Black Holes: Reinterpreting Horizons, Singularities, and Quantum Gravity

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Abstract: Dynamic symmetry theory, which frames symmetry as a fluid and context-dependent interplay between order and chaos, offers a new perspective on black hole physics that challenges and extends the standard models of general relativity and quantum mechanics. This paper explores how dynamic symmetry reinterprets black hole structure, information, and evolution, and examines the unique theoretical implications and testable predictions it offers. Drawing on recent research—including the proposal of CPT-symmetric "black mirrors," the role of symmetry breaking in scalar fields, and the impact of spontaneous Lorentz symmetry violation—this analysis shows how dynamic symmetry may resolve longstanding conflicts between general relativity and quantum mechanics in extreme gravitational regimes.

The quest to reconcile general relativity with quantum mechanics has long been stymied by the paradoxes and singularities that arise in black hole physics. General relativity predicts that gravitational collapse leads to the formation of an event horizon and a central singularity, where spacetime curvature becomes infinite and the laws of physics break down. Quantum mechanics, on the other hand, insists on unitarity and information conservation, leading to the infamous black hole information paradox. Dynamic symmetry theory, by rejecting the notion of symmetry as a static property and instead treating it as an evolving, context-dependent process, provides a new language for addressing these conflicts.

A central insight of dynamic symmetry is that the structure of a black hole need not be fixed by classical expectations. Instead, the horizon and interior may be subject to transformations that preserve certain symmetries while breaking others, leading to new classes of solutions. One of the most striking recent proposals is the "black mirror" model, which replaces the classical black hole's singular interior with a CPT-symmetric mirror image of the exterior spacetime. In this framework, the event horizon connects the familiar exterior to a region that is not a singularity but a reflection, under charge, parity, and time reversal, of the original spacetime. This CPT-symmetric solution has been shown to be a valid stationary point of the gravitational path integral when appropriate boundary conditions are imposed, and it eliminates the curvature singularity that plagues the conventional black hole solution. (Tzanavaris et al., 2024)

The black mirror model has several profound implications. First, it resolves the singularity problem: there is no region of infinite curvature inside the horizon, but rather a smooth continuation into a CPT-mirrored universe. Second, it provides a natural mechanism for information conservation. In the standard black hole scenario, information falling into the singularity is lost, apparently violating quantum unitarity. In the black mirror picture, however, global charge and information are preserved because matter entering the horizon on one side is mirrored by antimatter entering from the other, and the evaporation process radiates away the information rather than erasing it (Tzanavaris et al., 2024). This resolves the black hole information paradox without resorting to speculative mechanisms like firewalls or non-locality.

Dynamic symmetry also offers a new perspective on the thermodynamic properties of black holes. In the CPT-symmetric model, the entropy associated with the horizon can be understood as the boundary between two sheets of spacetime, each representing a pure state, with the mixed state arising from tracing over one sheet. This provides a statistical basis for the Bekenstein-Hawking entropy formula, linking it to the area of the horizon as a measure of the entanglement between the two CPT-related universes (Tzanavaris et al., 2024). The symmetry between the sheets also explains why black hole evaporation does not violate global symmetries, as the net charge is always balanced between the two sides.

The dynamic symmetry framework is not limited to static, uncharged black holes. The general stationary black mirror solution, including charge and rotation, has been constructed explicitly. CPT symmetry acts by reversing not only time and parity but also electric charge, so that the charge measured on one side of the horizon is cancelled by the opposite charge on the other. This has observable consequences: for instance, the trajectories of charged particles near the horizon are mapped to their CPT-mirrored counterparts, and the flow of charge and energy is reversed across the horizon (Tzanavaris et al., 2024). These effects could, in principle, be detected through the polarisation and spectrum of Hawking radiation or through precise measurements of black hole mergers.

Dynamic symmetry is also relevant to modified theories of gravity that introduce new forms of symmetry breaking. In Kalb-Ramond (KR) gravity, for example, a parameter l induces spontaneous Lorentz symmetry breaking, altering the geodesic structure and the periodic orbits around black holes (Junior et al., 2025). Numerical simulations show that this symmetry-breaking parameter has a significant impact on the innermost stable circular orbits, the shadow of the black hole, and the gravitational waveforms emitted by inspiralling objects. These deviations from the predictions of general relativity provide a testable signature of dynamic symmetry breaking in strong gravity regimes. With advances in gravitational wave detection, it may soon be possible to distinguish KR black holes from their Schwarzschild or Kerr counterparts by analysing the phase and amplitude of the emitted waves (Junior et al., 2025).

The interplay between symmetry breaking and black hole dynamics is further illustrated by studies of scalar fields in black hole spacetimes. When a Higgs-like field undergoes symmetry breaking near a black hole, numerical simulations reveal the formation of spherical domain wall shells around the singularity, with oscillations piling up near the horizon. (Traykova, 2018) This behaviour is a direct consequence of the mismatch between the surfaces of constant field and constant potential, imposed by the evolving symmetry-breaking potential. The emergence of domain walls and oscillatory structures is a novel feature that does not occur in flat spacetime, highlighting how the strong gravitational field of a black hole can induce new forms of symmetry-driven structure. These effects could have implications for the evolution of scalar fields in the early universe or in the vicinity of astrophysical black holes.

Dynamic symmetry theory also provides a framework for understanding the time evolution of evaporating black holes. In models where the mass, charge, and angular momentum of the black hole decrease smoothly over time, the Penrose diagram can be constructed to show the global causal structure of the spacetime (Braunstein, 2021). The continuity of these parameters ensures that there are no naked singularities, and the evaporation process can be analysed in terms of the changing symmetry properties of the horizon. This approach is consistent with the principle of background independence, which requires that spacetime itself be treated as a dynamical entity rather than a fixed backdrop (Ciupa, 2024). By allowing the symmetry of the spacetime to evolve dynamically, the theory accommodates the non-perturbative effects that are essential for a complete quantum theory of gravity.

One of the most persistent challenges in black hole physics is the information paradox: the apparent loss of information when matter falls into a black hole and is subsequently radiated away as thermal Hawking radiation. Dynamic symmetry theory offers several avenues for resolving this paradox. In the CPT-symmetric black mirror model, information is never truly lost but is encoded in the correlations between the two sheets of spacetime. (Tzanavaris et al., 2024) In other approaches, such as the AdS/CFT correspondence, the entanglement entropy of Hawking radiation can be calculated to show that the unitary Page curve is followed, indicating that information is preserved throughout the black hole's lifecycle (King, 2022). Dynamic symmetry, by emphasising the relational and processual nature of physical law, supports these interpretations by providing a mechanism for information flow that is not tied to a single, static spacetime region.

Another longstanding issue is the problem of time in quantum gravity. In general relativity, time is a dynamical variable, part of the fabric of spacetime itself, while in quantum mechanics, time is an external parameter. Dynamic symmetry theory, especially when combined with scale-invariant or Weyl-invariant models, suggests that time may emerge from the symmetry properties of the underlying quantum spacetime (81.71.198.114, 2024). For example, the thermal time hypothesis proposes that the flow of time is a macroscopic feature of thermodynamical origin, linked to the symmetry of the system's state. In scale-invariant quantum gravity, the conserved Weyl current associated with scale symmetry gives rise to a harmonic time, and the quantisation of time itself may be a consequence of the underlying symmetry group structure. These ideas offer new ways to reconcile the disparate treatments of time in quantum mechanics and general relativity.

The principle of minimal group representation, as discussed by Cirilo-Lombardo & Sanchez (2024), provides another mathematical foundation for dynamic symmetry in quantum spacetime. By mapping the real spacetime manifold to the quantum phase space of a symmetry group, one can derive the spacetime metric from the properties of the group's coherent states. This approach makes explicit the discrete structure of spacetime as a fundamental feature of a consistent quantum-field theory of gravity. In the continuum limit, the usual spacetime geometry is recovered, but at the quantum level, the metric reflects the underlying group symmetries. This perspective unifies matter/energy and spacetime as manifestations of the same symmetry principles, offering a route to a fully quantum theory of gravity.

Loop quantum gravity provides yet another example of dynamic symmetry at work. Numerical studies show that quantum gravity corrections can resolve classical singularities in black hole formation, replacing them with a radiation-like phase in the quantum collapse (Ziprick & Kunstatter, 2009). The black hole consists of a compact region of spacetime bounded by a smooth trapping horizon, and the evaporation process leaves behind a small expanding shell that disperses to infinity. This dynamical singularity resolution is a direct consequence of the interplay between quantum fluctuations and gravitational symmetry, and it demonstrates how dynamic symmetry can regularise the extreme behaviour predicted by classical general relativity.

Dynamic symmetry also has implications for the quantum measurement problem. The collapse of the wave function, which is incompatible with the linear evolution prescribed by the Schrödinger equation, can be interpreted as a form of symmetry breaking (Hossenfelder, 2019). In the context of black holes, the measurement problem is closely tied to the fate of information and the nature of Hawking radiation. Dynamic symmetry suggests that the apparent collapse is not a fundamental process but an emergent phenomenon arising from the interaction of quantum states with the gravitational field. This aligns with the Montevideo interpretation of quantum mechanics, where fundamental decoherence due to quantum clocks provides a natural resolution to the measurement problem in generally covariant theories (81.71.198.114, 2024).

Finally, dynamic symmetry theory makes concrete, testable predictions for black hole behaviour. The CPT-symmetric black mirror model predicts that black holes will not exhibit true singularities but will instead have horizons connecting to mirrored regions of spacetime. This could be tested by analysing the spectrum and polarisation of Hawking radiation, or by searching for deviations in the gravitational wave signals from black hole mergers (Tzanavaris et al., 2024) (Junior, 2025). The presence of domain wall shells and oscillatory structures in scalar field accretion could be observed in the dynamics of matter near black holes or in the early universe (Traykova, 2018). Lorentz symmetry-breaking effects in modified gravity theories could be detected through precise measurements of black hole shadows and gravitational waveforms (Junior, 2025). The discrete structure of spacetime predicted by group-theoretic approaches may manifest as quantised features in the gravitational field, accessible to future high-precision experiments (Cirilo-Lombardo & Sanchez, 2024) (Ziprick & Kunstatter, 2009).

In summary, dynamic symmetry theory reinterprets black hole physics by replacing static, singular solutions with evolving, symmetry-driven structures that preserve information, regularise singularities, and unify the principles of general relativity and quantum mechanics. Its unique predictions—such as CPT-symmetric black mirrors, symmetry-breaking-induced domain walls, and observable deviations in gravitational wave signals—offer concrete avenues for experimental and observational tests. By treating symmetry as a dynamic, context-dependent process, the theory provides a promising framework for resolving the deepest puzzles of black hole physics and quantum gravity.

References and Further Reading

Tzanavaris, K., Boyle, L., & Turok, N. (2024). Black Mirrors: CPT-Symmetric Alternatives to Black Holes. *arXiv:2412.09558*.

Junior, E. L. B. et al. (2025). Periodical orbits and waveforms with spontaneous Lorentz symmetry-breaking in Kalb-Ramond gravity. *arXiv*.

Traykova, D., et al (2018). Accretion of a symmetry-breaking scalar field by a Schwarzschild black hole. The Royal Society.

Braunstein, S. L. et al. (2021). Information recovery from evaporating black holes. University of York.

Ciupa, I. (2024). The Troubled Marriage of Gravity and Quantum Mechanics.

King, A. (2022). Resolving a paradox: AdS/CFT and black hole information loss. Imperial College London.

81.71.198.114 (2024). Problem of time.

Cirilo-Lombardo, D. J., & Sanchez, N. (2024). Quantum-Spacetime Symmetries: A Principle of Minimum Group Representation. Universe.

Ziprick, J., & Kunstatter, G. (2009). Dynamical singularity resolution in spherically symmetric black hole formation. Phys. Rev. D 80, 024032.

Hossenfelder, S. (2019). What is the quantum measurement problem? . Backreaction Blog.