

# Cat states in the many-body localized phase

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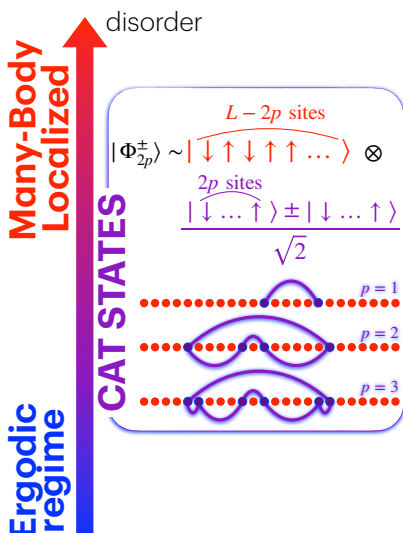
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After two decades of intense study and debate, many-body localization (MBL) continues to challenge our understanding of out-of-equilibrium quantum matter. In this talk we will discuss a very recent work [1], where we identified atypical long-range-entangled eigenstates in the strong-disorder regime of the paradigmatic random-field Heisenberg chain, a model often regarded as the “*Drosophila*” of MBL. These high-energy eigenstates appear as nearly degenerate pairs of cat states—coherent superpositions of distant spin configurations—and exhibit system-wide  $O(1)$  correlations and entanglement. Remarkably, such atypical eigenstates persist even at very strong disorder, where conventional diagnostics point to robust localization. Our findings provide new insight into the MBL problem and reopen fundamental questions about the mechanisms that may ultimately destabilize the MBL phase. Experimental consequences for out-of-equilibrium dynamics [2] and quasi-periodic potentials [3] will also be discussed.

## References

1. N. Laflorencie, J. Colbois, F. Alet, Phys. Rev. B **112**, 224207(2025).
2. A. Haldar, T. Scoquart, F. Alet, N. Laflorencie, arXiv:260105177.
3. A. Padhan, J. Colbois, F. Alet, N. Laflorencie, arXiv:251024704.



**Figure 1:** The ergodic-to-MBL phase diagram is reshaped by the presence of a newly identified family of long-range resonant pairs of cat states, unexpectedly emerging as mid-spectrum eigenstates of standard disordered spin-chain models.