phi_{\text{collapse}}(\mathcal{R}_c)$ requires a deeper understanding of gravitational collapse in quantum-modified spacetimes.

- The stability of this equilibrium state under perturbations is not guaranteed and requires further study.

The next section presents the mathematical framework necessary to formalize these equilibrium conditions.

3 Mathematical Framework

The self-regulating black hole core hypothesis relies on a balance between local Hawking-like radiation and gravitational collapse. To formalize this idea, we introduce a heuristic mathematical framework that describes how radiation emission depends on spacetime curvature and how this interplay leads to a stable core. However, we emphasize that this treatment remains speculative, and a full derivation from quantum field theory in curved spacetime or quantum gravity is required to establish its validity.

3.1 Local Radiation Emission as a Function of Curvature

Standard Hawking radiation is derived as a global effect dependent on the event horizon. In our model, we extend this concept to assume that radiation is generated locally throughout the black hole interior, with an emission rate that depends on the local curvature.

We introduce the heuristic expression:

$$\Gamma_H(r) = f(\mathcal{R}(r))\frac{1}{M^2}, \tag{7}$$

where:

- $\mathcal{R}(r)$ is the local Ricci scalar curvature,

- $f(\mathcal{R})$ is a function that encodes how local radiation depends on curvature,

- M is the black hole mass.

The function $f(\mathcal{R})$ must satisfy:

$$\frac{df}{d\mathcal{R}} > 0, \tag{8}$$

ensuring that radiation increases with curvature.

We propose the following candidate function:

$$f(\mathcal{R}) = f_0 \left(1 - e^{-\alpha(\mathcal{R} - \mathcal{R}_0)}\right), \tag{9}$$

where f_0, α, and $\mathcal{R}_0$ are free parameters that need to be constrained. This ensures that radiation grows with curvature but does not diverge indefinitely. However, we stress that the exact form of $f(\mathcal{R})$ must be derived from first principles.

3.2 Balance Between Radiation and Gravitational Collapse

For the black hole interior to avoid singularity formation, an equilibrium must be established where radiation emission counteracts the inward collapse of mass-energy.

We propose the approximate balance equation:

$$\Gamma_H(\mathcal{R}_c) = \Phi_{\text{collapse}}(\mathcal{R}_c), \tag{10}$$

where:

- $\mathcal{R}_c$ is the curvature at equilibrium,

- $\Phi_{\text{collapse}}(\mathcal{R})$ represents the inward mass-energy flux due to gravitational collapse.

This heuristic condition suggests that at sufficiently high curvature, radiation effects become strong enough to halt further collapse. However, a rigorous derivation of Φ_{collapse} is required to confirm whether such an equilibrium naturally arises from fundamental physics.

3.3   Energy Conservation and Core Formation

The evolution of mass-energy within the black hole interior follows a local conservation equation:

$$\frac{\partial M(r,t)}{\partial t} + \frac{\partial \Phi(r,t)}{\partial r} = -\Gamma_H(r,t), \tag{11}$$

where:

- $M(r,t)$ is the mass-energy contained within radius r,

- $\Phi(r,t)$ is the net energy flux,

- $\Gamma_H(r,t)$ represents local radiation loss.

The core radius r_c is defined as the radius at which the equilibrium curvature is reached:

$$\mathcal{R}(r_c) = \mathcal{R}_c. \tag{12}$$

If $\mathcal{R}_c$ is associated with quantum gravitational effects, then the core radius is expected to be:

$$r_c \sim \sqrt{\frac{\hbar G}{c^3}}, \tag{13}$$

suggesting a Planck-scale structure.

3.4   Avoidance of the Singularity

If equilibrium is reached, the curvature does not diverge, but instead remains finite:

$$\mathcal{R}(r) = \begin{cases} \mathcal{R}_c, & 0 \leq r \leq r_c, \\ \text{dynamical}, & r_c < r < r_s. \end{cases} \tag{14}$$

This implies:

- The singularity is replaced by a constant-curvature core.

- The mass-energy distribution remains structured rather than a collapsing point.

- The core remains dynamically stable (subject to further stability analysis).

3.5   Implications for Black Hole Evolution

If a self-regulating core forms, the evolution of the black hole follows a two-step process:

1. Hawking radiation emission at the event horizon, leading to gradual black hole evaporation.

2. Internal restructuring, where the core dynamically adjusts to maintain equilibrium.

As the black hole evaporates, the core radius r_c may shrink. The long-term behavior depends on whether the core fully evaporates or stabilizes as a remnant.

3.6 Limitations and Open Problems

While this framework offers an intriguing alternative to classical singularity formation, several theoretical gaps remain:

1. The function $f(\mathcal{R})$ must be rigorously derived from quantum field theory in curved spacetime or a quantum gravity approach.

2. The balance condition $\Gamma_H = \Phi_{\text{collapse}}$ is heuristic and requires a deeper understanding of quantum backreaction effects.

3. Stability analysis, including perturbations and nonlinear effects, is necessary to confirm whether the equilibrium core is dynamically viable.

4. The late-stage behavior of the black hole—whether it evaporates entirely or leaves behind a remnant—remains uncertain.

A full treatment incorporating quantum gravitational corrections is needed to evaluate whether this model represents a viable description of black hole interiors.

The next section explores stability considerations and the implications of this framework for black hole physics.

4 Stability and Open Questions

The self-regulating black hole core model introduces a structured interior where local Hawking-like radiation counteracts gravitational collapse, leading to an equilibrium curvature at $\mathcal{R}_c$. However, for this framework to be physically viable, the equilibrium state must be stable against perturbations. Additionally, this model raises fundamental questions regarding black hole thermodynamics, information flow, and long-term evolution.

We emphasize that this section provides a heuristic treatment of stability and highlights open problems rather than offering a definitive analysis. A full stability study requires a more detailed treatment of quantum backreaction effects and nonlinear dynamics.

4.1 Perturbative Stability of the Core

A key question is whether small perturbations in curvature or energy density within the core lead to divergence (instability) or are naturally damped (stability). Given the heuristic nature of this framework, we provide a preliminary discussion of potential stability conditions.

4.1.1 Linear Stability Analysis

We define a small perturbation $\delta\mathcal{R}(r,t)$ around the equilibrium curvature:

$$\mathcal{R}(r,t) = \mathcal{R}_c + \delta\mathcal{R}(r,t). \tag{15}$$

The evolution of $\delta\mathcal{R}$ can be modeled by an approximate transport equation:

$$\frac{\partial \delta\mathcal{R}}{\partial t} + v_r \frac{\partial \delta\mathcal{R}}{\partial r} = -\lambda \delta\mathcal{R}, \tag{16}$$

where:

- v_r represents an effective propagation velocity of curvature perturbations,

- λ is a damping (if positive) or growth (if negative) coefficient.

If $\lambda > 0$, perturbations decay over time, suggesting **stability**. If $\lambda < 0$, the core structure is unstable, potentially leading to either collapse or dispersion.

The value of λ depends on the radiation response function $f(\mathcal{R})$. If radiation increases rapidly with curvature, the feedback mechanism should dampen perturbations. However, if radiation saturates or responds too weakly, the system may be prone to instabilities.

4.1.2 Energy Density Stability

Since curvature and energy density are linked by Einstein's equations, perturbations in ρ also affect stability. The key question is whether energy density perturbations reinforce equilibrium or cause runaway behavior.

We define:

$$\rho(r,t) = \rho_c + \delta\rho(r,t), \tag{17}$$

where ρ_c is the equilibrium core density. The governing equation is:

$$\frac{\partial \delta\rho}{\partial t} + \frac{\partial}{\partial r}\left(\Phi_{\text{rad}} - \Phi_{\text{collapse}}\right) = 0. \tag{18}$$

If **radiation outflow adjusts dynamically to stabilize ρ_c**, the core remains stable.

We emphasize that this analysis remains heuristic; a full stability treatment requires a self-consistent perturbation theory in a quantum gravity framework.

4.2 Nonlinear Evolution and Late-Stage Dynamics

A complete treatment of stability must consider **nonlinear effects**. If the radiation response $f(\mathcal{R})$ saturates at high curvatures, feedback mechanisms could prevent instability. However, if radiation is not sufficiently responsive, perturbations could grow, leading to:

- A gradual deviation from equilibrium, leading to core shrinkage or expansion.

- A catastrophic breakdown of the core, leading to renewed collapse or dispersal.

A full nonlinear stability analysis requires solving the coupled mass-energy and radiation equations numerically. Additionally, the backreaction of local radiation on the spacetime metric must be incorporated to assess whether the equilibrium state remains self-consistent.

4.3 Information Retention and Black Hole Evolution

One of the major unresolved problems in black hole physics is the fate of information. If the singularity is avoided in favor of a structured core, several possibilities arise:

1. Information could be stored in the core and gradually released during late-stage evaporation.

2. The core itself could act as a quantum remnant, preventing information loss.

3. Information may be redistributed internally but remain inaccessible from the exterior.

Determining the core's role in information flow requires an explicit **quantum description** of the interior radiation process. This remains an open problem, as no fully developed theory of black hole interiors currently resolves the information paradox unambiguously.

4.4   Late-Stage Evolution and Possible Remnants

As the black hole loses mass due to Hawking radiation, the equilibrium core should dynamically adjust. Possible end states include:

- A shrinking core that eventually evaporates completely.

- A stable Planck-scale remnant that persists indefinitely.

The remnant hypothesis is appealing because it could provide a mechanism for resolving the black hole information paradox, but further work is required to determine whether a self-regulating core naturally transitions into a remnant.

The evaporation dynamics of such a core depend on the detailed form of $f(\mathcal{R})$ and how it interacts with Hawking radiation near the event horizon. If radiation emission slows down at high curvature, remnants may persist. If evaporation proceeds unhindered, the black hole may completely evaporate.

4.5   Open Questions

While this framework provides a compelling alternative to classical singularity formation, several questions remain:

1. **Derivation of the Radiation Function:** Can $f(\mathcal{R})$ be derived from first principles in quantum field theory or quantum gravity?

2. **Stability Under Perturbations:** Do numerical simulations confirm that the equilibrium core remains stable under small fluctuations?

3. **Modified Einstein Equations:** How should the field equations be modified to include quantum backreaction effects?

4. **Observational Signatures:** Could deviations from classical predictions be detected via gravitational wave echoes or other indirect observations?

5. **Final State of Black Holes:** Does this model favor total evaporation or remnant formation?

4.6   Limitations of This Analysis

Given the speculative nature of this framework, several caveats apply:

- The perturbation analysis is heuristic and does not incorporate full backreaction effects.

- Stability conclusions depend on the assumed form of $f(\mathcal{R})$, which is not yet derived from first principles.

- The possibility of nonlinear instabilities remains open and must be tested numerically.

A full treatment incorporating quantum gravitational corrections is needed to evaluate whether this model represents a viable description of black hole interiors.

The next section will summarize our findings and outline future directions for further investigation.

5   Conclusions and Future Work

The conventional view of black holes, based on general relativity, predicts the formation of singularities—regions where curvature and energy density diverge to infinity. However, the incorporation of quantum effects suggests that this picture may be incomplete. In this work, we have proposed a speculative framework in which black hole interiors evolve toward a self-regulating equilibrium state, preventing singularity formation. While this model presents an intriguing alternative to classical collapse, it remains heuristic and requires further theoretical justification.

5.1   Summary of Key Findings

The core hypothesis of this model is that black holes do not undergo unrestricted collapse but instead develop an equilibrium structure due to a balance between:

1. **Curvature-Dependent Local Radiation:** Hawking-like radiation is assumed to be generated throughout the interior, with an emission rate increasing as a function of local spacetime curvature.

2. **Equilibrium Condition:** The outward energy flux from radiation counteracts the inward flux from gravitational collapse, leading to a stable core.

3. **Finite Curvature Core:** Instead of a singularity, the interior settles into a regulated region of constant curvature, possibly near the Planck scale.

While this framework suggests that black hole interiors could have structured, dynamic properties, its assumptions remain speculative, and key derivations from fundamental physics are still lacking. A rigorous justification of the proposed balance mechanism, along with an explicit derivation of the local Hawking-like radiation term from quantum field theory in curved spacetime, is necessary for the model to be considered viable.

5.2   Implications for Black Hole Physics

If this heuristic framework captures essential aspects of black hole interiors, it suggests several important consequences:

- **No Singularity Formation:** The classical singularity could be replaced by a structured core with finite curvature, assuming the equilibrium conditions hold.

- **Modified Black Hole Evolution:** As black holes radiate, their internal structure may evolve dynamically rather than undergoing unrestricted collapse.

- **Possible Information Retention:** If the core stabilizes, it could provide a mechanism for preserving or eventually releasing information, though a rigorous treatment is required.

- **Remnant Formation:** If this framework holds, a Planck-scale remnant could persist after evaporation, though further analysis is required to assess whether this outcome is physically viable.

It is important to recognize that these implications depend on the assumption that local curvature-dependent radiation plays a significant role inside black holes. At present, there is no derivation from first principles that confirms this effect.

5.3 Directions for Future Research

While the proposed model offers an interesting conceptual framework, several open problems remain. Addressing these will require both theoretical developments and numerical simulations:

1. **First-Principles Derivation of Radiation Emission:** The function $f(\mathcal{R})$, which governs radiation as a function of curvature, needs to be rigorously derived from quantum field theory in curved spacetime or an appropriate quantum gravity framework.

2. **Stability Analysis and Numerical Simulations:** The stability of the equilibrium core must be tested through numerical simulations of Einstein's equations coupled with radiation backreaction. Both linear and nonlinear perturbations should be analyzed to determine whether the core remains dynamically stable.

3. **Modified Einstein Equations:** The effective energy-momentum tensor for the core must be identified to correctly model quantum effects on classical spacetime dynamics. Backreaction of local radiation on the metric must also be incorporated.

4. **Observational Signatures:** Any potential observational effects—such as deviations from classical black hole predictions or gravitational wave echoes—must be identified and assessed for detectability. However, given the speculative nature of this framework, any observational predictions remain purely hypothetical at this stage.

5. **Late-Stage Evolution and Final State:** The end state of black hole evaporation remains uncertain. A detailed study is required to determine whether the core dissipates entirely or persists as a remnant. The interaction between the local radiation effects and conventional Hawking radiation at the event horizon must also be analyzed.

6. **Implications for the Information Paradox:** If information is retained in the core, how is it released over time? Could this model provide a pathway to resolving the information paradox, or does it introduce new challenges?

5.4 Final Remarks

The self-regulating core hypothesis presents a speculative alternative to classical singularity formation, serving as an exploratory framework for further discussion and refinement. This model bridges classical relativity and quantum mechanics, providing a conceptual approach that could guide future research in quantum gravity, black hole thermodynamics, and high-energy astrophysics. However, it remains an incomplete theory, requiring further theoretical and computational development before any definitive conclusions can be drawn.

A complete resolution of these questions requires advances in both theoretical physics and numerical modeling. By further developing the mathematical framework, incorporating quantum gravitational effects, and exploring potential observational consequences, we may gain deeper insight into the fundamental nature of spacetime and the quantum structure of black holes.

AI Acknowledgment

This work began as an exploration of how Hawking radiation within a black hole might influence its internal structure. The process of formalizing these ideas and predicting their implications was significantly aided by AI-assisted tools. While the underlying questions originate from human intuition and inquiry, AI contributed to refining, organizing, and extending the theoretical framework.

Specifically, the AI system assisted in:

- Structuring and systematically developing theoretical concepts.

- Assisting with LaTeX document preparation and mathematical formalization.

- Suggesting refinements to definitions, notation, and consistency in presentation.

- Identifying potential gaps and logical dependencies within the proposed framework.

- Proposing lines of inquiry and highlighting where additional theoretical justification is required.

This paper does not claim to present a definitive theory but rather an exploration of an interesting question. The AI-assisted process led to a framework that extends beyond the author's ability to fully evaluate, making it an exercise in speculative theorization rather than confirmed physics. The hope is that this formalization may inspire further rigorous investigation by those with deeper expertise in quantum gravity and black hole physics.

All intellectual contributions, critical reasoning, and final theoretical judgments remain the responsibility of the human author. The AI served as a tool to enhance clarity, organization, and technical formulation, but the responsibility for correctness, validity, and originality of the work lies solely with the author.

References

[1] Roger Penrose. Gravitational collapse and space-time singularities. *Physical Review Letters*, 14:57–59, 1965.

[2] Stephen W. Hawking. Particle creation by black holes. *Communications in Mathematical Physics*, 43:199–220, 1975.

[3] Martin Bojowald. Nonsingular black holes and loop quantum gravity. *Classical and Quantum Gravity*, 23:391–411, 2005.

[4] Valeri P. Frolov. Notes on non-singular models of black holes. *Physical Review D*, 94:104056, 2016.

[5] James M. Bardeen. Non-singular general relativistic gravitational collapse. *Proceedings of GR5*, 1968. Conference presentation.

[6] Sean A. Hayward. Formation and evaporation of regular black holes. *Physical Review Letters*, 96:031103, 2006.

[7] Carlo Rovelli and Lee Smolin. Black hole entropy in loop quantum gravity. *Nuclear Physics B*, 442(3):593–619, 1996.

[8] Ram Brustein and A. J. M. Medved. Black hole interior in quantum gravity and the information paradox. *Fortschritte der Physik*, 67(10):1800056, 2018.