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Quantum-limited metrology and many-body physics[1]

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Questions about quantum limits on measurement precision were once viewed from the perspective of how to reduce or avoid the effects of the quantum noise that is a consequence of the uncertainty principle. With the advent of quantum information science came a paradigm shift to proving rigorous bounds on measurement precision. These bounds have been interpreted as saying, first, that the best achievable sensitivity scales as $1/N$, where N is the number of particles one has available for a measurement and, second, that the only way to achieve this Heisenberg-limited sensitivity is to use quantum entanglement. I will review these results and discuss a new perspective based on using nonlinear quantum dynamics to improve sensitivity. Using quadratic couplings of N particles to a parameter to be estimated, one can achieve sensitivities that scale as $1/N^2$ if one uses entanglement, but even in the absence of any entanglement at any time during the measurement protocol, one can achieve a super-Heisenberg scaling of $1/N^{3/2}$. Such sensitivity scalings might be achieved in Bose-Einstein condensates or in nanomechanical resonators.

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