

RAPHAEL POOSER

Senior Research Scientist, Computational Sciences and Engineering Division, Oak Ridge National Laboratory,
P.O. Box 2008, MS-6418, Oak Ridge, TN 37831; pooserrc@ornl.gov; 865-576-6658

RESEARCH INTERESTS AND AREAS OF EXPERTISE:

Quantum Sensing, Quantum Computing, Neuromorphic computing, Quantum Communication

EDUCATION:

University of Virginia; PhD, Engineering Physics, 2007; Dean's fellow, NSF IGERT fellow.

New York University; BS, Physics, 2001; Cum Laude, Dean's list.

RESEARCH EXPERIENCE:

Oak Ridge National Lab: Senior Research Scientist, 2016 – present

Oak Ridge National Lab: Research Scientist, 2011 – 2016

- Research Scientist in the Quantum Information Science Group.
- PI for several internally and externally funded research projects, head of quantum sensors lab which produces some of the world's most precise quantum sensors, PI for quantum computing with continuous variables project - both theoretical and experimental optics research
- Collaboration with quantum optics researchers at ORNL, University of Virginia, in Italy, University of Toronto, Vanderbilt University
- Published papers in *Physical Review A*, ***Optica***, ***Physical Review Letters***, *ACS Photonics*

University of Tennessee: Joint Faculty Assistant Professor, Physics Dept., 2014 – present

- Collaborations and ongoing research in UTK physics department; advising graduate students
- PI for quantum sensing project funded by W. M. Keck foundation
- coPI for Quantum Key Distribution project funded by ONR

Oak Ridge National Lab: Wigner Fellow, 2009 – 2011

- Fellow in the Center for Quantum Information Science and Technology.
- Developed continuous variable quantum light source for use in quantum information experiments
- Published papers in *Optics Letters*

National Institute of Standards and Technology: Intelligence Community Postdoctoral Fellow, 2007- 2009

- Performed research in quantum imaging, quantum optics, and quantum information with nonlinear optics.
- Published scientific articles in ***Science***, ***Nature***, and ***Physical Review Letters***.

University of Virginia: Graduate Physics Research Assistant, 2001 - 2007

- Performed nonlinear optics experiments using both pulsed and continuous wattage lasers, performed supporting nonlinear optics theoretical calculations.
- Published papers on theoretical and experimental quantum optics in *Optics Letters* and *Physical Review A*.

RESEARCH GRANTS:

- Office of Naval Research - \$600k / 2 yrs, coPI

- Intelligence Community Postdoctoral grant - \$240k / 2 yrs, PI
- Office of Naval Research - \$1.0M / 3 yrs, coPI
- Lab Directed Research and Development: Quantum plasmonic sensors – \$900k / 2 yrs, PI
- William and Mary Keck Foundation: Ultra-trace Sensors – \$1.5M/4 yrs, PI
- ORNL Seed fund: Quantum Computing with Continuous Variables - \$180k/1.5 yrs, coPI
- DOE IN: Chip imaging via compressive sampling - \$36.5k/yr, PI
- Lab Directed Research and Development: Self Correcting Quantum Random Number Generators - \$744k / 2 yrs, PI
- ORNL Seed fund: Secure token authentication via secure hashing - \$180k / 1 yr, PI
- Intelligence Community Postdoctoral grant - \$240k /yr, supports one postdoc for two years, PI
- Lab Directed Research and Development: Quantum Compressive Imaging – \$575k / 2 yrs, PI
- DOE office of electricity: Quantum Solutions for the Smart Grid - \$250k/yr, 3 yrs, coPI

PUBLICATIONS (JOURNALS): H=13 (see also http://scholar.google.com/citations?user=eHTCC_cAAAAJ)

- M. W. Holtfrerich, M. Dowran, R. Davidson, B. J. Lawrie, R. C. Pooser, A. M. Marino, *Towards Quantum Plasmonic Networks*, *Optica* **3**, 985-988 (2016).
- B. J. Lawrie, Y. Yang, M. Eaton, A. N. Black, and R. C. Pooser, *Robust and compact entanglement generation from diode-laser-pumped four-wave mixing*, *Applied Physics Letters* **108**, 151107 (2016); doi: 10.1063/1.4947026.
- R. C. Pooser and B. J. Lawrie, *Plasmonic trace sensing below the photon shot noise limit*, *ACS Photonics* **3**, 8 (2016). *article featured on cover of journal*
- AE Farah, R Davidson, A Malasi, RC Pooser, B Lawrie, R Kalyanaraman, *Cobalt stabilization of silver extraordinary optical transmission sensing platforms*, *Applied Physics Letters* **108**, 043101 (2016).
- K. Marshall, R. C. Pooser, G. Siopsis, and C. Weedbrook, *Quantum simulation of quantum field theory using continuous variables*, *Phys. Rev. A* **92**, 063825 (2015).
- W. Fan, B. J. Lawrie, R. C. Pooser, *Quantum Plasmonic Sensing*, *Phys. Rev. A* **92**, 053812 (2015).
- B Qi, P Lougovski, R Pooser, W Grice, M Bobrek, *Generating the local oscillator “locally” in continuous-variable quantum key distribution based on coherent detection*, *Physical Review X* **5**, 041009 (2015).
- K. Marshall, R. C. Pooser, G. Siopsis, and C. Weedbrook, *Repeat-until-success cubic phase gate for universal continuous-variable quantum computation*, *Phys. Rev. A* **91**, 032321 (2015).
- B. J. Lawrie, N. Otterstrom, R. C. Pooser, *Coherence area profiling in multi-spatial-mode squeezed states*, *Journal of Modern Optics*, 1-6, DOI:10.1080/09500340.2015.1080869 (2015).
- R. C. Pooser, and B. J. Lawrie, *Ultrasensitive measurement of MEMS cantilever displacement below the shot noise limit*, *Optica* **2**, 393 (2015). *One of the top-cited articles in Optica for 2015.*
- A. Malasi, H. Taz, A. Farah, M. Patel, B. Lawrie, R. C. Pooser, A. Baddorf, G. Duscher, R. Kalyanaraman, *Novel Iron-based ternary amorphous oxide semiconductor with very high transparency, electronic conductivity, and mobility*, *Scientific reports* **5**, 1 (2015).
- N. Otterstrom, R. C. Pooser, B. Lawrie, *Nonlinear optical magnetometry with accessible in situ optical squeezing*, *Optics Letters* **39**, 6533 (2014).
- R. C. Pooser and J. Jing, *Continuous Variable Cluster State Generation over the Optical Spatial Mode Comb*, *Phys. Rev. A* **90**, 04381 (2014).
- P. Lougovski and R. C. Pooser, *An Observed-Data-Consistent Approach to the Assignment of Bit Values in a Quantum Random Number Generator*, arXiv:1404.5977 (2014).
- W. P. Grice, P. G. Evans, and R. C. Pooser “Quantum Key Distribution for the Smart Grid” in *IEEE Vision for Smart Grid Communications: 2030 and Beyond*, IEEE standards, pp. 345-351 (2013).

- B. J. Lawrie and R. C. Pooser, *Toward Real Time Quantum imaging with a single pixel camera*, Optics Express **21**, 7549 (2013).
- B. J. Lawrie, P. Evans, R. C. Pooser, *Extraordinary optical transmission of multimode quantum correlations via localized surface plasmons*, Phys. Rev. Lett. **110**, 156802 (2013).
- R. C. Pooser, D. Earl, B. Williams, P. Evans, *FPGA-based gating and logic for multichannel single photon counting*, Journal of Modern Optics, special issue (invited), **59**, 1500 DOI: 10.1080/09500340.2012.706325 (2012).
- Z. Qin, J. Jing, J. Zhou, C. Liu, Z. Zhou, F. Hudelist, L. Cui, R. C. Pooser, and W. Zhang, *A compact diode-laser-pumped quantum light source based on four wave mixing in hot rubidium vapor*, Optics Letters **37**, Issue 15, pp. 3141-3143 (2012).
- C. Weedbrook, B. Perrett, K. V. Kheruntsyan, P. Drummond, R. C. Pooser, and O. Pfister, *Resonant cascaded down-conversion*, Phys. Rev. A **85**, 033821 (2012).
- C. Liu, J. Jing, Z. Zhou, R.C. Pooser, F. Hudelist, and W. Zhang, *Realization of low frequency and controllable-bandwidth squeezing based on a four-wave-mixing amplifier in rubidium vapor*, Optics Letters **36**, 2979 (2011).
- R. C. Pooser, A. M. Marino, V. Boyer, P. D. Lett, *Quantum correlated light beams from non-degenerate four-wave mixing in an atomic vapor: the D1 and D2 lines of 85Rb and 87Rb*, Optics Express, **17**, 16722 (2009).
- R. C. Pooser, K. M. Jones, A. M. Marino, V. Boyer, P. D. Lett, *Low-Noise Amplification of a Continuous Variable Quantum State*, Phys. Rev. Lett. **103**, 010501 (2009).
- A. M. Marino, R. C. Pooser, V. Boyer, P. D. Lett, *Tunable delay of EPR correlations*, Nature **457**, 859-862 (12 February 2009). Featured in *News and Views in Nature* **457**, 798-799 (12 February 2009).
- V. Boyer, A. M. Marino, R. C. Pooser, and P. D. Lett, *Entangling light in its spatial degrees of freedom with four-wave mixing in an atomic vapor*, ChemPhysChem, DOI: 10.1002/cphc.200800734, US: <http://dx.doi.org/10.1002/cphc.200800734>
- R. C. Pooser, V. Boyer, A. M. Marino, P. D. Lett, *Squeezed Light and Entangled Images from Four-Wave-Mixing in Hot Rubidium Vapor*, in Quantum Communications and Quantum Imaging VI, edited by Ronald Meyers, Yanhua Shih, Keith Deacon, Proceedings of SPIE Vol. **7092** (SPIE, Bellingham, WA, 2008) 70920G-1
- A. M. Marino, V. Boyer, R. C. Pooser, P. D. Lett, K. Lemons, and K. M. Jones, *Delocalized Correlations in Twin Light Beams with Orbital Angular Momentum*, Phys. Rev. Lett. **101**, 093602 (2008).
- V. Boyer, A. M. Marino, R. C. Pooser, and P. D. Lett., *Entangled Images From Four-Wave Mixing*, Science 25 July 2008 **321**: 544-547; published online 12 June 2008 in Science Express Reports, DOI: 10.1126/science.1158275. Work was featured in Physics Today vol. **61** August 2008 issue, pp 16-18. Also featured in Science *Perspective* article "Let Quantum Mechanics Improve Your Images" by Robert Boyd.
- A.S. Bradley, M.K. Olsen, O. Pfister, and R.C. Pooser, *Bright tripartite entanglement in triply concurrent parametric down conversion*, Physical Review A **72**, 053805 (2005).
- R.C. Pooser and O. Pfister, *Observation of triply coincident nonlinearities in periodically poled KTiOPO4*, Optics Letters **30**, 2635 (2005). Work featured in the November 2005 issue of the Materials Research Society Bulletin. Also Featured in Virtual Journal of Ultrafast Science, November 2005.
- O. Pfister, S. Feng, G. Jennings, R. Pooser, and D. Xie, *Multipartite continuous-variable entanglement from concurrent nonlinearities*, Physical Review A **70**, 020302(R) (2004).
- R.C. Pooser and O. Pfister, *Particle-number scaling of the phase sensitivity in realistic Bayesian twin-mode Heisenberg-limited interferometry*, Physical Review A **69**, 043616 (2004).

PATENT APPLICATIONS:

Quantum Random Number Generator; WNJ Ref: 138974.156077-US
System and Method for Secured Communication; US Patent 20,150,288,517

PATENTS:

System and method for key generation in security tokens PG Evans, TS Humble, NR Paul, RC Pooser, SJ Prowell, US Patent 9,172,698

Quantum Random Number Generator, R.C. Pooser, US Patent 9,335,973

Self-correcting random number generator, RC Pooser, TS Humble, Patent App. 14/178,863 (granted)

INVITED TALKS AND COLLOQUIA (INCLUDING UPCOMING):

R. C. Pooser, *Quantum Information with Highly Accessible Continuous Variable States of Light: "local" Local Oscillators and Long Range Quantum Networks*, SPIE Photonics West, Jan. 2017.

R. C. Pooser, *Practical Quantum Sensing at Ultra Trace Levels with Squeezed States of Light*, SPIE Photonics West, Jan. 2017

R. C. Pooser, *Quantum Sensors*, University of Toronto Dept. of Physics Seminar, Sept. 12, 2014.

R. C. Pooser, *Towards Real Time Quantum Imaging Below the Diffraction Limit*, presented at the Department of Physics Colloquium, University of Oklahoma, Jan 24, 2013.

R. C. Pooser, *Quantum Optics from Four Wave Mixing in Rb vapor: from quantum noise reduction to quantum imaging*, presented at the Department of Physics Colloquium, University of Tennessee, Jan 23, 2012.

R. C. Pooser, *Quantum Optics from Four Wave Mixing in Rb vapor: from quantum imaging to entanglement*, given at the East China Normal University Department of Physics Colloquium on December 3, 2010, Shanghai, China.

R. C. Pooser, *Quantum Optics for Quantum Sensors: from quantum imaging to force measurement*, given at the Quantum Technology Applications Workshop, November 22, 2010, Santa Fe, NM.

CONFERENCE PRESENTATIONS:

RC Pooser, B Lawrie, Ultratrace Plasmonic Sensing below the Shot Noise Limit, CLEO: QELS_Fundamental Science, FF1C. 7 (2016)

B Lawrie, W Fan, RC Pooser, Plasmonic Sensing with Quantum Noise, CLEO: QELS_Fundamental Science, FM4N. 1 (2016)

A Malasi, H Taz, A Farah, M Patel, B Lawrie, RC Pooser, A Baddorf, G. Duscher, R. Kalyanaraman, Novel Iron-Based Amorphous Transparent Conducting Oxide, CLEO: Science and Innovations, JTh2A. 87 (2016)

M Dowran, M Holtfrerich, B Lawrie, R Davidson, R Pooser, A Marino, Transduction of Entangled Images by Localized Surface Plasmons, Bulletin of the American Physical Society, DAMOP (2016).

E Layden, T Coulter, J Lukens, B Lawrie, R Pooser, Locked SU (1, 1) Nonlinear Interferometer for Phase Shift Measurements in Triangular Nanohole Arrays, Bulletin of the American Physical Society, DAMOP (2016).

A Black, M Eaton, R Pooser, B Lawrie, Continuous-Variable Quantum Cluster-State Generation Using a Tapered Amplifier, 82nd Annual Meeting of the APS Southeastern Section (2015).

B Qi, HK Lo, CCW Lim, G Siopsis, EA Chitambar, RC Pooser, PG Evans, WP Grice, Free-space reconfigurable quantum key distribution network, 2015 IEEE International Conference on Space Optical Systems and Applications (2015).

B Lawrie, W Fan, P Evans, RC Pooser, Ultratrace Quantum Plasmonic Sensing, Optical Sensors, SeW1B. 4 (2015).

KA Marshall, R Pooser, G Siopses, C Weedbrook, Repeat-Until-Success Cubic Phase Gate, CLEO: QELS_Fundamental Science, FTu4A. 8 (2015).

PG Evans, R Pooser, JC Schaake, Compressive Image Reconstruction Optimization for Single-Photon

Gaussian Beam Profiles, *Frontiers in Optics*, FTh4C. 2 (2014).

B Lawrie, R Pooser, Ultrasensitive measurement of MEMS cantilever displacement below the photon shot noise limit, *CLEO: QELS_Fundamental Science*, FM1A. 2 (2014).

Raphael C. Pooser and Benjamin Lawrie, Ultrasensitive Measurement of MEMS Cantilever Displacement Below the Photon Shot Noise Limit, *Quantum Information and Measurement* (2014).

WP Grice, RC Pooser, BP Williams, Quantum repeater for spectrally entangled photons, *CLEO: QELS_Fundamental Science*, FTu1A. 6 (2014).

RC Pooser, P Evans, T Humble, W Grice, B Williams, Self correcting quantum random number generators using tapered amplifiers, *Quantum Information and Measurement*, W6. 37 (2013).

Raphael C. Pooser, Travis S. Humble, Philip G. Evans, Warren P. Grice and Brian W. Williams, An algorithmically defined QRNG, *Qcrypt* (2013).

R. C. Pooser, P. G. Evans, T. S. Humble, Self Correcting Quantum Random Number Generators using Tapered Amplifiers, *IEEE summer topicals in photonics*, July 20, 2013, Waikaloa, HI.

T. S. Humble, R. C. Pooser, and K. A. Britt, Quantum Statistical Testing of a QRNG Algorithm, *IEEE summer topicals in photonics*, July 20, 2013, Waikaloa, HI.

R. C. Pooser, P. G. Evans, T. S. Humble, W. P Grice, B. P. Williams, Self Correcting Quantum Random Number Generators using Tapered Amplifiers, *Single Photon Workshop*, Oct 15, 2013, Oak Ridge, TN.

R. C. Pooser, B. J. Lawrie, J. Schaake, D. D. Earl, T. S. Humble, Real Time Quantum Imaging via Compressed Sensing, *Frontiers in Optics, Compressive sampling and image reconstruction*, Oct 15, 2012, Rochester, NY.

W. P. Grice, D. Guo, E. Martin, D. Earl, E. Ferragut, R. C. Pooser, A beam profiler based on compressive imaging, *Frontiers in Optics, Quantum measurements II*, Oct 17, 2012, Rochester, NY.

B. J. Lawrie, P. Evans, R. C. Pooser, Multi-mode Squeezed Light Transduction via Localized Surface Plasmons, *Frontiers in Optics, Quantum Plasmonics*, Oct 17, 2012, Rochester, NY.

R. C. Pooser, B. J. Lawrie, J. Schaake, D. D. Earl, T. S. Humble, Real Time Quantum Imaging via Compressed Sensing, *CLEO: Quantum Security and Imaging*, May 16, 2012, San Jose, CA.

D. D. Earl, W. P. Grice, R. C. Pooser, D. Guo, E. Martin, A beam profiler based on compressive imaging, *CLEO*, May 11, 2012, San Jose, CA.

W. P. Grice, B. P. Williams, R. S. Bennink, D. D. Earl, P. G. Evans, T. S. Humble, R. C. Pooser, and J. Schaake, Multi-Client Quantum Key Distribution using Wavelength Division Multiplexing, *SPIE Optics and Photonics: Quantum Communications and Quantum Imaging IX*, August 21, 2011, San Diego, CA.

R. C. Pooser, D. D. Earl, P. G. Evans, T. S. Humble, FPGA-based gating and logic for multichannel single photon counting, *Single Photon Workshop 2011*, June 27 – July 1, 2011, Braunschweig, Germany.

P. G. Evans, W. P. Grice, R. C. Pooser, J. Schaake, and B. P. Williams, Polarization Manipulating Quantum Lightwave Circuits, *Single Photon Workshop 2011*, June 27 – July 1, 2011, Braunschweig, Germany.

B. P. Williams, R. S. Bennink, D. D. Earl, P. G. Evans, W. P. Grice, T. S. Humble, R. C. Pooser, and J. Schaake, Multi-Client Quantum Key Distribution using Wavelength Division Multiplexing, *42nd Annual DAMOP Meeting*, June 13, 2011, Atlanta, GA.

W. P. Grice, R. S. Bennink, P. G. Evans, T. S. Humble, R. C. Pooser, J. Schaake, and B. P. Williams, Strong Spectral Entanglement in Spontaneous Parametric Down-Conversion, *Frontiers in Optics*, October 24, 2010, Rochester, New York.

R. C. Pooser, A. M. Marino, V. Boyer, K. M. Jones, and P. D. Lett, Low Noise Amplification of a Continuous Variable Quantum State, *SPIE 2010 Defense, Security, and Sensing meeting*, April 8-9, 2010, Quantum Information and Computation VIII session, Orlando, FL.

HONORS AND AWARDS:

UT Battelle Awards Night; Scientific Research Accomplishment award for “pioneering work in quantum sensing beyond the Heisenberg Limit,” 2015.

Significant Event Award; “New Discovery of Plasmonic Mediation of Quantum Information,” Oak Ridge National Laboratory, 2013.

Wigner Fellowship at Oak Ridge National Lab, 2009 - 2011.

First place in Sigma Xi annual poster competition at NIST, 2009.

Intelligence Community Postdoctoral fellowship at NIST, 2007 - 2009.

TEACHING EXPERIENCE:

Oak Ridge National Laboratory, summer 2015

Taught a quantum optics course to senior level undergraduates.

National Institute of Standards and Technology, 2007

Taught a quantum optics course to senior level undergraduates.

University of Virginia: Teaching Assistant, 2006

Held study sessions, tutored students, and graded papers for an advanced Photonics course.

New York University: Teaching Assistant, 2000 - 2001

Answered questions online and graded assignments for C-programming class.

ADVISING:

Emily Layden, University of Alabama, Post Masters, Jan 2015 – present.

Jason Schaake, Graduate Student, University of Tennessee, 2010 – present.

Miller Eaton, SULI program research, Summer 2015; Summer 2016.

Anthony Giljum, SULI program, Summer 2016.

Marisol Beck, SULI program, Summer 2016.

Nick Black, SULI program, 2015; HERE program, 2016.

Tabitha Colter, SULI program, Summer 2015.

Wenjiang Fan, University of Virginia, GO program, Oct. 2014 – April 2015.

Allison Sachs, University of Tennessee, HERE program research, May 2014 – Dec. 2014.

Ben Lawrie, Intelligence Community Postdoc, 2011 – 2013, PhD: Vanderbilt, June 2011.

Brian Williams, Graduate Student, University of Tennessee, 2011 – 2014.

Cunjing Liu, Visiting Graduate Student, University of Tennessee, Jan. 2012 – Jan. 2013.

Eric Martin, undergraduate student, University of Tennessee, summer 2011.

Robert Goodman, undergraduate student, University of Tennessee, summer 2010, 2011.

COLLABORATORS:

- Richard Haglund, Vanderbilt University
- Jason Valentine, Vanderbilt University
- George Siopsis, University of Tennessee
- Christian Weedbrook, University of Toronto
- Olivier Pfister, University of Virginia
- Jietai Jing, East China Normal University
- Alberto Marino, University of Oklahoma

COMMUNITY OUTREACH AND PROFESSIONAL MEMBERSHIPS:

Joint Faculty Appointment – University of Tennessee Dept. of Physics

Optical Society of America – member

American Physical Society – member

Society of Photo-optical Instrumentation Engineers – member

Reviewer – Phys. Rev. Lett.; Optics Express; European Physics Letters; New Journal of Physics; Phys. Rev. A., Optics Letters, JOSA B.

Boys and Girls Clubs of the Tennessee Valley board of advisers – volunteer member and **spokesperson** since 2001

United Way of Greater Knoxville – Campaign spokesperson in 2004 and 2016.

Optimist club of Knoxville – reserve member

REFERENCES:

The following individuals have served as references in the past and may be asked in the future if appropriate

- Dr Paul D. Lett – National Institute of Standards and Technology; postdoc advisor
- Dr William D. Philips – National Institute of Standards and Technology; group leader
- Dr Olivier Pfister – University of Virginia Department of Physics; PhD advisor