### Contents

<table>
<thead>
<tr>
<th>Page</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>WELCOME LETTERS</td>
</tr>
<tr>
<td>12</td>
<td>AGENDA</td>
</tr>
<tr>
<td>18</td>
<td>STATE UNIVERSITY OF NEW YORK POLYTECHNIC INSTITUTE CAMPUS MAP</td>
</tr>
<tr>
<td>20</td>
<td>AIR FORCE RESEARCH LABORATORY MAP / GRIFFISS INSTITUTE MAP</td>
</tr>
<tr>
<td>21</td>
<td>CLOSE UP OF STATE UNIVERSITY OF NEW YORK POLYTECHNIC INSTITUTE CAMPUS</td>
</tr>
<tr>
<td>22</td>
<td>KEYNOTE AND INVITED SPEAKERS</td>
</tr>
<tr>
<td>32</td>
<td>SPEAKER ABSTRACTS</td>
</tr>
<tr>
<td>36</td>
<td>ABSTRACTS &amp; POSTERS BY COUNTRY</td>
</tr>
<tr>
<td>116</td>
<td>POINTS OF CONTACT</td>
</tr>
</tbody>
</table>

Login ID: quantum@sunypoly.edu

**PASSWORD**

**SUNYpoly2019**

Password is case sensitive

WIFI AVAILABLE ON SUNY POLY CAMPUS
Welcome
from the Air Force Research Laboratory
Information Directorate
Director
Dean QIS Attendees,

It’s my honor to welcome you all on behalf of the Air Force Research Laboratory, Information Directorate and Air Force Office of Scientific Research, to the 1st Air Force Research Laboratory (AFRL) International Quantum Information Science Workshop. Over the course of the next three days, you will learn about a vast array of research conducted in different Quantum Technology areas – both in the United States and from countries around the world. Keynote speakers, specialized breakout sessions, and technical poster sessions will inspire and foster valuable discussions between our international guests and the US government participants. Our workshop will culminate with a tour of AFRL's state-of-the-art quantum laboratories and our planned Open Innovation Environment.

The key to quantum technological progress comes from the synergy between researchers located around the globe. This workshop will provide a forum to strengthen and ignite new collaborations, as well as advance current research areas. Recent progress in quantum information science and technology will ultimately lead to revolutionary advances in global technology capabilities. Specifically, taking advantage of quantum mechanical properties introduces game-changing developments for the areas of timing, sensing, communications, networking, and computing. In these areas specific examples include: improved timing for GPS denied environments, miniature field sensors, secure point-to-point and networked-based communication systems, and enhanced speed compared to conventional computing. For these very reasons, quantum technologies are one of the key trajectories of the Air Force 2030 Study.

We are confident that these presentations and poster sessions will be informative and give new insight into the challenges being faced in your own research areas. In this regard, we are encouraging you to take this opportunity to speak with the briefers and colleagues presenting posters, during the sessions, during lunch, and the evening receptions.

As you can imagine, a tremendous effort was required to plan and orchestrate this event in a short period of time. I would like to thank my lead organizers, the AFRL Quantum Team, and SUNY Poly staff, who provided countless hours and incredible energy to make this event a success.

Thank you for attending and being a part of the 1st AFRL International Quantum Workshop!

TIMOTHY J. LAWRENCE, Col, USAF
Director, Information Directorate
COLONEL TIMOTHY J. LAWRENCE

Col. Timothy J. Lawrence is Director, Information Directorate, and Commander, Detachment 4, Air Force Research Laboratory, Rome, New York. The Information Directorate (RI) is the Air Force's leading research organization for command, control, communications, computers and intelligence (C4I) and cyber (+1) technologies. The mission of RI is to explore, prototype and demonstrate high-impact, game-changing technologies that enable the Air Force and nation to maintain its superior technical advantage. RI consists of more than 1,200 military, civilians, and on-site contractors and an annual budget of over $1 billion, including $184 million in core funding.

Col. Lawrence, a native of Waterloo, Iowa, graduated with a Bachelor of Science from the US Air Force Academy in 1988, Master of Science from MIT in 1991, and a PhD from the University of Surrey (UK) in 1998. His PhD research led him to receive the Thomas Hawksley Gold Medal from the Institute of Mechanical Engineering in 1999. That research, coupled with swimming the English Channel, led him to be named one of the top 10 outstanding young people of the world in 2001 by the World Jaycees. Col. Lawrence has served at the Air Force Research Laboratory's directorates in Edwards AFB and London as an advanced space propulsion engineer and space technology liaison officer. He authored a textbook on nuclear propulsion in 1995. At USAFA, he was director of the Department of Astronautics Space Systems Research Center where he worked on the design, assembly, and flight programs of FalconSAT-2, FalconSAT-3, and FalconSAT-5 small satellites. Col Lawrence spent eight and a half months in Kabul, Afghanistan where he was a mentor to the Afghan Dean of the National Military Academy Afghanistan. Before coming to the Information Directorate, he was the Director, Air Force Office of Scientific Research International Office, London U.K. and previously the Commandant and Vice Chancellor of the Air Force Institute of Technology.

EDUCATION

1988 Bachelor of Science degree in Mathematical Sciences, United States Air Force Academy, Colorado Springs, CO
1993 Master of Science degree in Nuclear Engineering, Massachusetts Institute of Technology, Cambridge, MA
1995 Squadron Officer School, Maxwell AFB, AL
1998 Doctor of Philosophy degree in Electrical and Satellite Engineering, University of Surrey, Guildford, UK
2003 Air Command and Staff College, Maxwell AFB, AL
2008 Masters of Art degree in Military Operations and Scientific Art, Air Command and Staff College, Montgomery, AL

ASSIGNMENTS

Aug 88 - Aug 91, Advanced Space Propulsion Engineer, AFRL Rocket Propulsion Directorate, Edwards AFB, CA
Aug 91 - Jul 93, Student, Massachusetts Institute of Technology, Cambridge, MA
Jul 93 - Aug 95, Research Officer and Assistant Professor, Dept of Astronautics, United States Air Force Academy
Aug 95 - Oct 98, Student, University of Surrey, UK
Oct 98 - Jul 01, Program Manager, Space Technology, European Office of Aerospace Research and Development, London, UK
Jul01 - Jul 02, Systems Division Chief, Assistant Professor, Dept of Astronautics, United States Air Force Academy

ACADEMY
Jul 02 - Jul 03, Student, Air Command and Staff College, Maxwell AFB, AL
Jul 03 - Jul 04, Navigation Guidance & Control Division Chief, Dept of Astronautics, United States Air Force Academy
Feb 08 - Feb 09, Vice Dean, National Military Academy Afghanistan, Kabul Afghanistan
Jul 04 - Oct 10, Space Systems Research Center Director, Associate Professor, United States Air Force Academy
Oct 10 - Jun 11, Senior Military Professor/Associate Dean, Air Force Institute of Technology
Jul 11 – Jul 14, Commandant and Vice Chancellor, Air Force Institute of Technology
Jul 18 – Present, Director, Information Directorate, Air Force Research Laboratory, Rome, NY

MAJOR AWARDS AND DECORATIONS
Defense Service Medal
Meritorious Service Medal (6 OLC)
Air Force Commendation Medal (1 OLC)
Tau Beta Pi-Zeta Top Instructor 2003-2004 Outstanding Academy Educator (May 2002)
World Jaycees Outstanding Young Person of the World for Technology (2001)
First American to swim from Jersey (UK) to France, 19 miles, 2006, set new world record

EFFECTIVE DATES OF PROMOTION
Second Lieutenant - Jun 1, 1988
First Lieutenant - Jun 1, 1990
Captain - Jun 1, 1992
Major - Oct 1, 1999
Lieutenant Colonel - Sep 1, 2004
Colonel – Feb 1, 2010

Current as of: Jul 2018
Greetings
from the State University of New York
Chancellor and President

“One major vision for SUNY is to forge powerful new partnerships, and with our Educational Partnership Agreement with the Air Force Research Laboratory’s Information Directorate, we will be at the forefront of the new frontier in computing by focusing on quantum information science. This work, which many of you will be sharing throughout the workshop, will address problems that are currently intractable, whether it be life-saving drug discovery, turning sunlight into jet fuel, or building absolutely secure communication systems. As you take in the presentations, panel sessions, and keynotes, I urge you to look for further collaborations to move our great state and nation forward through quantum science and engineering. Thank you to the AFRL for sponsoring this workshop, and to SUNY Poly for hosting this event at their Utica campus to create a space where all can learn and inspire.”

Dr. Kristina M. Johnson
Chancellor Of The State University Of New York
Dear Workshop Participant,

Welcome to SUNY Polytechnic Institute! We are pleased you are joining us as we host the first internationally focused Quantum Information Science (QIS) Workshop with the Air Force Research Laboratory. I am thrilled to share with you brief highlights showcasing how SUNY Poly represents a new, innovative educational and research paradigm. SUNY Poly has two locations, with the colleges of Arts and Sciences, Engineering, Business Management, and Health Sciences located in Utica, and the colleges of Nanoscale Sciences, and Nanoscale Engineering and Technology Innovation located in Albany. The Utica campus has a 50-year history in the Mohawk Valley and houses twenty-four undergraduate and nine graduate degree programs, in addition to five graduate certificate programs. It is home to collaborative Makerspace labs; the new Center for Global Advanced Manufacturing (CGAM), which boasts the new Hage Family Robotics Lab, enabling robotics and automation capabilities-based R&D and educational opportunities for faculty, students, and the community; and NCAA Division III athletics. The Albany site has become a world leader in research and innovation of leading-edge nanoscience and nanoengineering-based concepts in areas ranging from biomedical research to electronics and photonics, with two undergraduate and eight graduate degree programs. As a testament to its highly relevant, hands-on education, SUNY Poly has recently seen exciting enrollment growth.

Amid this backdrop, IBM, a long-time anchor tenant at our Albany campus, plans to invest over $2 billion to grow its high-tech footprint there and throughout New York State. Applied Materials, Inc., plans to invest $600 million to establish the Materials Engineering Technology Accelerator (META Center) at our Albany campus for leading-edge materials research. We are proud to be working closely with a number of Mohawk Valley-based partners, such as the Air Force Research Laboratory and Griffiss Institute, on innovative R&D to catalyze nextgen research and career opportunities. I hope you enjoy your time at SUNY Poly. We look forward to receiving your feedback about the best ways to collaboratively drive quantum information science-centered success for our global community as we lead the way toward an even brighter 21st century, together.

Sincerely,

Dr. Grace Wang
Interim President
Dr. Kristina M. Johnson

Chancellor of the State University of New York

Dr. Kristina M. Johnson joined The State University of New York as its 13th Chancellor in September 2017.

Immediately prior to joining SUNY, Dr. Johnson was co-founder and CEO of Cube Hydro Partners, LLC, a clean-energy infrastructure company focused on building and operating hydropower plants in North America. She served as Under Secretary of Energy at the U.S. Department of Energy and spent nearly 25 years in academia, including leadership roles at Johns Hopkins University and Duke University, and faculty positions at the University of Colorado, Colorado State University, and Trinity College in Dublin, Ireland.

Dr. Johnson holds 118 U.S. and international patents, has published 149 referenced papers and proceedings. She cofounded ColorLink, Inc., which was sold to RealD, and is responsible for 3D effects in movies such as Avatar, Gravity, and hundreds of other films. Dr. Johnson was inducted into the Women in Technology International Hall of Fame (2003) and the National Inventors Hall of Fame (2015). She received the Society of Women Engineers Lifetime Achievement Award 2 (2004), the Woman of Vision Award for Leadership by the Anita Borg Institute for Women and Technology (2010), and "40 years of Title IX - 40 Women Who Have Made an Impact" by ESPNW (2012).

Dr. Johnson is married to Ms. Veronica Meinhard, the senior executive director of principal gifts and senior associate athletic director at the University of Maryland, College Park (UMCP).

ABOUT THE STATE UNIVERSITY OF NEW YORK

The State University of New York is the largest comprehensive system of higher education in the United States, with 64 college and university campuses located within 30 miles of every home, school, and business in the state. In total, SUNY served nearly 1.4 million students in credit-bearing courses and programs, continuing education, and community outreach programs in the 2017-18 academic year. There are 3 million SUNY alumni worldwide, and one in three New Yorkers with a college degree is a SUNY alum.
DR. GRACE WANG

Senior Vice Chancellor for Research and Economic Development
The State University of New York (SUNY)
Interim President, SUNY Polytechnic Institute

Appointed by SUNY Board of Trustees, Dr. Wang has served as Senior Vice Chancellor and previously as Vice Chancellor for Research and Economic Development since January 2017. In this role, Dr. Wang plays a lead role in designing, directing, and expanding the footprint of SUNY’s research, industry relations, and economic development activities. She supports the SUNY Chancellor in advancing SUNY’s overall strategy and mission, and serves as a liaison to the SUNY Board of Trustees in the areas of research and economic development. She is committed to supporting SUNY research faculty and chairs the SUNY Research Council, and Vice Presidents for Research Council. She works with the Research Foundation for SUNY (SUNY RF), providing the research vision and strategic directions SUNY RF operationally supports.

In June 2018, SUNY Board of Trustees and SUNY Chancellor Kristina M. Johnson also appointed Dr. Wang as SUNY Polytechnic Institute Interim President.

During Academic Year 2017/2018, Dr. Wang also served as Interim System Provost. In this role, Dr. Wang supported the Chancellor and Board of Trustees to drive academic programs and policies; led strategic enrollment across SUNY campuses; guided the enrichment of the educational experience; enabled pathways for student success and completion; supported the university’s deep commitment to diversity, equity, and inclusion; and led the identification and implementation of best practices at scale.

Prior to SUNY, Dr. Wang served as acting Assistant Director for Engineering at the National Science Foundation (NSF). In this role, she led the Engineering Directorate at NSF, managing a funding portfolio of over $900 million dedicated to investments in frontier engineering research, supporting engineering education, and fostering innovation and technology commercialization. She previously served as NSF’s Deputy Assistant Director for Engineering, overseeing the operation of the Directorate for Engineering and helping to identify and implement research, innovation, and education priorities. Previously at NSF, Dr. Wang was the Division Director of Industrial Innovation and Partnerships (IIP) division. She joined NSF in June 2009 as a Program Director for the SBIR/STTR Program, focusing on investing in small businesses in the areas of nanotechnology, advanced materials, and manufacturing.

Dr. Wang began her career at IBM/Hitachi Global Storage Technologies, focusing on research and development of magnetic thin film and carbon overcoat for data storage. She holds seven U.S. patents. Dr. Wang received her Ph.D. in Materials Science and Engineering from Northwestern University.
SUNY STUDENT CENTER - LOBBY

7:30 CHECK IN

SUNY STUDENT CENTER - MULTI-PURPOSE ROOM

8:20 WELCOME HELLO AND ADMINISTRATIVE
Rebecca Mills – Senior International Focal Point

8:30 WELCOME AND WORKSHOP OPENING
Colonel Timothy Lawrence, PhD, Director, Information Directorate (RI), Commander, Detachment 4, Air Force Research Laboratory (AFRL)

WELCOME MESSAGE
Dr. Grace Wang, Senior Vice Chancellor for Research and Economic Development, The State University of New York (SUNY), Interim President, SUNY Polytechnic Institute

CONGRESSMEN WELCOME (VIA VIDEO MESSAGE)
New York State Senator, Chuck Schumer
United States Representative, Anthony Brindisi

9:15 KEYNOTE ADDRESS: THE NATIONAL QUANTUM INITIATIVE
Dr. Alexander Cronin, Senior Quantum Coordinator, National Quantum Coordination Office, Office of Science and Technology Policy (OSTP), United States of America

SUNY STUDENT CENTER - LOBBY

10:15 BREAK

SUNY STUDENT CENTER - MULTI-PURPOSE ROOM

10:35 KEYNOTE ADDRESS: "LANDSCAPE OF US DOD QUANTUM SCIENCE RESEARCH"
Dr. Paul Lopata, Assistant Director, Quantum Science, Office of the Under Secretary of Defense for Research and Engineering, Office of Secretary of Defense (OSD), United States of America

WILDCAT FIELD HOUSE

11:35 LUNCH

SUNY STUDENT CENTER - MULTI-PURPOSE ROOM

1:00 INVITED SPEAKER: "QUANTUM INFORMATION SCIENCE AT AFRL: THE WAY AHEAD"
Colonel Timothy Lawrence, PhD, Director, Information Directorate (RI), Commander, Detachment 4, Air Force Research Laboratory (AFRL)
1:30 INVITED SPEAKER: "OVERVIEW OF SUNY RESEARCH ENTERPRISE AND QUANTUM RESEARCH CAPACITY"
Dr. Grace Wang, Senior Vice Chancellor for Research and Economic Development, The State University of New York (SUNY), Interim President, SUNY Polytechnic Institute

SUNY STUDENT CENTER - LOBBY
2:00 BREAK

SUNY STUDENT CENTER - MULTI-PURPOSE ROOM
2:20 KEYNOTE ADDRESS: "QUANTUM ATOMICS FROM 30,000 AND FROM 3 FEET"
Dr. Dana Anderson, Founder, Chief Technical Officer, Founder, Chief Technical Officer

DONOVAN HALL
3:20 TECHNICAL BREAKOUT SESSIONS
(run in parallel) 30 min Chairperson Topic Briefing, followed by open discussions

3:20 QUANTUM TIMING & SENSING
Chairperson: Professor Erling Riis, Department of Physics, University of Strathclyde, Glasgow, UK
ROOM G152/AUDITORIUM

3:20 QUANTUM COMMUNICATION & NETWORKING
Chairperson: Dr. Thomas Jennewein, Science Lead for QEIYSSat, Associate Professor in the Department of Physics and Astronomy at Institute for Quantum Computing, University of Waterloo, ON, Canada
ROOM G172/COLLABORATIVE DESIGN STUDIO

3:20 QUANTUM COMPUTING
Chairperson: Dr. Joe Fitzsimons, Singapore University of Tech and Design, Centre for Quantum Technologies
ROOM G225/MAKER SPACE

5:00 END OF DAY SHUTTLE BUS DEPART FOR CONTRACTED HOTELS
Wednesday, 10 JULY 2019

SUNY STUDENT CENTER - LOBBY
8:00   CHECK IN

SUNY STUDENT CENTER - MULTI-PURPOSE ROOM
8:20   Good Morning Administrative

8:30   INVITED SPEAKER: "FROM RABI OSCILLATIONS TO REAL-WORLD APPLICATIONS: TAKING QUANTUM COMPUTERS TO THE NEXT LEVEL"
Dr. Doug McClure, Manager, Research Staff Member, IBM Research Center, Yorktown Heights, NY
Mr. Daniel Maynard, Business Development Executive, IBM Research Center, Yorktown Heights, NY

9:30   INVITED SPEAKER: "THE AFRL-USRA-NYSTEC QUANTUM INFORMATION SCIENCE PROGRAM"
Dr. Davide Venturelli, Quantum Computing Team Lead, Research Institute of Advanced Computer Science (RIACS) at Universities Space Research Association (USRA)

10:00  INVITED SPEAKER: "HARDWARE AND SOFTWARE ADVANCES IN QUANTUM ANNEALING"
Dr. Edward (Denny) Dahl, Principal Research Scientist, D-Wave Systems, Inc., Burnaby, British Columbia
Dr. Victoria Horan Goliber, Research Scientist, D-Wave Systems, Inc., Burnaby, British Columbia

10:30  BREAK
11:00  Technical Breakout Session Outbrief

WILDCAT FIELD HOUSE
11:45  LUNCH

SUNY STUDENT CENTER - MULTI-PURPOSE ROOM
1:15   KEYNOTE ADDRESS
Dr. Walter Copan, Director, Undersecretary of Commerce and National Institute of Standards and Technology (NIST), United States of America

2:15   BREAK

2:30   GE LIVE DEMO: "QUANTUM COMPUTING FOR ASSET SUSTAINMENT DEMO"
Dr. Austars Schnore, GE Global Research

2:50   POSTER SESSION

5:00   END OF DAY SHUTTLE BUS DEPART FOR CONTRACTED HOTELS

DELTA HOTEL BALLROOM
6:00   RECEPTION
8:30   END OF EVENING SHUTTLE BUS TRANSIT RUNS TO CONTRACTED HOTELS
Thursday, 11 JULY 2019

GRIFFISS INSTITUTE

8:00  CHECK IN

GRIFFISS INSTITUTE AUDITORIUM

8:15  GOOD MORNING
   Administrative
   GI WELCOME
   Griffiss Institute President, Bill Wolf
   Rome, NY Mayor, Jackie Izzo
   New York State Senator, Joseph Griffio

GRIFFISS INSTITUTE

8:30  KEYNOTE ADDRESS
   Dr. Richard Joseph, Chief Scientist, US Air Force, United States of America

POSTERS SETUP AT GI FOR ADDITIONAL EXPOSURE AND DISCUSSION OPPORTUNITIES

BUSES START TO SHUTTLE SMALL GROUPS ON TOURS

9:30-4:45  ROTATING TOUR GROUPS*  AIR FORCE RESEARCH LABORATORY QUANTUM LABS AND OPEN INNOVATION ENVIRONMENT  * see schedule

GRIFFISS INSTITUTE

LUNCH

CONTINUED, ROTATING TOUR GROUPS*  AIR FORCE RESEARCH LABORATORY QUANTUM LABS AND OPEN INNOVATION ENVIRONMENT  * see schedule

GRIFFISS INSTITUTE

4:45  Closing Remarks

5:00  END OF EVENT! SHUTTLE BUS DEPART FOR CONTRACTED HOTELS
## Rotating tour schedule

### TOUR GROUP #1

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:30</td>
<td>CHECK IN – TOUR GROUP #1</td>
</tr>
<tr>
<td>9:40</td>
<td>SHUTTLE BUS TO THE AIR FORCE RESEARCH LABORATORY</td>
</tr>
<tr>
<td>10:00</td>
<td>AIR FORCE RESEARCH LABORATORY TOUR</td>
</tr>
<tr>
<td>11:30</td>
<td>SHUTTLE BUS TO GI</td>
</tr>
<tr>
<td>11:40</td>
<td>LUNCH</td>
</tr>
<tr>
<td></td>
<td>Posters setup at GI for additional exposure and discussion opportunities</td>
</tr>
<tr>
<td>1:10</td>
<td>SHUTTLE BUS TO OPEN INNOVATION ENVIRONMENT</td>
</tr>
<tr>
<td>1:30</td>
<td>OPEN INNOVATION ENVIRONMENT TOUR</td>
</tr>
<tr>
<td>3:00</td>
<td>SHUTTLE BUS TO GI</td>
</tr>
<tr>
<td>3:10</td>
<td>POSTERS SETUP AT GI FOR ADDITIONAL EXPOSURE AND DISCUSSION OPPORTUNITIES</td>
</tr>
</tbody>
</table>

### TOUR GROUP #2

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:30</td>
<td>BREAK</td>
</tr>
<tr>
<td></td>
<td>Posters setup at GI for additional exposure and discussion opportunities</td>
</tr>
<tr>
<td>10:00</td>
<td>SHUTTLE BUS TO OPEN INNOVATION ENVIRONMENT</td>
</tr>
<tr>
<td>10:20</td>
<td>OPEN INNOVATION ENVIRONMENT TOUR</td>
</tr>
<tr>
<td>11:50</td>
<td>SHUTTLE BUS TO GI</td>
</tr>
<tr>
<td>12:00</td>
<td>LUNCH</td>
</tr>
<tr>
<td></td>
<td>Posters setup at GI for additional exposure and discussion opportunities</td>
</tr>
<tr>
<td>12:30</td>
<td>CHECK IN – TOUR GROUP #2</td>
</tr>
<tr>
<td>12:40</td>
<td>SHUTTLE BUS TO THE AIR FORCE RESEARCH LABORATORY</td>
</tr>
<tr>
<td>1:00</td>
<td>AIR FORCE RESEARCH LABORATORY TOUR</td>
</tr>
<tr>
<td>2:30</td>
<td>SHUTTLE BUS TO GI</td>
</tr>
<tr>
<td>2:40</td>
<td>POSTERS SETUP AT GI FOR ADDITIONAL EXPOSURE AND DISCUSSION OPPORTUNITIES</td>
</tr>
</tbody>
</table>
TOUR GROUP #3

9:30  BREAK
   Posters setup at GI for additional exposure and discussion opportunities

11:00 CHECK IN – TOUR GROUP #3
11:10 SHUTTLE BUS TO THE AIR FORCE RESEARCH LABORATORY

11:30 AIR FORCE RESEARCH LABORATORY TOUR
1:00  SHUTTLE BUS TO GI

1:10  LUNCH
   Posters setup at GI for additional exposure and discussion opportunities

2:40  SHUTTLE BUS TO OPEN INNOVATION ENVIRONMENT

3:00  OPEN INNOVATION ENVIRONMENT TOUR
4:30  SHUTTLE BUS TO GI

4:40  POSTERS SETUP AT GI FOR ADDITIONAL EXPOSURE AND DISCUSSION OPPORTUNITIES

TOUR GROUP #4

9:30  BREAK
   Posters setup at GI for additional exposure and discussion opportunities

11:30 SHUTTLE BUS TO OPEN INNOVATION ENVIRONMENT

11:50 OPEN INNOVATION ENVIRONMENT TOUR
13:20 SHUTTLE BUS TO GI

13:30 LUNCH
   Posters setup at GI for additional exposure and discussion opportunities

2:00  CHECK IN – TOUR GROUP #4
2:10  SHUTTLE BUS TO THE AIR FORCE RESEARCH LABORATORY

2:30  AIR FORCE RESEARCH LABORATORY TOUR
4:00  SHUTTLE BUS TO GI

4:10  POSTERS SETUP AT GI FOR ADDITIONAL EXPOSURE AND DISCUSSION OPPORTUNITIES
Directions to Utica Campus:

From the NYS Thruway (I-90)
Take Exit 31/Utica. After toll, bear right onto N. Genesee St. and stay in right lane. Turn right at light and immediately turn right onto ramp for West I-790/Rtes. 5/8/12/Rte. 49. Travel 1.5 miles and take the SUNY Polytechnic Institute exit. Go straight at the light and continue for about a half-mile; bear right onto Technology Drive.

From NYS Rte. 49
Take the SUNY Polytechnic Institute exit. Go straight at the light and continue for about a half-mile; bear right onto Technology Drive.

From Rtes. 5/8/12
Take the I-790/Rt./I-90/Rte. 49 exit and stay in the left lane, following the sign for West 49 Rome. Take the SUNY Polytechnic Institute exit. Go straight at the light and continue for about a half-mile; bear right onto Technology Drive.

Two other campus entrances (Horatio St. and Mulaney Rd.) can be used from Rtes. 8/12 by taking the Horatio St. exit and following signs for SUNY Polytechnic Institute.
Directions to Utica Campus:

From the NYS Thruway (I-90)
Take Exit 31/Utica. After toll, bear right onto N. Genesee St. and stay in right lane. Turn right at light and immediately turn right onto ramp for West I-790/Rtes. 5/8/12/Rte. 49. Travel 1.5 miles and take the SUNY Polytechnic Institute exit. Go straight at the light and continue for about a half-mile; bear right onto Technology Drive.

From NYS Rte. 49
Take the SUNY Polytechnic Institute exit. Go straight at the light and continue for about a half-mile; bear right onto Technology Drive.

From Rtes. 5/8/12
Take the I-790/Rt./I-90/Rte. 49 exit and stay in the left lane, following the sign for West 49 Rome. Take the SUNY Polytechnic Institute exit. Go straight at the light and continue for about a half-mile; bear right onto Technology Drive.

Two other campus entrances (Horatio St. and Mulaney Rd.) can be used from Rtes. 8/12 by taking the Horatio St. exit and following signs for SUNY Polytechnic Institute.
Day 3 will start at the Griffiss Institute (GI) with opening remarks and keynote speaker, Dr. Richard J. Joseph.

Overviews of the GI and its partnership with the Air Force Research Laboratory (AFRL) Information Directorate (RI) to grow international collaborations will be provided.

Group tours will rotate throughout the day for AFRL/RI Quantum Lab tours and RI's new Open Innovative Environment (currently under construction). Buses will be provided for transport from the GI to AFRL. **All people must board the bus at the GI to go on the tour.**

The posters will be moved from the SUNY Polytechnic Institute to the Griffiss Institute to give people a final opportunity to learn about others research in the quantum community while waiting for an AFRL/RI tour.
Directions to Utica Campus:

From the NYS Thruway (I-90)
Take Exit 31/Utica. After toll, bear right onto N. Genesee St. and stay in right lane. Turn right at light and immediately turn right onto ramp for West I-790/Rtes. 5/8/12/Rte. 49. Travel 1.5 miles and take the SUNY Polytechnic Institute exit. Go straight at the light and continue for about a half-mile; bear right onto Technology Drive.

From NYS Rte. 49
Take the SUNY Polytechnic Institute exit. Go straight at the light and continue for about a half-mile; bear right onto Technology Drive.

From Rtes. 5/8/12
Take the I-790/Rt./I-90/Rte. 49 exit and stay in the left lane, following the sign for West 49 Rome. Take the SUNY Polytechnic Institute exit. Go straight at the light and continue for about a half-mile; bear right onto Technology Drive.

Two other campus entrances (Horatio St. and Mulaney Rd.) can be used from Rtes. 8/12 by taking the Horatio St. exit and following signs for SUNY Polytechnic Institute.
Keynote Speakers

DR. ALEXANDER CRONIN

Senior Quantum Coordinator, National Quantum Coordination Office.

Alexander Cronin joined the National Quantum Coordination Office (NQCO) in April, 2019. The NQCO itself was established in March, 2019, by the Office of Science and Technology Policy (OSTP) in response to the National Quantum Initiative Act. Cronin is on detail to the NQCO from the National Science Foundation (NSF) where he has been a Program Director for the Quantum Information Science program and the Atomic Molecular and Optical Physics Experiment program in NSF’s Physics Division from 2016-2019. Alex Cronin received a BS in Physics from Stanford University in 1993, a PhD in Physics from the University of Washington in 1999, and was a postdoc at MIT from 1999-2002. Cronin became an Assistant Professor at the University of Arizona in 2002, where he is now a Professor in the Department of Physics with a joint appointment in the College of Optical Sciences. Cronin’s research team uses an atom interferometer to measure atom-surface van der Waals interactions, atomic polarizabilities, and tune-out wavelengths; and to study quantum decoherence processes. Cronin has authored over 40 articles on atom optics and another 20 on solar power plants. Cronin has won several teaching awards including: the University of Arizona Koffler Prize for teaching in 2009; the Early Career Distinguished Teaching Award from the UA College of Science in 2008; and the Outstanding Undergraduate Teaching Award from the UA Department of Physics in 2005. In 2019, Cronin received an NSF Director’s Award for Excellence in recognition for his work with the Quantum Leap Working Group.
PAUL LOPATA, PhD

Assistant Director, Quantum Science
Office of the Under Secretary of Defense for Research & Engineering

Paul Lopata serves as the Assistant Director for Quantum Science in the Office of the Under Secretary of Defense for Research and Engineering. In this role he leads the Department’s efforts at technology modernization in quantum science, one of DoD’s top technology modernization priority areas. He currently serves as Executive Secretary for the Defense Science Board’s Task Force on Applications of Quantum Technologies.

In his previous role as Associate Director for Cyber Technologies in the Office of the Secretary of Defense, Dr. Lopata was engaged with coordination and oversight of cyber research across the Department of Defense. This work included providing support for implementing the 2015 Department of Defense Cyber Strategy, and representing the Office of Secretary of Defense in shaping the 2016 Federal Cybersecurity Research & Development Strategic Plan. He has served on several cyber research coordinating bodies, including the SCORE interagency cyber research committee and the Cyber Security and Information Assurance Interagency Working Group. His efforts at coordinating research projects between the DoD and international partners led to fruitful bilateral engagements with Australia, Japan, the United Kingdom and others.

Prior to these positions, Dr. Lopata was a Researcher and Program Manager at the Laboratory for Physical Sciences focused on quantum computing research. There he managed a multi-year international research effort advancing the fundamentals of quantum computing technology. Earlier career roles included consulting at Booz Allen Hamilton in support of cutting-edge government research programs at DARPA and IARPA, and a post-doctoral National Research Council Fellowship at the Army Research Lab where he investigated the effectiveness of quantum sensors.

Dr. Lopata is a recognized technical leader on the topics of cyber security and quantum information science. He is regularly invited to speak to diverse audiences on these subjects, and has served on numerous technical advisory boards across the Department and for Federally Funded Research and Development Centers. He received his PhD in mathematical physics from the University of Illinois at Chicago, and a Bachelor of Engineering degree from Stevens Institute of Technology.
Dr. Dana Z. Anderson is Chief Technology Officer of ColdQuanta, Inc., a company he founded in 2007 that develops and manufactures cold and ultracold matter-based quantum technology. He is also a Fellow of the JILA Institute at the University of Colorado and a Professor of the Department of Physics and the Department of Electrical, Computer and Energy and Engineering at the University. Dr. Anderson received his BSEE from Cornell University in 1975 and his Ph.D. in quantum optics from the University of Arizona in 1981. His Ph.D. thesis research focused on the development of ring laser gyroscopes with experiments performed at Litton Guidance and Control Systems (now Northrop-Grumman Mission Systems). He did postdoctoral research at the California Institute of Technology working on the early prototypes of the Laser Interferometer Gravitational Observatory (LIGO) systems. In 1984 is took a faculty position at the University of Colorado where he continued research in laser gyroscope technology and also carried out pioneering research in the field of optical neural networks, for which he received the R.W. Wood Prize from the Optical Society of America in 1994. Together with Nobel Laureate Eric Cornell, Dr. Anderson demonstrated the first on-chip atom interferometer, and with theoretical colleague Murray Holland, pioneered the field of atomtronics, the atom analog of electronics. Dr. Anderson is known for his contributions to enabling technology in quantum atomics including, the development of atom chip technology, and for the miniaturization of cold and ultracold atomic systems. His current research includes the development of atom based inertial sensors, RF sensing, quantum communications systems, quantum computing and atomtronics. He is a recipient of Sloan Foundation and Humboldt Foundation awards, and in 2014 won the Colorado Governor’s CO-Labs award for his contributions leading to the commercialization of ultracold matter technology. Dr. Anderson is a Fellow of the American Physical Society and the Optical Society of America.
Invited Speakers

DOUG MCCLURE

Doug McClure is a Research Staff Member and Manager at IBM Research. Since joining IBM in 2012, he has focused on improving quantum measurements, qubit coherence times, and most recently the performance and reliability of large multi-qubit devices. He received his PhD in experimental physics from Harvard University, where he studied the physics of fractional quantum Hall states with potential applications in topological quantum computing.

DAN MAYNARD

Dan Maynard is a Business Development Executive for IBM Research, establishing external relationships, creating alliances and partnerships, and licensing intellectual property. Prior to joining IBM Research in 2015, Dan spent six years in the business office of IBM Microelectronics Division, responsible for several foundry technology offerings including the P&Ls. Before taking on business roles, he was a Technology Development Manager at IBM Microelectronics 200mm Fabricator, where his team qualified derivative BCD client-specific technologies, as well as other CMOS based technologies. He is also a co-inventor on 41 patents. Dan received his BSEE, MSEE, and MBA, all from the University of Vermont.

DR. DAVIDE VENTURELLI

Davide Venturelli graduated from Ecole Normale Superieure de Lyon and obtained his Ph.D. in Numerical Simulations of the Condensed Matter at the International School for Advanced Studies (SISSA) in Trieste and in Nanophysics at the Universite de Grenoble (CNRS/UJF). He worked as a post-doc at Scuola Normale Superiore in Pisa, Italy, in the Condensed Matter and Information Theory group. He is currently Quantum Computing team lead of the Research Institute of Advanced Computer Science (RIACS) at USRA and he works in the NASA Intelligent System Division (TI) as a research scientist under the NASA Academic Mission Service contract, as one of the first members of the Quantum AI Laboratory (QuAIL). His past publications include quantum condensed matter, many-body theory, device designs in collaboration with experimentalists, quantum thermodynamics, quantum phase transitions, and non-equilibrium spin/charge/energy transport in mesoscopic systems. His current applied focus on algorithms is in advanced scheduling, telecommunication networks, robotics, AI planning, in collaborations with other governmental institutions, universities and the private sector.
EDWARD (DENNY) DAHL, PhD

Dr. Edward (Denny) Dahl received his Ph.D. in theoretical physics from Stanford University in 1985. His thesis work was with Richard Blankenbecler at the Stanford Linear Accelerator Center on Hamiltonian methods in lattice gauge theories. Dr. Dahl transitioned into the field of neural networks in the 1980's, applying Hopfield networks to a variety of optimization problems and studying accelerated convergence techniques for stochastic gradient descent. He worked at Thinking Machines Corporation in the technical marketing group and was responsible for helping users develop algorithms that could run in the SIMD (single instruction multiple data) computational model. He obtained a patent for mapping irregular grid architectures to the hypercube architecture of the CM-2 system and was instrumental in the development of a macro programming language for the vector processors of the CM-5. Since then, Dr. Dahl has provided development support for management and optimization of high data volume and high complexity decision support systems at a variety of companies (Teradata, eBay, Wells Fargo, JP Morgan Chase, Bank of America). He joined D-Wave Systems in 2012, and has been involved in algorithm research, training, technical support for sales and communication functions within the company. He is a frequent speaker at public seminars and university events, with the ability to speak to a wide variety of audiences on otherwise complex subjects.

VICTORIA HORAN GOLIBER, PhD

Dr. Victoria Horan Goliber received her Ph.D. in discrete mathematics from Arizona State University in 2012 through the U.S. Department of Defense Science, Mathematics, and Research for Transformation (SMART) Scholarship Program. Her doctoral research bridged both mathematics and computer science with a focus on de Bruijn sequences and Gray codes for combinatorial objects. After graduating, Dr. Goliber worked as a Senior Mathematician with the U.S. Air Force Research Laboratory’s Information Directorate, along with a special assignment as the Executive Officer to the Director. In early 2018, she joined D-Wave Systems as a Research Scientist and works to support the sales team through customer interaction and training. In her current role, Dr. Goliber travels around the world to bring quantum annealing to a variety of groups through seminars, workshops, and conferences. In addition, Dr. Goliber is pursuing a MS degree in Computer Science with a specialization in machine learning through Georgia Tech University.
WALTER G. COPAN

Under Secretary of Commerce for Standards and Technology and NIST Director

Dr. Walter G. Copan was confirmed by Congress as Under Secretary of Commerce for Standards and Technology and NIST Director on October 5, 2017.

As NIST Director, Dr. Copan provides high-level oversight and direction for NIST.

He has had a distinguished and diverse career as a science and technology executive in large and small corporations, U.S. government, nonprofit and other public-sector settings.

Dr. Copan formerly served as president and CEO of the IP Engineering Group Corporation, providing services in intellectual property strategy, technology commercialization and innovation. Until June 2017, he was founding CEO and chairman of Impact Engineered Wood Corporation, an advanced materials technology company. He also is a founding board member of Rocky Mountain Innovation Partners, where he led technology transfer programs and innovation services on behalf of the U.S. Air Force Academy, U.S. federal labs and academic institutions and helped foster entrepreneurial businesses in the Rocky Mountain West. He also served with the National Advisory Council to the Federal Laboratory Consortium for more than 5 years, providing industry inputs to advance the U.S. economic impacts of the federal laboratory system.

From 2010–2013, Dr. Copan served as managing director of Technology Commercialization and Partnerships at DOE’s Brookhaven National Laboratory (BNL). Among his accomplishments were leading the creation and implementation of the new DOE technology transfer mechanism, “Agreement for Commercializing Technology” (ACT), to facilitate collaborations between the federal labs and U.S. corporations. He led the “Startup America” initiative on behalf of DOE for entrepreneurial business creation, and he initiated the DOE’s new Small Business Innovation Research – Technology Transfer (SBIR-TT) program, which built upon the experiences of NIST. He served as founding partner and board member of the “Accelerate Long Island” alliance for innovation, economic development and early stage investment.

From 2005–2010, Dr. Copan was executive vice president and chief technology officer at Clean Diesel Technologies, Inc., an international technology development and licensing firm. He spearheaded the company’s transformation, growth and listing on NASDAQ (CDTI), as well as the company’s subsequent merger. Prior to joining CDTI, Dr. Copan served at the DOE’s National Renewable Energy Laboratory (NREL) as Principal Licensing Executive, Technology Transfer. There, he led organizational changes that strengthened relationships with industry and the investment community, and led to the more productive commercialization of energy-related technologies.

After earning dual B.S./B.A. degrees in chemistry and music from Case Western Reserve University in 1975, Dr. Copan began his career in chemicals and materials research at the Lubrizol Corporation (now part of the Berkshire Hathaway Group). He earned a Ph.D. in physical chemistry from Case Western in 1982, and subsequently held leadership positions at Lubrizzol in research and development, strategy, business unit management, venture capital, and mergers, acquisitions and strategic alliances in the U.S. and abroad. As managing director, Technology Transfer and Licensing, from 1999–2003,
he was responsible for Lubrizol’s corporate venturing and open innovation, technology strategy, business development, intellectual assets and the technology licensing business.

Dr. Copan is a patent holder, has authored numerous professional publications and presentations, and has served on the boards of many organizations, including the Licensing Executives Society (LES) USA and Canada, where he recently served as regional vice president for LES USA. He has contributed to the U.S. National Academy of Sciences, the Council on Competitiveness, the World Intellectual Property Organization and the United Nations on innovation, technology transfer, energy and economic development matters.
Dr. Richard J. Joseph is the Chief Scientist of the United States Air Force, Washington, D.C. He serves as the chief scientific adviser to the Chief of Staff and Secretary of the Air Force, and provides assessments on a wide range of scientific and technical issues affecting the Air Force mission. In this role, he identifies and analyzes technical issues and brings them to the attention of Air Force leaders, and interacts with other Air Staff principals, operational commanders, combatant commands, acquisition and science and technology communities to address crossorganizational technical issues and solutions. He also interacts with other services and the Office of the Secretary of Defense on issues affecting the Air Force technical enterprise. He serves on the Executive Committee of the Air Force Scientific Advisory Board. He is the principal science and technology representative of the Air Force to the civilian scientific and engineering community and to the public at large.

Dr. Joseph has more than 40 years of experience as a physicist, directed energy researcher, senior program manager, national security advisor and executive. Prior to assuming his current position, Dr. Joseph was the Chief Executive Officer for Earthstar LLC, a small consulting firm he founded in 1998. In this position, he has served government agencies, national laboratories and public companies on the development and management of programs in a broad range of technical areas.


Upon leaving active duty, Dr. Joseph joined Los Alamos National Laboratory in the Accelerator Technology group. In 1985 he was chosen as the Neutral Particle Beam program manager in the Strategic Defense Initiative Office’s Directed Energy Office. While in this role he instituted and directed three major spacecraft-based programs.

In 1987 he divided his time between serving as a senior advisor to the Defense and Space Delegation in the Nuclear and Space Talks with the Soviet Union in Geneva, acting as a senior policy analyst for national security at the White House Office of Science and Technology Policy, and directing a large study on deployment of an initial missile defense capability for the Secretary of Defense.

Between 1988 and 1990 Dr. Joseph led multiple research programs in laser remote sensing to include an airborne laser system capable of detecting biological warfare agents at LANL. This system, designed to support Operation Desert Storm, was built and successfully tested in 28 days.

In 1992 Dr. Joseph took a leave of absence to join the National Aeronautics and Space Administration where he was part of a small group of senior managers directing the restructuring of the agency. While at NASA he also led an interagency task force on remote sensing that moved the agency from using very large satellites for the Earth Observing System to constellations of smaller platforms.

Upon returning to Los Alamos in 1993, he directed the Laboratory’s missile defense programs and in 1995 he joined the
Accelerator Production of Tritium program which intended to use a new approach in a new production plant to produce material for the nuclear weapons program.

EDUCATION

1970 Bachelor of Science Physics, Georgetown University, Washington D.C.
1979 Ph.D. Physics, University of Texas, Austin

CAREER CHRONOLOGY

1983 – 1985, Program manager, Neutral Particle Beam program, SDIO Directed Energy Office
1986 – 1987, Director, Missile Defense Study, Office of the Secretary of Defense, the Pentagon, Washington, D.C.
1993 – 1995, Missile Defense Program Director, LANL, N.M.
1995 – 1998, Accelerator Production of Tritium program, Department of Energy, LANL, N.M.
1998 – 2017, Owner, Earthstar LLC, LANL, N.M.

BOARDS AND ADVISORY GROUPS (Recent)

Oak Ridge National Laboratory, Global Security Advisory Group
Oak Ridge National Laboratory, Nuclear Science and Engineering Advisory Board
Argonne National Laboratory, Global Security Advisory Group
Nevada Test Site, Senior Advisory Group

(Current as of February 2018)
**QUANTUM INFORMATION SCIENCE AT AFRL: THE WAY AHEAD**

Colonel Timothy Lawrence, PhD | Director, Information Directorate (RI), Commander, Detachment 4, Air Force Research Laboratory (AFRL)

Recent advances in Quantum Information Science (QIS) indicate that future applications of quantum mechanics will lead to revolutionary advances in capabilities for the US Air Force. Controlling and exploiting quantum mechanical phenomena will enable inertial sensors and atomic clocks that provide GPS-like positioning and timing accuracy for extended periods of time in degraded environments, communications networks with provable information security, unprecedented sensor resolution, and computers with an exponential increase in processing speed. To ensure that the future Air Force warfighter maintains a technological advantage the AF must implement a QIS strategy that leads to robust and deployable quantum systems. This invited talk will discuss the AFRL QIS strategy that encompasses timing, sensing, communications and networking, and computing along with related capability development.

**OVERVIEW OF SUNY RESEARCH ENTERPRISE AND QUANTUM RESEARCH CAPACITY**

Dr. Grace Wang | Senior Vice Chancellor for Research and Economic Development, The State University of New York (SUNY), Interim President, SUNY Polytechnic Institute

*Abstract not available at time of publication*

**THE NATIONAL QUANTUM INITIATIVE**

Dr. Alexander Cronin | Senior Quantum Coordinator, National Quantum Coordination Office, Office of Science and Technology Policy (OSTP), United States of America

Dr. Alexander Cronin of the White House’s National Quantum Coordination Office will discuss the National Quantum Initiative Act, landmark legislation to accelerate the research and development of quantum information science (QIS) and technology in the United States. Signed into law by President Trump in December 2018, the National Quantum Initiative Act established a coordinated 10-year national program to promote long-term strategic investment in QIS R&D, support a quantum-smart workforce, and partner across the Federal government, industry and academia to ensure American QIS leadership. The law also created the National Quantum Coordination Office to oversee and support Federal activity in QIS. Dr. Cronin’s keynote will elaborate upon the goals and successful implementation of the National Quantum Initiative Act, the Trump Administration’s National Strategic Overview for QIS, and progress made by the National Science and Technology Council Subcommittee on QIS to strengthen coordination across the R&D enterprise.

**LANDSCAPE OF US DOD QUANTUM SCIENCE RESEARCH**

Dr. Paul Lopata | Assistant Director, Quantum Science, Office of the Under Secretary of Defense for Research and Engineering, Office of Secretary of Defense (OSD), United States of America

*Abstract not available at time of publication*
QUANTUM ATOMICS FROM 30,000 AND FROM 3 FEET
Dr. Dana Anderson  |  Founder, Chief Technical Officer  |  ColdQuanta Inc, Boulder, CO
Abstract not available at time of publication

FROM RABI OSCILLATIONS TO REAL-WORLD APPLICATIONS: TAKING QUANTUM COMPUTERS TO THE NEXT LEVEL
Dr. Douglas McClure  |  Manager, Research Staff Member, IBM T.J. Watson Research Center, IBM Research
Dan Maynard  |  Business Development Executive, IBM T.J. Watson Research Center, IBM Research, Yorktown Heights, NY
Thanks to decades of basic research on quantum devices and algorithms, progress in quantum computing technology has reached an inflection point. With quantum processors on a trajectory toward becoming large and accurate enough to begin to tackle real-world problems of interest, collaboration is intensifying among quantum physicists, hardware engineers, computer architects, software developers, and potential end-users. Enhanced by the rapid growth of quantum programming platforms such as Qiskit, the advent of cloud-based access to small quantum processors has dramatically lowered the barriers to entry for learning and research in quantum computing. Harnessing these tools, novel approaches to solving problems on today’s quantum processors are now being developed and demonstrated, and the path toward realizing a quantum advantage is becoming clearer.

THE AFRL-USRA-NYSTEC QUANTUM INFORMATION SCIENCE PROGRAM
Dr. Davide Venturelli  |  Quantum Computing Team Lead  |  Research Institute of Advanced Computer Science (RIACS) at Universities Space Research Association (USRA)
In this presentation we will review the QIS workforce development program by AFRL, NYSTEC, and USRA that consists in a series of lectures and seminars on Noisy-Intermediate-Scale-Quantum (NISQ) computing, a monthly newsletter, and research and development program. The talk will discuss the content of the program, introducing the latest featured material in quantum optimization as well as recent research conducted thanks to sponsored internships at the NASA Quantum AI Laboratory – related to software development for compilation of quantum algorithms.

HARDWARE AND SOFTWARE ADVANCES IN QUANTUM ANNEALING
Dr. Edward (Denny) Dahl  |  Principal Research Scientist, D-Wave Systems, Inc.
Dr. Victoria Horan Goliber  |  Research Scientist, D-Wave Systems, Inc.
Abstract not available at time of publication

Dr. Walter Copan  |  Director, Undersecretary of Commerce and National Institute of Standards and Technology (NIST), United States of America
Abstract not available at time of publication

Dr. Richard Joseph  |  Chief Scientist, US Air Force, United States of America
Abstract not available at time of publication
COUNTRY POSTERS

ITALY

40 QUANTUM SCIENCE AND TECHNOLOGY IN ITALY (A NON EXHAUSTIVE OVERVIEW)
Professor Marco Affronte "Marco" | Università Modena Reggio Emilia and CNR NANO
Abstract not available at time of print

SINGAPORE

42 QUANTUM TECHNOLOGY LANDSCAPE IN SINGAPORE
Dr. John Ng Wee Teck "JOHN" | MINISTRY OF DEFENCE

44 QUANTUM TECHNOLOGIES FOR ENGINEERING (QTE) PROGRAMME IN SINGAPORE
Dr. Leonid Krivitsky "Leo" | Agency for Science Technology and Research (A*STAR)

SCIENCE AND TECHNOLOGY DETAIL POSTERS

AUSTRALIA

46 QUANTUM FEEDBACK NETWORKS AND CONTROL
Dr. Matthew James "Matt" | Australian National University
Poster not available at time of print

48 DELIVERING AN AUSTRALIAN PORTABLE QUANTUM OPTICAL CLOCK
Dr. Russell Anderson "Russell" | La Trobe University
Poster not available at time of print

50 QUANTUM SENSING USING HYBRID DIAMOND MATERIALS
Professor Brant Gibson "Brant" | RMIT University

52 ROADS LESS TRAVELED IN QUANTUM INFORMATION: CONTINUOUS VARIABLES AND RELATIVITY
Dr. Nicolas Menicucci "Nick Menicucci" | RMIT University

54 QUANTUM INFORMATION SCIENCE AND TECHNOLOGY AT UOM - BIO-SENSING TO QUANTUM COMPUTING
Professor Lloyd Hollenberg | University of Melbourne

56 HOLOGRAPHIC QUANTUM ERROR CORRECTING CODES
Dr. Nathan McMahon "Nathan" | University of Queensland

58 QUANTUM TECHNOLOGY LAB AT UQ
Dr. Till Weinhold "Till" | University Of Queensland
Poster not available at time of print
60  **TOWARDS A LEO TO LEO QUANTUM LASER COMMUNICATIONS LINK**  
A/Prof Andrew Lambert - 2nd registration  
"Andrew" | UNSW Canberra Space

**AUSTRIA**

62  **LIGHT-MATTER ENTANGLEMENT OVER 50 KM OF OPTICAL FIBRE**  
Mr. Vojtech Krcmarsky "Vojtech" | IQOQI Innsbruck

**CANADA**

64  **AN ION-TRAP QUANTUM SIMULATION IN A SELF-ASSEMBLED SETUP**  
Dr. Paul C Haljan "Paul" | Simon Fraser University

66  **ALTERNATIVE PHOTON ENCODINGS FOR FREE-SPACE QUANTUM COMMUNICATIONS**  
Dr. Thomas Jennewein "TJ" | University of Waterloo  
*Poster not available at time of print*

**CHILE**

68  **OPTICAL AND MAGNETIC PROPERTIES OF SINGLE QUANTUM EMITTERS**  
Dr. Professor Jeronimo Maze "Jero Maze" | Institute of Physics - Pontificia Universidad Catolica  
*Poster not available at time of print*

**ITALY**

70  **MOLECULAR SPINS FOR QUANTUM SCIENCE AND TECHNOLOGIES**  
Professor Marco Affronte "Marco" | Università Modena Reggio Emilia and CNR NANO

**JAPAN**

72  **QUANTUM CHEMICAL CALCULATIONS ON QUANTUM COMPUTERS: QUANTUM ALGORITHMS**  
Professor Takeji Takui "TT" | Osaka City University

**SINGAPORE**

74  **SECURE QUANTUM COMPUTING**  
Dr. Joseph Fitzsimons "Joe" | Centre for Quantum Technologies

76  **INFRARED METROLOGY WITH VISIBLE LIGHT**  
Dr. Leonid Krivitsky "Leo" | Institute of Materials Research and Engineering
<table>
<thead>
<tr>
<th>South Korea</th>
<th>United States of America</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Korea</td>
<td>United States of America</td>
</tr>
</tbody>
</table>
| 78 | **Quantum Algorithm Optimization, Gravity Effects on Satellite QKD and Quantum Related Research in Korea**  
Dr. Ahn Doyeol "David" | University of Seoul |
| 80 | **Quantum Stand-Off Sensing Project**  
Dr. Yong Sup Ihn "YSI" | Agency for Defense Development |
| 82 | **Enabling-Free Space QKD Under Strong Turbulent Conditions with Double-Loop Wavefront Tilt Correction**  
Dr. Veronica Fernandez-Marmol "Veronica Fernandez" | Consejo Superior de Investigaciones Científicas |
| 84 | **Accrediting Outputs of NISQ Processors**  
Dr. Animesh Datta "Animesh Datta" | University of Warwick |
| 86 | **Quantum Metrology and Sensing at Strathclyde**  
Professor Erling Riis "Erling" | University of Strathclyde |
| 88 | **Computing, Detection, and Transduction with Superconducting Circuits**  
Dr. Olli Pentti Saira "Ollie" | Brookhaven National Laboratory |
| 90 | **Quantum for Logistics**  
Mr. Aussie Schnore "Aussie" | GE Research |
| 92 | **From Atoms to Applications: Quantum Information Science at Oak Ridge National Laboratory**  
Dr. Travis Humble "Travis" | Oak Ridge National Laboratory |
| 94 | **Quantum Algorithm for Spectral Projection by Measuring an Ancilla**  
Ms Yanzhu Chen "Yanzhu" | Stony Brook University |
| 96 | **Role of Material Informatics and 3D Atomic Scale Chemical Imaging for Design and Discovery of New Quantum Materials**  
Dr. Mazumder Baishakhi "Baishakhi" | SUNY Buffalo |
| 98 | **Planning and Optimization in Quantum Markov Models**  
Dr. Christino Tamon "Tino" | Clarkson University |
| 100 | **Entangled States Are Reactive**  
Dr. Warner Miller "Warner" | Florida Atlantic University |
102 FLIPPED BASIS QUANTUM KEY DISTRIBUTION
Dr. Victor Bucklew "Victor" | Harris Corporation

104 QUANTUM COMPUTING APPLICATIONS RESEARCH AT LOCKHEED MARTIN
Dr. Adachi Steven "Steve" | Lockheed Martin

106 Q-MEANS AND SUPERVISED LEARNING: APPLYING QC TO SPACE SITUATIONAL AWARENESS
Dr. Vic Putz "Vic" | QC Ware

108 QUANTUM-FIRST HIGH PERFORMANCE COMPUTERS
Amanda Birch "Mandy" | Rigetti Computing

110 DETECTOR TOMOGRAPHY ON IBM QUANTUM COMPUTERS AND MITIGATION OF IMPERFECT MEASUREMENT
Mr. Maziar Farahzad "Maziar" | Stony Brook University

112 CHIRAL QUBIT - QUANTUM COMPUTING WITH CHIRAL ANOMALY
Mr. Evan Philip "Evan" | Stony Brook University

114 PULSE ENHANCED TWO-PHOTON INTERFERENCE WITH SOLID STATE QUANTUM EMITTERS
Dr. Herbert F. Fotso "Herbert F." | University at Albany, SUNY

SCALABLE NANOPHOTONIC STRUCTURES FOR LONG-DISTANCE QUANTUM COMMUNICATIONS
Professor Spyridon Galis "Spyros" | SUNY Poly

Abstract and poster not available at time of print
Abstract not available at time of print
Quantum related research areas your country is pursuing:
- Q-Computing
- Q-Simulation
- Q-Sensing and Metrology
- Q-Communications & Cryptography
- Q Information theory
- Enabling Quantum technologies (nanotech. cryogenics, photonics...)

Workforce development goals/plans:
- More than 60 groups in Italy
- http://www.qtflagship.cnr.it/

International collaborations pursuing:
- EU Quantum Technologies Flagship 1B€/10yrs
- EU Quantum Communication Infrastructure
- EU Molecular Magnetism and Spintronics network

Quantum Science and Technology in Italy
(a non exhaustive overview)

 Centers for Nanotechnologies
- Superconductors qubits & detectors
- Semiconductor qubits (QD & topological materials)
- Photonics
- Spin systems

Bose Einstein condensates
- Cold atoms & molecules
- Quantum gases

Optical Fiber italian backbone.
The Italian network connects a multiplicity of research institutes and universities (CNR, INAF, ASI, LENS, UNITO, UNIFI, UNINA) thus allowing to start innovative experiments on various research themes, using different experimental techniques for the distribution of time and frequency signals.

Quantum Information Theory
- quantum control, speed limits and geometric aspects
- quantum networking
- quantum many-body systems
- quantum thermodynamics
- quantum gravity
- entanglement
- open quantum systems, decoherence and non-Markovianity
- quantum measurement
- Quantum simulation
ABSTRACT

Singapore has been steadily investing in R&D on Quantum Technologies since 2007. Our research activities cover fundamental curiosity-led Quantum foundations research, and applications driven research in Quantum communications, Quantum sensing and Quantum computing & algorithms. With the Quantum expertise built up over the years, a national level initiative was started in 2018 to focus on validation of Quantum Technologies and translation to industries over the next 5 years.
Quantum community in Singapore

Mr Ng Wee Teck John
Future Systems & Technology Directorate (FSTD), MINDEF
Singapore

Quantum Engineering Programme
- Started in 2018
- Initial tranche of S$25M
- To focus on validation of Quantum Technologies and translation to industries

QKD-QubeSat: UK-SG Collaboration
- CQT, Singapore provides entangled photon source
- RAL Space, UK provides satellite with optical terminal
- One Optical Ground station each in UK and Singapore
- Launch targeted for 2022

Optical Atomic Clock
- Ultra-stable laser
- Locked to a high finesse cavity
- Disciplined to a high Q atomic transition
- Optical comb as counter
- Novel Candidate $^{176}$Lu$^+$
- Three clock transitions
- Low sensitivity to external fields
- All diode laser-based

Quantum Computing & Simulation: Google-CQT Collaboration
- Quantum computation/simulation with NISQ quantum devices of few hundred physical qubits to solve certain problems from material science, chemistry, econometrics, big data
- Hybrid digital/analog and classical approach

Nature Communications 9, 1650 (2018)
QUANTUM TECHNOLOGIES FOR ENGINEERING (QTE) PROGRAMME IN SINGAPORE

Dr. Leonid Krivitsky | Agency for Science Technology and Research (A*STAR), Singapore

ABSTRACT

A*STAR is perusing a variety of quantum-related topics including quantum sensing, quantum computation, and quantum networking. These activities leverage on existing capabilities across various institutes and universities in Singapore while growing A*STAR domain expertise into quantum technologies. The key effort in this area is organized in the Quantum Technologies for Engineering program (QTE), launched in 2017. A key strategic focus of this program is to leverage on the key capabilities areas where Singapore might genuinely make a difference in achieving scientific impact.

The objective of the program is to demonstrate a scalable approach to the realization of multiple logic qubit gates for quantum computation. The program is investigating solid-state spins, 3D electrical interconnects, and chipscale photonics in materials/substrates compatible with integrated circuit planar processing methods. The QTE programme focuses on 2D TMDCs (transition metal dichalcogenides) and SiC materials attempting to exploit long spin coherence time needed for quantum computations. Integrated electronic interconnect and integrated photonics approaches are being developed for qubit transmission, manipulations and entanglement.

Additional information about the program can be found online:

https://www.a-star.edu.sg/imre/Research/Programmes-Centres/Quantum-Technologies-for-Engineering-Programme
**Point of Contact**
Dr Leonid Krivitsky, Prof Dennis Polla
Agency for Science Technology and Research (A*STAR), Singapore

**Program aim:**
Demonstrate a scalable approach to the realization of multiple logic qubit gates for quantum information processing.

**Overview of pursued research areas:**

1. **Solid-State Materials**
   - SIC Vacancy Qubits
   - Multi-Chip Interposers and 3D Interconnects

2. **Photonics**
   - Frequency Conversion of Photons
   - Nano-Photonic Fiber Platform

3. **Planar Processing**
   - Multi-Chip Interposers and 3D Interconnects
   - Scalable Logical Qubit

**New insights:**
1. **New material physical platforms for quantum computing:**
   - Demonstration of a new type of electrically controlled spin-valley qubits with long coherence times and scalable fabrication
   - Demonstration of quantum entanglement between distant spins on the novel Silicon Carbide platform

2. **Miniaturization and power management**
   - 3D interconnects and multi-chip interposers for miniaturized ion traps

3. **Coherent photonics interconnects**
   - Fiber-based photonic data bus for qubits manipulation and transfer
   - A new class of non-linear on-chip optical devices for coherent conversion of single photons from UV/visible to IR

**Processing and manipulation of qubits**
PI: Johnson Goh, A*STAR
- To demonstrate a robust and scalable platform for quantum operations
- > 5 working spin-valley qubits
- Coherence time $T_2^* > 10$ ns

**Multi-qubit system integration**
PI: Weibo Gao, NTU
- Quantum logic devices based on novel SIC platform
- Fabrication and control of qubits
- Observation of quantum entanglement

**Transmission and interconnection of qubits**
PI: Chuan Seng Tan, NTU
- Multi-chip integration on Si interposer for compact and scalable ion traps
- Gold-free TSV and solder-free assembly

PI: Nikolay Zheudev, NTU
- All-fiber entangled photon sources
- Single photon manipulation and detection
- Quantum gate networks

PI: Leonid Krivitsky, A*STAR
- Photonic “gearbox” for quantum communication and hybrid systems
- Highly efficient on-chip coherent signal processing

**Quantum Computing Architecture** [Ref: PRA 89, 2014]
QUANTUM FEEDBACK NETWORKS AND CONTROL

Matt James  |  Australian National University, Australia

ABSTRACT

The aims of our research are to develop systematic engineering methods for describing and designing complex networks involving quantum systems as components, and to apply these approaches to emerging problems in quantum technology including computing and communications.

Our engineering methods are based on strong mathematical foundations that provide a modern, forward-looking approach to quantum mechanics. These include non-commutative quantum probability, quantum stochastic differential equations, and quantum filtering theory. These approaches allow for continuous modes and feedback and are useful for physical descriptions at levels above and below the abstractions of standard ‘quantum circuits’.
Poster not available at time of print
DELIVERING AN AUSTRALIAN PORTABLE QUANTUM CLOCK

Russell Anderson1. Co-authors: Charlie Ironside2, William Rickard2, Tom Stace3, Mirko Lobino4, David Pulford5, and Andre Luiten6 | 1. Institute for Molecular Science, La Trobe University, Australia. 2. John de Laeter Centre, Curtin University, Australia. 3. School of Mathematics and Physics, University of Queensland, Australia. 4. Centre for Quantum Dynamics, Griffith University, Australia. 5. Defence Science and Technology, Australia. 6. Institute for Photonics and Advanced Sensing (IPAS), University of Adelaide, Australia

ABSTRACT

We are developing a portable optical clock based using bi-directional cold atomic beams. This project marries compact laser cooled atomic sources (2D+ GMOTs) with leading-edge photonics to provide a new noiseimmune interrogation protocol. The design improves upon former atomic beam optical clocks such as those using thermal atoms, replacing the conventional two cat’s-eye retroreflector for the Ramsey-Bordé interrogation beams with in-vacuum integrated chip photonics. The use of counter-propagating atomic beams can suppress unwanted shifts as shown recently by NIST. Using the cold atom flux demonstrated by AFRL of 4 × 10^8 atoms/s at 16m/s and a few cm long interrogation zone, our target specification is a fractional frequency stability of 10^{-16} for integration times longer than 100 s. A compact frequency comb will convert the optical output of the clock into an electronic signal for driving conventional electronics. The comb also greatly simplifies the approach to laser stabilization over the usual approach.
Poster not available at time of print
QUANTUM SENSING USING HYBRID DIAMOND MATERIALS

Professor Brant Gibson | ARC Centre of Excellence for Nanoscale BioPhotonics, RMIT University, Melbourne, Australia

ABSTRACT

Fluorescent diamond has a range of unique properties which makes this material highly desirable for quantum sensing applications. The fluorescence is produced via optical excitation of atomic defects, such as the negatively charged nitrogen vacancy centre, within the diamond crystal lattice. Possessing long-wavelength emission, high brightness, no photobleaching, no photoblinking, a room temperature sensitivity to magnetic, electric and microwave fields, and an exceptional resistance to chemical degradation makes diamond almost the ideal fluorescent sensing material for a diverse range of applications. I will discuss these exciting properties in detail and also discuss hybrid sensing applications including the incorporation of nanodiamonds into glass to realise optical fibres that are intrinsically sensitive to magnetic fields, which is in contrast to conventional telecommunication-grade fibres.
**Point of Contact**
Presenter: Professor Brant Gibson  
Organization: RMIT University, Melbourne  
Country: AUSTRALIA

**Problem**
- How to make optical fibers intrinsically sensitive to magnetic and microwave fields which operate at room temperature

**Solution**
- Incorporate fluorescent nanodiamonds containing high densities of nitrogen vacancy (NV) centres into optical fibers

**Results**
- Current magnetic field sensitivity of 650 nT/√Hz at room temperature.
- Versatile and compact with optical readout
- Increased light collection efficiency by NV fluorescence coupling into fibre mode
- Field-deployable magnetometry scalable solution
- Potential to reduce sensitivity further to sub-nT/√Hz

**Quantum Sensing using Hybrid Diamond Materials**

Schematic of the incorporation of diamond into the optical fiber during the drawing process

**Characterisation of diamond-doped waveguiding optical fibre for magnetic field sensing applications**

**Funding**

**Collaborators**

**References**

ROADS LESS TRAVELED IN QUANTUM INFORMATION: CONTINUOUS VARIABLES AND RELATIVITY

Dr. Nicolas C Menicucci | Vice-Chancellor's Senior Research Fellow and Senior Lecturer, ARC Centre for Quantum Computation and Communication Technology (CQC2T), School of Science | RMIT University, Australia

ABSTRACT

The flow, manipulation, and measurement of quantum information offers a novel way to study physical problems. The benefits of this approach reach beyond qubits and can also inform our understanding of fundamental physics. The QuRMIT group at RMIT University in Melbourne, Australia, is applying quantum information (a) to continuous-variable systems for scalable quantum computing and (b) to relativity for new insights and pedagogical tools. This poster will introduce the interested delegate to our key results in these areas.
**Abstract**

The flow, manipulation, and measurement of quantum information offers a novel way to study physical problems. The benefits of this approach reach beyond qubits and can also inform our understanding of fundamental physics. The QuRMIT group at RMIT University in Melbourne, Australia, is applying quantum information (a) to continuous-variable systems for scalable quantum computing and (b) to relativity for new insights and pedagogical tools. This poster will introduce the interested delegate to our key results in these areas.

**Continuous-variable cluster states**

Continuous-variable cluster states are resource states for measurement-based quantum computing. These states must be large and have a 2D entanglement structure to be useful. The QuRMIT team regularly supports U Tokyo in producing large-scale cluster states [2] based on our designs (see Figure). We also characterize [3] and reduce the requirements [4] for fault-tolerant quantum computing.

**Bosonic codes**

The Gottesman-Kitaev-Preskill (GKP) encoding of a qubit into an oscillator is an appealing bosonic code due to its error correction properties. The QuRMIT group has shown that, given a source of approximate code states, whose ideal (periodic) Wigner functions are shown here, fault-tolerant quantum computation requires only Gaussian operations [1], greatly simplifying the experimental requirements for using it. This is the only known code that has this property.

**Relativistic quantum information**

Quantum information is fundamentally about measurements made by agents. The QuRMIT group has produced new insights into a sonic analogue of relativity [5] and demonstrated that ordinary (Newtonian) particles would appear to be Lorentz-violating objects to observers living in an analogue universe and limited to using sound for measurements [6]. This provides new pedagogical tools for relativity, as well as new ways to use laboratory experiments to study relativistic effects.

**References**


QuRMIT group website: qurmit.org
QUANTUM INFORMATION SCIENCE AND TECHNOLOGY AT UOM - BIO-SENSING TO QUANTUM COMPUTING

Lloyd Hollenberg | University of Melbourne, Australia

ABSTRACT

We summarise research at the University of Melbourne (UoM) in quantum computing and quantum sensing. In quantum computing, areas of interest range from topological quantum error correction, algorithm development and implementation on physical hardware (through the IBM Q Hub @ UoM), to quantum device simulation and theoretical considerations in the scale-up of architectures. In quantum sensing, the focus is on the experimental implementation of nano-magnetic resonance sensing, imaging and spectroscopy using the nitrogen-vacancy centre in diamond, with applications in biology and condensed matter systems.
Quantum Science and Technology at UoM

At UoM we work on a range of areas in quantum sensing and quantum computing:

- Quantum information and quantum error correction
- Applications on NISQ devices
- Silicon quantum computer architecture design
- Diamond-based quantum sensing/imaging technology in biology and condensed matter
- Quantum education

Quantum Computing

Quantum circuit/algorithm simulation

L: Simulation of Shor’s algorithm (60 qubits) [1]
R: Error cross-over in IQP circuits [2]

Quantum computing on IBM Q devices

Entanglement in a 20-qubit graph state on IBM Q “Poughkeepsie” [5]

Quantum error correction and architectures

L: Surface-code error threshold determination [3]
R: Silicon quantum computer architecture [4]

Atomistic quantum device simulation in silicon

L: Donor STM imaging – theory vs. experiment [6]
R: Atomic Si:P device simulation [7,8]

Quantum Sensing (NV diamond)

Quantum sensing in biological systems

L-R: NV sensing: in cells [9], lipid bi-layers [10], neurons [11], magnetic structures [12-14]

Quantum imaging of 2D materials/devices


Nano magnetic resonance (ESR and NMR)

L-R: Ultra-sensitive ESR/NMR [18,19], quantum hyperpolarisation [20], molecular microscope [21]

References


Education:
Quantum User Interface
Try it at: QUlspace.org

Web: blogs.unimelb.edu.au/quantum-technology/

Funding:

ARC Centre of Excellence for Quantum Computation & Communication Technology

IBM Q Hub @ UoM

Point of Contact
Author/Presenter: Lloyd Hollenberg
Organization: University of Melbourne (UoM)
Country: Australia
HOLOGRAPHIC QUANTUM ERROR CORRECTING CODES

Nathan McMahon | EQUS (Engineered quantum systems) centre of excellence, University of Queensland, Australia

ABSTRACT

A key requirement for quantum communication and computation is the ability to perform error correction on the underlying quantum systems. These systems are particularly sensitive to noise sources and this is the biggest hurdle to these kinds of quantum engineering tasks. There are two sources of noise: loss errors, errors due to the loss of a qubit during the communication or computation process, and Pauli errors, errors which alter the state of the machine for example flipping a qubit from the 0 state to the 1 state, or by changing the phase of the qubit. Both kinds of noise can be overcome using quantum codes which encode logical qubits into physical qubits to protect the quantum state from noise.

One class of quantum codes is the holographic quantum code, inspired by the “holographic principle” from cosmology. These holographic codes are constructed by concatenating smaller seed quantum codes, the pattern of concatenation is formed by the holographic geometry, leading to logical qubits in the bulk of a hyperbolic disc being encoded onto physical qubits at the boundary of the disc. This process keeps the ratio of logical qubits encoded into physical qubits roughly constant, while spreading the logical qubits over the boundary qubits.

We have studied a particular holographic code based on the quantum Steane code and its tolerance to error sources. We have shown that for sufficiently large holographic codes we can recovery the logical qubits when each physical qubit has a 33% chance of being loss. We also showed that if each physical qubit has no more than a 5% chance of a bit flip or phase flip Pauli error then we can also recover logical qubits in sufficiently large holographic codes.

Finally we have also studied the construction of holographic codes using cluster states, and found that any sized holographic code may be systematically constructed in a constant number of steps.
Holographic Quantum Error Correcting Codes

Quantum systems respond poorly to noise. Quantum error correction is required to deal with errors created by noise, either loss errors, or Pauli errors (bit flip or phase flip errors).

"Holographic codes" are inspired by the "holographic" principle from cosmology, the logical information of the bulk is stored on the physical boundary.

Quantum seed codes can be built from cluster states (right). Concatenating seed codes is achieved by combining (fusing) two data qubits into one internal data qubit. Two concatenated seed codes are shown below.

Radius 3 holographic code, 43 Logical qubits (red dots) are encoded into 203 physical qubits (white dots) on the boundary of a negatively curved disc.

Recovery probability of holographic codes (vertical axis) as the Pauli error rate increases (horizontal axis). Bigger codes (larger R) perform better for error rates below 5%.

Recovery probability of holographic codes (vertical axis) as the erasure rate increases (horizontal axis). Bigger codes (larger R) perform better for loss rates below 33%.

Harris et al. (2018). PRA, 98(5), 052301.
QUANTUM TECHNOLOGY LAB AT UQ

Dr. Till Weinhold "Till" | Quantum Technology Laboratory, ARC Centre of Excellence for Engineered Quantum Systems, School of Mathematics and Physics, The University of Queensland, Brisbane, Australia

ABSTRACT

We present an overview over the range of experiments undertaken at the Quantum Technology Laboratory (QT Lab). We utilise single photons encoded in either time, space, polarisation or orbital angular momentum modes to investigate and harness quantum effects and the foundations of quantum mechanics.

At the QT Lab we utilise spontaneous parametric down conversion sources as well as cavity embedded quantum dot sources for single photon generation and have access to the common single photon avalanche diodes, superconducting nanowire detectors and the uncommon, but highly sensitive and photon number resolving transition edge sensors for photon detection.

We will present an overview over our areas of work, ranging from storage of single photons in a gradient echo memory, investigation of the quantum causal order, quantum limited imaging, post-selected opto-mechanical state generation and our work towards temporally multiplexed high-photon number quantum tasks enabled by temporal multiplexing of photons generated from tuneable quantum dots.
Poster not available at time of print
ABSTRACT

UNSW Canberra Space has a number of research projects related to achieving a Low Earth Orbit inter-satellite optical link capable of performing a number of different quantum channel interactions including discrete variable and continuous variable systems that can transfer the quantum state using polarisation or orbital angular momentum modes. These include laboratory and in-orbit flight experiments. The relative satellite pose and positioning is to be achieved by a combination of attitude determination instruments and fine pointing. The fine pointing comes for a combination of LEO drag and lift manoeuvres, plasma interaction effects through charging, and optical MEMS pointing. Links to space from the ground and vice versa are also being investigated.
Towards Inter-Satellite Laser and Quantum Communications

We develop laser communications between Nanosatellites for the purposes of supporting Quantum Key Distribution and Quantum Entangled Networks. Whether the link is classical or quantum state is transferred, either by polarisation with discrete variable or continuous variable, or by orbital angular momentum, the free-space optical specifications require substantial refinement. Considerations include:

- Fine Pointing
- Beam Capture and Tracking.
- Relative Body motion (reference axis)
- Light budget with Range
- Low Size, Weight and Power (SWAP)

On-orbit and Laboratory Experiments

UNSW Canberra Space have a number of Low Earth Orbit (LEO) satellites with experiments to provide fine pointing and stability using:

- Bespoke star-trackers and ADCS
- Aerodynamic lift and drag for formation control
- Plasma-charged surface interaction
- Novel image sensing for fast acquisition and tracking using LED and Laser Beacons
- Fast Steering Mirror
- Flight experiments through M2 risk mitigation and M2 dual 6U satellites.

Future Advances

Australasia are working on a network of Quantum Ground Stations. First of these is funded by ACT Government PIP Scheme.

Acknowledgements

Thanks to the Windows on Science WOS-192118 AFOSR/AOARD
NUS-UNSW collaboration

References


Bai X; Islam MT; Ilangovan K; Nguyen HN; Chandrasekara R; Tang Z; Tang Z; Barraclough S; Griffin D; Boyce R; Ling A, “SpooQy-1, a CubeSat to demonstrate an entangled photon light source”, Advances in the Astronautical Sciences, pp. 565 – 575 (2018).
LIGHT-MATTER ENTANGLEMENT OVER 50 KM OF OPTICAL FIBRE

V. Krcmarsky1,2, V. Krutyanskiy1, M. Meraner1,2, J. Schupp1,2, H. Hainzer1,2, and B. P. Lanyon1,2

1 Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstr. 21A, 6020 Innsbruck, Austria. 2 Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

ABSTRACT

When shared between remote locations, entanglement opens up fundamentally new capabilities for science and technology. Envisioned quantum networks use light to distribute entanglement between their remote matter-based quantum nodes. Here we report on the observation of entanglement between matter (a trapped ion) and light (a photon) over 50 km of optical fibre. Our methods include an efficient source of ion-photon entanglement via cavity-QED techniques (0.35 probability on-demand fibre-coupled photon from the ion) and a single photon entanglement-preserving quantum frequency converter to the 1550 nm telecom C band (0.25 device efficiency). Modestly optimising and duplicating our system would already allow for 100 km-spaced ion-ion heralded entanglement at rates of over 1 Hz.[1].

REFERENCES

Point of Contact
Presenter: Vojtech Krcmarsky
Organization: Institute for Quantum Optics and Quantum Information; University of Innsbruck
Country: Austria

Abstract
When shared between remote locations, entanglement opens up fundamentally new capabilities for science and technology [1,2]. Envisioned quantum networks distribute entanglement between their remote matter-based quantum nodes, in which it is stored, processed and used. Here we report on the observation of entanglement between a trapped ion and a photon over 50 km of optical fibre. Our methods include an efficient source of light-matter entanglement via cavity-QED techniques [3] and a quantum photon converter to the 1550 nm telecom C band. Our results show a direct path to entangling remote registers of quantum-logic capable trapped-ion qubits and the optical atomic clock transitions that they contain spaced by hundreds of kilometers.

Long-term vision:
Long-distance light-matter network
• Matter nodes for storage and manipulations
• Linked with photonic channels

Our approach to scaling up distance
A. Ion-cavity coupling for efficient infra-red photon collection and entanglement
• Ca40: natural wavelength 854 nm good for few km network (att. 3dB/km)
B. Quantum frequency-conversion to 1550 nm: good for >100km (att. 0.2dB/km)

Results
i. 2D red bars: histogram of photon detection times (photon wavepacket in dashed box), following the generation of an 854nm photon with a 30µs Raman laser pulse ≈250 µs earlier, repeated at 2.2 kHz. Ion-photon state tomography is performed for photon detection events recorded in the dashed box (total contained probability P = 5.3 × 10⁻⁴). ii. 3D bars: absolute value of experimentally-reconstructed density matrix of the telecom photonic polarisation qubit and ion-qubit state. Concurrence C= 0.75 ± 0.05; Fidelity F = 0.86 ± 0.03

Outlook: 100 km ion – ion entanglement
By duplicating our experiment, and following a two-photon click heralding scheme we can project ions A1 & B1 into an entangled state with a rate of 0.1 cps. Following a one-photon click heralding scheme instead we could achieve rate of 4 cps. Deterministic intranode quantum logic and measurement between e.g. B1 & B2 and A1 & A2 can swap the entanglement over larger distances (quantum repeater).
AN ION-TRAP QUANTUM SIMULATION IN A SELF-ASSEMBLED SETUP

Paul C Haljan | Department of Physics, Simon Fraser University, Canada

ABSTRACT

Trapped ions with engineered laser and microwave interactions are a versatile technology for quantum information processing and quantum simulation. An intrinsic feature of trapped ions in a linear Paul trap is the transition from the linear to zigzag crystalline structure, which provides a ‘built-in’ setup to study the dynamics of a mesoscopic phase transition in the vicinity of its critical point. Using technologies from trapped-ion quantum information processing, we are studying the linear-to-zigzag transition close to the critical point for the first time at temperatures near the ground state. We are ultimately interested to see whether superposition states of the zig and zag symmetry-broken configurations can be prepared, and how the decoherence of such states depends on the number of ions.
An Ion-Trap Quantum Simulation in a Self-Assembled Setup

**Question:** Can we prepare superpositions of the zig and zag crystal structures?

$$|\Psi\rangle = \frac{1}{\sqrt{2}} \left( |\text{zig}\rangle + |\text{zag}\rangle \right)$$

**Superposition state and double well near the critical point.**

**Technological challenges:** Ground-state cooling of ion strings, high-stability trap potential, motional decoherence ....

**Technologies**

**3-D Sisyphus cooling of ion strings**

- Simple, robust pre-cooling of all modes in 3D.

**Transition control using optical dipole force with single-atom resolution.**

**Trap potential stabilization**

- Passive/active stabilization of RF and DC voltages.
- Axial/Transverse: ≤6 ppm in 200 s, ≤15 ppm over 1 hour

**Transverse trap stability**

Transverse results ~2X improvement compared to K. G. Johnson et al. (2016).

**Energy levels for ideal transition.**

**Measured energy levels near the critical point:**

Spectroscopy reveals bias in double well with high sensitivity.

**Future:**

This work sets the stage for investigations of coherence effects near the critical point.
ALTERNATIVE PHOTON ENCODINGS FOR FREE-SPACE QUANTUM COMMUNICATIONS

Thomas Jennewein | Science Lead for QEYSSat, Associate Professor in the Department of Physics and Astronomy, Quantum Photonics Laboratory at Institute for Quantum Computing, University of Waterloo, ON, Canada

ABSTRACT

Satellite based quantum communications enables long distances and will lead to global quantum networking. I will present recent results towards implementing the Canadian Quantum Satellite Mission, QEYSSAT, which will be primarily be a quantum receiver for signals from ground to space. I will give an overview of recent laboratory tests of payload components and its demonstration for a quantum link between a ground station and an aircraft. I will discuss recent advances on implementations and tools useful for generating and distributing photonic quantum entanglement, as well as our work towards implementing the Canadian quantum satellite mission.
Poster not available at time of print
OPTICAL AND MAGNETIC PROPERTIES OF SINGLE QUANTUM EMITTERS

Dr. Professor Jeronimo Maze "Jero Maze" | Institute of Physics, Pontificia Universidad Católica de Chile, Santiago, Chile

ABSTRACT

The control of degrees of freedom associated to single quantum emitters has increased the possibilities for implementing novel applications in quantum metrology and quantum information. A successful quantum emitter is the nitrogen-vacancy center in diamond which has enabled high sensitive and high-resolution magnetometry applications, and provided access to several other nuclear quantum bits in diamond for information processing. The exploration of new single emitters in other materials might lead to novel systems with improved properties for these applications such as larger emission intensities and longer coherence times. We present a project to create color centers in large bandgap materials, in particular, two dimensional materials which shows spin-dependence optical properties in order to optically prepare and readout electronic spins. In particular we will focus on new emitters in bulk hexagonal boron nitride and how to produce these systems in single layer hexagonal boron nitride through ion implantation. We discuss about the possible defects and their configurations that can be created by this method and the expected spin multiplicity and dynamics that will play a crucial role on their characterisation through optically detected magnetic resonance and spin spectroscopy to evaluate their coherence. Creating stable color centers in two-dimensional systems will be useful to study surface properties of other materials such as topological insulators for novel information processing devices.
Poster not available at time of print
MOLECULAR SPINS FOR QUANTUM SCIENCE AND TECHNOLOGIES

Prof. Marco Affronte | Università di Modena e Reggio Emilia & CNR, Italy

ABSTRACT

Molecular spins have shown genuine quantum properties, both as collection of independent units as well as individual objects. For instance, spin entanglement between different molecular units has been demonstrated and coherence time of selected electron molecular spin allows observation of Rabi oscillations at room temperature. Their characteristics and performances can be engineered at molecular level while advanced technologies to coherently manipulate magnetic objects and to address them with unprecedented spatial and energy resolution have emerged in the last years. For instance, Quantum (Grover’s) algorithm has been encoded in a single molecule with electrical read out. Molecular spins are model systems whose dynamics can be described by precise models offering test bed for quantum simulation. Advanced quantum control by microwave pulses will also allow us to exploit these spin systems for quantum sensing.
Molecular Spins for Quantum Science and Technology

Objectives
- To Select Molecular Spins as Quantum objects
- To develop Quantum control for manipulating molecular spins
- To develop quantum hybrid devices working at microwave.

Problem: Quantum control for Molecular Spins

Next Challenges:
- Read out of single spin by photon
- To develop Quantum control for possible applications in biology as Quantum Sensors
- molecular spin clusters for Quantum Simulation (both as simulators and physical system to be simulated)

International Collaborations
Prof. Takeji Takui, Osaka City University (Jp)
Prof. Stephen Hill, Florida State University (USA)

AFRL AOARD Grant No. FA2386-17-1-4040

Spin of single molecules embedded in electronic circuits can be read and manipulated for qubit encoding

Nanoletters 11, 2634 (2011)
Dalton Transactions, 45, 16570 (2016)

Coherent coupling of molecular spins with microwave photons

Design fabrication and use of high Tc superconducting planar MW resonators for hybrid Quantum Electrodynamic circuits

Scientific Reports 7, 13096 (2017)
Advances in Physics X3:1, 1435305, (2018)
QUANTUM CHEMICAL CALCULATIONS ON QUANTUM COMPUTERS: QUANTUM ALGORITHMS

Kenji Sugisaki, Shigeaki Nakazawa, Kazunobu Sato, Kazuo Toyota, Daisuke Shiomi, Takeji Takui | Department of Chemistry and Molecular Materials Science, Graduate School of Science, Osaka City University, Japan

ABSTRACT

Quantum computing and quantum information processing (QC/QIP) is one of the most innovative research fields not only in computer and information sciences, but also in interdisciplinary areas among physics, mathematics, chemistry, materials science, and so on. The appearance of a quantum computer processor consisting of 72 quantum bits (qubits) from Google LLC reminds us that it is close to “quantum supremacy”,1 and intercontinental quantum communications between China and Austria have been demonstrated very recently.2 Among the diverse subjects in QC/QIP, quantum simulation of electronic structure problems of atoms and molecules is one of the most intensively studied realms.3

The full configuration interaction (full-CI) method is capable of providing the numerically best wave functions and energies of atoms and molecules within basis sets being used, although it is intractable for classical computers. Quantum computers can perform full-CI calculations in polynomial time against the system size by adopting a quantum phase estimation algorithm (QPEA). In the QPEA, the preparation of initial guess wave functions having sufficiently large overlap with the exact wave function is recommended. The Hartree–Fock (HF) wave function is a good initial guess only for closed shell singlet molecules and high-spin molecules carrying no spin-β unpaired electrons, around their equilibrium geometry, and thus, the construction of multiconfigurational wave functions without performing post-HF calculations on classical computers is highly desired for applying the method to a wide variety of chemistries and physics. In this work, we propose a method to construct multiconfigurational initial guess wave functions suitable for QPEA-based full-CI calculations on quantum computers, by utilizing diradical characters computed from spin-projected UHF wave functions. The proposed approach drastically improves the wave function overlap, particularly in molecules with intermediate diradical characters.4

ACKNOWLEDGMENTS

This work was supported by AOARD Scientific Project on Quantum Properties of Molecular Nanomagnets” (Award FA2386-13-1-4029, 4030, 4031) and AOARD Project on “Molecular Spins for Quantum Technologies” (Grant FA2386- 17-1-4040), USA, and by Grants-in-Aid for Scientific Research B (17H03012) and Scientific Research C (18K03465) from the MEXT, Japan. This work has been partially supported by Grants-in-Aid for Scientific Research on Innovative Areas (Quantum Cybernetics), Scientific Research B (23350011), Grants-in-Aid for Challenging Exploratory Research (25620063) from MEXT, Japan, and by FIRST Quantum Information Processing Project, the Cabinet Office, Japan.

REFERENCES

(1) Kelly, J. Engineering superconducting qubit arrays for quantum supremacy; APS March Meeting, 2018.


**Objectives of Project**
The full configuration interaction (full-CI) method is capable of providing the numerically best wave functions and energies of atoms and molecules within basis sets being used, although it is intractable for classical computers. Quantum computers can perform full-CI calculations in polynomial time against the system size by adopting a quantum phase estimation algorithm (QPEA). In the QPEA, the preparation of initial guess wave functions having sufficiently large overlap with the exact wave function is recommended. The Hartree–Fock (HF) wave function is a good initial guess only for closed shell singlet molecules and high-spin molecules carrying no spin-β unpaired electrons, around their equilibrium geometry, and thus, the construction of multiconfigurational wave functions without performing post-HF calculations on classical computers is highly desired for applying the method to a wide variety of chemistries and physics. In this work, we propose a method to construct multiconfigurational initial guess wave functions suitable for QPEA-based full-CI calculations on quantum computers, by utilizing diradical characters computed from spin-projected UHF wave functions. The proposed approach drastically improves the wave function overlap, particularly in molecules with intermediate diradical characters.

**References:**
SECURE QUANTUM COMPUTING

Dr. Joseph Fitzsimons "Joe" | Centre for Quantum Technologies, Singapore

ABSTRACT

This poster gives an overview of research into various secure quantum computation protocols. These include blind quantum computation, in which privacy is protected from an untrusted quantum computer used to perform calculations; verification protocols for quantum computation; quantum analogues of homomorphic encryption; quantum one-time programs; and schemes for computing on secret-shared quantum information.
**Point of Contact**
Author/Presenter: Dr. Joseph Fitzsimons
Organization: Centre for Quantum Technologies
Country: Singapore

**Overview of Secure Quantum Computation Research**
Quantum information processing offers the possibility of new cryptographic functionality and improved security guarantees. At the same time, quantum computation offers more efficient algorithms for a range of computational tasks. We explore the intersection of quantum computation and cryptography in the context of securing delegated quantum computation.

**Blind Computation**
Quantum computation can be delegated to a remote computer while maintaining privacy over input and computation, even if server is malicious.

- Requires single qubit preparation and transmission.

**Verification**
Blind computation protocols can be made verifiable through the introduction of trap qubits. The simple scheme illustrated below leads to a success probability of \(1/n\) of detecting a malicious server.

This can be made arbitrarily close to 1 using a more complicated embedding of the computation.

**Imperfect one-time programs**
Imperfect one-time programs can be constructed by encoding the truth table for individual gates in anti-commuting observables of quantum states. Although imperfect, these can be used to realize perfect one-time delegation of digital signatures.

**Homomorphic encryption**
Information theoretically secure fully-homomorphic quantum encryption is not possible, but many somewhat-homomorphic schemes are.

**Computing on shared quantum secrets**
Computation on \((n,n)\)-shared secrets without an honest majority.
INFRARED METROLOGY WITH VISIBLE LIGHT

Dr. Leonid Krivitsky  |  Institute of Materials Research and Engineering (IMRE), Agency for Science Technology and Research (A*STAR), Singapore

ABSTRACT

Infrared (IR) optical range is important for material characterization and sensing. Also, imaging in the IR range yields superior image contrast due to a significant reduction of scattering losses. Thus IR metrology is widely used in petrochemical, pharma, biomedical, homeland security, and other areas.

Even though there are well-developed conventional methods for IR metrology, the remaining challenges are associated with high cost, low efficiency and regulatory requirements for IR light sources and detectors. To mitigate these issues we are developing new quantum-enabled techniques which allow us retrieving properties of materials in the IR range from the measurements of visible range photons.

The approach is based on the nonlinear interference of frequency correlated photons produced via spontaneous parametric down conversion (SPDC) [1, 2]. Within this process, one of the photons is generated in the visible range, and its correlated counterpart in the IR range is used to probe the properties of the medium. The visibility and phase of the observed fringes depend on the properties of the IR photon, which interacts with the sample. This allows us inferring the properties of the sample in the IR range from the measurements of visible range photons.

In a series of experiments, we demonstrate the IR spectroscopy [1-3], tunable optical coherence tomography (OCT) [4], and polarimetry [5]. In all these demonstrations the IR properties (absorption spectra, refractive index, 3D images, and polarization) are inferred from the measurements of the interference pattern in the visible range thus making IR measurements more affordable.

REFERENCES

**IR metrology with visible light**

In our IR-metrology technique the information about properties of the samples in the IR range is inferred from the detection of visible range photons. It is used for IR spectroscopy, polarimetry and optical coherence tomography.

**Our approach: nonlinear interferometer**

Correlated VIS and IR photons are generated in nonlinear crystals, assembled in the interferometer. Interference fringes for the VIS photons depend on the properties of the IR photons which interact with the sample.

**Advantages of the technique**

- Measurements of IR properties with low-cost and efficient components for visible light
- Widely tunable wavelength range
- No export control components

**Optical setup**

Interference pattern for the visible photon is affected by the absorption of the IR photon

Visibility and phase of the fringes depend on losses and dispersion in the IR channel

**IR spectroscopy**

Visibility and phase of the fringes depend on losses and dispersion in the IR channel

**IR optical coherence tomography**

Sensitivity to positions of reflective surfaces

**Summary and references**

We can substitute and/or complement conventional IR-methods of spectroscopy, imaging and polarimetry by using well-developed components for the visible range.

- Paterova et al. NJP 20, 043015 (2018)
- Paterova et al. Opt Express 27, 2589 (2019)
QUANTUM ALGORITHM OPTIMIZATION, GRAVITY EFFECTS ON SATELLITE QKD AND QUANTUM RELATED RESEARCH IN KOREA

Doyeol (David) Ahn | University of Seoul, South Korea

ABSTRACT

Every quantum algorithm is represented by a set of quantum circuits. A quantum Karnaugh map that operates on the Hilbert space state vectors is studied to facilitate the efficient design of universal quantum circuits. The map could provide an efficient method for reducing the complexity of quantum circuits substantially. Einstein's "spooky action at a distance" is quickly being forged into a global spacetime quantum communication with the recent launch of China's Micius satellite. It extends length and time scales for tests of quantum theory to relativistic distances and velocities. We investigated a quantum mechanical Wigner rotation of photons caused by the gravitational field difference between the ground station and the satellites in Earth Orbit and found that quantum effects on the photon polarization should be measurable. This would be a unique setup to understand the intertwining of the theories of the quantum and of gravitation. Quantum information science research at the University of Seoul and South Korea is introduced. A brief introduction of the spin-off startup from the University of Seoul in related area is also given.
**Problem or Objective**
Quantum Algorithms are represented by quantum circuits. New protocol, Quantum Karnaugh Map, to reduce the complexity of the quantum circuits is proposed and verified theoretically.

**Solution or Approach**
We proposed new material for very high efficient optoelectronic devices and proved the concept. A spin-off venture company is founded in 2015.

**Results**
40% reduction of quantum circuit complexity is achieved with QKM; Quantum effects is pronounced in satellite QKD system; New hybrid GaN/CuI LED is demonstrated. Experimentally verified that PL of CuI is 10 times larger than that of GaN at RT; Lasing of vertical cavity CuI is demonstrated; Acoustic half-bipolar cylindrical cloak is theoretically verified.

**Quantum related research areas in Korea:**

**International collaborations with:**
AOARD(Maj. Christopher Vergien), AFRL (Dr. Paul M. Alsing), Florida Atlantic University (Prof. W. A. Miller) & IITP (Korea)
QUANTUM STAND-OFF SENSING PROJECT

Yong Sup Ihn, Su-Yong Lee, Sin Hyuk Yim, Tae Hyun Kim, Sangkyung Lee, Kyu Min Shim and Zaeill Kim | Agency for Defense Development (ADD) / South Korea

ABSTRACT

ADD is an advanced research institute of national security in South Korea. The technical research division develops the subsystems used in various weapon systems through research on high-tech common/core technologies. ADD also supports the theoretical and experimental research activities conducted by the academic society to acquire new knowledge necessary for the fundamental and core technology development. As the opening stage, Quantum Physics Technology Directorate in ADD is planning to pursue workforce development in theoretical and experimental study for quantum sensing.
Poster not available at time of print
ENABLING-FREE SPACE QKD UNDER STRONG TURBULENT CONDITIONS WITH DOUBLE-LOOP WAVEFRONT TILT CORRECTION

Veronica Fernandez-Marmol | Spanish National Research Council (CSIC), Spain

ABSTRACT

Future Quantum Networks will require efficient Quantum Key Distribution (QKD) links operating under realistic conditions of atmospheric channels, which implies high turbulent scenarios and daylight conditions. Wavefront tilt correction reduces the effects of atmospheric beam deflections (beam wander) at the optical receiver and allows reduction of its field of view, which decreases solar background noise, the main contribution to the Quantum Bit Error Rate (QBER) in QKD free-space systems. Typical tilt correcting systems use one control proportional-integrative-derivative (PID) loop with a position sensitive sensor (PSD) and a fast steering mirror (FSM). However, with this configuration, correction is obtained only in one plane, imposing severe restrictions to both the optical design of QKD receivers and to the performance of PSD detectors, since these are forced to operate in the focal plane of the receiver, where the performance of PSDs is not optimal. In our implementation, we have used two control loops, placed in separate planes of the optical receiver, and tested for a QKD system in a 300 meter-link. A reduction of the beam area of fluctuations at the focal plane of the QKD receiver of more than 80% in strong turbulent regimes was measured, which is equivalent to the same reduction in the QBER caused by solar radiation. Moreover, the double-loop strategy achieves correction in infinite planes of the receiver and achieves a 25% increased reduction of the beam area than a single-loop strategy.
Problem or Objective
Future quantum networks will require high speed and robust free-space Quantum Key Distribution (QKD) links. Removing atmospheric fluctuations an efficient manner is a necessary requirement to achieve this.

Solution or approach

Single-Loop correction. Simplest setup for correcting atmospheric tilt is through a Proportional-Integrative-Derivative (PID) loop with a position sensitive detector and a fast steering mirror.

Double-Loop correction. Using two loops in separate optical planes of the receiver allows correction of atmospheric effects in the whole optical axis of the receiver, which:
- removes limitations in the optical design,
- allows PSD detectors to operate away from the focal plane,
- removes effect of optical lens aberrations.

Results

Double-Loop correcting system. Two beams in the transmitter: 1550 nm-wavelength for the tilt correction and 850 nm for the quantum channel. In the receiver, a 25.4 cm Schmidt-Cassegrain telescope collected both tracking and quantum signals, and a Dichroic Mirror (DM) spectrally discriminated and directed them to their corresponding channels.

Experimental correction. The correction with double-loop achieves an increased 25% reduction in beam fluctuations compared to single-loop and improves the usability in QKD systems since correction is achieved in the whole receiver and not in a single plane.

Figure 1. 300-meter link between Alice and Bob, sender and receiver of a quantum key distribution system.

Correcting tilt allows reducing the area of beam fluctuations at the field of view of the receiver, which reduces the solar background noise, the main contribution to the Quantum Bit Error Rate of free-space QKD systems.

Figure 2. Results from a QKD system with non corrected tilt showing increase of QBER in daylight (secondary axis).

Figure 3. Single control loop for correcting atmospheric beam fluctuations.

However, using a single control loop allows correction in only one plane of the receiver, which places restrictions on the optical setup and obliges the detectors to operate in the focal plane.

Figure 4. Double-loop configuration in the receiver of a QKD system.

Figure 5. Double-loop experimental configuration for a QKD system.

Figure 6. Experimental and theoretical errors of the tilt correction with single and double-loop strategies.
ACCREDITATION OF NOISY INTERMEDIATE-SCALE QUANTUM COMPUTING DEVICES
Animesh Datta, Samuele Ferracin, Theodoros Kapourniotis | University of Warwick, United Kingdom

ABSTRACT

We present an accreditation protocol for the outputs of noisy intermediate-scale quantum devices. By testing entire circuits rather than individual gates, our accreditation protocol can provide an upper-bound on the variation distance between noisy and noiseless probability distribution of the outputs of the target circuit of interest. Our accreditation protocol requires implementation of quantum circuits no larger than the target circuit, therefore it is practical in the near term and scalable in the long term. Inspired by trap-based protocols for the verification of quantum computations, our accreditation protocol assumes that noise in single-qubit gates is bounded (but potentially gate-dependent) in diamond norm. We allow for arbitrary spatial and temporal correlations in the noise affecting state preparation, measurements and two-qubit gates.
Poster not available at time of print
QUANTUM METROLOGY AND SENSING AT STRATHCLYDE

Erling Riis | University of Strathclyde, United Kingdom

ABSTRACT

The use of cold atoms has led to a substantial increase in the accuracy achievable in many atomic physics measurements. This has most notably been demonstrated in the atomic clock relying on the interference of internal states of weakly interacting atoms in free fall. However, it has also led to an additional layer of experimental complexity which, combined with the physical size of state-of-the-art setups, impose significant limitations on wider practical applications.

The combination of coherent population trapping (CPT) and laser cooled atoms is a promising platform for realising the next generation of compact atomic frequency references. Towards this goal, we have developed an apparatus based on the grating magneto-optical trap (gMOT) and the high-contrast lin–lin CPT scheme in order to explore the performance that can be achieved [1].

The gMOT concept has provided a step-change in miniaturised cold-atom technology. The ability to design and manufacture an efficient optical component (effectively a hologram), that from one incoming beam generates the other beams required for a magneto-optic trap, has enabled the realisation of a compact setup for laser cooled atoms. The performance of the gMOT and subsequent optical molasses is on par with conventional techniques, but is significantly more compact and with a vastly reduced alignment requirement [2,3].

In a separate programme, unshielded optically pumped atomic magnetometers (OPM) are developed as portable, miniaturised sensors. Based on microfabricated MEMS vapour cells and a single VCSEL light source a compact sensor (physics package ~10 cm3) has been developed and field-tested. Using bespoke digital control system and FPGA based signal processing a sensitivity for unshielded operation of ~3 pT/√Hz and a bandwidth of >600 Hz has been demonstrated [4]. The simplicity, size, weight and power of this sensor combined with its high sensitivity (<0.1 ppm of Earth field), bandwidth and low drift makes this an excellent sensor for portable, distributed and field-deployable sensor networks.

References

Objectives

Development of miniaturised and portable measurement devices based on laser/atom interactions with particular interests in:

- Cold atom microwave clocks
- Optically pumped atomic magnetometers

Cold atom microwave clock

The coherent population trapping (CPT) transition in cold Rb atoms is driven by $\text{lin} \perp \text{lin}$ polarisation [1]

Bichromatic laser interacts with cold atoms in free fall

Bichromatic laser interacts with cold atoms in free fall

Allan deviation plot for a free evolution time of $T=10$ ms

Microfabrication of gratings

e-beam lithography on Si wafer

Si wafer e-beam Coating Test

Microfabricated gratings [4]

Realisation with mirrors [2]

Microfabricated optical gratings are commercialised by Kelvin Nanotechnology – www.kntnano.com/quantum/gmotgrating/

Realisation with blazed gratings [3]

Atomic magnetometry

The magnetic moment of an atom precesses in a magnetic field with a frequency proportional to the field: $\omega_L = \gamma B_0$

Four parts to setup:
1. Laser (VCSEL)
2. Vapour cell
3. Detector
4. Control and signal processing

Sensitivity: a few $\mu$T/$\sqrt{\text{Hz}}$

Bandwidth: >600 Hz [5]

Compact sensor based on scalable MEMS vapour cell

References

COMPUTING, DETECTION, AND TRANSDUCTION WITH SUPERCONDUCTING CIRCUITS

Olli Saira  |  Brookhaven National Laboratory, United States of America

ABSTRACT

I present three research directions of varying levels of maturity that I’m personally involved with. The first topic is transduction between superconducting resonators and cold atomic memories. Here, we aim to engineer strong coupling between a microwave excitation in a compact, sub-wavelength resonator and the hyperfine clock transition in a cold ensemble of $10^5$ Rb-87 atoms trapped in the vicinity of the resonator. The second topic is thermal photodetection with two-dimensional van der Waals materials. We aim to create a number-resolving and wavelength-sensitive photodetector based on the kinetic inductance detector (KID) principle using a graphene absorber. Initial data showing dispersive readout of the flake temperature and square-law response to Joule heating at 150 mK is shown. The final topic is resource-efficient computation with superconducting logic. We repeat a classic demonstration of Landauer-efficient bit resent using a modified flux qubit circuit.
Transduction between superconducting resonators and cold atomic memories

Objective: Realize coherent transduction between optical photons and microwave excitations in superconducting circuits. Connect superconducting quantum processors to existing quantum network to create a distributed computing platform.

Our approach: Trap a cold ensemble of $^{87}\text{Rb}$ atoms ($N = 10^5$) in the magnetic field of a sub-wavelength resonator tuned to the hyperfine clock transition.

Status: Collaboration between Stony Brook University, Brookhaven Lab, and NIST. Major funding requests pending.

Two-dimensional van der Waals materials for ultra-high resolution thermal detectors

Objective: Realize a number-resolving and wavelength-sensitive thermal photodetector using graphene. Target $\Delta E = h \times 0.1 \text{ THz}$. Study thermal conductance and heat capacity of two-dimensional van der Waals materials.

Background: The heat capacity and (parasitic) thermal conductance of a graphene flake are small, leading to good figures-of-merit for detector. Electrical and optical signals can be efficiently coupled to the flake. Graphene-based photodetectors are abundant in the literature.

Our approach: We couple a ballistic, hBN-encapsulated graphene flake to a superconducting resonator through superconducting edge contacts. This realizes a dispersive, minimally invasive readout of the flake temperature similar to MKID (microwave kinetic inductance) detectors.

Status: Measurements of first device are underway. Observed thermalization down to 150 mK. Strong tuning of resonance frequency with backgate voltage. Square-law response to electrical Joule heating applied through independent heating contacts. Collaboration with Caltech and University of Kansas.

Statistics of information erasure in superconducting flux logic

Objective: Realize thermodynamically efficient and high clock rate logic using superconducting circuit elements and flux quantization.

Background: Minimization and mitigation of waste heat are outstanding issues in modern HPC design. Landauer (1961) presented the seminal theoretical work on the limits of physical computation devices, which were refined and extended over the last few decades. Computing devices operating at the Landauer limit of heat dissipation have been demonstrated. However, all demonstrations to date are fairly slow and/or not amenable to scaling up in complexity to usable processors.

Our approach and results:

We demonstrate thermal-fluctuation-driven bit reset at 500 mK in a modified superconducting flux qubit and simultaneous measurement of heat dissipation with sub-$k_B T$ resolution. Next iteration of experiment to target GHz clock rate and quantum-coherent evolution. Collaboration with Caltech and University of Kansas.
QUANTUM FOR LOGISTICS

Austars Schnore "Aussie" | GE Global Research, United States of America

ABSTRACT

GE builds and maintains things that move, power and cure the world. Sustaining these things to maintain a high level of availability for our customers requires a significant investment in labor and equipment. So the question that we would like the quantum computer to help us with is “How can GE improve availability of these assets and the efficiency of sustainment operations”? This is an interactive demonstration where participants will be able to setup a repair shop with a number of repairs that need to be performed across a set of shared repair resources. The problem will then be formulated into a format that can be used by quantum computer to minimize congestion of all the repairs across these resource. After formulation the participant will be able to apply the problem to a DWave quantum computer. The results of the minimization and the mapping used by the quantum computer will be available for visualization. This is not a canned demo and it will uses a real quantum computer. If this is your first time running a quantum computer we might even give you a free gift.
Quantum Computing at GE Research

ASSET SUSTAINMENT

QC will act as accelerators to existing computers

Aussie Schnore, Annarita Giani

Quantum Computing at GE Research

Energy = Cost + Constraints

Scaling Challenges

<table>
<thead>
<tr>
<th>Repairs</th>
<th>Sequences/Qubits</th>
<th>Resources</th>
<th>Combinations</th>
<th>Constrained Choices</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>12</td>
<td>6</td>
<td>128</td>
<td>12</td>
<td>Small Farm</td>
</tr>
<tr>
<td>10</td>
<td>48</td>
<td>94</td>
<td>268,435,456</td>
<td>12,288</td>
<td>Corner Garage</td>
</tr>
<tr>
<td>30</td>
<td>100</td>
<td>230</td>
<td>~10^27</td>
<td>~10^4</td>
<td>Dealer Service Shop</td>
</tr>
<tr>
<td>15000</td>
<td>40k</td>
<td>6000</td>
<td>~10^1300</td>
<td>~10^6900</td>
<td>GE Problem</td>
</tr>
</tbody>
</table>

Current Effort in Quantum Computing at GE Research

NEEDS

Better architecture
- Better topology
- Lower noise machine
- More qubits

Preprocessing
- Restrict paths around highly congested resource
- Lower precision requirement to better represent the problem

Hybrid approach
- Reformulate the problem to suit to the unique properties of the QPU

Improve performance
- Making this problem more realistic

Bigger program on Logistic and Asset Sustainment
- New real world applications of interest to GE

Other Quantum Computing Approaches

schnore@ge.com
annarita.giani@ge.com

© 2019, General Electric Company. All Rights Reserved.
FROM ATOMS TO APPLICATIONS: QUANTUM INFORMATION SCIENCE AT OAK RIDGE NATIONAL LABORATORY

Travis Humble  |  Oak Ridge National Laboratory, United States of America

ABSTRACT

Quantum information science offers opportunities to transform scientific discovery and energy security. We present the goals and capabilities of Oak Ridge National Laboratory to advance QIS from atomic-level synthesis and characterization of quantum materials to a variety of use-inspired applications in quantum computing, communications, and sensing. Prioritizing a mixture of fundamental and applied sciences, ORNL is leveraging our unique expertise and infrastructure for QIS research and development to lead the innovation of quantum technologies.
From Atoms to Applications
Quantum Information Science at Oak Ridge National Laboratory

Our vision is to be the international leader in quantum information science for the 21st century.

- Advance QIS research from atoms to applications.
- Innovate applications in scientific discovery and energy security.
- Support national priorities with world-class talent and capabilities.
- Impact the public good through strategic partnerships.

Advancing QIS Research from Atoms to Applications

Scientific Discovery and Energy Security

- Quantum Applications
- Quantum Materials
- Synthesis and Characterization
- Quantum Devices
- Interfaces and Control

Innovate applications in scientific discovery and energy security

- Physical Sciences
  - Chemistry, Materials, High Energy Physics, Nuclear Physics, Fusion
- Applied Sciences
  - Engineering, Verification and Validation, Energy Sciences
- Data Sciences
  - Artificial Intelligence, Statistics, Learning, Inference and Mining

1-3 Years
3-5 Years
>

9-11 July 2019

Point of Contact
Presenter: Travis Humble, humblets@ornl.gov
Organization: Oak Ridge National Laboratory
Country: United States of America
QUANTUM ALGORITHM FOR SPECTRAL PROJECTION BY MEASURING AN ANCILLA

Yanzhu Chen | SUNY at Story Brook, United States of America

ABSTRACT

We propose a quantum algorithm for projecting to eigenstates of any hermitian operator, provided one can access the associated control-unitary evolution and measurement of the ancilla of the control. The procedure is iterative and the distribution of the projected eigenstates obeys the Born rule. This algorithm can be used as a subroutine in the quantum annealing procedure by measurement to drive the system to the ground state, and we demonstrate its feasibility by simulating the procedure.
Simulation - Part 1
1-D Ising model of 5 qubits in transverse field with periodic boundary condition (g=2/3), starting with state $| −, +, −, +, + \rangle$.

$$H(g) = \sum_{i=1}^{N} (g \sigma_i^x \sigma_{i+1}^x - (1-g) \sigma_i^z)$$

Example runs of the spectral projection procedure. Taking $\Delta t = 10, 3, 0.3, 0.1, ...$ in each run.

Algorithm
1. Prepare the ancilla in the state $\frac{1+i \tau}{\sqrt{2+\tau^2}} |0\rangle + \frac{1}{\sqrt{2+\tau^2}} |1\rangle$.
2. Act on the system with controlled unitary $U = e^{-\Delta t \hat{H}}$ conditioned on the ancilla.
3. Measure the ancilla in the basis $\frac{1}{\sqrt{2}} (|0\rangle \pm |1\rangle)$.
4. Decrease the parameters $\tau$ and repeat from Step 1, until $\tau = 0$.  
5. Repeat the whole procedure for either the same of an altered $\Delta t$, until the system converges to an eigenstate of $H$.

Potential way of adaptively implementing one Trotter imaginary time step, suffering from exponentially small probability for many Trotter steps.

Simulation - Part 2
1-D Ising model of 16 qubits in transverse field with periodic boundary condition.

Using our algorithm as the subroutine that carries out the measurement to project to eigenstates in the annealing method in Ref. [2]. Starting with ground state of $H(g = 0)$.

Subsequent work and outlook
- Study of how fast the wavefunction converges.
- Systematic analysis of influence from decoherence and other types of error. Possible resilience to decoherence assuming error-free ancilla [3].
- Comparison to other methods in terms of cost, pros and cons.
- Any way to implement imaginary time evolution?

References
ROLE OF MATERIAL INFORMATICS AND 3D ATOMIC SCALE CHEMICAL IMAGING FOR DESIGN AND DISCOVERY OF NEW QUANTUM MATERIALS

Krishna Rajan and Baishakhi Mazumder | Department of Materials Design and Innovation, University at Buffalo, Buffalo, New York, United States of America

ABSTRACT

This presentation is an overview of our research program built on a data driven science with experimental and computational efforts that allows the accelerated design and synthesis of quantum materials and devices. Critical to our capabilities is the use of unique 3D atomic scale chemical imaging technique that holds the key to design and optimize new quantum materials. This provides unmatched insight into the complex influence of the nanoscale spatial variations in chemistry and structure on the electronic states in quantum materials. When supported by our leadership in AI driven materials science, we can guide materials-synthesis platform to explore the chemical and processing space of discovery in response to emerging knowledge of structure-property relationships in new quantum materials and devices. Our department is in unique position establishing diverse workforce development leveraging existing educational and outreach programs in quantum materials.
**Point of Contact**
Author/Presenter: Krishna Rajan and Baishakhi Mazumder
Organization: University at Buffalo
Country: United States

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need for a pilot discovery strategy for new quantum materials.</td>
<td>Lack of strong multiscale theoretical foundation and experimental data.</td>
</tr>
</tbody>
</table>

**Methodology**
- Develop informatics methods to rapidly integrate experiment and theory.
- Harness new materials characterization methods that link surface with bulk properties.

**Impact**
- Accelerated discovery of new quantum materials.
- New methods linking experimental characterization for quantum materials.

**MDI@UB Workforce Development**
- Materials Informatics based education
- Master’s and Doctorate degrees
- Industry scholar resident program
- Secondary/post-secondary training
- Primary-level educational programs

---

**Informatics Driven Discovery**
- New machine learning techniques for discovery and design of materials.
- Integrate geometric and chemical bonding information to characterize new structures.
- Discovery of unique structure-property correlations.
- Manifold learning-based analysis allows for mapping of materials based on structural similarities.
- Correlations offer strategies to tune properties and uncover new material relationships.

**Molecular Metrology for Quantum Materials**
- Atom Probe Tomography (APT) allows for 3D single atom scale chemical imaging.
- APT has superior resolution and competitive detection rate compared to alternative methods.
- Carrier localization and quantum confinement can be optimized through accurately quantifying QWs composition and thickness.
- Resulting structural data provides insight for the design of improved device performances.

3D imaging of QWs structure from APT data (left). In-situ chemical imaging of solid-radiation interactions (right).
PLANNING AND OPTIMIZATION IN QUANTUM MARKOV MODELS

C. Tamon, W. Xie | Clarkson University, United States of America

ABSTRACT

Relevant discrete-time Markov models in machine learning include Markov chains, Hidden Markov Models, Markov Decision Processes, and Partially Observable Markov Decision Processes. Quantum generalizations of these models were proposed in several recent works. In this work, we show how to capture these quantum models under the unifying framework of quantum transducers. Our work builds upon connections between automata theory and quantum computing. This provides a natural and useful framework to study planning and optimization problems related to quantum Markov models. The complexity of these problems can then be analyzed via this connection.
Quantum Markov Models

Relevant discrete-time Markov models in machine learning include Markov chains, Hidden Markov Models (HMM), Markov Decision Processes (MDP), and Partially Observable Markov Decision Processes (POMDP) (see [6]).

Quantum generalizations of these models were proposed recently:
- Quantum Markov chains (see Lardizabal [4]).
- Hidden quantum Markov models (HQMM) (see Monras, Beige and Wiesner [5]).
- Quantum observable Markov decision processes (QOMDP) (see Barry, Barry and Aaronson [2]).

In this work, we show how to capture these quantum models under the unifying framework of quantum transducers. Our work builds upon connections between automata theory and quantum computing (see Ambainis and Yakaryılmaz [1]).

Planning and Optimization in Quantum Markov Models

Quantum transducers provide a natural and useful framework to study quantum Markov models and their corresponding planning and optimization problems. The complexity of these problems is analyzed via this connection.

Quantum Transducers

A transducer is a finite automaton with output (see [3]). Our formalization of quantum transducer uses notions from quantum information (see [7, 8]). A quantum transducer is a tuple $M = (Q, \Sigma, \Delta, \Phi, \Omega, \rho, \Pi)$ where $\Phi$ is a conditional channel $\{\Phi_a : a \in \Sigma\}$. $\Omega$ is a quantum instrument given by $\{\Omega_b : b \in \Delta\}$. $\rho$ is an initial state, and $\Pi$ is a projection (onto some accepting subspace).

Planning and optimization problems

Planning: Given a QOMDP, is there an input which causes the machine to accept with probability greater than a certain threshold?

Likelihood: Given a QOMDP, are there input and output pairs so that the value of the machine is less than a certain threshold?

Barry et al. [2] proved that a related planning problem is undecidable. We show the same result holds for Planning and Likelihood using connections with quantum transducers. But, an instance of the planning problem with unitary channels admits algorithmic solution (see [1]).

Acknowledgments

This material is based on research sponsored by Air Force Research Laboratory under agreement number FA8750-18-1-0104. The U.S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright therin. The views and conclusions contained here are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of Air Force Research Laboratory or the U.S. Government.

References

ENTANGLED STATES ARE REACTIVE

Warner A. Miller | Florida Atlantic University, United States of America

ABSTRACT

General relativistic (GR) effects are an integral part today's command, control and communications. There is rapid development of quantum secure communications and quantum networks. It is more sensitive to GR effects and requires new analyses. It's imperative that we deeply understand and control this new frontier. Entanglement is the gasoline for quantum computers. We present here a new measure of this quantum correlation that we refer to as quantum reactivity. This satisfies all required properties of such a measure and is scalable to higher dimensions. We also present an experiment verifying for the first time Schumacher’s triangle inequality violation from entanglement. We demonstrated that for a quantum network that the “Traffic on the Quantum Highway: The Direct Path May Not Be the Shortest.” We also show another project on quantum drones that we have started with Harris Corporation (Mike Lange) and UIUC (Paul Kwiat). We maintain strong research collaboration with Paul Alsing and Mike Fanto of (AFRL/RI) and two of our recent PhD students have been hired. This is collaborative work between the University of Seoul (Doyeol Ahn) and Florida Atlantic University (Warner A. Miller) under a jointly funded international project between IITP and AOARD grant entitled “Gravitational Effects on the Free Space Quantum Key Distribution for Satellite Communication,” (FA2386-17-1-4070). We acknowledge support from the Griffiss Institute under the VFRP program.
Objectives

- To understand GR effects on quantum bit error rate (QBER) of quantum key distribution (QKD).
- To include high-dimensional QKD to increase both the (1) tolerance to QBER and the (2) bandwidth.
- Design lab demonstration GR QKD experiment demonstrating these pronounced effects.

Results 2018-2019

1. Q-OWLS Laboratory (DURIP)
2. Quantum Entanglement Network Geometry
3. Schumacher’s Triangle Inequality Violation EXP
4. Quantum Reactivity: Defined, Proven and Tested
5. QKD to Moving Targets (Harris Corp, UIUC & RIQ)
6. Two former PhD students hired at AFRL/RIQ

Experiment: Quantum Information Geometry

Quantum reactivity based on usual definition of reactivity, and is the surface to volume ratio.

Quantum reactivity based on novel definitions of information area and volumes. Applied to Werner state, and compared with Concurrence and Discord.

Modern battlefield: Interconnected, reconfigurable global, multilayered, inhomogeneous and mobile. A GR quantum backbone network will enhance C4I.
FLIPPED BASIS QUANTUM KEY DISTRIBUTION

Victor Bucklew "Victor", PhD | Harris Corporation, United States of America

ABSTRACT

Single-photon self-interference, the phenomenon of Talbot reimaging at the single-photon level, and the no-cloning theorem of quantum mechanics, are together utilized as resources to securely encode quantum information in communication channels. In one example, single-photon self-interference, achieved through the quantum Talbot effect, is numerically shown to increase the sensitivity of a prepare and measure QKD protocol to attacks, which could potentially allow the Quantum Bit Error Rate (QBER) thresholds of these protocols to increase. An increase in the QBER threshold provides a path towards implementing quantum secure protocols into lossy and contested military communication links.
**RESULTS: FLIPPED BASIS QKD**

In SOA protocols, if Eve chooses the same basis as Alice, she obtains the same information as Alice. However, if single-photon self-interference is incorporated into the basis states of the protocol, even if the correct basis is chosen, Eve’s information is less than Alice’s or Bob’s, providing performance advantages (e.g., an up to 2x reduction in Eve’s information can potentially provide a 2x increase in the QBER threshold).

**APPRAOCH:**

Exploring how single-photon self-interference, the phenomenon of Talbot reimaging at the single-photon level, and the no-cloning theorem of quantum mechanics can be utilized as resources to securely encode quantum information in communication channels.

The input state undergoes self-interference that broadly redistributes its probability distribution function (PDF) and foils attempts to gain info about it within public link sections.

The receiver is positioned at a Talbot re-imaging point in the link where, due to single-photon self-interference, the PDF of the initial state is reconstructed.

Single-photon self-interference provides a way to effectively increase the sensitivity of QKD protocols to attacks, which can potentially allow the QBER thresholds of these protocols to increase. An increase in the QBER threshold could provide a path forward for implementing quantum secure protocols into demanding military environments.

For a time-phase BB84 protocol, if Eve and Bob know the basis the initial state was prepared in, the probability of correctly identifying it (here, representing phase state 2 in the protocol) by measuring in the time or phase bases, is shown as a function of link position. In all places in the link except for “Alice (A)” and “Bob (B)”, the probability of identifying the initial state is reduced to a nearly random guess. Simulations suggest that Alice and Bob must prepare and measure in opposite bases for maximum security (e.g., Flipped Basis QKD).
QUANTUM COMPUTING APPLICATIONS RESEARCH AT LOCKHEED MARTIN

Steve Adachi | Lockheed Martin, United States of America

ABSTRACT

While quantum computing technology is still in its infancy, hands-on access to near-term quantum computing hardware is nevertheless extremely valuable both for applications developers to understand how quantum computing could be applied in the future to solve real-world problems, and to provide feedback to hardware designers that may guide the evolution of physical implementations and design tradeoffs. Starting in 2011 with the acquisition of a D-Wave quantum annealer, Lockheed Martin has been exploring potential applications of quantum computing to the aerospace industry. More recently, we have also investigated next-generation quantum annealing on the Intelligence Advanced Research Projects Activity (IARPA) Quantum Enhanced Optimization (QEO) program, and are working with multiple commercial companies to evaluate gate-based Noisy Intermediate Scale Quantum (NISQ) devices.

This poster gives an overview of applications Lockheed Martin has studied in the areas of optimization, machine learning, and materials simulation. Portions of this work were performed under contracts from AFRL and IARPA; in collaborations with AFRL, the Fermi National Accelerator Laboratory, and the Colorado School of Mines; and with Internal Research and Development funding from Lockheed Martin.
Quantum Computing Applications Research at Lockheed Martin

**Quantum-Assisted Training of Deep Belief Nets**
(AFRL FA8750-18-C-0164, in progress)

**Galaxy Classification**
(FermiLab CRADA, in progress)

**Circuit Fault Diagnosis**
(WARPQ OEO, W911NF-17-C-0050)

**Strongly Correlated Materials**
(with Colo. School of Mines)

**Using deBruijn Graphs**
(AFRL CRADA, 14-RI-CRADA-02)

---

**Acknowledgments**

This work was supported in part by the Air Force Research Laboratory under contract FA8750-18-C-0164. The research is based upon work partially supported by the Office of the Director of National Intelligence (ODNI), Intelligence Advanced Research Projects Activity (IARPA), via the U.S. Army Research Office contract W911NF-17-C-0050. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the Air Force Research Laboratory, the Defense Advanced Research Projects Agency, or the United States government.

**Collaborators**


AFRL – P. Alsing, S. Bak, V. Horan (Goliber), L. Wessing

USC – R. Li, D. Lidar, A. Pearson, F. Spedalieri

FNAL – J. Caldeira, J. Kowalkowski, B. Nord, G. Perdue

Mines – G. Brennecka, N. Kumar, M. Singh, M. Walden

1Currently at QxBranch; 2Currently at D-Wave Systems

---


**Question:** Can the apparent advantage of quantum-assisted training be explained classically, or is this a "quantum" effect?

---

**HARDWARE PLATFORMS**

• Quantum Annealing (D-Wave)
• Next Generation Quantum Annealing (QEO)
• Noisy Intermediate Scale Quantum (NISQ)

---

**Example of "Galaxy Zoo" decision tree**

**Example multiplier circuit**

**Proposed logical circuit architecture, highly suitable for circuit fault diagnosis**

**Benchmarking results on single I/O pairs**

---

**Relevant to sensor network design**

**Perovskite structure**

**Effective 1-D spin chain**

**Fermi-Hubbard model**

**Qubit Hamiltonian**

**• Traditional Kohn-Sham Density Functional Theory (DFT) gives poor agreement with experiment for strongly correlated materials**

**• Alternative approach using quantum simulation**

---

**QUANTUM INFORMATION SCIENCE**

**1ST INTERNATIONAL WORKSHOP**

---

**Acknowledgments**

This research was sponsored in part by the Office of the Director of National Intelligence (ODNI) via the Intelligence Advanced Research Projects Activity (IARPA). This research was sponsored in part by the Office of the Director of National Intelligence (ODNI) via the Intelligence Advanced Research Projects Activity (IARPA) under contract W911NF-17-C-0050. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the Office of the Director of National Intelligence, the Intelligence Advanced Research Projects Activity, or the United States Government.

---

**OPTIMIZATION**

**Identifying Codes on deBruijn Graphs**
(AFRL FA8750-18-C-0164, in progress)

**Strongly Correlated Materials**
(with Colo. School of Mines)

**MACHINE LEARNING**

**Quantum-Assisted Training of Deep Belief Nets**
(AFRL FA8750-18-C-0164, in progress)

**Galaxy Classification**
(FermiLab CRADA, in progress)

**Circuit Fault Diagnosis**
(WARPQ OEO, W911NF-17-C-0050)

**Collaborators**


AFRL – P. Alsing, S. Bak, V. Horan (Goliber), L. Wessing

USC – R. Li, D. Lidar, A. Pearson, F. Spedalieri

FNAL – J. Caldeira, J. Kowalkowski, B. Nord, G. Perdue

Mines – G. Brennecka, N. Kumar, M. Singh, M. Walden

1Currently at QxBranch; 2Currently at D-Wave Systems

---

**Example of "Galaxy Zoo" decision tree**

**Example multiplier circuit**

**Proposed logical circuit architecture, highly suitable for circuit fault diagnosis**

**Benchmarking results on single I/O pairs**

---

**Relevant to sensor network design**

**Perovskite structure**

**Effective 1-D spin chain**

**Fermi-Hubbard model**

**Qubit Hamiltonian**

**• Traditional Kohn-Sham Density Functional Theory (DFT) gives poor agreement with experiment for strongly correlated materials**

**• Alternative approach using quantum simulation**

---

**Acknowledgments**

This research was sponsored in part by the Office of the Director of National Intelligence (ODNI) via the Intelligence Advanced Research Projects Activity (IARPA). This research was sponsored in part by the Office of the Director of National Intelligence (ODNI) via the Intelligence Advanced Research Projects Activity (IARPA) under contract W911NF-17-C-0050. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the Office of the Director of National Intelligence, the Intelligence Advanced Research Projects Activity, or the United States Government.

---

**OPTIMIZATION**

**Identifying Codes on deBruijn Graphs**
(AFRL FA8750-18-C-0164, in progress)

**Strongly Correlated Materials**
(with Colo. School of Mines)

**MACHINE LEARNING**

**Quantum-Assisted Training of Deep Belief Nets**
(AFRL FA8750-18-C-0164, in progress)

**Galaxy Classification**
(FermiLab CRADA, in progress)

**Circuit Fault Diagnosis**
(WARPQ OEO, W911NF-17-C-0050)
Q-MEANS AND SUPERVISED LEARNING: APPLYING QC TO SPACE SITUATIONAL AWARENESS

Victor B. Putz "Vic" | QC Ware, United States of America

ABSTRACT

While progress on Quantum Computing Machine Learning algorithms is proceeding, the early generations of current QC hardware prohibit analysis of many meaningful real-world data sets. We find that the problem of satellite glint / Iridium flare classification for space situational awareness to likely be amenable to QC vector classification algorithms due to the low dimensionality and reducibility of the candidate vectors to lowerdimensional representations.
Theoretical: Clustering and Classification

Quantum Computers have shown promise in optimization and quantum simulation, but practical results in machine learning have been slim. QC Ware is making strides in both heavily used support functions such as clustering (via a Q-means algorithm) and supervised vector classification.

Applied: Space Situational Awareness

Any algorithm needs to be tested on real-world data, but current QC hardware limits the size and complexity of data that can be analyzed.

One sort of data which can be meaningfully reduced and yet still has real-world relevance to USAF/Space needs is satellite glint data, or Iridium flare observations. As a satellite orbits, it can reflect sunlight to the earth from its main mission antennae, solar panels, or body, resulting in a characteristic glint or flare.

Clustering: Towards Q-means

On any given day, even a subset of unclassified observations collected by the Unified Data Library can consist of over 180,000 observations per day.

If no sensor data was provided, these observations could be clustered into meaningful signals using the classical k-means algorithm due to their proximity in space (right ascension and declination) and observation time. With only three variables but many observations, this is also amenable to a Q-means algorithm (Kerenidis et al) on QC hardware which promises a potential speedup from linear to polylogarithmic scaling.

Another method by Dr. Kerenidis, from Quantum classification of the MNIST dataset via Slow Feature Analysis, might be used to extract features and classify a series of glints by using Quantum Slow Feature Analysis to reduce dimensionality and classifying the result with a Quantum Frobenius Distance algorithm.

Progress So Far

QC Ware has made good progress on the quantum classifier side, with Dr. Kerenidis implementing supervised learning classifiers with a sklearn-style API on circuit-model backends. Initial results on simple test data are quite promising!

We hope to implement the Q-means algorithm thanks to an agreement with AFRL/RI in the fall, and, with better access to satellite glint data, show a practical application of Quantum Machine Learning by spring of 2020.
QUANTUM-FIRST HIGH PERFORMANCE COMPUTERS

Mandy Birch | Rigetti Computing, United States of America

ABSTRACT

Rigetti Computing is helping to solve humanity’s greatest problems by building advanced computing infrastructure for quantum-acceleratable workloads, delivered over the cloud. We integrate classical processors with the advanced computational power of our quantum chips to accelerate deployment of quantum computing in the near term. By partnering with key government and Fortune 500 customers, we are co-developing full-stack quantum supercomputing systems and solutions.
We build the world’s most powerful computers to solve humanity’s most pressing problems.

Combining leading-edge advances in quantum mechanics, physics, computer science, and engineering, we build the world’s most powerful hybrid quantum-classical computers.

Our full-stack approach combines software, hardware, and services to solve unsolvable problems, including: materials research, medical diagnostics, climate simulation, drug discovery, artificial intelligence, and national security.

Applications

- **Combinatorial Optimization**
  - Solving complex optimizations such as job shop scheduling and traveling salesperson problems will drive critical efficiencies in businesses, military and public sector logistics, energy, business, and science.

- **Advanced Simulation**
  - Quantum computing enables simulation of complex physical systems both at the microscopic level, such as molecules for materials research, and at the macroscopic level, for simulations of multidomain platforms and forces to support decisions.

- **Machine Learning**
  - Training advanced AI on quantum computers will advance computer vision, pattern recognition, voice recognition, and machine translation.

Building quantum computers is hard. It combines advances in engineering, physics, computer science, and manufacturing. Integrating all these specialties under one roof and in one technology stack allows us to build the best quantum platform for our customers.

For enterprise customers, we offer preferential QCS access plus enhanced support and access to in-house expertise. Our Enterprise Plus program offers proof-of-concept application development and long-term expert consultation.

For government and large-scale enterprise, we offer our exclusive Advantage program for co-development, co-location, and deep partnerships for application development over a 2-4 year timescale.

Our full-stack approach allows us to build the best quantum platform for our customers.

QCS Research

Quantum Cloud Services let you build and run programs on our real quantum hardware with the ease of a virtual development environment.

QCS Enterprise / Enterprise Plus

For enterprise customers, we offer preferential QCS access plus enhanced support and access to in-house expertise. Our Enterprise Plus program offers proof-of-concept application development and long-term expert consultation.

Rigetti Advantage Program

For government and large-scale enterprise, we offer our exclusive Advantage program for co-development, co-location, and deep partnerships for application development over a 2-4 year timescale.

Applications

- **Combinatorial Optimization**
  - Solving complex optimizations such as job shop scheduling and traveling salesperson problems will drive critical efficiencies in businesses, military and public sector logistics, energy, business, and science.

- **Advanced Simulation**
  - Quantum computing enables simulation of complex physical systems both at the microscopic level, such as molecules for materials research, and at the macroscopic level, for simulations of multidomain platforms and forces to support decisions.

- **Machine Learning**
  - Training advanced AI on quantum computers will advance computer vision, pattern recognition, voice recognition, and machine translation.

Building quantum computers is hard. It combines advances in engineering, physics, computer science, and manufacturing. Integrating all these specialties under one roof and in one technology stack allows us to build the best quantum platform for our customers.

For enterprise customers, we offer preferential QCS access plus enhanced support and access to in-house expertise. Our Enterprise Plus program offers proof-of-concept application development and long-term expert consultation.

For government and large-scale enterprise, we offer our exclusive Advantage program for co-development, co-location, and deep partnerships for application development over a 2-4 year timescale.

Applications

- **Combinatorial Optimization**
  - Solving complex optimizations such as job shop scheduling and traveling salesperson problems will drive critical efficiencies in businesses, military and public sector logistics, energy, business, and science.

- **Advanced Simulation**
  - Quantum computing enables simulation of complex physical systems both at the microscopic level, such as molecules for materials research, and at the macroscopic level, for simulations of multidomain platforms and forces to support decisions.

- **Machine Learning**
  - Training advanced AI on quantum computers will advance computer vision, pattern recognition, voice recognition, and machine translation.

Building quantum computers is hard. It combines advances in engineering, physics, computer science, and manufacturing. Integrating all these specialties under one roof and in one technology stack allows us to build the best quantum platform for our customers.

For enterprise customers, we offer preferential QCS access plus enhanced support and access to in-house expertise. Our Enterprise Plus program offers proof-of-concept application development and long-term expert consultation.

For government and large-scale enterprise, we offer our exclusive Advantage program for co-development, co-location, and deep partnerships for application development over a 2-4 year timescale.

Applications

- **Combinatorial Optimization**
  - Solving complex optimizations such as job shop scheduling and traveling salesperson problems will drive critical efficiencies in businesses, military and public sector logistics, energy, business, and science.

- **Advanced Simulation**
  - Quantum computing enables simulation of complex physical systems both at the microscopic level, such as molecules for materials research, and at the macroscopic level, for simulations of multidomain platforms and forces to support decisions.

- **Machine Learning**
  - Training advanced AI on quantum computers will advance computer vision, pattern recognition, voice recognition, and machine translation.

Building quantum computers is hard. It combines advances in engineering, physics, computer science, and manufacturing. Integrating all these specialties under one roof and in one technology stack allows us to build the best quantum platform for our customers.

For enterprise customers, we offer preferential QCS access plus enhanced support and access to in-house expertise. Our Enterprise Plus program offers proof-of-concept application development and long-term expert consultation.

For government and large-scale enterprise, we offer our exclusive Advantage program for co-development, co-location, and deep partnerships for application development over a 2-4 year timescale.

Applications

- **Combinatorial Optimization**
  - Solving complex optimizations such as job shop scheduling and traveling salesperson problems will drive critical efficiencies in businesses, military and public sector logistics, energy, business, and science.

- **Advanced Simulation**
  - Quantum computing enables simulation of complex physical systems both at the microscopic level, such as molecules for materials research, and at the macroscopic level, for simulations of multidomain platforms and forces to support decisions.

- **Machine Learning**
  - Training advanced AI on quantum computers will advance computer vision, pattern recognition, voice recognition, and machine translation.

Building quantum computers is hard. It combines advances in engineering, physics, computer science, and manufacturing. Integrating all these specialties under one roof and in one technology stack allows us to build the best quantum platform for our customers.

For enterprise customers, we offer preferential QCS access plus enhanced support and access to in-house expertise. Our Enterprise Plus program offers proof-of-concept application development and long-term expert consultation.

For government and large-scale enterprise, we offer our exclusive Advantage program for co-development, co-location, and deep partnerships for application development over a 2-4 year timescale.

Applications

- **Combinatorial Optimization**
  - Solving complex optimizations such as job shop scheduling and traveling salesperson problems will drive critical efficiencies in businesses, military and public sector logistics, energy, business, and science.

- **Advanced Simulation**
  - Quantum computing enables simulation of complex physical systems both at the microscopic level, such as molecules for materials research, and at the macroscopic level, for simulations of multidomain platforms and forces to support decisions.

- **Machine Learning**
  - Training advanced AI on quantum computers will advance computer vision, pattern recognition, voice recognition, and machine translation.

Building quantum computers is hard. It combines advances in engineering, physics, computer science, and manufacturing. Integrating all these specialties under one roof and in one technology stack allows us to build the best quantum platform for our customers.

For enterprise customers, we offer preferential QCS access plus enhanced support and access to in-house expertise. Our Enterprise Plus program offers proof-of-concept application development and long-term expert consultation.

For government and large-scale enterprise, we offer our exclusive Advantage program for co-development, co-location, and deep partnerships for application development over a 2-4 year timescale.

Applications

- **Combinatorial Optimization**
  - Solving complex optimizations such as job shop scheduling and traveling salesperson problems will drive critical efficiencies in businesses, military and public sector logistics, energy, business, and science.

- **Advanced Simulation**
  - Quantum computing enables simulation of complex physical systems both at the microscopic level, such as molecules for materials research, and at the macroscopic level, for simulations of multidomain platforms and forces to support decisions.

- **Machine Learning**
  - Training advanced AI on quantum computers will advance computer vision, pattern recognition, voice recognition, and machine translation.

Building quantum computers is hard. It combines advances in engineering, physics, computer science, and manufacturing. Integrating all these specialties under one roof and in one technology stack allows us to build the best quantum platform for our customers.

For enterprise customers, we offer preferential QCS access plus enhanced support and access to in-house expertise. Our Enterprise Plus program offers proof-of-concept application development and long-term expert consultation.

For government and large-scale enterprise, we offer our exclusive Advantage program for co-development, co-location, and deep partnerships for application development over a 2-4 year timescale.

Applications

- **Combinatorial Optimization**
  - Solving complex optimizations such as job shop scheduling and traveling salesperson problems will drive critical efficiencies in businesses, military and public sector logistics, energy, business, and science.

- **Advanced Simulation**
  - Quantum computing enables simulation of complex physical systems both at the microscopic level, such as molecules for materials research, and at the macroscopic level, for simulations of multidomain platforms and forces to support decisions.

- **Machine Learning**
  - Training advanced AI on quantum computers will advance computer vision, pattern recognition, voice recognition, and machine translation.

Building quantum computers is hard. It combines advances in engineering, physics, computer science, and manufacturing. Integrating all these specialties under one roof and in one technology stack allows us to build the best quantum platform for our customers.

For enterprise customers, we offer preferential QCS access plus enhanced support and access to in-house expertise. Our Enterprise Plus program offers proof-of-concept application development and long-term expert consultation.

For government and large-scale enterprise, we offer our exclusive Advantage program for co-development, co-location, and deep partnerships for application development over a 2-4 year timescale.

Applications

- **Combinatorial Optimization**
  - Solving complex optimizations such as job shop scheduling and traveling salesperson problems will drive critical efficiencies in businesses, military and public sector logistics, energy, business, and science.

- **Advanced Simulation**
  - Quantum computing enables simulation of complex physical systems both at the microscopic level, such as molecules for materials research, and at the macroscopic level, for simulations of multidomain platforms and forces to support decisions.

- **Machine Learning**
  - Training advanced AI on quantum computers will advance computer vision, pattern recognition, voice recognition, and machine translation.
DETECTOR TOMOGRAPHY ON IBM QUANTUM COMPUTERS AND MITIGATION OF IMPERFECT MEASUREMENT

Mr. Maziar Farahzad "Maziar" | Stony Brook University, NY, United States of America

ABSTRACT

We use quantum detector tomography to characterize the qubit readout in terms of measurement POVMs on IBM Quantum Computers IBM Q 5 Tenerife and IBM Q 5 Yorktown. Our results suggest that the characterized detector model deviates from the ideal projectors by a few percent. Further improvement on this characterization can be made by adopting two- or more-qubit detector models instead of independent single-qubit detectors for all the qubits in one device. An unexpected behavior was seen in the physical qubit labeled as qubit 3 of IBM Q 5 Tenerife, which can be a consequence of detector crosstalk or qubit operations influencing each other and requires further investigation. This peculiar behavior is consistent with characterization from the more sophisticated approach of the gate set tomography. We also discuss how the characterized detectors' POVM, despite deviation from the ideal projectors, can be used to estimate the ideal detection distribution.
Goal:
We use quantum detector tomography to characterize the qubit readout in terms of measurement POVMs on IBM Quantum Computers IBM Q 5 Tenerife and IBM Q 5 Yorktown. We also discuss their mitigation.

Detector Model:
The N-qubit detector is characterized by a POVM:

$$\Pi_N^{(\tilde{n})} = \sum_{\tilde{i}} c^{(\tilde{i})} \sigma_0 \otimes \cdots \otimes \sigma_j \cdots \otimes \sigma_{N-1},$$

where $$\tilde{n} = (n_0, \ldots, n_{N-1})$$ is the measurement outcome and $$\tilde{i} = (i_0, \ldots, i_{N-1}) \in \{0,1,2,3\}^N$$. The Pauli basis is $$\sigma_0 = I$$, $$\sigma_1 = \sigma_x$$, $$\sigma_2 = \sigma_y$$, $$\sigma_3 = \sigma_z$$. For example, the single qubit detector is $$\Pi_1^{(n)} = \sum_{i=0}^{3} a_i^{(n)} / \sigma_i$$.

Results:

Mitigation:
Under the condition that $$|a_1^{(n)}|, |a_2^{(n)}| \ll |a_3^{(n)}|$$:

$$\hat{P}_n \approx \sum_m \hat{M}_{\tilde{n}, \tilde{m}} P_m$$

$$\hat{M}_{\tilde{n}, \tilde{m}} \equiv \sum_{\tilde{i}} c^{(\tilde{i})} (-1)^{\tilde{m}} \tilde{i} / 3$$

where $$\hat{P}_n$$ denotes the experimental distribution, $$P_n$$ denotes the ideal distribution, and $$\tilde{i} \in \{0,3\}^N$$. Example for $$\frac{1}{\sqrt{2}}(|000\rangle + |111\rangle)$$ on IBMQX2:

Conclusion:
Our resultant POVM shows deviation from the ideal projectors $$\{|0\rangle\langle 0|, |1\rangle\langle 1|\}$$ and can be used for a first-order correction in experiments. We also found evidence of crosstalk between qubits in one device. We believe adopting two- or more-qubit detector models can improve the results.

References:
CHIRAL QUBIT - QUANTUM COMPUTING WITH CHIRAL ANOMALY

Mr. Evan Philip "Evan" | Stony Brook University, United States of America

ABSTRACT

Chiral quasi-particles recently observed in Dirac and Weyl semimetals, along with the physics of chiral anomaly, enables us to design a new kind of qubit. These "chiral qubits" may be capable of operating at THz frequency at room temperature. I will briefly present this recent idea and our progress.
Chiral Qubit
Quantum Computing with Chiral Anomaly

Chiral Anomaly
- Chiral charge is expected to be conserved like regular charge, but this does not happen due to quantum effects. Quantum effects lead to chiral anomaly.

The Chiral Qubit
- Using chiral charge in place of superconducting charge and chiral anomaly in place of Josephson tunnelling, we get a chiral qubit [1].

Advantages
- Mathematically analogous to superconducting qubits.
- High operating temperature: can possibly function even at room temperature
- Speed: can be operated about 10,000 times faster than superconducting qubits.

Chiral Charge
- If an electron is massless, it has an additional property called chirality.
- Chirality means handedness. You get two types of electrons – left-handed and right-handed.
- Though such particles have been of interest to particle physicists for long, they were only observed in recently discovered Dirac and Weyl semimetals.

Challenges
- Still at early very early stage. Needs further theoretical understanding and experimental support.
- Short coherence time. High operating speed may remedy this.
- Ring geometry is structurally challenging.

Ongoing Efforts
- Understand details of ring-shaped chiral qubit with the goal of advancing to experiments.
- Devise a method to use 3D geometry, rather than a ring, to construct a qubit.
- We have proposed that circularly polarised light can be used to control the current in 3D Dirac/Weyl materials [2]. This is being tested experimentally.
- Recently observed THz frequency near field generated by chiral photocurrents [3] (collaboration with UESTC, China) can be utilised for entangling chiral qubits.

References
PULSE ENHANCED TWO-PHOTON INTERFERENCE WITH SOLID STATE QUANTUM EMITTERS

Dr Herbert F. Fotso "Herbert F." | University at Albany, SUNY; New York, United States of America

ABSTRACT

The ability to generate distributed entanglement across distant quantum nodes is essential for the construction of scalable quantum networks and for various quantum information processing operations such as quantum teleportation and Bell inequality tests[1, 2]. For solid state spin qubits, entangling two qubits can be achieved through photon interference on a beam splitter. This operation can have its efficiency drastically reduced by fluctuations in the uncorrelated environments of the respective qubits. We simulate the two-photon interference operation in a Hong-Ou-Mandel-type experiment for two distant solid state quantum emitters that are driven by suitable pulse sequences. We find that besides their emission/absorption spectrum having little dependence on their environments[3], photon indistinguishability can be restored to optimal values allowing for highly improved efficiency of photon-mediated QIP operations.

Objective: Pulse-Enhanced Two-Photon Interference with Solid State Quantum Emitters

Solid State Quantum Emitters:
- Complex dynamic solid state environment
- Fluctuations modify quantum states
- Uncontrolled drift of emission/absorption spectral line
- Low efficiency of fundamental photon-mediated QIP operations

Spectral Diffusion

NV’s, SiV, QDots, Trapped atoms, ions, ...other qQubits in dynamic environments.

Can we prevent spectral diffusion from adversely affecting essential QIP operations?

Results

Milestone experiments: distant entanglement, teleportation, Bell inequality tests.

Approach:
- Use pulse sequences to control spectral properties
  - Periodic sequence of \( \pi \) pulses
  - Intensity Correlation at detectors (Photon indistinguishability) in HOM experiment
  - Analytical and numerical solution

References:
- H.F.Fotso and V.V.Dobrovitski, Phys. Rev B 95, 214301 (2017);
QIS Points of Contact

Dr. Michael Hayduk
Deputy Director, AFRL Information Directorate
AFRL/RI
Office phone: 315-330-7701
Cell phone: 315-404-5462

Rebecca Mills
Senior International Focal Point
AFRL/RIB
Office phone: 315-330-2918
Cell phone: 315-617-2122

Dr. Kathy-Anne Soderberg
AFRL/RITE
Senior Research Physicist
Office phone: 315-330-3687
Cell phone: 315-795-5569

Mr. Steve Johns
Chief, Quantum Science and Technology Branch
AFRL/RITQ
Office phone: 315-330-4982
100 SEYMOUR AVE
UTICA, NY 13502
9-11 JULY 2019

AIR FORCE RESEARCH LABORATORY
INFORMATION DIRECTORATE
ROME, NY, 13440, USA

STATE UNIVERSITY OF NEW YORK
SUNY POLYTECHNIC INSTITUTE
UTICA, NY, 13502 USA