

# Correlated Noise Effects in Quantum Metrology

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## Popular Summary

In classical physics there is no fundamental limitation on precision with which we can measure physical quantities, as the character of all the measurement uncertainties is purely technical. The measurement itself is also not a central concept of the theory, as all the physical quantities of the objects involved have well defined values, and the measurements is just revealing values of these pre-existing quantities.

Quantum mechanics, with the central role of the measurement in the structure of the theory, provides a new perspective on questions regarding the fundamental limits on achievable measurement precision of physical quantities. Outcomes of elementary measurement on a single quantum system such as an atom or photon are inherently probabilistic. By applying the tools from statistical estimation theory it is possible to quantify the amount of information on a physical parameter of interest that may in principle be extracted by measuring quantum systems optimally.

An appealing example is the measurement of length using optical interferometric techniques. The information on the distance between mirrors of an interferometer is imprinted onto the states of the photons that are the fundamental constituents of light. Knowledge of the properties of photons and their behaviour, allows to compute the probabilities with which photons will be detected by a given detector, and this allows to find out the ultimate amount of information on the quantity of interest that can be extracted from observation of photons.

The field of physics that investigates the ultimate metrological potential of quantum systems and proposes practical protocols that harness this potential is called *quantum metrology*. The most spectacular example of application of quantum metrology are gravitational wave detectors, which are in fact giant optical Michelson interferometers. Tiny oscillatory movements of the mirrors (caused e.g. by a passing gravitational wave) with amplitude smaller than the size of a nucleus, modify the state light travelling through the interferometer in a measureable way. Even more surprisingly, it has been demonstrated, that sensitivity of the detectors can be further increased by utilizing the so called squeezed states of light involving entanglement between photons.

The main challenge for theoretical investigations in the field of quantum metrology is to understand the potential of quantum states of light and atoms in realistic scenarios taking into account the unavoidable sources of noise that cause unwanted decoherence of quantum states.

Most of the research carried out until now, have focused on *uncorrelated* noise models, where noise acting on different quantum particles or at different moments of evolution is completely independent. While this approach is justified in some physical scenarios, such as e.g. optical interferometry in presence of optical loss, it is not satisfactory in a number of other important situations relevant for atomic clocks stabilization, magnetic field sensing, atomic interferometry, fluctuating sources optical imaging and many others.

This project aims at deriving fundamental precision bounds and optimal protocols taking into account realistic correlated noise models. The results will play a role of a guide for the field, pointing out towards the most promising experimental direction where significant quantum enhancements may be exploited in practical measuring devices.