5° CONVEGNO INTERNAZIONALE E INTERDISCIPLINARE SU IMMAGINI E IMMAGINAZIONE
5th INTERNATIONAL AND INTERDISCIPLINARY CONFERENCE ON IMAGES AND IMAGINATION

IMG2025

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IMG2025 IMAGE ETHICS

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a cura di / edited by
Valeria Menchetelli
Francesco Cotana
Eleonora Dottorini

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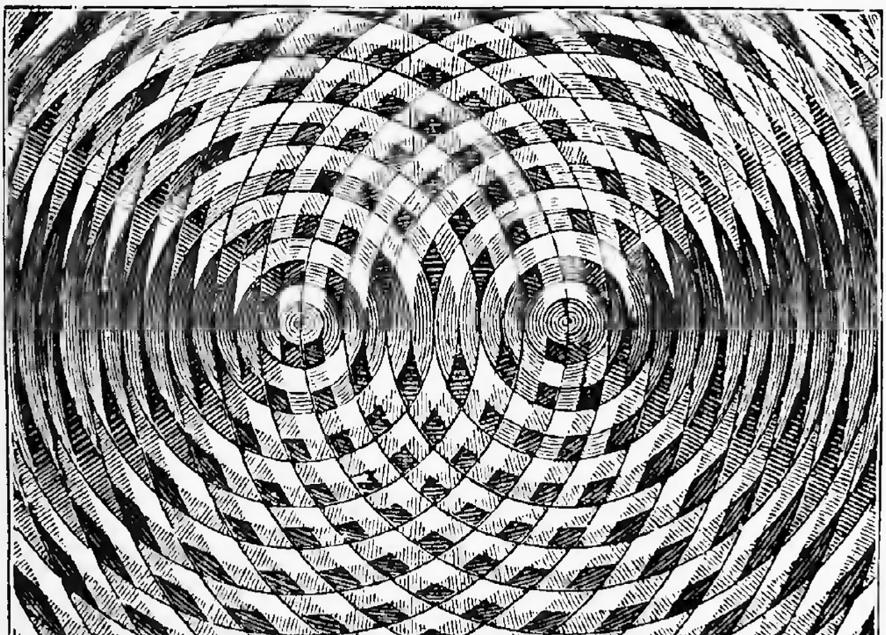
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DANIELE VILLA

Entangled Visions: Quantum Imaging and the Horizons of Scientific Pareidolia

Abstract
This paper explores the epistemological and cultural implications of quantum entanglement imaging, highlighting the risks of scientific pareidolia. Examining the visual analogy between entangled particles and the Yin-Yang symbol interrogates the interplay between scientific visualization and cultural symbolism, underscoring the need for critical reflection and precise interpretation in the visual culture of quantum science.

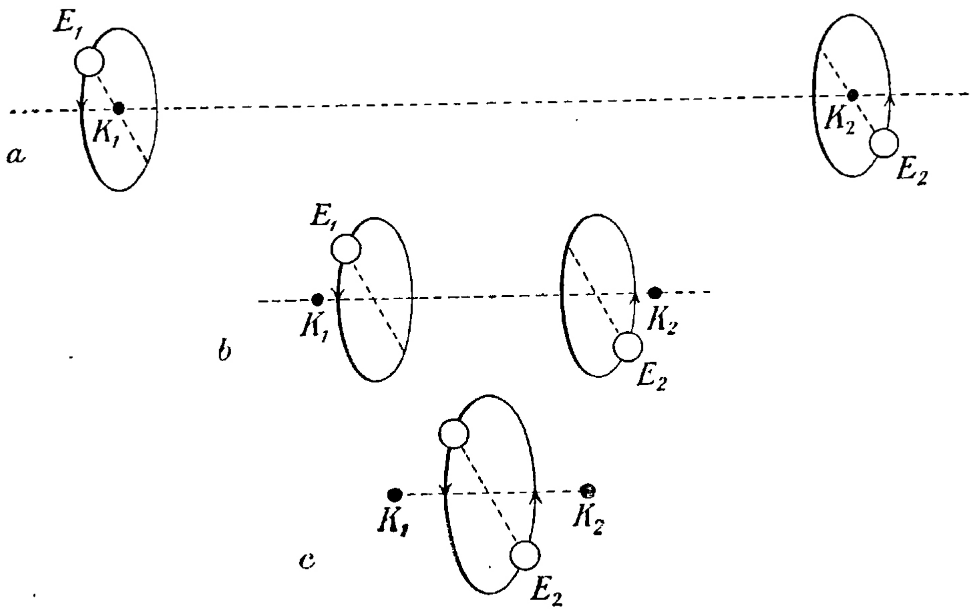
Keywords
quantum imaging, entanglement, visual science studies

Quantum entanglement stands as one of the most profound and counterintuitive phenomena to emerge from twentieth-century physics, posing a fundamental challenge to classical notions of locality, causality, and representation. At its core, entanglement describes a state where two or more particles become interconnected so that their physical properties, when measured, reveal correlations irrespective of spatial separation, defying classical intuition and generating substantial epistemological debate. This remarkable characteristic was first critically explored by Schrödinger in 1935, who identified it as "the essence of quantum mechanics" due to its fundamental departure from classical descriptive frameworks (Caponigro et al., 2010; Zia et al., 2023). What renders quantum entanglement so profoundly fascinating from an epistemological perspective is not merely its resistance to conventional paradigms of scientific visualization, but its deep, structural challenge to the foundations of conventional logic and common-sense reasoning. Unlike classical physical systems, where the properties and states of objects are defined locally and independently, entangled quantum systems defy such separability: the measurement outcome of one particle instantaneously influences the state of its entangled partner, regardless of the spatial distance between them. This phenomenon, famously described by Einstein as "spooky action at a distance", does not simply stretch our habitual categories of pictorial or diagrammatic representation; it fundamentally unsettles the classical intuition that causality and information transmission must be local and temporally ordered. The entanglement exposes the inadequacy of classical conceptual and visual schemes for capturing quantum reality, demanding instead a new regime of visualization that can accommodate nonlocal correlations and holistic properties that cannot be reduced to the sum of their parts, as Caponigro and colleagues (note: "Quantum mechanics exhibits non-locality when it remains contextual even in this spatially separated setting. The phenomenon of quantum entanglement is among the most counterintuitive concepts in quantum mechanics", Caponigro et al., 2010). In contrast to classical mechanics, where visual representations can typically function as straightforward, intuitive analogues of physical reality, quantum mechanics demands a far more intricate and mediated relationship between visualization and the phenomena it seeks to describe. In the quantum domain, images and diagrams are not mere windows onto an underlying reality but conceptual constructs that mediate, translate, and often abstract the profoundly non-intuitive nature of quantum processes.

This dynamic finds a compelling analogue in astronomy, where researchers continually confront phenomena that fundamentally elude direct sensory access. Astronomers have developed and refined a repertoire of advanced visual strategies and representational techniques that translate these otherwise imperceptible processes into forms amenable to human perception. By deploying such sophisticated visual methodologies, ranging from composite imaging to the manipulation of spectral data, astronomy exemplifies how scientific inquiry can bridge the gap between the inherent inaccessibility of its objects and the cognitive faculties of its observers, rendering the invisible open to interpretation and further analysis.

Cover
Kramers, H.A. & Holst, H. (1923). *The Atom and the Bohr Theory of its Structure*. Gyldendal. Fig. 6. Schematic representation of an interference.

Fig. 1
Early representation of the formation of a hydrogen molecule, Bohr, 1913 (Kramers & Holst, 1922, p. 181).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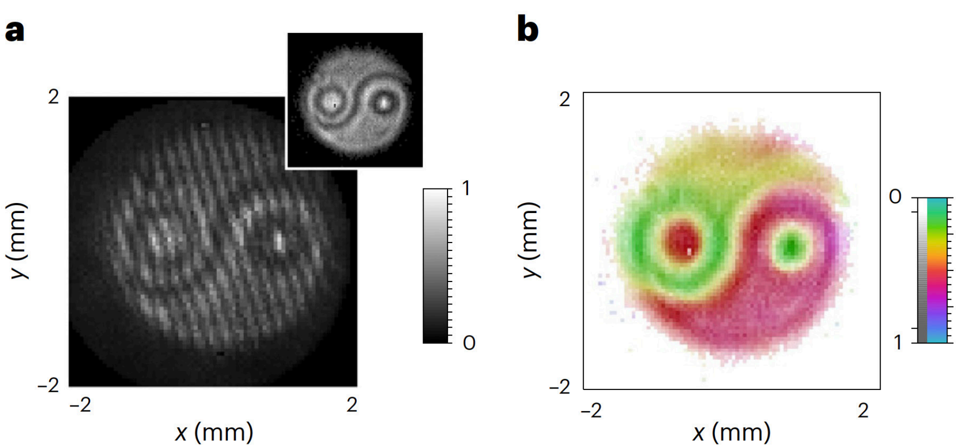
For instance, the visualization of black holes (Fig. 1) entails the assignment of false colors, the integration of data from multiple sources, and the use of algorithmic reconstructions, all aimed at rendering phenomena that are intrinsically invisible to both the naked eye and conventional optical instruments perceptible. Both quantum physics and astronomy demonstrate that scientific visualization is not merely a matter of 'seeing', but rather an act of constructing meaning through carefully mediated and often highly conventionalized visual codifications. These strategies are shaped as much by the epistemological limits of observation as by the creative imperative to render the unseeable thinkable.

This issue becomes evident even in the well-established visual model of the Bohr atom, popularly depicted as a miniature solar system (Fig. 2). While intuitive, such a depiction constitutes an ambiguous simplification, since the atomic structure is highly complex and less suitable for simplified visual modeling. Instead, it possesses a probabilistic and partially statistical nature, where electrons occupy quantized energy levels defined by probability densities rather than fixed trajectories. Thus, while culturally entrenched, the solar-system-like representation misrepresents the fundamentally probabilistic and indeterminate nature of atomic-scale phenomena. This inclination to translate intricate subatomic phenomena into intuitive, frequently misleading, visual metaphors highlights a broader challenge in visualizing scientific concepts. Galison's reflections on scientific visualization underline this complexity by demonstrating how visual culture within scientific practices functions as a static medium for conveying results and actively shapes scientific knowledge and interpretation (Galison, 2014). Galison's insight into "visual science studies" posits that images in science are not merely representational devices but serve as epistemic instruments that profoundly influence scientific knowledge production, dissemination, and conceptualization (Galison, 2014). When considering quantum entanglement, the epistemic transition becomes increasingly evident: scientific images no longer function as direct operational models that mirror observable reality but as inferential representations mediating our access to phenomena that are fundamentally inaccessible to classical intuition. The dynamic interplay among scientific visualization, cognitive perception, and cultural representation underpins much of the epistemological and interpretive work within the hard sciences. This profound interconnection becomes particularly evident in the parallel trajectories along which scientific inquiry strives to render visible both the infinitely small, manifest in the exploration of atomic and subatomic realms, and the infinitely vast, as revealed through astronomical investigation and the study of singular celestial bodies. In both directions, the practices of visualization and interpretation are shaped by the converging demands of scientific rigor, cognitive perception, and culturally embedded ways of making sense of the unseen. The drive to visualize quantum entanglement, whether as a strategy for conceptually clarifying the phenomenon or as an effort to render the entangled state of two particles perceptible to human experience, extends far beyond its purely technical origins. It acquires broader significance as these visualizations

Fig. 2
Image of Supermassive black hole M87 generated from data gathered by the Event Horizon Telescope (EHT), 2017 (Galison & Kessler, 2019, p. 75).

Fig. 3
Image reconstruction.
a. Combined image showing the interference between a reference state and a state shaped like a Yin-Yang symbol;
b. Reconstructed amplitude and phase structure of the image imprinted on the unknown pump (Zia et al., 2023, fig. 6).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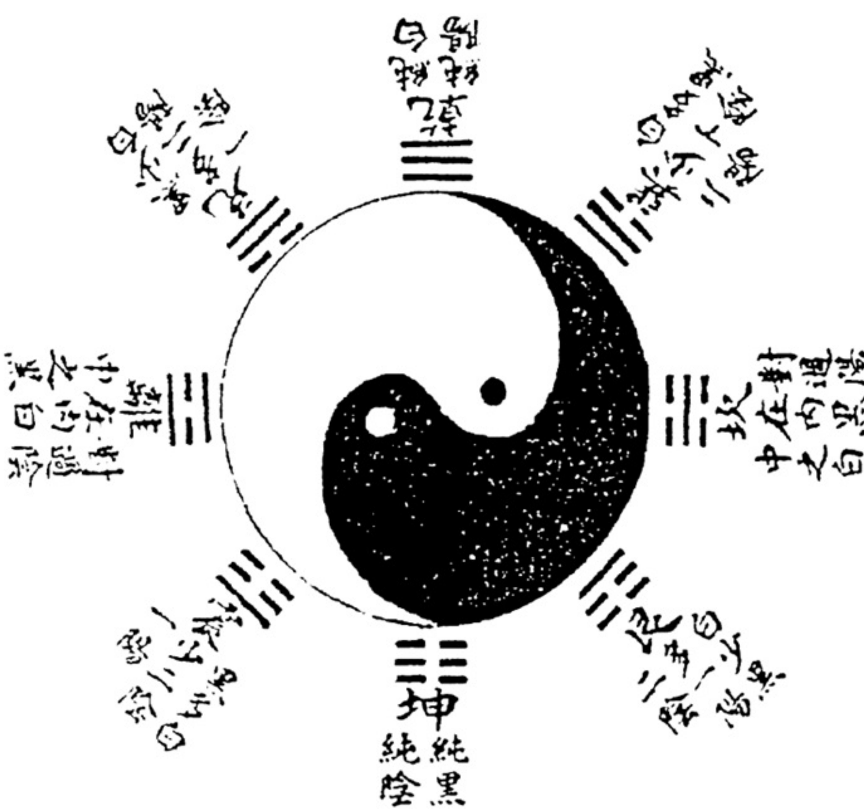
are refracted through the interpretive lenses of human perception, imbued with metaphorical meanings, and integrated into the broader narratives and imaginaries that shape our understanding of scientific reality.

Innovations in quantum imaging techniques have opened unprecedented pathways for visualizing quantum entanglement, providing empirical substance to previously abstract theoretical constructs. Unlike conventional photography, which directly records an optical impression on photosensitive media, quantum imaging techniques such as interferometric imaging and quantum holography rely on complex inferential procedures to reconstruct visual representations from quantum states.

Within this area of research, the experimental work culminating in the article *Interferometric imaging of amplitude and phase of spatial biphoton states* (Zia et al., 2023), published in *Nature Photonics*, represents a noteworthy contribution. The authors detail the generation and characterization of spatial biphoton states through advanced interferometric techniques, emphasizing the profound conceptual divergence that quantum imaging represents in contrast to classical visual methodologies. Their work introduces novel approaches to imaging quantum states (Fig. 3) and highlights the fundamental differences in how quantum and classical systems must be visualized and understood. These advanced approaches employ the intrinsic correlation properties of entangled photons, reconstructing spatial information from intricate interference patterns rather than straightforward optical paths. Unlike classical optical imaging, quantum visualizations cannot simply be interpreted as direct representations of external realities. Instead, they manifest as interpretative constructs shaped profoundly by theoretical frameworks and computational processing algorithms. This interpretative dependency introduces a new layer of epistemic uncertainty and critical reflection into the practice of scientific visualization, raising compelling questions, not only about the nature of observation and the role of theoretical models in defining what can be visually apprehended as real, but also about the ethical responsibilities inherent in constructing and communicating quantum images. The images generated through these techniques are not passive records but active constructions embedded within specific theoretical, computational, and ethical frameworks. This realization aligns with Galison's broader argument regarding scientific visualization as an active, critical, and analytical practice, suggesting that quantum images are both shaped by and shape the theoretical landscape in which quantum mechanics operates. However, despite the study's indisputable scientific merit, it also produced an entirely unforeseen side effect that offers valuable insight into our cultural engagement with scientific imagery. Specifically, the authors' deliberate, albeit methodologically arbitrary, decision to utilize a Yin-Yang-shaped template as a test image for their quantum holography technique inadvertently gave rise to a cascade of misunderstandings. While these may appear trivial at first glance, they reveal much about the interpretative frameworks through which scientific images circulate. It is crucial to underscore that the emergence of a Yin-Yang-shaped figure among the experimental results was not a serendipitous discovery but a direct consequence of the initial template choice. The

Fig. 4
The Taiji Diagram of the Heart of the Changes as Mysteriously Revealed by Fuxi, from Lai Zhide, Yijing Laizhu Tujie (1688), (Leong, 2023, p. 32).

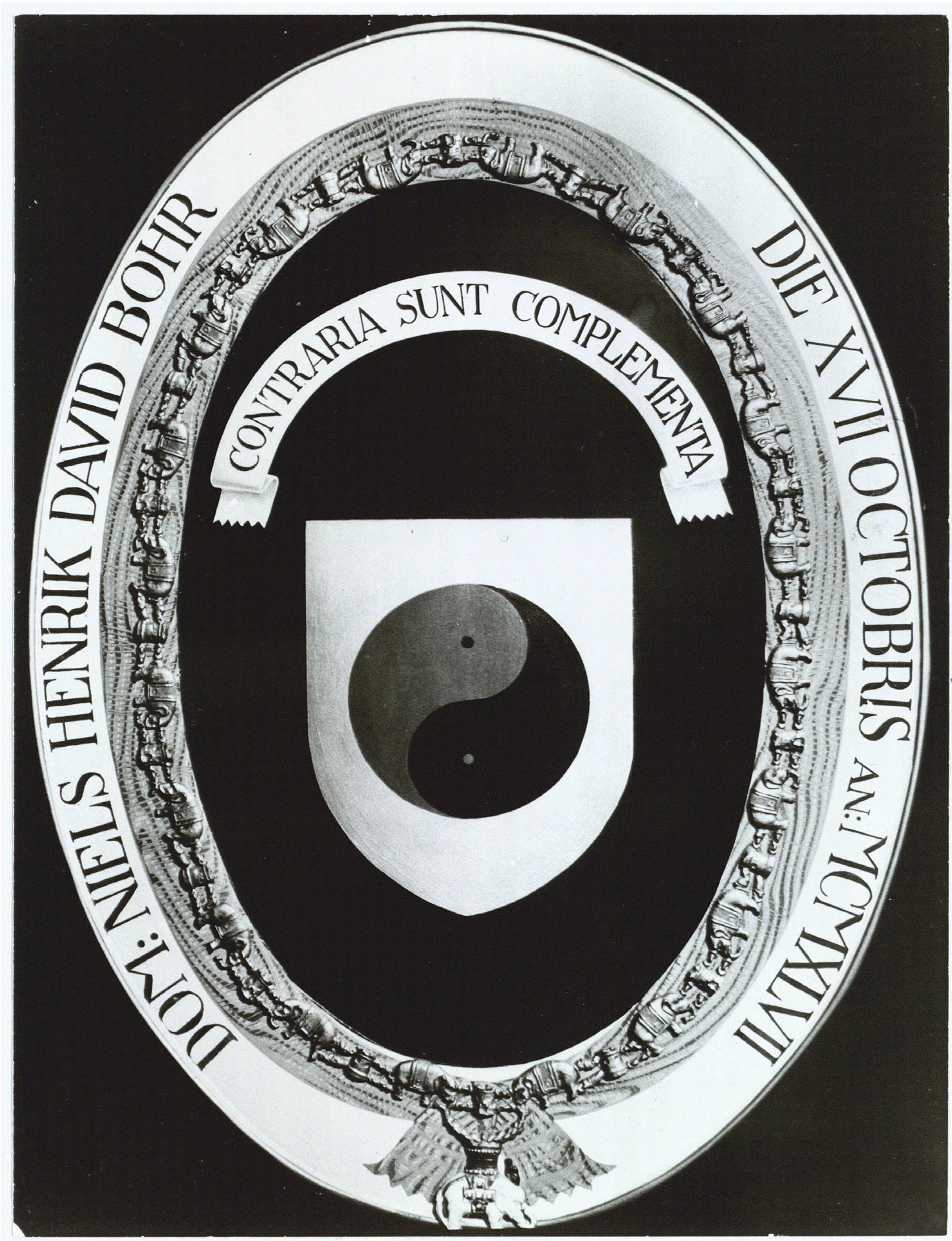
心易發微伏羲太極之圖



正南純陽方也故畫為乾正北純陰方也故畫為坤畫離于東象陽中有陰也畫坎于西象陰中有陽也東北陽生陰下于是乎畫震西南陰生陽下于是乎畫巽觀陽長陰消是以畫兌于東南觀陰盛陽微是以畫艮于西北也

experiment was never intended to 'reveal' a pre-existing, yin-yang-like structure within the spatial configuration of entangled particles. Instead, its primary objective was to demonstrate the robustness and precision of a novel detection and reconstruction method in quantum imaging. In other words, the appearance of the Yin-Yang symbol (Fig. 4) was entirely determined by the researchers' explicit decision to imprint that shape onto the quantum system under investigation.
Nevertheless, this detail was frequently overlooked or misrepresented in subsequent media reports, both in the popular press and even in some scientific outlets. Many accounts presented the experiment as though it had yielded a 'quantum yin-yang' that depicts two photons becoming entangled in real time, drawing particular attention to the striking visual similarity with the ancient Yin-Yang symbol. In doing so, these narratives helped reinforce a sense of quasi-mystical convergence between contemporary quantum physics and the cosmological principles of classical Chinese thought. This enthusiastic and rhetorically charged, but ultimately misleading, coverage calls for a critical reflection on how scientific images can accumulate layers of cultural and symbolic meaning that diverge significantly from their original technical context. It also highlights the necessity for rigorous interpretation and precise communication within the visual culture of science. As Ciann-Dong Yang discusses in depth (Yang, 2024), the connections between the ancient Yin-Yang symbol and contemporary physics are complex and varied. One especially revealing instance is Niels Bohr's decision to feature the classical diagram of complementarity on his personal coat of arms, a choice prompted by his investiture as a Knight of the Order of the Elephant by the King of Denmark in 1947 (Fig. 5). Moreover, it is important to recognize that the Yin-Yang symbol possesses significant semantic and theoretical affinities with various foundational aspects of quantum mechanics. At its core, the symbol embodies essential Taoist notions of duality, complementarity, interconnectedness, and mutual definition, which resonate strongly with the ontological frameworks of modern particle physics. Both traditions fundamentally question reductionist models of reality, positing that existence is constituted by inseparable relationships rather than isolated, independently definable entities. Bohr's principle of complementarity, which stands at the very core of quantum theory, finds a close conceptual parallel in Taoist thought by stressing the necessary coexistence of apparently contradictory conditions. In this sense, the visual motif of the Yin-Yang serves as a visual metaphor for dynamic equilibrium and simultaneous contradiction, mirroring the way quantum entanglement, in our specific case, manifests as complementary physical states that persist in superposed potentiality until measurement brings forth their definite properties. This rich, multilayered cultural milieu, which connects two seemingly disparate worlds, is fundamentally distinct from the straightforward assertion that the image of two entangled particles resembles the form of the Yin-Yang symbol. Restating this distinction enables us to highlight a subtle but crucial issue that frequently goes unaddressed: any process of visual representation, even in the scientific realm, inevitably involves the latent risk of pareidolia, that is, the

Fig. 5
Professor Niels Bohr's Coat of Arms at Frederiksborg Castle Chapel, Hillerød by Nordisk Pressefoto - The Royal Library: The National Library of Denmark and Copenhagen University Library, Denmark - CC BY-NC-ND.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inclination to discern or impose recognizable forms upon random or dissimilar patterns.
This phenomenon, which could be described as a peculiar kind of 'scientific pareidolia', underscores how visual cognition is predisposed to project significance and structure onto inherently ambiguous or indeterminate data. Such an epistemological intersection invites deeper reflection on the reciprocal influences between cultural symbolism and scientific visualization. It compels scholars to consider whether these analogical resonances are merely coincidental or indicative of deeper cognitive structures guiding human attempts to make sense of complex realities. As Galison and Neumüller (2023) emphasize, visual analogies often reveal subconscious cognitive frameworks underpinning scientific reasoning, suggesting that the human mind inherently seeks patterns of relational coherence that transcend disciplinary boundaries. However, analogies between philosophical symbols and scientific phenomena are not without epistemic and ethical risks. While analogies facilitate understanding, they also risk imposing interpretative biases, potentially obscuring or simplifying the nuanced complexities inherent in quantum phenomena. This proposed framework is intentionally left open-ended, recognizing the existence of unresolved questions, uncertainties, and persistent epistemological tensions. How can visual representations of intrinsically non-classical phenomena maintain conceptual rigor while remaining accessible and meaningful to broader audiences? Furthermore, what do scientists and communicators face regarding limits and ethical responsibilities as they navigate the interpretative ambiguities inherent in visualizing quantum phenomena?

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