Criticality as a Resource for quantum devices:
Topological Protection, Supersymmetry, and Quantum-Enhanced Sensing

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Abstract: We show how criticality can be exploited in quantum devices to induce novel phenomena including topological protection against noise, a concrete realization of supersymmetry, and a significant quantum enhancement for parameter estimation.

Criticality enables profound changes in the accessible states of a quantum system, thereby providing a powerful resource for the emergence of unconventional phenomena in quantum technologies. In this talk, I will show how novel quantum devices with spontaneous symmetry breaking can be engineered to exhibit intrinsic topological protection against noise and losses, to concretely realize supersymmetry, and to achieve also significant enhancements in parameter estimation.

A paradigmatic realization of such devices is provided by twisted cuprate Josephson junctions, where the d-wave nature of the order parameter induces a transition from a conventional single-well to a symmetric double-well effective potential. In the double-well regime, the quantum tunnelling between symmetry-related configurations enables the encoding of a novel qubit in quasi-degenerate states, called "flowermon", where decoherence is strongly suppressed due to topological protection [1].

When two twisted junctions are integrated into a SQuiD, the external magnetic flux gives rise to a high degree of tunability yielding a rich phase diagram (Fig. 1) which hosts a supersymmetric point in the spectrum. The realization of supersymmetry induces sharp modifications in the device decoherence mechanisms [2].

An external magnetic flux can also be used to induce two-photon generation processes and realize devices known as parametric quantum resonators. These devices can be driven from a low-excitation regime into a highly populated, spontaneously symmetry-broken phase governed by nonlinearities. Near the critical point, small parameter variations induce large changes in the system state, such that arrays of resonators function as highly responsive quantum sensors [3].. This enhanced sensitivity can be quantified by the Quantum Fisher Information, which, in the presence of nearest-neighbour interactions, exhibits Heisenberg scaling with respect to all relevant resources, including the size of the system (Fig. 2).

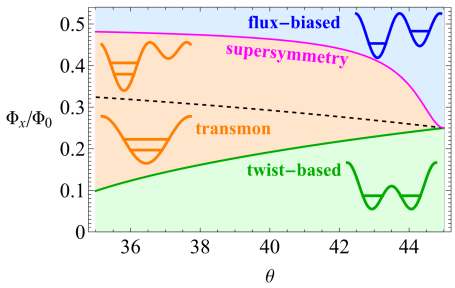

Fig. 1 The phase diagram of two twisted junctions are integrated into a SQuiD (θ is the twisting angle and Φ the magnetic

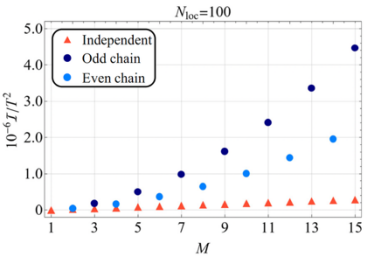

Fig. 2 The quadratic Heisenberg scaling of the Quantum Fisher Information w.r.t of the number M of the resonators of the array.

References

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[2] A. Coppo, L. Chirolli, N. Poccia, U. Vool, and V. Brosco "Flux-tunable regimes and supersymmetry in twisted cuprate heterostructures" Appl. Phys. Lett. **125**, 054001 (2024).

[3] U. Alushi, A. Coppo, V. Brosco, R. Di Candia, and S. Felicetti "Collective quantum enhancement in critical quantum sensing" Commun. Phys. **8**, 74 (2025).

Title of the contribution

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This is a sample document format for the one-page extended abstract for submissions to the 1st annual meeting of the National Quantum Science and Technology Institute. The conference will take place in Rome, January 15th -16th, 2024.

Please be concise in your presentation, highlighting what is novel and original about your submission. Simple equations should be included in-line wherever possible, whereas more complex expressions should be centred and numbered if there are several. Figures should be relevant to the submission and preferably centred as shown below. They should be placed as close as possible to where they are mentioned in the text. Placing subfigures side-by-side is a convenient way to include multiple results within the one-page limit. The figures can be provided in greyscale or colours. Figure captions should be centred beneath figures and in an 8-point font. Figure captions should be indented 1 cm on both sides and justified on both right and left sides.

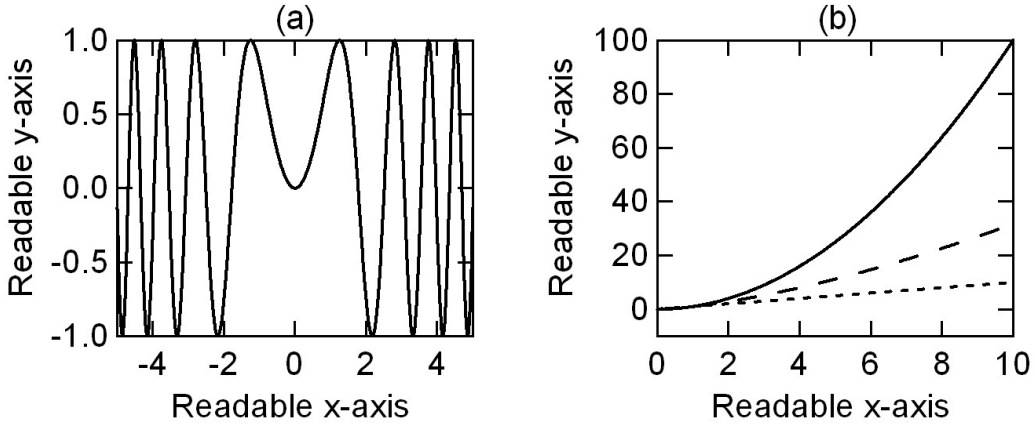

Fig. 1 The abbreviation "Fig." (for figure) should appear first, followed by the figure number, a period, and then the figure caption.

References should appear at the end of the article in the order in which they are referenced in the body of the paper. The font should be 8 points, and the references should be aligned left. A suggested format for references is given below. Within the main text, references should be designated by a number in brackets [1], and they should precede a comma or period [2]. Two references cited at once should be included together [2,3], separated by a comma, while three or more consecutive references should be indicated by the bounding numbers and a dash [1–3].

Example References

[1] J. Itatani, D. Zeidler, J. Levesque, D. M. Villeneuve, and P. B. Corkum, "Controlling High Harmonic Generation with Molecular Wave Packets," Phys. Rev. Lett. **94**, 123902 (2005). For journal articles, authors are listed first, followed by the article's full title in quotes, the journal's title abbreviation, the volume number in bold, page number, and the year in parentheses.

[2] G. P. Agrawal, *Nonlinear Fiber Optics*, 3rd. ed., (Academic Press, Boston, 2001). For citation of a book as a whole: authors, followed by title in italics, and publisher, city, and year in parenthesis.

[3] R. Kienberger and F. Krausz in, *Few-cycle laser pulse generation and its applications,* F.X. Kärtner ed. (Springer Verlag, Berlin, 2004). For citation of a book chapter, authors are listed first, followed by book title in italics, editors, and publisher, city, and year in parenthesis. Chapter number may be added if applicable.