

Project Summary/Abstract: Paths to Quantum Supremacy

To date, all experimental demonstrations of quantum computing have either been extremely small-scale (e.g., the use of Shor’s algorithm to factor 21 into 3×7), or else have not clearly demonstrated an enhancement due to quantum effects (e.g., D-Wave). How can we change that situation, and finally answer the skeptics who believe there’s some fundamental obstacle to scalable quantum computing? And can we achieve this scientific milestone, of demonstrating quantum supremacy on some task, *without* needing to solve the staggering technical problems of building a fault-tolerant, universal quantum computer?

This proposal is about the theoretical aspects of the above questions. Its starting point is *BosonSampling*: a rudimentary form of optical quantum computing, proposed by the PI and his student Alex Arkhipov in 2011, which has since been demonstrated in experiments involving 3-4 photons. Crucially, the PI and Arkhipov proved that BosonSampling samples a probability distribution that is hard to sample classically, assuming fundamental conjectures in computational complexity theory. The current proposal will push that work further—for example, by understanding the complexity-theoretic effects of photon losses. The proposal will involve direct collaboration between mathematicians and computer scientists on the one hand, and experimental physicists on the other. It will branch out far beyond BosonSampling, to study other “physics-inspired” quantum computing models, including the commuting-Hamiltonians model, stoquastic Hamiltonians, the one-clean-qubit model, models with limited entanglement, and models based on permutations and the Yang-Baxter equation. Finally, the proposal will deepen our understanding of *classical* computing, by developing new techniques to understand when its apparent limitations are really fundamental, and when quantum computing can provide an advantage.

The PI is internationally known for his outreach efforts—including his blog, magazine articles, and *Quantum Computing Since Democritus* book—and teaching and outreach will be a fundamental part of the proposal as well.