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Implications of 2025 Breakthroughs for Coherence Theory

Unifying Physics from Microscale to Cosmos

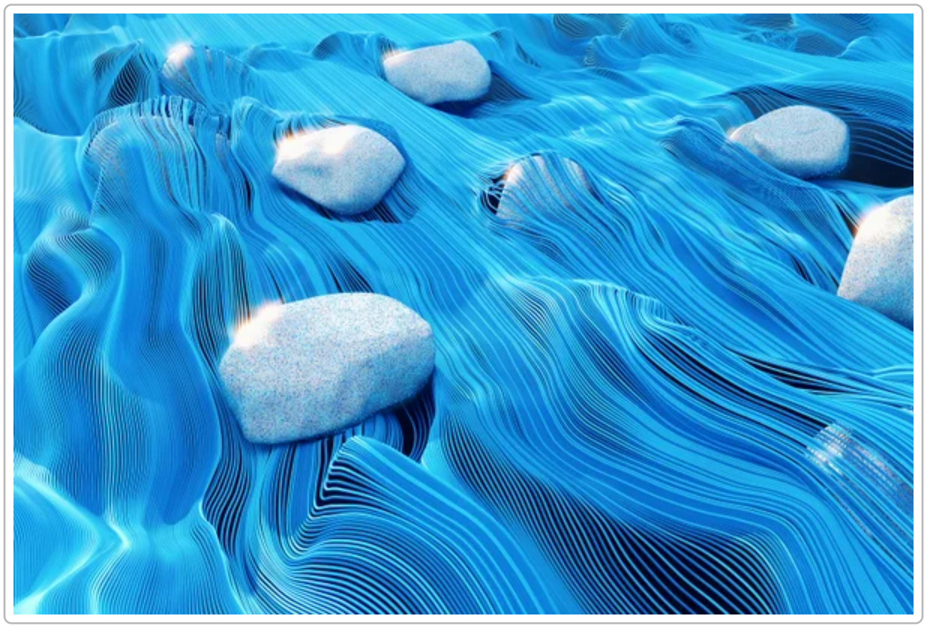
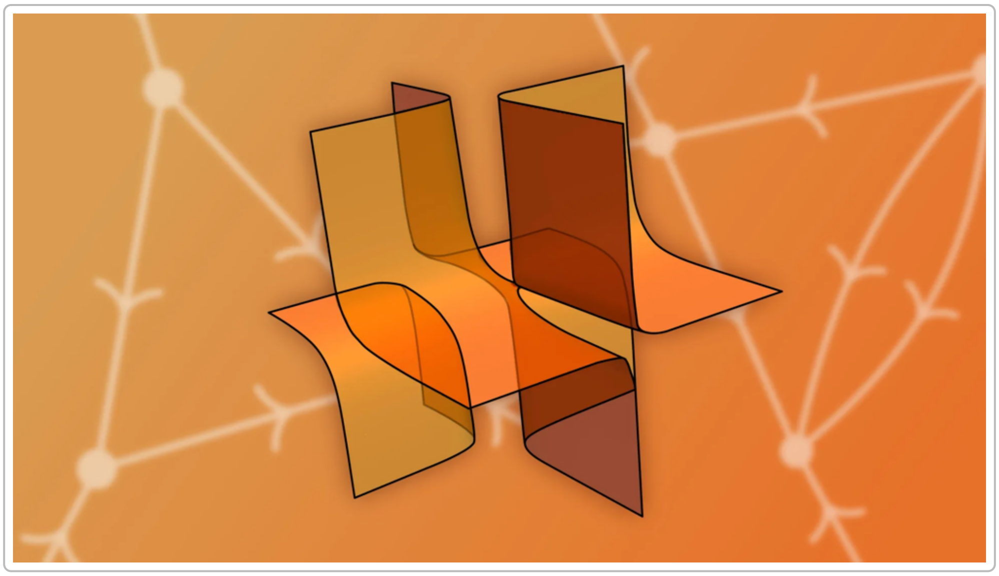


Illustration of fluid flow lines over obstacles, representing fluid dynamics across scales.

One of the major achievements of 2025 was a solution to part of **Hilbert's sixth problem**, which aimed to axiomatize physics. Mathematicians Deng, Hani and Ma successfully unified three levels of fluid dynamics theory – Newton's particle mechanics, Boltzmann's statistical equation, and the Euler/Navier-Stokes continuum equations – into a single consistent framework [1]. This breakthrough rigorously shows that the microscopic laws lead to the same macroscopic fluid behavior, establishing a mathematical bridge from particles to flowing liquids. In practical terms, it **confirms a coherence across scales**: the different theories are just convenient perspectives that **"converge on one ultimate theory describing one reality"** [1]. This is a major step toward the vision of physics underpinned by a single cohesive foundation, boosting confidence that our multiscale descriptions are *internally coherent* and complete. It opens the door to similar unifications in other fields [2] [1], suggesting that nature's laws at different scales are deeply connected rather than disjoint.



An abstract positive geometry shape (center) alongside Feynman diagrams (background), hinting at a unifying geometric language.

Another 2025 advance showed how **abstract geometry can unify disparate realms of physics**. Mathematicians Fevola and Sattelberger explored *positive geometry*, uncovering hidden high-dimensional shapes that link subatomic particle interactions to the structure of the cosmos [3] [4]. This approach, inspired by the amplituhedron in quantum field theory, represents particle scattering processes as volumes of geometric objects rather than traditional calculus integrals [5]. Intriguingly, similar geometric constructs (like *cosmological polytopes*) can describe patterns in the cosmic microwave background [6]. In effect, **the same mathematical language may describe scales from collider experiments to the Big Bang** [4] [6]. Researchers emphasized that *"positive geometry is more than a tool. It is a language… that might unify our understanding of nature at all scales."* [7]. This indicates a growing belief that there are underlying *coherent structures* bridging quantum physics and cosmology. Such cross-cutting formalisms reinforce the idea that a **universal coherence principle** could be at work, weaving a common thread through the fabric of reality from the smallest to largest scales.

Emergent Phenomena and Coherence in Quantum Systems

A striking discovery in late 2025 revealed a **new phase of matter** that blurs the line between open and closed quantum systems. Physicists in Tokyo identified a *"stable exceptional fermionic superfluid"* – a superfluid phase of ultracold atoms that inherently hosts **exceptional points (EPs)**, which are mathematical singularities typical of *non-Hermitian* (open, dissipative) systems [8] [9]. Normally, allowing particle loss or dissipation destroys delicate quantum order, but here *dissipation actually stabilizes a new form of coherent order*: spin-selective loss was introduced into a Hubbard model and ended up **actively stabilizing the superfluid state with EP singularities embedded in it** [10]. In other words, the system finds a new balance where some coherence (superfluidity) persists alongside continual particle leakage. This challenges the intuition that coherence and dissipation are opposites, showing instead that **dynamical systems can self-organize into new coherent states under the right conditions**. It also underscores the importance of system structure – the underlying lattice geometry dictated whether this exotic phase could exist [11] [12]. For our theory, this finding illustrates that **coherence can emerge in unexpected regimes**, even when conventional theory might predict instability. It hints that a fundamental coherence principle might manifest as novel phases of matter when combined with nonequilibrium dynamics, expanding the scope of where ordered, unified behavior can be found in nature.

Further evidence of surprising order emerging from complexity came from mathematics and physics intersections. In 2025, a long-standing quantum puzzle known as the *"Ten Martini problem"* was finally solved, revealing that the energy spectrum of a certain crystal electron model forms a Cantor set – a self-similar fractal [13]. This means a **deeply ordered mathematical pattern (a fractal)** underlies what was thought to be a complicated quantum system. Such results reinforce that when viewed with the right math, even chaotic-looking systems may have *coherent patterns* (in this case, infinitely repeating structures across scales). Altogether, these developments in quantum matter and mathematical physics suggest that **order and coherence are ubiquitous**, appearing in forms like superfluid phases with built-in singularities or fractal spectra in quantum mechanics. They inspire us to broaden our notion of coherence as a fundamental feature that can survive or arise through complexity, rather than being easily washed out by disorder.

Information as a Fundamental Principle

One of the boldest proposals of 2025 was the idea that **information might be as fundamental to the universe as energy or mass**. Scientist Robert Hazen (a mineralogist) and Michael Wong (an astrobiologist) put forward a new *"law of nature"* positing that the *functional information* content of systems tends to increase over time, much like entropy does [14] [15]. In their view, **complexity naturally accumulates** in the cosmos: from chemical elements synthesizing in stars, to minerals diversifying on planets, to life and intelligence evolving [16] [17]. They define "functional information" as the information that enables an entity to perform some function or fulfill a purpose (originally a concept from biology, generalized to all matter) [18] [19]. Over Earth's history, for example, mineral species have become more complex, and new materials with novel structures have appeared – indicating an *increase* in this functional information of the mineral world [20] [21]. Hazen and Wong argue that such trends are not coincidental but flow from a **basic principle of selection for function**, driving the universe toward greater organized complexity [22] [23]. As Wong succinctly put it, *"information itself might be a vital parameter of the cosmos, similar to mass, charge and energy."* [24]

This provocative hypothesis has broad implications. It suggests that the **current laws of physics may be incomplete** in describing why the universe structures itself as it does [25]. Traditional physics can predict how isolated systems evolve, but it doesn't by itself explain the spontaneous emergence of complex organized phenomena (like life or even the intricate nonliving structures we see). Hazen and Wong's idea attempts to fill that gap by adding a new fundamental tendency toward complexity. Some researchers have embraced this as a *"grand narrative"* expanding science's framework, making such questions of evolution and complexity "legitimate" for fundamental physics [25]. Others are critical, noting that the measure of information used is context-dependent and hard to quantify, making the proposal difficult to test rigorously [26]. Regardless of the debate, this development is significant for our coherence theory. It shows a mainstream move toward recognizing **emergent order (coherence/complexity)** as something law-like in nature, not just an accident. Our premise that *coherence is a foundational principle* finds a parallel here: Hazen and Wong basically propose a law of coherent complexity growth. If information/complexity is indeed fundamental, then coherence – the orderly arrangement of parts – is **central to how the universe evolves**. This gives us both conceptual support and a cautionary tale: any proposed new law (like a coherence principle) must be formulated in a measurable, testable way to gain acceptance [26]. In summary, the "information as a force" idea in 2025 strongly reinforces the spirit of our theory, suggesting that the scientific community is increasingly open to fundamental principles beyond the standard four forces – principles that drive the emergence of organized complexity in the cosmos [24].

Mathematical Discoveries Underpinning Reality

Several headline math breakthroughs in 2025 further underscored the intimate link between abstract mathematics and the structure of reality. We've already noted the solution to Hilbert's sixth problem for fluids – hailed as *"a lofty proof [that] unifies three physical theories that explain the motion of fluids."* [27] This was celebrated as **"math at the heart of reality,"** emblematic of how mathematical rigor can illuminate the coherence of physical laws. In other advances, mathematicians proved a sweeping new theorem about hyperbolic surfaces and finally settled the three-dimensional *Kakeya conjecture* (a problem about how a needle can be rotated in space) [28]. A 17-year-old prodigy, Hannah Cairo, cracked a 40-year-old conjecture in harmonic analysis, showing fresh perspectives can unlock long-standing problems [29] [30]. And set theorists even **"invented two new types of infinity"** – exotic sizes of infinity with unexpected properties [31]. This last development highlights that even the very fundamentals of mathematics (like the nature of infinity) are not fully settled; new conceptual entities can be consistently defined, expanding the "universe" of math [32] [31].

For our theory, these mathematical milestones carry a few implications. First, the success of rigorous proofs connecting different scales or structures (as in the fluid dynamics proof, or the appearance of fractals in quantum problems) shows that **achieving coherence in theoretical frameworks is possible** and valued. It validates the effort to seek unifying formalisms that span multiple domains – exactly what CCFT (Classical Coherence Field Theory) attempts by bridging microphysical foundations to emergent continuum behavior. Second, the creation of new infinities and solutions to century-old puzzles suggests that mathematics is flexible and growing; analogously, *physical theory may also have room for new fundamental quantities or laws*. Just as mathematicians extended the hierarchy of infinities or found a new aperiodic tile (the "einstein" monotile) that can cover a plane without repeating [33], physics might accommodate a new foundational concept like coherence. The notion of an "invisible equation" underlying reality was poetically mentioned in Scientific American [34], expressing that some hidden mathematical structure ties together the facets of our world. This resonates with our pursuit of a coherence principle – essentially an underlying rule or equation that produces the observed order in nature. In short, the year's math breakthroughs deepen the conviction that **reality has a logical, even beautiful, mathematical underpinning** and encourage us that formulating coherence in precise mathematical terms (as we do in CCFT) is the right approach.

AI and the Future of Scientific Discovery

2025 was also a year where **artificial intelligence intersected with scientific research** in remarkable ways. Physicist Mario Krenn demonstrated how AI algorithms can act as "artificial scientists," autonomously proposing creative experiments and solutions. In fact, Quanta Magazine reported that advanced computers *"have a knack for concocting bizarre physics experiments — designs that humans wouldn't think of — which nevertheless work."* [35] For example, AI systems have been used to design new quantum optics experiments and suggest novel hypotheses, effectively expanding the scientist's toolkit. This shows that **machine learning can detect patterns and coherences in data or theory spaces that might elude human intuition**, potentially accelerating discoveries in complex fields.

However, along with these positives, we also saw challenges: AI-generated content began to flood preprint servers with convincing-looking but nonsensical papers, straining the filters of platforms like arXiv [36] [37]. This reminded the community that while AI is powerful, it requires careful oversight and validation. The implication for our theory and research is twofold. On one hand, we can leverage AI and computational algorithms to explore the vast parameter space of coherence field theory – for instance, to find stable solutions of our equations or to identify hidden structures in simulation data. AI might help in discovering regimes where coherence emerges or suggesting links between our framework and observable phenomena. On the other hand, we must maintain rigor, ensuring that any AI-produced results in support of CCFT are thoroughly vetted and not "hallucinations" of a model. The marriage of AI and science in 2025 ultimately points to a more **cooperative future between human insight and machine pattern-finding**, which could greatly benefit an ambitious, complex theory like ours. By embracing these tools wisely, we might uncover deeper coherences or simplify our models in ways we alone would not have considered.

Implications for Coherence Theory (CCFT)

Bringing all these threads together, the developments of 2025 strongly reinforce the trajectory and philosophy of **Classical Coherence Field Theory (CCFT)** – our proposal that coherence is a fundamental principle or "force" in the universe. CCFT posits that beyond the four known forces, there is a unifying tendency for systems to self-organize, maintain structured order, and exhibit coherence across scales. The year's breakthroughs provide both conceptual validation and new material to refine this theory:

- **Multiscale Unification Achieved:** The solution of Hilbert's sixth problem for fluid dynamics is a concrete example of the kind of multilevel coherence that CCFT aspires to explain. In CCFT, we envision a unified classical field framework linking micro-level physics to macro-level phenomena. The fluid unification result shows this is achievable – microscopic laws (molecular collisions) were shown to logically produce macroscopic equations (fluid flow) [1]. It strengthens our confidence that a single theoretical structure can encompass multiple scales without internal contradiction. CCFT's mathematical formulation (as outlined in our papers) similarly strives to derive large-scale coherent behavior (e.g. wave phenomena, patterns) from microphysical assumptions. Seeing the fluid case succeed suggests we should examine CCFT for analogous derivations: can we rigorously show how a coherence force at small scales yields emergent classical fields at larger scales? This is a direction for updated work, inspired by the methods used in the fluids proof (e.g. taking certain limits and controlling long-time behavior) [2] [38].

- **Geometric and Unified Languages:** The emergence of positive geometry as a cross-domain framework [7] hints that formulating physics in terms of geometry and information could be very fruitful. CCFT already introduces novel mathematical constructs (like coherence functionals and penalties) to encode order in fields. We might explore whether these have an interpretation in a geometric or information-theoretic language. For instance, is there a "coherence geometry" underpinning our field equations, akin to how the amplituhedron underpins particle amplitudes? The **unifying role of positive geometry** also encourages us to think of coherence in terms of constraints that hold universally (from quantum interactions to cosmic correlations). Perhaps the **coherence principle can be cast as an optimization or extremal principle** on a geometric object, which would naturally unify different physical contexts. This is speculative, but the lesson from 2025 is that abstract math can reveal unity in physics – a lesson CCFT should take to heart in its ongoing development.

- **Coherence in Novel Regimes:** The discovery of a stable superfluid in a non-Hermitian system [8] [10] is a striking case where coherence (superfluid order) appears under conditions previously thought unfavorable (i.e. with particle losses). For CCFT, which asserts coherence is a fundamental driving force, this is a satisfying piece of evidence: it shows the **universe finding ways to preserve or create order even in open, dissipative environments**. It prompts us to incorporate open-system dynamics into coherence theory. Our current framework has been largely developed for conservative (closed) systems (e.g. a Lagrangian formalism with a coherence-regularizing term). The *updated CCFT* might need to account for dissipative or non-Hermitian effects – perhaps by extending the theory to non-equilibrium situations or including terms that represent "coherence influx/outflux." The reward would be a theory that can explain phenomena like the exceptional superfluid: why adding a bit of chaos (asymmetry, loss) can paradoxically lead to a new stable order. In essence, the lesson is to **broaden the scope of CCFT to include coherent structures in non-ideal environments**, underlining that coherence can be resilient and emergent even amid entropy.

- **Complexity as Evidence of a Coherence Principle:** Hazen and Wong's proposal that complexity (functional information) inexorably increases provides a narrative and quantitative angle that CCFT can draw upon [23]. If we interpret "coherence" in our theory as a form of functional organization, then their empirical observations (minerals evolving greater complexity, etc.) serve as real-world data points suggesting a coherence-driving mechanism at work in nature. We should attempt to connect CCFT's abstract constructs to measurable quantities like functional information. For example, does the coherence term in our Lagrangian correspond to maximizing some information metric or complexity measure? If so, CCFT could provide the theoretical underpinning for why "information is a vital parameter of the cosmos" [24] – because a coherence field drives physical systems toward states of higher functional information (order that performs work or functions). Additionally, Hazen and Wong faced criticism about testability [26]; CCFT should heed that by clearly outlining how a "coherence force" could be detected or measured (perhaps in controlled experiments showing spontaneous pattern formation, or deviations from entropy-alone predictions in complex systems). The growing acceptance of ideas like an "arrow of complexity" helps legitimize our theory's core premise. It tells us that **scientists are actively seeking laws beyond traditional physics to explain organized complexity**, and CCFT aims to be exactly such a law focused on coherence.

- **Mathematical Rigor and New Concepts:** The fact that mathematicians could introduce new infinities and solve old conjectures in 2025 encourages us to be rigorous but also bold in defining new concepts. CCFT introduces a new fundamental field/property (coherence) – this is akin to introducing a new element into the equations of nature. We should ensure our definitions (e.g. coherence density, coherence pressure, etc.) are mathematically consistent and, where possible, connect to known mathematics (just as the notion of different infinities builds on set theory). The successes of 2025 suggest that even if our theory includes unconventional terms (like a "coherence penalty" in a Lagrangian [39] [40]), it can find acceptance if it yields verifiable results and meshes with mathematical logic. The "invisible equation" metaphor from SciAm [34] is inspiring – it implies that underneath the complexity of the world, there might be a single unifying mathematical statement. Perhaps CCFT's ultimate form is a candidate for that *invisible equation*, one that reproduces the known laws as a special case of a more general coherence principle. Moving forward, our task is to sharpen CCFT's equations and solutions so that this claim can be made – and supported – with the same confidence as other big mathematical results.

- **Embracing Computational Tools:** Finally, the rise of AI in research suggests CCFT's development can be accelerated by computational experimentation. We already use simulations to study our nonlinear field equations; we can augment this with machine learning to search for patterns (e.g. hidden symmetries, conservation laws, or optimal parameters for coherence). The key is to maintain scientific rigor: use AI to generate conjectures or candidates, but then prove or derive them analytically. By doing so, we tap into the best of both worlds – human intuition and machine brute-force – to explore the vast design space of a new theory. The cautionary tales of AI-generated fake proofs [36] remind us to keep a tight logical leash on any results. Nonetheless, **computational assistance could help find experimental signatures of coherence** (perhaps suggesting specific experiments in fluid dynamics, optics, or condensed matter where a coherence force would make a measurable difference). This will be crucial in making CCFT a testable science, not just a theoretical curiosity.

In general, *all* of the developments above point toward a scientific paradigm that is increasingly aligned with what CCFT proposes: that there are unifying principles and patterns connecting all domains of physics and mathematics, and that **coherence/complexity is as fundamental to the universe's story as entropy and forces**. Our theory receives encouragement that such ideas are no longer fringe – they are being discussed in Scientific American, Quanta, and top journals. The task now is to integrate these insights into CCFT's framework. Concretely, we will update our CCFT models to incorporate the latest math (for greater rigor in bridging scales), consider new terms or analogies (inspired by the positive geometries and information metrics) and outline clearer predictions (taking cues from where coherence might visibly manifest, like the exceptional superfluid or evolutionary complexity trends). By doing so, we aim to position CCFT at the forefront of this emerging movement in science – one that sees **nature's coherence as a lawful, explicable phenomenon**. In the words of Scientific American's year-end reflection, *"an invisible equation seems to undergird every facet of reality"* [34] – with our continued work, we hope to reveal that equation, and we suspect it has **coherence** at its core.

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