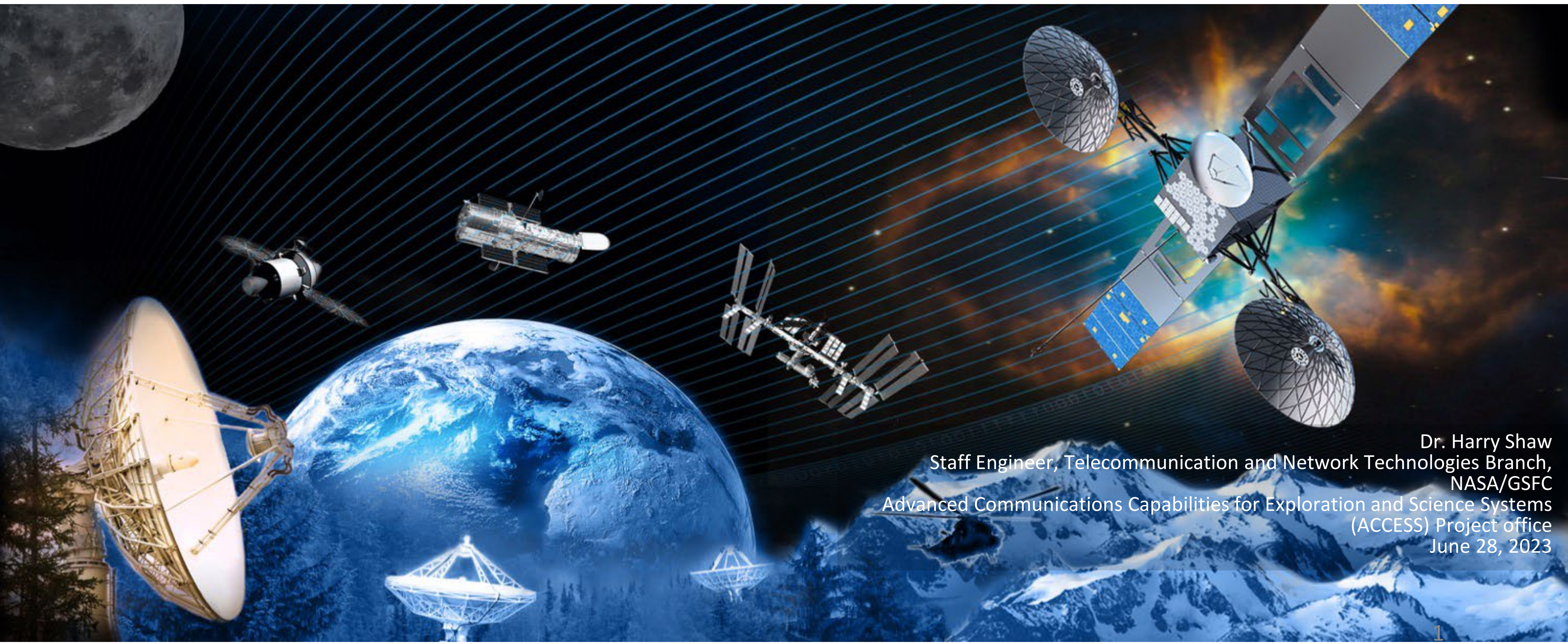
National Aeronautics and Space Administration

NASA

Exploration & SPACE Communications

More than you ever imagined...

Virginia Tech Quantum Information Sciences Symposium



Dr. Harry Shaw
Staff Engineer, Telecommunication and Network Technologies Branch, NASA/GSFC
Advanced Communications Capabilities for Exploration and Science Systems (ACCESS) Project office
June 28, 2023

Introduction

- I lead the technical work in quantum research in the Exploration and Space Communications division, Advanced Communications Capabilities for Exploration and Science Systems (ACCESS) Project office at NASA/GSFC along with Dr. Haleh Safavi Our primary focus areas are:
  - Basic and applied research with our partners to support the development of doctorates in quantum-related fields.
    - Some of them will end up within NASA
  - Planning for eventual operations of quantum enabled satellites
  - Improving "quantum literacy" within the American student population with an emphasis on bringing women and underrepresented minorities into the quantum world
    - We have a very robust intern program.
  - We are not full-time researchers. We have "day jobs" operating communications satellites and ground stations

Objectives

- NASA is fortunate to have two former doctoral interns at Virginia Tech
  - Nathan Myers, University of Maryland Baltimore County (Quantum Engines At The Frontiers Of Physics

  - Kyle Sherbert, University of North Texas (Band Theory And Beyond: Applications Of Quantum Algorithms For Quantum Chemistry)

- NASA/GSFC is interested in continuing collaboration with them and expanding into more areas of mutual interest
- We will provide some background on the work we are currently doing

ACCESS Project Quantum Team

Professional Staff	Degree	Institution	Major
Tyler Williams	M.S	Capitol Technology University	Cyber Security
Alejandro Rodriguez Perez	Ph.D	University of California Irvine	Materials Physics
Deborah Preston	Ph.D	University of California Los Angeles	Chemistry
Erika Jones	Ph.D	George Mason University	Computational Sciences and Informatics
Haleh Safavi	Ph.D	University of Maryland Baltimore County	Electrical Engineering
Harry Shaw	D. Sc.	George Washington University	Electrical Engineering
Robert Lafon	Ph.D	SUNY Stonybrook	Physics

Doctoral Students	Institution	Major
Manon Bart	Tulane University	Physics
Naveed Naimipour	University of Illinois Chicago	Electrical Engineering
Nick Savino	Tulane University	Physics

Post-doctoral	Institution	Major
Ian Nodurft	University of Illinois Chicago	Physics

Dr. Deborah Preston Tyler Williams Dr. Harry Shaw

Dr. Ian Nodurft

Manon Bart

Naveed Naimipour

Dr. Haleh Safavi

Dr. Robert Lafon

Dr. Erika Jones

Nick Savino

Jake Barnes

Dr. Alejandro Rodriguez-Perez

Grants and Subcontracts

New Mexico State (PI Steven Stochai) – Development of an optical communications testbed

Michigan State (PI Virginia Ayres) - Quantum Demonstration Project

UMBC (PI Sebastian Deffner) – Quantum Thermodynamics

A little bit about how GSFC is organized

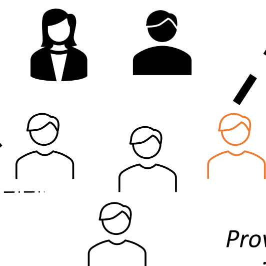
Engineering Directorate

A set of specific engineering disciplines called Branches.

Signs timecards, does performance evaluations.
Serves as our "straight line" boss that we directly report to

Flight Project Directorate

Instead of Branches there is a set of Projects that executes missions and generally gets the funding from HQ for the matrixed Engineering Branch employees. We are matrixed to the ACCESS Project which operates the Tracking and Data Relay satellites and ground stations around the world. Our HQ boss is the Space Communications and Navigation Directorate (SCaN)



Science Directorate

A set of Branches that usually define what science is to be accomplished via spaceflight missions which are proposed and run by GSFC If awarded by HQ. We talk to them to understand what services they require.

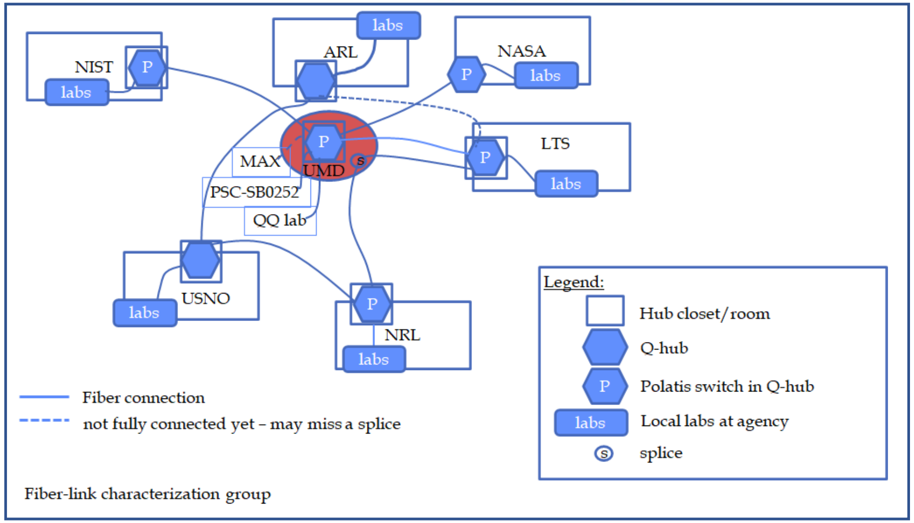
Our main customers

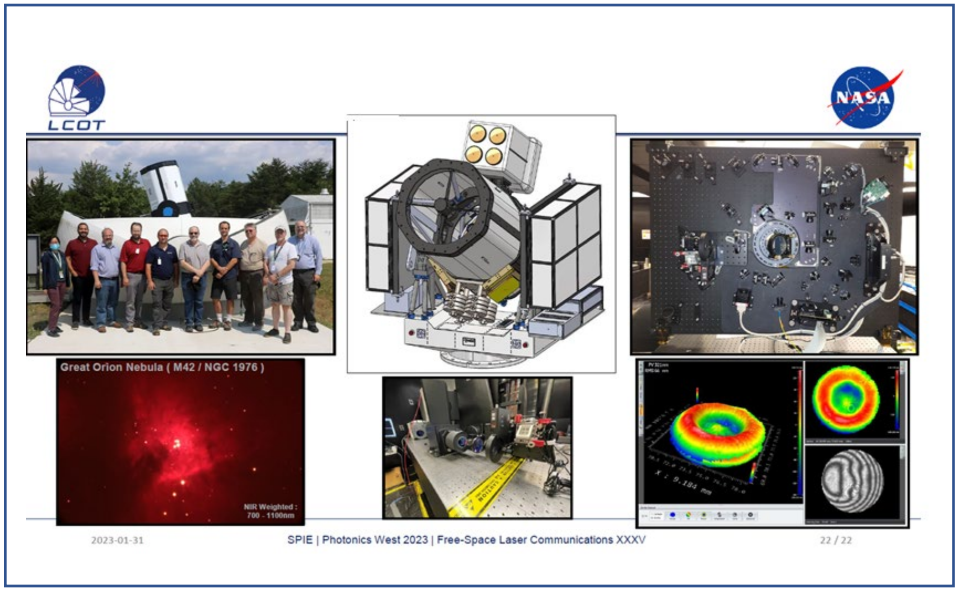
Provides funding and work assignments
Provides inputs to our Performance Evaluations
Serves as our "dotted line boss"

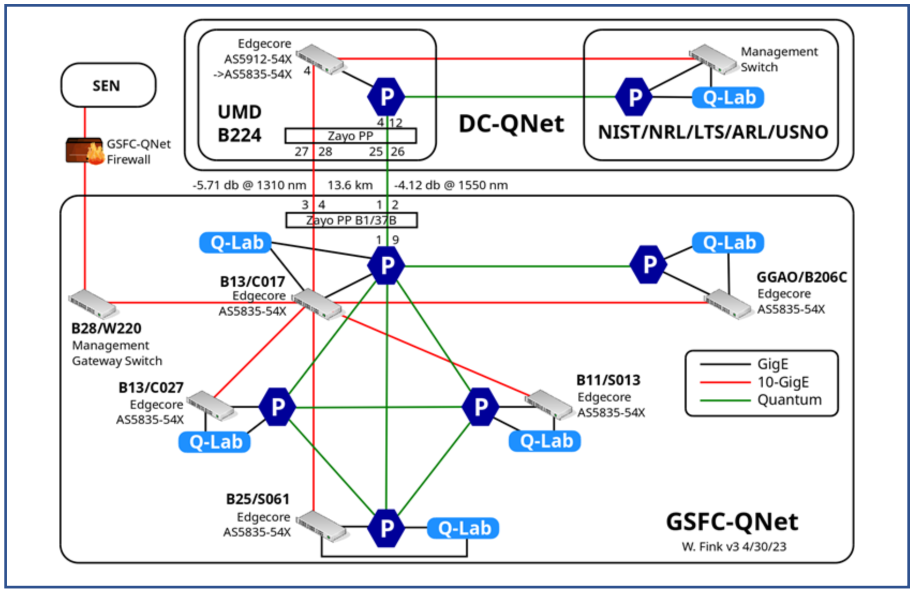
GSFC Quantum Networking

Recent Accomplishments:

- GSFC is establishing a campus wide quantum network
- GSFC is establishing quantum networking links with local government agencies and universities.
- GSFC is developing an optical terminal ground stations for classical and quantum communications (LCOT). It will be used as part of a space based quantum network

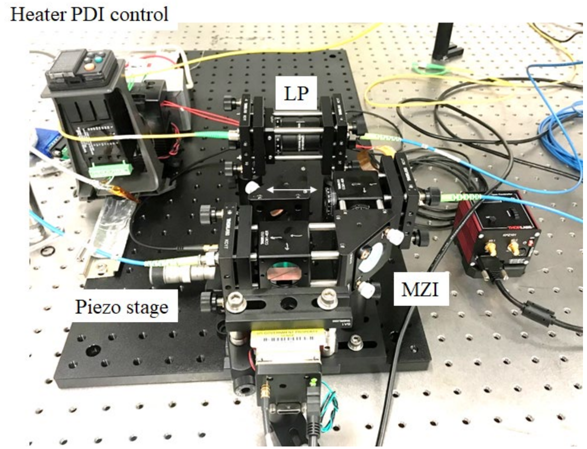






Quantum thermodynamics – Temperature dependence and materials effects in quantum eraser experiments

- Recent Accomplishments
  - Partnership with the Quantum Thermodynamics group at University of Maryland Baltimore County Physics department. PI is Dr. Sebastian Deffner
  - The quantum eraser provides an excellent test bed for a variety of investigations
  - Nathan Myers, granted Ph.D in 2022, Quantum Engines At The Frontiers Of Physics. Now a post-doc at Virginia Tech



Aifer, Maxwell, Nathan Myers, and Sebastian Deffner. "Thermodynamics of quantum information in noisy polarizers." *arXiv preprint arXiv:2212.00651* (2022).

ACKNOWLEDGMENTS

We would like to thank Todd Pittman, Alejandro Rodriguez Perez, Steve Campbell, and Pat Eblen for enlighting discussions. M.A. gratefully acknowledges support from Harry Shaw of NASA Goddard Space Flight Center. N.M.M. acknowledges support from AFOSR (FA2386-21-1-4081, FA9550-19-1-0272, FA9550-23-1-0034) and ARO (W911NF2210247, W911NF2010013). S.D. acknowledges support from the John Templeton Foundation under Grant No. 62422.

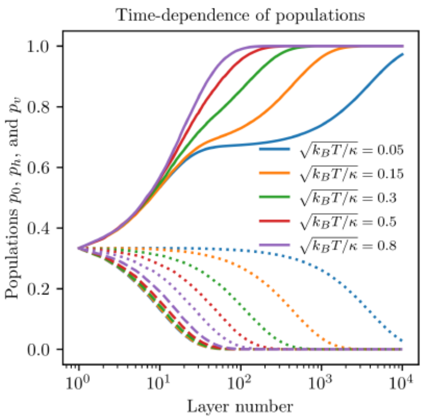
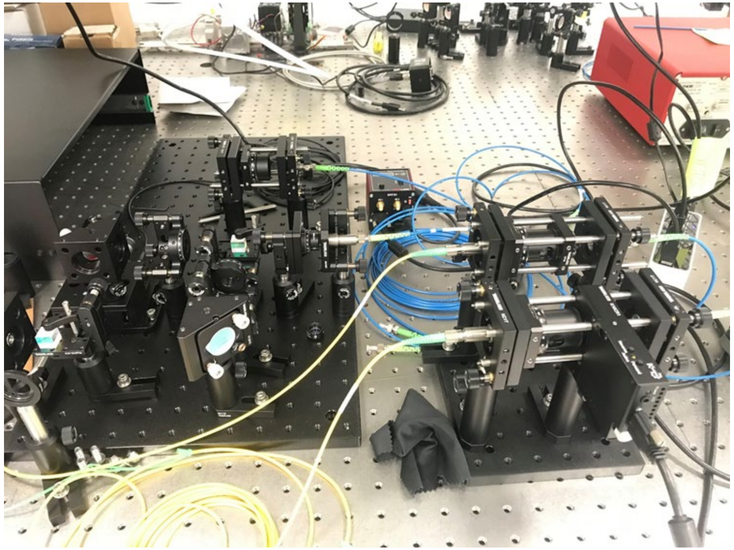


FIG. 7. Populations $p_0 = \rho_{00}$ (solid lines), $p_h = \rho_{11}$ (dotted lines), and $p_v = \rho_{22}$ (dashed lines). The vertical population p_v rapidly decays to zero but the horizontal component takes longer. As a result the vacuum population has a plateau that is flatter at lower temperatures.

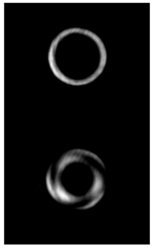


Quantum Communications

Recent Accomplishments:

- Established the first quantum communications laboratory at GSFC
- Baselining quantum entanglement equipment performance of systems at 1550nm and 810 nm
- Conducting experiments in Orbital Angular Momentum for superdense
- Investigating novel materials for propagation and storage of quantum states at > LN_2 temperatures

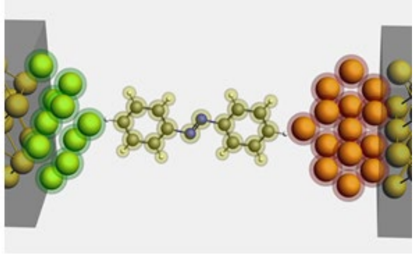
- Photons like other quantum particles contain both spin angular momentum (SAM) and orbital angular momentum (OAM)
  - While SAM is relegated to two-dimensional space, OAM belongs to infinite-dimensional space
- OAM modes are orthogonal
  - Allows multiplexing of Classical information
  - Can implement super-dense coding utilizing OAM modes

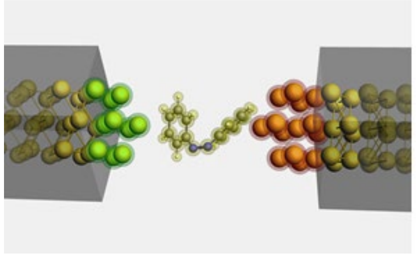


Partner: Tulane University, Ryan Glasser, PI

Harry Shaw, PI

Quantum chemistry simulation of electronic transport through azobenzene. single molecule circuit simulation





2023 NASA Fundamental Physics Workshop May 23-25, Santa Barbara, California.

Partner: Michigan State University, Virginia Ayres, PI

Hybrid State Effects in Quantum Entanglement Experiments
N. Sebasco[1], J. Vetere[1], G. Panda[1], V.M. Ayres[1] and H.C. Shaw[2]
[1] Department of Electrical & Computer Engineering, Michigan State University, East Lansing, MI 48824 USA,
[2]Code 5560, NASA Goddard Space Flight Center, Greenbelt, MD, 20771 USA

Presented

Entanglement in Perovskite Quantum Conductive Layers
G. Panda, N. Sebasco, J. Vetere, V. M. Ayres and H. C. Shaw
Department of Electrical & Computer Engineering, Michigan State University, East Lansing, MI 48824 USA
Code 5560, NASA Goddard Space Flight Center, Greenbelt, MD, 20771 USA

Submitted

Fractalized Quantum Evolutionary Computation
J. Vetere[1], N. Sebasco[1], G. Panda[1], V.M. Ayres[1] and H.C. Shaw[2]
[1] Department of Electrical & Computer Engineering, Michigan State University, East Lansing, MI 48824 USA,
[2]Code 5560, NASA Goddard Space Flight Center, Greenbelt, MD, 20771 USA

Submitted

Quantum Computing

Recent accomplishments:

- Established access to the AWS Braket Quantum as a Service. This will allow our quantum algorithms to be tested on actual quantum computers.
- Developed and published approach on quantum compressive sensing

Quantum Compressive Sensing Algorithms

- Built upon algorithms work by Kyle Sherbert (Ph.D Physics 2022, U of North Texas, VT post-doc) & Naveed Naimipour
- Bridging compressive sensing algorithms to quantum computing/communication infrastructure
  - Effects of Shot Noise
- Explored Advantages of Quantum Compressive Sensing
- Key Takeaways
  - Basics of quantum computation and circuitry for work on quantum algorithms
    - QISKIT
    - Methods for testing quantum algorithms
  - Built understanding of tomography, noise & quantum noise, compressive sensing techniques

Kyle Sherbert

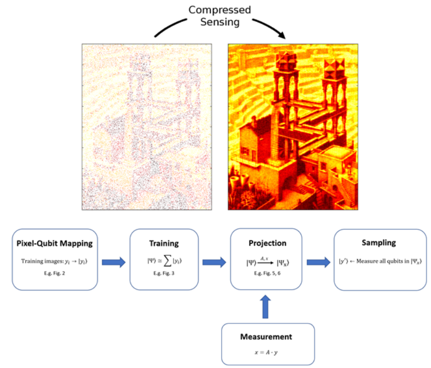
Naveed Naimipour

- Implemented a Projection Method for Quantum Phase Estimation

Sherbert, K. M., Naimipour, N., Safavi, H., Shaw, H. C., & Soltanalian, M. (2022). Quantum Compressive Sensing: Mathematical Machinery, Quantum Algorithms, and Quantum Circuitry. *Applied Sciences*, *12*(15), 7525.

Current and Future Tomography Work

- Exploring post processing areas is integral to the development of quantum tomography
  - Quantum Compressive Sensing
    - Bridging the gap between the quantum and classical worlds of reconstruction
- We present the algorithms and quantum circuits required to implement the training, projection, and sampling steps on a quantum computer
  - We supplement these theoretical results by simulating these circuits with a qualitative model of LIDAR imaging of Earth forests
- Our results indicate that a quantum, data-driven approach to compressive sensing may have significant promise



Amazon Braket Service - Quantum Computing Investigations into Implementing Quantum Compressive Sensing Algorithms

Amazon Braket Features

- "fully managed quantum computing service"
- "build, test, and run quantum algorithms on AWS"
- "access to different types of quantum computers, a unified development environment, a choice of classical circuit simulators, and fully managed execution of hybrid quantum-classical algorithms"

—Amazon Braket Features webpage

NASA Mission Cloud Platform (MCP)

"In collaboration with Amazon Web Services (AWS), MCP provides a consolidated cloud service within NASA, giving mission customers a streamlined process for implementing and using secure, compliant cloud resources."

Provider		Technology
IonQ	universal gate-based	trapped ion — *chain of ionized ytterbium atoms where internal states of individual $^{171}Yb^{+}$ serve as qubits and gate operations are via laser pulses to drive two-photon Raman transitions*
Oxford Quantum Circuits (OQC)	universal gate-based	superconducting — *superconducting qubits in 3D (proprietary "Coaxmon") architecture, i.e., "qubit control electronics perpendicular to the plane of the qubits" [Amazon Braket]*
Rigetti	universal gate-based	superconducting — *"tileable lattices of alternating fixed-frequency and tunable superconducting qubits" [Amazon Braket]*
QuEra	analog Hamiltonian simulation	neutral atom — *arrays of rubidium where internal states of individual Rb atoms serve as qubits, connection of qubits is by Rydberg blockade, and current computational applications target quantum optimization and quantum simulation*

GSFC Quantum Communications Lab Plans

- **Use cloud service to run algorithms for quantum compressive sensing protocols**
- Access QC technology type of interest for low-cost setup of QC hardware in house

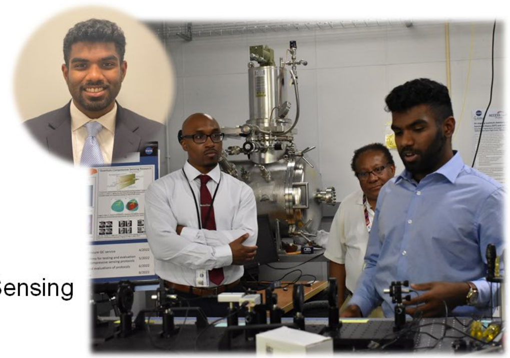
STEM

Recent Accomplishments:

- Expanded the intern program to include promising undergraduate students
- Expanding subject matter in the quantum areas

Nishanth Anand

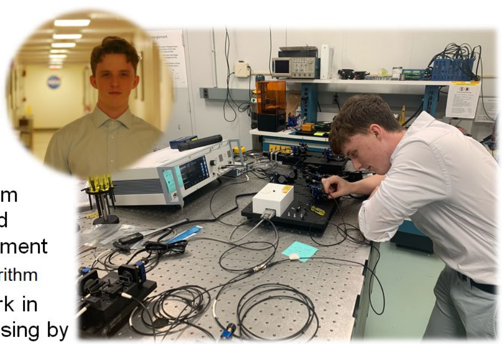
- **University of California, Berkeley**
- ***Bachelor of Arts, Astrophysics / Computer Science, May 2023***



- Performed Experiments
  - QKD with BB84 protocol
  - Quantum Eraser
- Quantum Compressive Sensing Algorithms

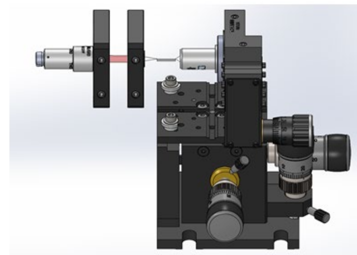
Collin Frink

- **University of Wisconsin, Madison**
- ***Bachelor of Science, AMEP (Applied Math, Engineering, Physics) and Computer Science, December 2022***



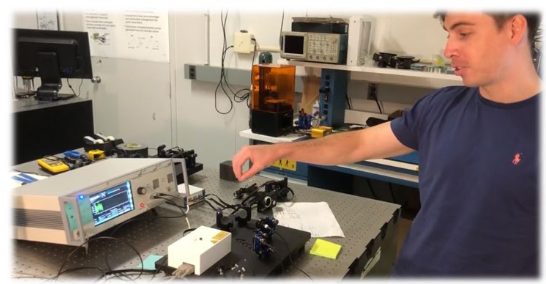
- Trained on low-cost quantum computing tools (Qiskit) and quantum algorithm development
  - Culminated with Shor's algorithm
- Extended previous lab-work in quantum compressive sensing by integrating quantum noise effects

- 2023 NRO Summer Intern Cordell Mazzetti, UT Austin, building a polarization entangled photon source.

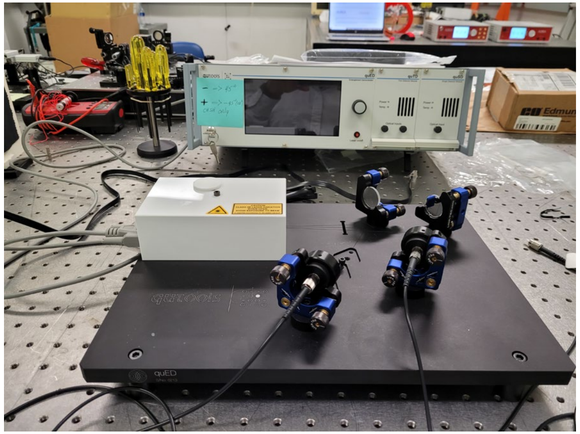


Nick Sebasco

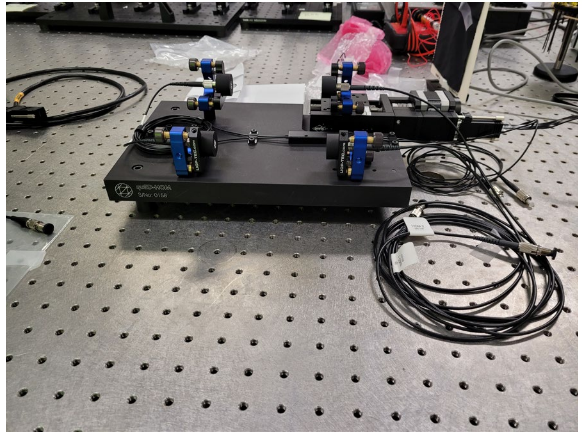
- **Developed our Franson Interferometer setup and performed multiple entanglement verification experiments**
- **Michigan State University**
- ***MS, Electrical and Computer Engineering, 2023***



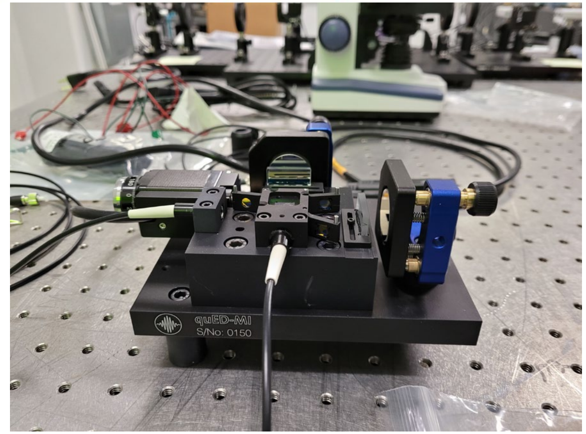
Qutools: This equipment will be used together to perform a variety of experiments



810nm Polarization Entanglement System



Hong-Au-Mandel fixture



Michelson Interferometer

Single Photon Experiments without Interference

Particle Nature of Photons
Quantum Cryptography/QKD: BB84 Protocol
Tomographic Single Photon State Reconstruction
Quantum Random Number Generation

Single Photon Experiments with Interference

Wave Nature of Photons: Single Photon Michelson Interferometer
Quantum Eraser
Wave-Particle Dualism: Michelson + HBT

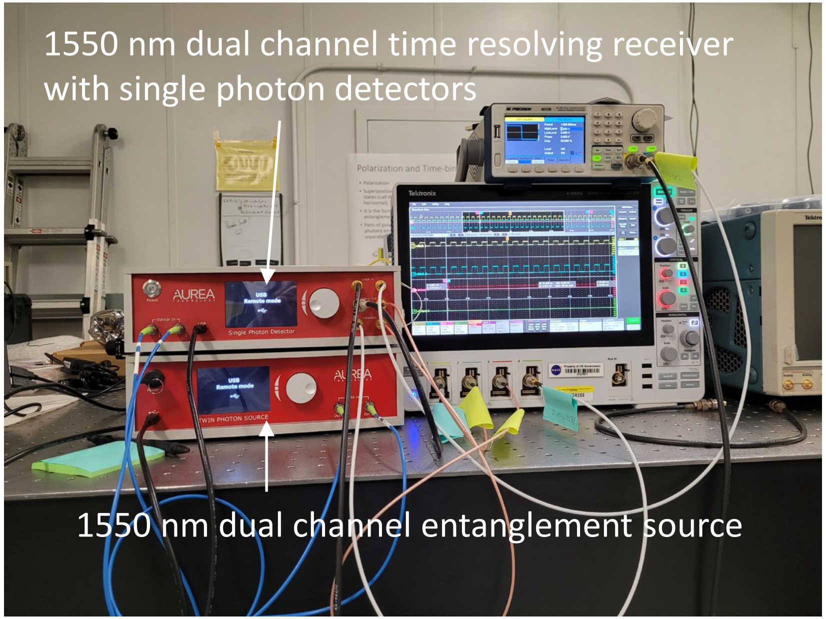
Photon Pair Experiments with Polarisation Entanglement

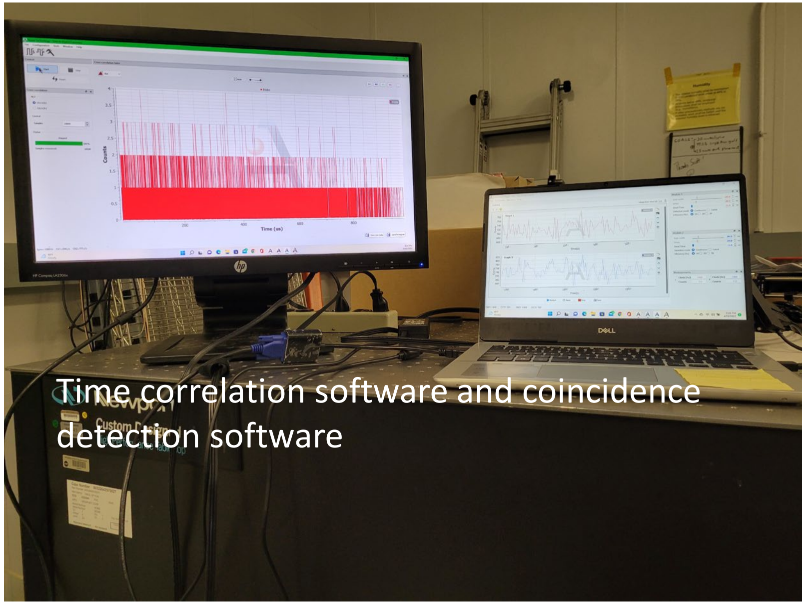
Violation of Bell's Inequality (CHSH)
"Non-Classical" Polarisation Correlations
Tomographic State Reconstruction of an Entangled Photon State
Quantum Cryptography/QKD: BBM Protocol
Quantum Cryptography: Ekert Protocol

Photon Pair Experiments without Polarisation Entanglement

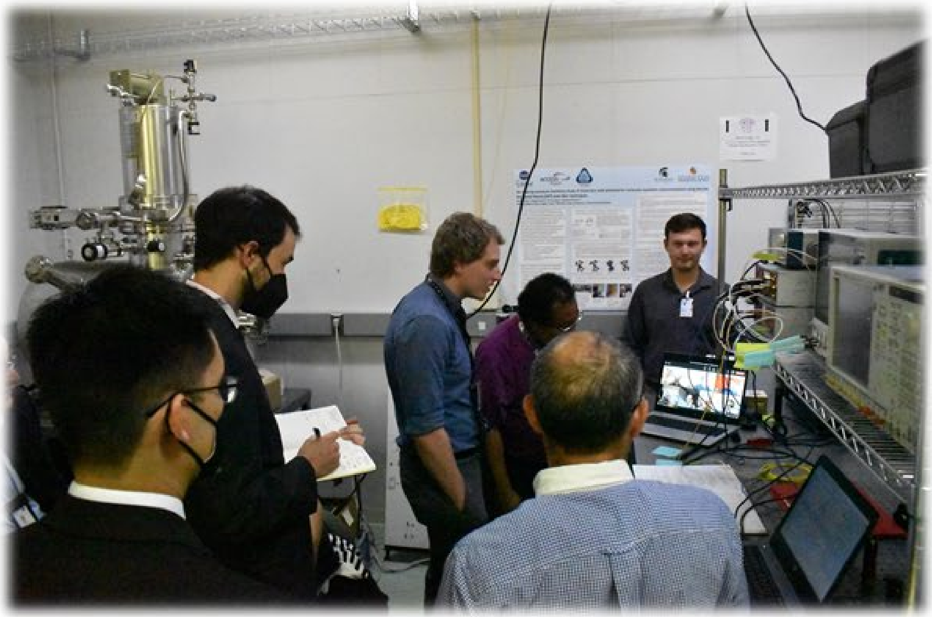
Hong-Ou-Mandel 2-Photon Interference
Hong-Ou-Mandel Interference + Hanbury Brown & Twiss
Franson Interference

Aurea: This equipment will be used as building blocks for experiments with other equipment





White House Office of Science and Technology, National Quantum Coordination Office visit (August 2022)



OSTP NQCO Drs. Wong and Stambaugh (far left) with the ACCESS Project Quantum Comm team

ACCESS Project Quantum Comm team with Dr. Nasser Barghouty (far right)

Summary of main experiments being crafted or in progress

1. Quantum Eraser
2. Fast steering of entangled beams
3. Investigations into entanglement verification and quantum state tomography
   - Clauser-Horne-Shimony-Holt (CHSH) inequality violation
   - Hong-Ou-Mandel (HOM) dip
   - Single Photon Interference with a Michelson interferometer
   - Hanbury-Brown Twiss (HBT) experiment
   - Continue exploring capabilities of our quantum entanglement systems
4. Advancing Orbital Angular Momentum (OAM) investigations towards superdense coding
5. Quantum characterizations of a simulated LCRD downlink
6. Investigations into novel materials for quantum memories and circuits
7. Continue Quantum Compressive Sensing research on LIDAR datasets using Machine Learning
   - Use of commercial quantum computing capabilities to determine the suitability of those capabilities for quantum algorithm solutions
8. Quantum Thermodynamics investigations

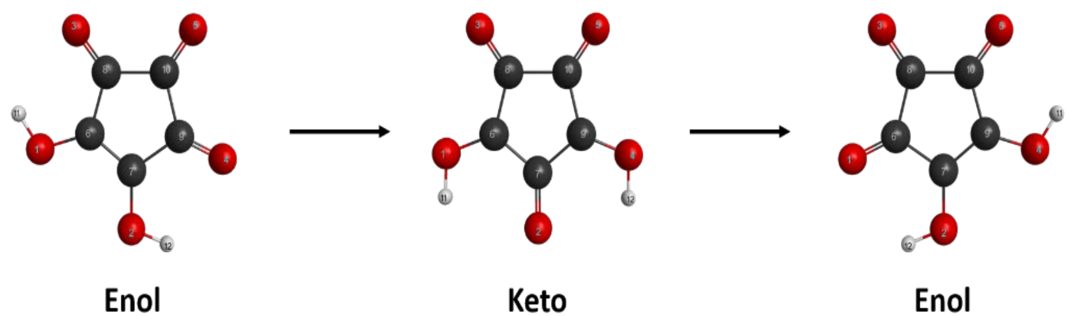
Unpublished Work in Progress

Low cost, above LN_2 temperature quantum circuits

- We have a research project to develop quantum circuits relying on stable tautomeric isomers
- Tautomers are conformational isomers that can take two states
- General questions we are looking at include:
  - Does the transition in states involve a superposition of states?
  - Does it involve quantum entanglement?
  - What is uniquely "quantum" about the circuit implementation?
  - How do we implement these materials in real-world quantum circuits?
- We have two tautomers we are looking at in great detail in simulation
  - Croconic acid
  - Azobenzene

Proton tautomerism in croconic acid

- Croconic acid is an important ferroelectric organic with favorable properties for classical circuits.
- The proton shift certainly provides for a possibility of a quantum oscillator
- There are a number of interesting thermodynamic issues to be explored

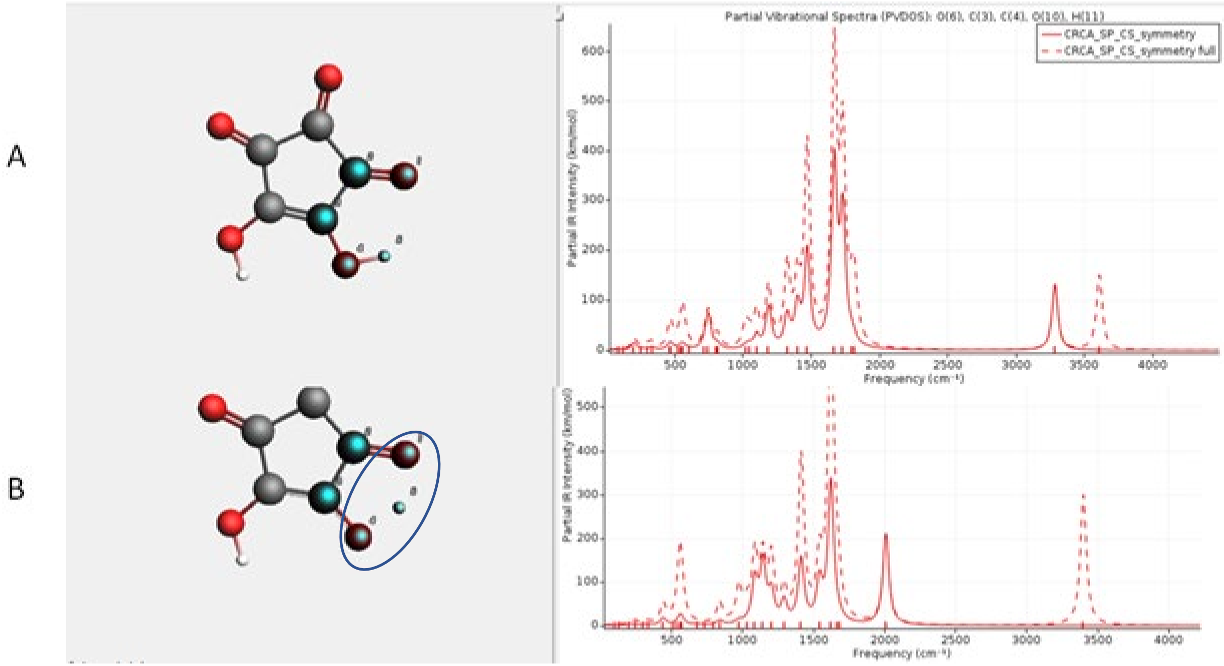


Kyle Sherbert's GAMESS simulation

Transition path and the potential energy surface

- We are performing simulations of the transition involving the proton transfer in croconic acid.
- We are using the Amsterdam Modeling Suite (AMS) from SCM and GAMESS
- AMS has a Potential Energy Surface explorer tool
- You define Expeditions and Explorers. They seek out potential energy scans with minimum energy.
- Required multiple iterations
  - 1st iteration: Use many expeditions and a few explorers
  - 2nd iteration. Narrow down candidates from the 1st iteration
  - Speed is tied to the number of cores in the machine. I have 4 cores, so I used only 12 explorers and 50 expeditions the first run and 12 explorers and 8 expeditions for second run

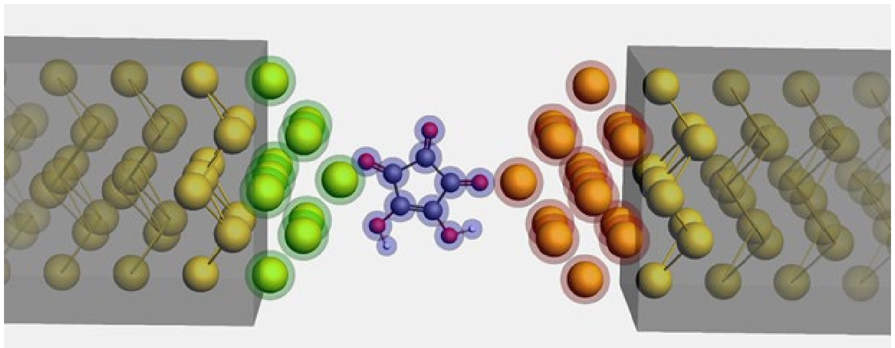
- Both are important in understanding the mechanisms at work and how we might implement a functioning circuit



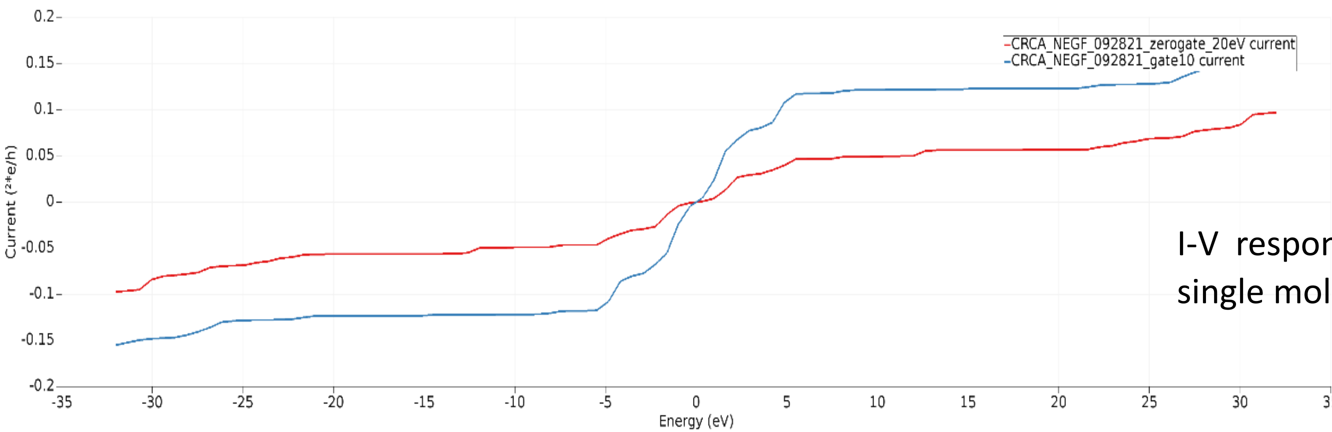
Vibrational spectra of the ground state (A) vs the transition state (B). The stretching mode of H11-O6 (circled) is the single imaginary vibrational mode at -886 cm^{-1} in the tautomeric transition state Note the appearance of the peak at 2005 cm^{-1} in the transition state and the split carbonyl peaks at 3282 cm^{-1} and 3607 cm^{-1} in the ground state appear as a single peak at 3395 cm^{-1} in the transition state.

Electronic transport through croconic acid. Single molecule circuit simulation

- AMS uses a non-equilibrium Green’s function approach to simulate electron transport
- There is much refinement to be done on these models. We need to include the polarization reversal that occurs under tautomerization. And deep dives into the practical interpretation of the simulation results are to be conducted.
- Additional work is planned to investigate electron and hole mobilities



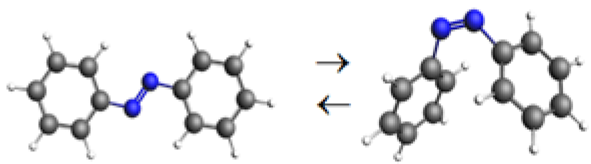
Single molecule circuit of croconic acid between gold electrodes



I-V response at zero bias and 10V bias for single molecule croconic acid circuit

cis- & *trans-* tautomerism in azobenzene

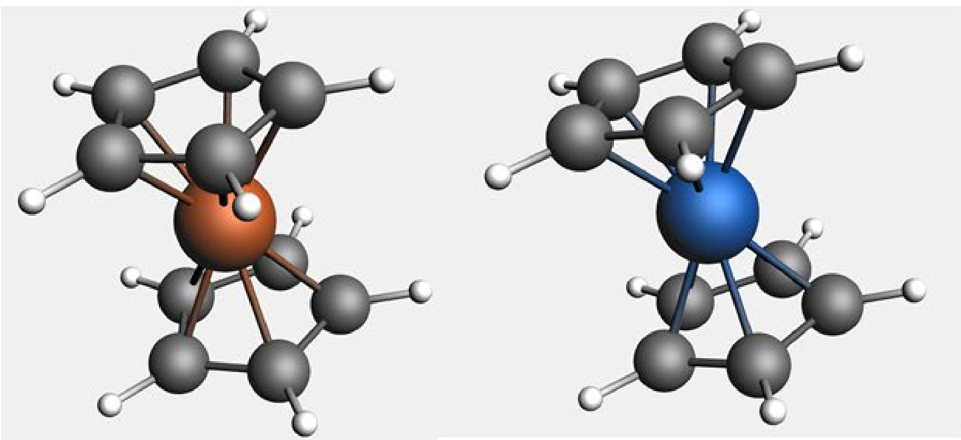
- Azobenzene can be optically stimulated at UV between the ground state (*trans-*) and an excited state (*cis-*) with reasonable thermal stability and reverse switched with visible light
- Azobenzene, and a number of derivatives are also important candidates for classical organic circuit elements such as photoswitches. In our case, we are interested in quantum memories
- We are using AMS modeling suite, GAMESS and ChemOffice which has a good MM2 and MM94 modeling interface



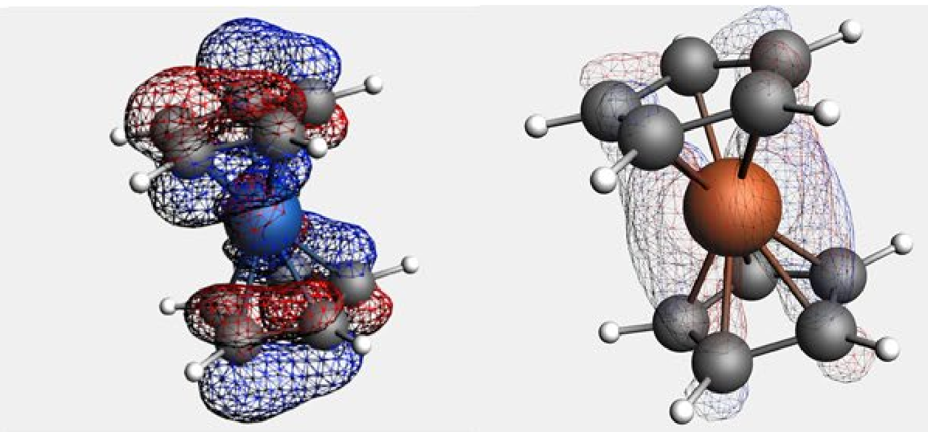
trans-azobenzene *cis*-azobenzene

Spin transport through metal cyclopentadienyls

- We are investigating the use metal cyclopentadienyls such as ferrocene and cobaltocene for quantum spin transport
- These molecules are exceeding difficult to model correctly. The highly delocalized nature of the central transitional metal atom to the cyclopentadienyl rings must be accounted for in evaluating the simulation options and results.
- Ferrocene, Cobaltocene and their derivatives are under evaluation with considerations for Aufbau and non-Aufbau[6] solutions, staggered, eclipsed and skewed configurations, with each constituting a separate symmetry basis



Ground state, Ferrocene and Cobaltocene eclipsed configuration



Cobaltocene and Ferrocene HOMO occupations

6. Ghosh, Sayantani, et al. "Entangled quantum state of magnetic dipoles." Nature 425.6953 (2003): 48-51

Sol-gels

- We have our quantum materials, how are we going to implement them in a practical application?
- Dr. Preston and I are investigating doping silica sol-gel as a substrate.
- We specialize in low temperature synthesis of silica sol-gel and doping them for novel applications [8,9]
- Next applications are quantum dots

The sol-gel synthesis process involves acid catalyzed hydrolysis and condensation resulting in polymerization and shrinkage over time. Patience is required to synthesize monoliths.

Mid-cure blank silica sol-gel

Mid-cure azobenzene doped Sol-gel. Note the two phases

3 months later Shrinkage into a Single doped monolith

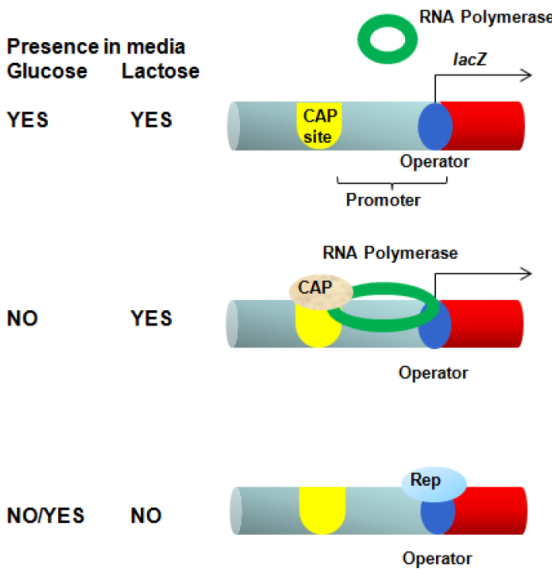
8. US 6,445,861 B1, 9/3/2002, Sol-Gel Processing To Form Doped, Sol-Gel Monoliths Inside Hollow Core Optical Fiber And Sol-Gel Core Fiber Devices Made Thereby. Harry Shaw, Melanie Ott, Michele Manuel (U of Florida)

9. Preston, Deborah, Jean Claude Pouxviel, Thomas Novinson, William C. Kaska, Bruce Dunn, and Jeffrey I. Zink. "Photochromism of spiropyrans in aluminosilicate gels." Journal of Physical Chemistry 94, no. 10 (1990): 4167-4172.

Off the beaten track

Some other interesting things I've been working on (Ultimately, it's all about communications)

- I have a series of papers using genomics and proteomics for information security which culminated in a patent
- I explore the synergy between molecular biology and information security[10]



State	Operations	Comments
Basal (Encrypted) *lacZ* low level of expression	D(key $_{Lactose}$, *lacZ*) E(key $_{Glucose}$, *lacZ*) E(key $_{CAP}$, *lacZ*)	lacZ gene is encrypted by presence of glucose and lack of CAP at the *lacZ* promoter binding site
Activated (Decrypted) *lacZ* expressed	D(key $_{Lactose}$, *lacZ*) D(key $_{Glucose}$, *lacZ*) D(key$_{CAP}$, *lacZ*) MAC(key$_{CAPsite}$, *lacZ*) MAC($_{keyRNA\ Polyermase\ site}$, *lacZ*)	Absence of glucose and presence of CAP at *lacZ* promoter decrypts the *lacZ* gene. CAP and RNA polymerase MAC authenticate the binding sites so that RNA Polymerase can bind to *lacZ* promoter
Off (Encrypted) *lacZ* repressed by Rep protein	E(key $_{Lactose}$, *lacZ*) MAC (key$_{Rep\ site}$, *lacZ* E($_{keyRep}$, *lacZ*)	Absence of lactose allows Repressor protein to authenticate binding site to *lacZ* operator and encrypts *lacZ* gene by binding to operator site

Figure 12. Conceptual example of Confidentiality and Authentication in *E. coli* using *lacZ* expression

10. Shaw, Harry, Sayed Hussein, and Hermann Helgert. "Genomics-based Security Protocols: From Plaintext to Cipherprotein." International Journal on Advances in Security 4, no. LEGNEW-OLDGSFC-GSFC-LN-1046 (2011).

Information theory and signal processing methodology to identify nucleic acid-protein binding sequences in RNA-protein interactions

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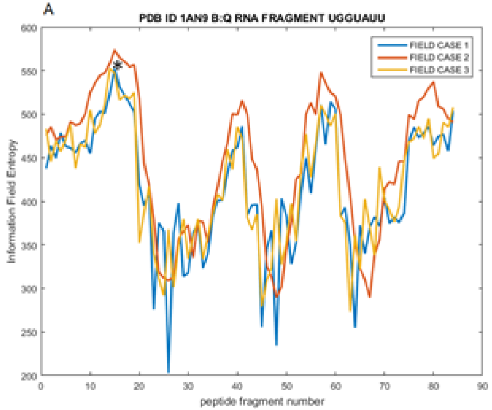
Introduction and Approach

- RNA-protein binding is central to cellular processes
    - Knowledge of the structure of the RNA-protein complex and its formation are key to understanding these processes.
    - In only a fraction of known RNA-protein complexes, structures of bound complexes have been produced using X-ray crystallography or solution NMR.

- The initial goal of this research: predict the binding sites of the microRNA to the each protein using MS/MS assay data.
    - Stretch goal: distinguish the strongly bound microRNA-proteins from the weakly bound microRNA-proteins in the same assay.
- Develop a model that predicts ΔG for RNA-protein binding sites
- Test the model against published RNA-protein binding data. Testing over 200,000 nucleotide:peptide fragments
- The result is an information entropy derived model calibrated against published RNA-protein ΔG for an entire set of assay data.
- Apply to mass spec data from RNA-protein co-immunoprecipitation assays

Produce information field entropy spectra and apply digital signal processing techniques to tease out peaks of interest

A

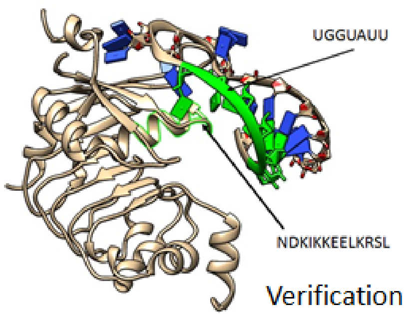


B

Eight-four peptide fragments of 1A9N

MDIRPNHTIYINN	NDKIKKEELKRSL	LKTMKMRGQAFVI	QGFPFYGKPMRIQ
DIRPNHTIYINNM	DKIKKEELKRSLY	KTMKMRGQAFVIF	GFPFYGKPMRIQY
IRPNHTIYINNMN	KIKKEELKRSLYA	TMKMRGQAFVIFK	FPFYGKPMRIQYA
RPNHTIYINNMND	IKKEELKRSLYAL	MKMRGQAFVIFKE	PFYGKPMRIQYAK
PNHTIYINNMNDK	KKEELKRSLYALF	KMRGQAFVIFKEL	FYGKPMRIQYAKT
NHTIYINNMNDKI	KEELKRSLYALFS	MRGQAFVIFKELG	YGKPMRIQYAKTD
HTIYINNMNDKIK	EELKRSLYALFSQ	RGQAFVIFKELGS	GKPMRIQYAKTDS
TIYINNMNDKIKK	ELKRSLYALFSQF	GQAFVIFKELGSS	KPMRIQYAKTDSD
IYINNMNDKIKKE	LKRSLYALFSQFG	QAFVIFKELGSST	PMRIQYAKTDSDI
YINNMNDKIKKEE	KRSLYALFSQFGH	AFVIFKELGSSTN	MRIQYAKTDSDII
INNMNDKIKKEEL	RSLYALFSQFGHV	FVIFKELGSSTNA	RIQYAKTDSDIIS
NNMNDKIKKEELK	SLYALFSQFGHVV	VIFKELGSSTNAL	IQYAKTDSDIISK
NMNDKIKKEELKR	LYALFSQFGHVVD	IFKELGSSTNALR	QYAKTDSDIISKM
MNDKIKKEELKRS	YALFSQFGHVVDI	FKELGSSTNALRQ	YAKTDSDIISKMR
	ALFSQFGHVVDIV	KELGSSTNALRQL	AKTDSDIISKMRG
	LFSQFGHVVDIVA	ELGSSTNALRQLQ	
	FSQFGHVVDIVAL	LGSSTNALRQLQG	
	SQFGHVVDIVALK	GSSTNALRQLQGF	
	QFGHVVDIVALKT	SSTNALRQLQGFP	
	FGHVVDIVALKTM	STNALRQLQGFPF	
	GHVVDIVALKTMK	TNALRQLQGFPFY	
	HVVDIVALKTMKM	NALRQLQGFPFYG	
	VVDIVALKTMKMR	ALRQLQGFPFYGK	
	VDIVALKTMKMRG	LRQLQGFPFYGKP	
	DIVALKTMKMRGQ	RQLQGFPFYGKPM	
	IVALKTMKMRGQA	QLQGFPFYGKPMR	
	VALKTMKMRGQAF	LQGFPFYGKPMRI	
	ALKTMKMRGQAFV		

C



Verification of predicted binding sites on 1AN9 from the calibration data set performed using Chimera and PDB structural data[4]

PDB ID	total number of predicted matches	total number of predicted matches within 3. 5 A	clash score	Ram outliers	sidechain outliers	RNA backbone	total number of RNA:peptide fragments
1A9N	20	20	C	CD	BC	D	2952
1EC6	16	12	DE	A	D	BC	1050
3AEV	49	33	B	A	D	DE	1035
1SI3	38	22	DE	A	BC	B	411
3R2C	39	21	B	A	BC	DE	816
3K49	30	15	C	B	A	D	1428
1HQ1	9	4	D	E	E	B	3999
2PJP	57	24	D	DE	E	D	1853
2ERR	10	4	AB	C	C	D	97

Sample evaluation data. Each entry in calibration dataset underwent a qualitative evaluation of the structure based upon the metrics. The 73 entries were reduced to 30 usable entries based upon this evaluation
A positive hit was registered if one amino acid in the protein segment was within 3.5 Å of any of the nucleotides in the 7 nucleotide RNA segment.

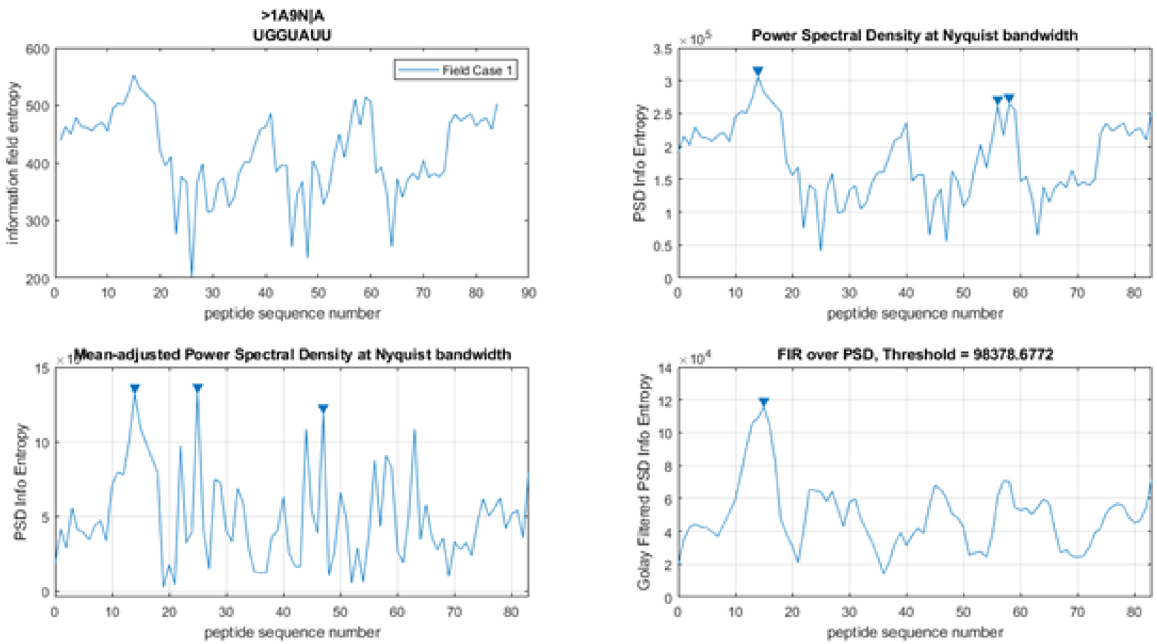
[15]Pettersen, Goddard, Huang, Couch, Greenblatt, Meng, Ferrin. J Comput Chem. (2004)

Molecular graphics and analyses performed with the UCSF Chimera package, Resource for Biocomputing, Visualization, and Informatics UCSF

Apply digital signal processing to enhance analysis of peaks

D1

D2



D3

D4

Fig. D represents the results of signal processing the raw spectrum as a time-domain spectrum of the RNA fragment sliding across the protein fragments. Fig. D1 shows the raw information entropy spectra, Fig. D2, D3, and D4 represent successive applications of filtering to enhance location of potential binding peaks.

Connection between quantum entanglement and biochemistry

- It is possible that quantum entanglement in biological systems is more common than originally thought
- NASA is very interested in biomimetic and bio-inspired systems.
  - Biomimetics for NASA Langley Research Center, NASA STTR 2017 Phase I Solicitation, T15.02 Bio-inspired and Biomimetic Technologies and Processes for Earth and Space, Biomimetic strategies for selective carbon dioxide capture with metal-organic frameworks, V.I.N.E. (Virtual Interchange for Nature-inspired Exploration) is a convergence of researchers who are involved in bio-inspired philosophy, sharing tools and research to enable systematic design of nature-inspired systems (GRC)
- It's possible that quantum biochemistry will become an important thrust area for NASA.
- Only researchers with a background in both biochemistry and quantum mechanics, especially the processes of quantum entanglement and the superposition of states will be capable of working in this area
  - Experimental indications of non-classical brain functions, Christian Matthias Kerskens[1] and David López Pérez[2,1] Journal of Physics Communications, Volume 6, Number 10 *J. Phys. Commun.* **6** 105001**DOI** 10.1088/2399-6528/ac94be
  - François Fillaux, Quantum entanglement and nonlocal proton transfer dynamics in dimers of formic acid and analogues, Chemical Physics Letters, Volume 408, Issues 4–6, 2005, Pages 302-306, ISSN 0009-2614, https://doi.org/10.1016/j.cplett.2005.04.069.

Conclusion

- We are looking for collaboration opportunities with Virginia Tech
- We will cast a wide net.
- We are open to collaboration activities that we have not previously considered