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Quantum Sensing - Detecting Faint and Fleeting Signals using Quantum Systems

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Our best sensors, used for fundamental physics, navigation, medical imaging, and many other applications, employ quantum systems such as atoms or photons, and use quantum interference to obtain signals that depend strongly on whatever physical variable we are trying to measure. Designing, building, and understanding such instruments is the topic of quantum sensing. Interference necessarily involves superposition states, and measuring superposition states necessarily leads to probabilistic outcomes. The statistics of quantum measurement is thus intrinsic to quantum sensing, and much effort has gone into designing strategies that minimize the resulting measurement uncertainty. Often these efforts involve entanglement, because entangled states allow for strong signals together with small uncertainties. Many important sensors moreover track the evolution of a quantum system such as a collection of atoms, as they coherently respond to a signal of interest over time. Because the act of observing necessarily disturbs a quantum system, there will be a trade-off between the precision of an observation now and the accuracy of an observation later. This "measurement back-action" (MBA) problem also involves quantum statistics, but now the statistics of monitored open quantum systems. This is a rather complex physics problem, and is far from fully solved. Nonetheless, it is known that some sensing strategies are fundamentally limited by MBA, while other strategies appear to evade MBA entirely. I will illustrate with recent experiments using squeezed and entangled states for sensing, and a high-performance magnetic sensor that avoids measurement back-action.

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