

Disorder Has an Optimal Sweet Spot

Not too weak, not too strong—just right for quantum design.

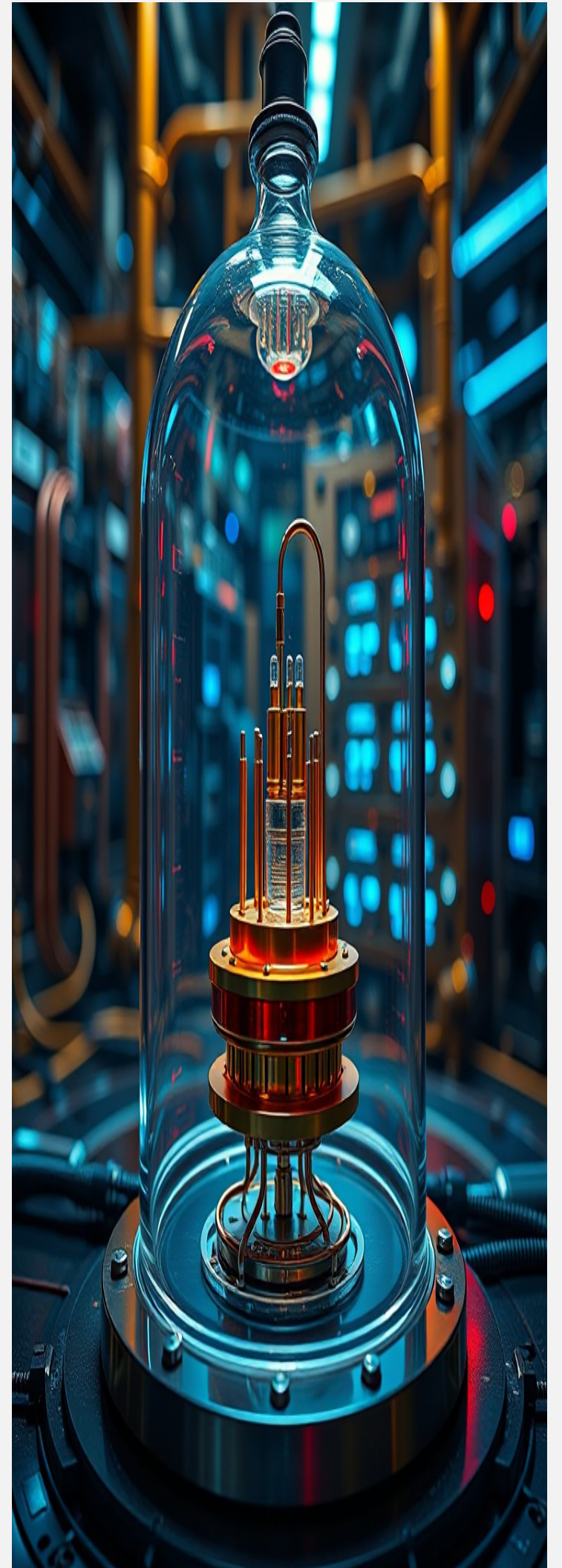
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$$\sigma_c \sim J_{xy}$$

Optimal Disorder Strength

The crossover point where quantum dynamics balance randomness and localization.

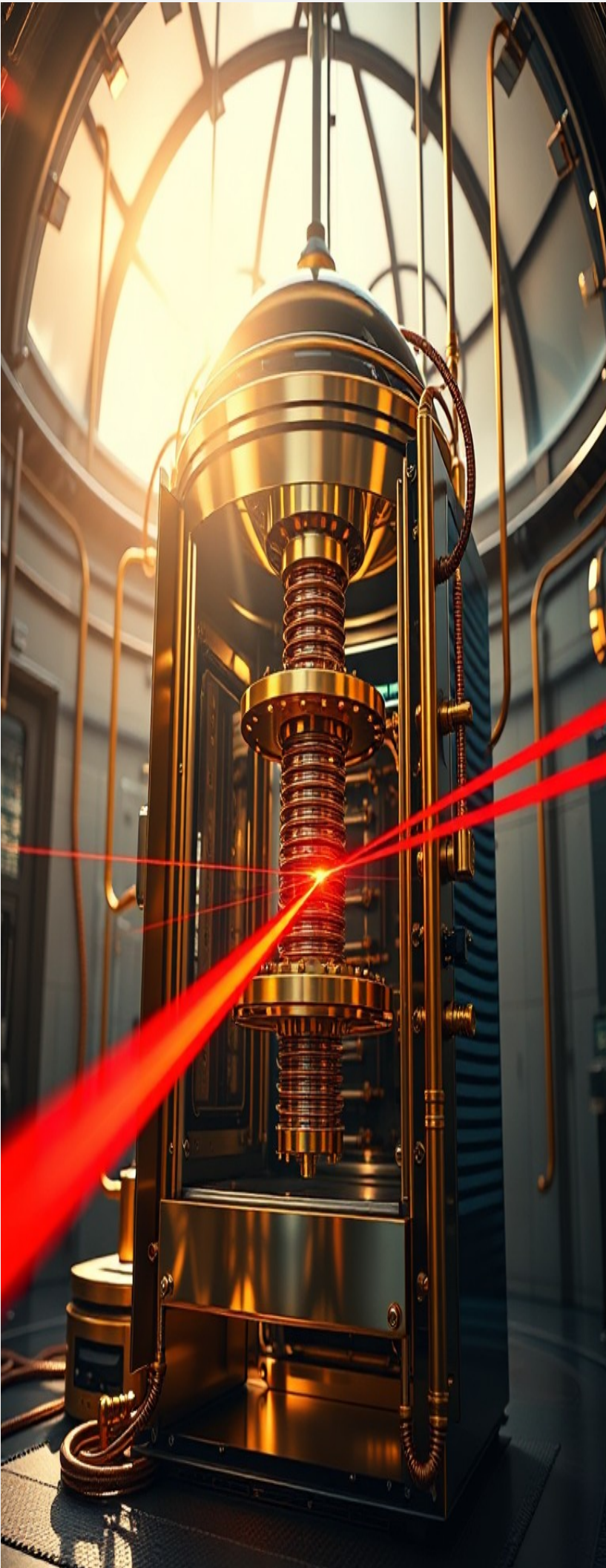
This study identifies $\sigma_c \sim J_{xy}$ as the precise disorder strength that maximizes the fidelity of approximate unitary k-designs in spin chains. It resolves a long-standing empirical challenge by showing that intermediate disorder—not extreme—optimizes quantum simulation performance. The result emerges from a perturbative theory of the moment gap Δ^k , which non-monotonically scales with disorder strength.



01

Localization Blocks Both Thermalization and Design

The paper reveals a unified mechanism: strong disorder suppresses both thermalization and the formation of unitary k -designs through dynamical localization. This implies that quantum simulators cannot rely on strong disorder to achieve randomness—doing so collapses the system into the computational basis. The optimal regime lies in a delicate balance where entanglement and scrambling are preserved without localization-induced freezing.



02

Quenches Exponentially Suppress Design Error

A multi-quench protocol is shown to suppress the moment gap Δ^k exponentially with the number of quenches. This is a critical insight for scalable quantum algorithms: error mitigation can be engineered through protocol design rather than hardware refinement. It suggests that classical control sequences—when properly timed—can enhance quantum coherence and design fidelity in noisy, disordered systems.

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