# Quantum Information and Quantum Computation

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### Introduction

Quantum computers and communication systems are devices that store and process information on quantum systems such as atoms, photons, superconducting systems, etc. Quantum information processing differs from classical information processing in that information is stored and processed in a way that preserves quantum coherence. The Quantum Information Group is investigating methods for constructing quantum computers and quantum communication systems using atomic physics,quantum optics, and superconducting systems. In addition, the group is investigating applications of quantum information processing including novel quantum algorithms and communication protocols.

## 1. Quantum Communication

**Sponsors**
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The problem of maintaining the coherence of quantum information as it is moved from atoms to photons, transported through space, and moved back from photons to atoms, is a difficult one. Exactly because quantum information provides additional opportunities for storing and processing information, it also provides additional opportunities for errors, loss, and the corruption of that information. We are investigating the capacities of noisy quantum channels.

We have shown how quantum channel capacity can be enhanced using entanglement. We have derived limits on the capacities of broadband quantum channels with and without entanglement assistance. Finally, we are investigating the ultimate physical limits to the accuracy of sensing and measurement.

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## 2. Superconducting Quantum Computers

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Superconducting systems present a variety of opportunities for quantum information processing. In collaboration with Delft Institute of Technology, we demonstrated the first macroscopic quantum superposition of circulating supercurrents, and have designed devices in which such systems function as quantum bits in a quantum computer. We are currently collaborating with Delft and NEC to investigate mechanisms of errors and decoherence in superconducting quantum bits and are designing experiments to demonstrate quantum logic operations, quantum algorithms and quantum entanglement using superconducting systems. We have presented novel designs for quantum computers that compute while remaining in their ground state. We have shown how adiabatic methods can be used to perform coherent quantum computation.l

## Publications

### Journal Articles Published

Zanardi, P., and S. Lloyd, `Topological Protection and Quantum Noiseless Subsystems,' Phys. Rev. Lett 90, 067902 (2003).

Gutmann, H., Wilhelm, F.K., Kaminsky, W.M., Lloyd, S., et al., `Compensation of decoherence from telegraph noise by means of an open-loop quantum-control technique,' Phys. Rev. A 71, Art. No. 020302 (2005).

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Cappellaro, P., Emerson, J., Boulant, N., Ramanathan, C., Lloyd, S., Cory, D.G., `Entanglement Assisted Metrology,' Phys. Rev. Lett. 94, 020502 (2005); quant-ph/0411128.

Giovannetti, V., Lloyd, S., Ruskai, M.B., `Conditions for the multiplicativity of maximal l_p-norms of channels for fixed integer p,' J. Math. Phys. 46, 042105 (2005); quant-ph/0408103.

Fan, H., Lloyd, S., `Entanglement of eta-pairing state with off-diagonal long-range order,' J. Phys. A 38, 5285 (2005); quant-ph/0405130.

Giovannetti, V., Maccone, L., Guha, S., Lloyd, S., et al. `Minimum output entropy of a Gaussian Bosonic channel,' Int. J. Quant. Inf. 3, 153-158 (2005).

Lloyd, S, `Almost Certain Escape from Black Holes in Final State Projection Models,' Phys. Rev. Let. 96, 061302 (2006); quant-ph/0406205.

Bennett, C.H., Harrow, A.W., Lloyd, S., `Universal quantum data compression via gentle tomography,' to appear in Physical Review A 2006; quant-ph/0403078.

Giovannetti, V., Lloyd, S., Maccone, L., `Quantum metrology,' Phys. Rev. Lett. 96, 010401 (2006); quant-ph/0509179.

Lloyd, S., `Decoherent histories and generalized measurements,' to appear in Phys. Rev. A 2006; quant-ph/0504155.

**Journal Articles, Submitted for Publication**

Kaminsky, W.M., Lloyd, S., Orlando, T.P. `Scalable superconducting architecture for adiabatic quantum computation,' submitted to Phys. Rev. Lett., quant-ph/0403090.

Lloyd, S., `A theory of quantum gravity based on quantum computation,' submitted to Phys. Rev. A, quant-ph/0501135.

Pirandola, S., Vitali, D., Tombesi, P., Lloyd, S., `Macroscopic entanglement by entanglement swapping,' submitted to Phys. Rev. Lett.; quant-ph/0509119.

Lloyd, S., `Quantum limits to the measurement of spacetime geometry,'submitted to Phys. Rev. Lett.; quant-ph/0505064.