**Building MSU leadership in quantum information science**

1. ***Overview; Why now?***

Though the disruptive potential of QIS has been known for over 20 years, it has been in a nascent state with a number of academic, industrial and government groups striving to understand the basics physics, and to build and control many-qubit systems. However there has been steady progress to a tipping point where the realization of practical QIS systems is imminent [1,2]; for example the leading group in the field (Google Quantum AI) recently argued that small scale commercialization of quantum computing devices is expected within 5 years [1]; moreover quantum chemistry may be a “killer app” for small quantum computing systems [3]; and prototype demonstrations are already emerging [4]. IBM is providing a 20 QUBIT system for public use, and they expect to deliver a 50 QUBIT system in the near future [2]. Strategic partnerships are developing between universities, large corporations, startups, as well as federal and private funding agencies. Some of the major industrial and government investors are Google [1]; IBM [2]; Microsoft [5]; DoD [6]; IARPA [7]; the NSF has a QIS program and several initiatives; including Quantum Leap and IDEAS: PFCQC [8]; and the DOE is investing [9].For some time the NSA has been concerned about the potential of quantum computing to crack often used encryption systems, and they now consider these encryption systems to be vulnerable to QIS in the near future [10]. Disruptive quantum technologies based on emerging QIS systems are expected to be widespread and are not fully explored; but will include precision sensing; complex simulations; quantum computing; secure information transmission and new encryption systems.

Three critical QIS basic research themes are:

1. Experimental realization of architectures for QIS, and in particular quantum computing
2. Theoretical studies of the underlying physics of these architectures, in particular noise, control of interactions, entanglement and coherence lifetimes
3. Algorithms; including error correction strategies; and design of algorithms to take advantage of analog and digital quantum computing systems for a variety of applications
4. ***Existing MSU leadership in QIS***

Three faculty at MSU have established national and international leadership in QIS in areas (i) and (ii) listed above.

1. Experimentalist Professor Norman Birge is funded through Northrop-Grumman for a project by IARPA to develop superconducting flux storage systems which will be an important part of future quantum computing systems. This project includes a collaboration with Station-Q (Microsoft); and Microsoft has provided significant additional funding to the Birge group for hardware and technician support. Two previous PhD students from CMP in PA now work at Northrup-Grumman in this area (Eric Gingrich, Ian Dayton).
2. Experimentalist Assistant Professor Johannes Pollanen is in his second year at MSU and is funded by the NSF in a joint project with theorist Mark Dykman. Pollanen works on a variety of quantum architectures; and of particular interest here, he plans to characterize a novel and relatively unexplored qubit system consisting of individual electrons trapped in vacuum above the surface of superfluid helium.
3. Theorist Professor Mark Dykman (funded by NSF) studies fluctuations and noise in many body quantum systems and is the leading theorist in studies of quantum processes of electrons on liquid helium. In this area, he also collaborates with Johannes Pollanen and with Michael Shapiro in the MSU mathematics department. One of professor Dykman’s previous postdocs, Vadim Smelyanskiy, is part of the Google AI team (see ref. [1]) and is a regular visitor to MSU. In collaboration with Google, they recently made an important step towards solving optimization problems using dissipative quantum systems.
4. ***Proposed hiring directions in Physics and Astronomy***

Superconducting circuit based quantum bits (qubits) are currently leading the major efforts to build large-scale quantum simulators and universal processors, but the race is far from over. During his keynote presentation at the recent Q2B conference[11] John Preskill of Caltech emphasized this by stating that we are currently living in the “*Noisy Intermediate-Scale Quantum (NISQ) Era*” where important fundamental and applied questions remain regarding qubit quality, scalability, computation speed, and the nature of decoherence when these systems are coupled to a noisy external environments. At the forefront of this research is controlling the coupling between the qubit and its environment to enhance coherence, simulate complex many-body states in physics, and to create hybrid systems that interface with trapped ions, electrons, spins, or quantized mechanical degrees of freedom; which are encompassed in basic research themes (i) and (ii) in section 1 above. At their core these are interdisciplinary ideas and questions that must bring together experimental and theoretical physicists, engineers, and mathematicians. Hiring experimental physics faculty in this field will build upon, and leverage, our existing expertise and collaborations in experimental QIS and position us as a leader in this emerging field. Professor Norman Birge and his collaborators at Northrop Grumman are recognized world leaders in the field of superconducting classical computing. Very recently [12] researchers working with IBM have identified a scheme to interface this technology with superconducting quantum computing to solve key problems in scaling to large quantum processors. Furthermore, the *Laboratory for Hybrid Quantum Systems* (LHQS) at MSU led by PI Johannes Pollanen is working with collaborators to build hybrid systems using superconducting qubits to create non-classical itinerant states of motion, which will provide feedback to improve qubit performance and potentially transmit quantum information between multiple spatially separated qubits. Furthermore, Pollanen and his team are working to developing a truly unique qubit formed by the quantum motion of a single electron trapped in vacuum. Synergy and close collaboration between new experimental faculty working with superconducting qubits and MSU’s quantum scientists will dramatically raise the profile of MSU’s QIS effort and help to cultivate new, and strengthen existing, partnerships outside of academia.

We request funding for two additional faculty working in these and related areas, which will make MSU competitive for the 1-10M scale funding opportunities typical in this area. The existing interdepartmental connections and the existing PA expertise provide a basis for creating a coordinated interdisciplinary group of researchers in Physics, Mathematics, and Engineering to foster the work on quantum information at MSU and to bring MSU to the forefront in this fast developing area. On the Physics side, this requires bringing in new faculty with expertise in the realization of well controlled entangled quantum systems. They should complement the existing strengths in condensed matter physics, mesoscopic physics, and nanotechnology. The natural niche for MSU is the experimental and theoretical study of comparatively small coupled quantum systems, which will be the building blocks of future large scale quantum information devices. Such systems will allow exploration of new architectures; new quantum measurement protocols; and they will provide deep insight into the very nature of quantum measurements. These well controlled and characterized subsystems will provide platforms for developing new means of performing quantum operations, and explore many-body mesoscopic quantum effects in the presence of dissipation. The required expertise on the theory side will include, but will not be limited, to many-body phenomena on the mesoscopic scale, theory of quantum measurements, and the physics of dissipative, strongly coupled, non-equilibrium systems.

[1] Masoud Mohseni, Peter Read, Hartmut Neven, Sergio Boixo*,* Vasil Denchev*,* Ryan Babbush*,* Austin Fowler*,* Vadim Smelyanskiy, John Martinis (Google Quantum AI team); Nature 543, 171-174 (2017)

[2] https://www.research.ibm.com/ibm-q/

[3] K. Bourzac, Chemical and Engineering News, 95 (43), 27-31 (2017)

[4] Abhinav Kandala, Antonio Mezzacapo, Kristan Temme, Maika Takita, Markus Brink, Jerry M. Chow & Jay M. Gambetta, Nature 549, 242-246 (2017)

[5] https://www.microsoft.com/en-us/research/group/microsoft-quantum-santa-barbara-station-q;

[6] <https://www.arl.army.mil/www/default.cfm?page=2424>;

<https://www.onr.navy.mil/en/Science-Technology/Departments/Code-31/All-Programs/312-Electronics-Sensors/Quantum-Information-Science>;

<https://community.apan.org/wg/afosr/w/researchareas/21011/quantum-information-sciences/>

[7] <https://www.iarpa.gov/index.php/research-programs/quantum-programs-at-iarpa>

[8] <https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505229>

[9] https://www.ornl.gov/news/two-ornl-led-research-teams-receive-105-million-advance-quantum-computing-scientific

[10] https://www.technologyreview.com/s/600715/nsa-says-it-must-act-now-against-the-quantum-computing-threat/

[11] *Quantum Computing for Business*, NASA-Ames Research Center, Mountain View, California, December 4-6, 2017.

[12] *Quantum--Classical Interface Based on Single Flux Quantum Digital Logic*, R. McDermott, M.G. Vavilov, B.L.T. Plourde, F.K. Wilhelm, P.J. Liebermann, O.A. Mukhanov, and T.A. Ohki, arXiv:1710.04645 (October 12, 2017).