Princeton-TAMU
Summer School on Quantum Physics

Quantum Science Camp

Casper College, Casper, Wyoming
July 17-28, 2023

Princeton-TAMU Summer School on Quantum Physics

Casper College, Casper, Wyoming, July 17-28, 2023

Sunday, July 16, 2023

3:00 PM: Snack food is being delivered to the Residence Hall kitchen (1st floor, Room 144)

6:00 PM: Dinner is set in the Residence Hall kitchen (1st floor) and stored in fridge for late arrivals

Monday, July 17, 2023

All Talks will be in the Wold Physical Science Center, Room 103 (**PS103**)

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria on bottom floor of Union/University (UU building)
PS103	Session chair: Vlad Yakovlev	
8:10 – 8:20 AM	Marlan Scully, *Quantum Camp & Symposium*	**Overview and Welcome**
8:20 – 8:30 AM	Darren Divine, *Casper College*	
8:30 – 8:40 AM	Szymon Suckewer, *Princeton*	
8:40 – 8:50 AM	John Junkins, *TAMU*	
8:50 – 9:00 AM	BREAK	
9:00 – 9:40 AM	Aart Verhoef, *TAMU*	Multiphoton super-resolution microscopy
9:40 – 10:20 AM	Alexei Sokolov, *TAMU*	Quantum Sensing in Biophotonics
10:20 – 10:50 AM	BREAK	
	Session chair: Aart Verhoef	
10:50 – 11:30 AM	Vlad Yakovlev, *TAMU*	Brillouin microscopy: seeing life in a new light
11:30 – 12:10 PM	Jifa Tian *University of Wyoming*	Two-dimensional topological superconductors for future fault-tolerant quantum computing
12:10 PM	**LUNCH**	Tobin Cafeteria (bottom floor UU Bldg.)
	Afternoon recreational activities	
6:15 – 7:00 PM	**DINNER**	Outside PS 103
PS103	Session chair: TeYu Chien	
7:00 – 7:40 PM	Zhenhuan Yi, *TAMU*	Atomic coherence, cooperative emission and some applications
7:40 – 8:00 PM	Jizhou Wang, *TAMU*	Label-free wide-field imaging with high spatial resolution enabled by infrared-resonant third-order sum-frequency technique
8:00 – 8:30 PM	POSTER SESSION / BREAK	
8:30 – 8:55 PM	Suyash Bajpai *Howard University*	Rabi sideband emission from excitation gratings in filament wake channels in a dense argon gas
8:55 – 9:20 PM	Reed Nessler, *TAMU*	Jittering the photon distribution

Link to Book of Abstracts

Tuesday, July 18, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
PS103	Session chair: Jifa Tian	
8:10 – 8:50 AM	Rafael Quintero-Torres *CAPAT*	Laser-induced thermal profile in liquids and self-induced diffraction patterns
8:50 – 9:30 AM	Jinke Tang *University of Wyoming*	Investigation of the thermal transport and magnetic properties of potential quantum materials
9:30 – 10:10 AM	TeYu Chien *University of Wyoming*	Manipulating physical properties toward quantum information application through phase control and Moiré patterns in mixed phase 2M-2H WS_2
10:10 – 10:40 AM	POSTER SESSION / BREAK	
	Session chair: Yusef Maleki	
10:40 – 11:20 AM	Norbert Kroo *Wigner Research Center*	Medium high field plasmonics and one of its special applications
11:20 – 12:00 PM	Zhenrong Zhang, *Baylor*	Laser-printed plasmonic structural coloration on TiN substrate
12:00 PM	**LUNCH**	Tobin Cafeteria
	Afternoon recreational activities	
6:15 – 7:00 PM	**DINNER**	Outside PS 103
PS103	Session chair: Bob Brick	
7:00 – 8:00 PM	**Poster Presentations**	Posters 1-11
8:00 – 8:30 PM	POSTER SESSION / BREAK	
8:30 – 9:30 PM	**Poster Presentations**	Posters 12-21

Wednesday, July 19, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
PS103	Session chair: Rafael Quintero-Torres	
8:10 – 8:50 AM	Dawei Wang, *Zhejiang University*	Quantum induced coherence light detection and ranging
8:50 – 9:20 AM	Debsuvra Mukhopadhyay *Washington University St. Louis*	Quantum Multiphoton Rabi Oscillations in Waveguide QED
9:20 – 9:45 AM	Qihang Liu, Washington University in St. Louis	Coherent States of Photonic Dimers
9:45 – 10:05 AM	Rohil Kayastha, *Baylor*	Characterization of optical vortex beam in free space and optical fiber
10:05 – 10:35 AM	POSTER SESSION / BREAK	
	Session chair: Zhenrong Zhang	
10:35 – 11:15 AM	Yusef Maleki, *TAMU*	Quantum network sensors and distributed phase estimation metrology
11:15 – 11:45 AM	Muzzamal Iqbal Shaukat *Univ. of Texas at Dallas*	Dark Soliton Qudits: A Novel Quantum Information Platform
11:45 – 12:00 PM	Sijmon Verhoef *Wildwood Secondary*	Radio Waves in World War II
12:00 PM	**LUNCH**	Tobin Cafeteria
	Afternoon recreational activities	
6:15 – 7:00 PM	**DINNER**	Outside PS 103
PS103		
7:00 – 7:40 PM	Marcelo Terra Cunha, *Unicamp*	The Hardy argument for quantum contextuality
7:40 – 8:30 PM	Robert Nevels, *TAMU*	Radio and the Science of Wireless Transmission
8:30 – 8:50 PM	POSTER SESSION / BREAK	
8:50 – 9:30 PM	Aart Verhoef & Alma Fernandez *TAMU*	Identification of molecules using Raman spectrometer

Thursday, July 20, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
PS103	Session chair: Marcelo Terra Cunha	
8:10 – 8:50 AM	Shiyao Zhu & Dawei Wang *Zhejiang University*	From quantum interference to quantum simulation
8:50 – 9:30 AM	Philip Kurian *Howard University*	Quantum optical mega-networks in biological architectures
9:30 – 10:10 AM	Kaden Hazzard, *Rice*	Programmable Ultracold Quantum Matter
10:10 – 10:40 AM	POSTER SESSION / BREAK	
	Session chair: Kaden Hazzard	
10:40 – 11:20 AM	Anatoly Svidzinsky, *TAMU*	Noise induced coherence, vacuum entanglement, and efficiency of quantum heat engines
11:20 – 12:00 PM	Arash Azizi, *TAMU*	Kappa vacua: Enhancing the Unruh temperature
12:00 PM	**LUNCH**	Tobin Cafeteria
	Afternoon recreational activities	
6:15 – 7:00 PM	**DINNER**	Outside PS 103

5:00 PM, Dinner, Hamburgers & hot Dogs, Gateway Center (GW) 221/225

6:00 PM, After-dinner entertainment (moderators: Ming-Hsun Chou, Richard Sprague, Jiru Liu)

Friday, July 21, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
PS103	Session chair: Marlan Scully	
8:10 – 8:50 AM	Gary Eden *University of Illinois*	Fractal laser modes, speckle-free optical imaging, water optics, and other fascinating topics in optical physics and engineering (Zoom)
8:50 – 9:30 AM	Carmen Menoni *Colorado State University*	Bright extreme ultraviolet laser sources and their applications (Zoom)
9:30 – 10:10 AM	Jorge Rocca *Colorado State University*	Relativistic nanophotonics: creating extreme plasma and fields with ultra-intense, ultrafast lasers (Zoom)
10:10 – 10:40 AM	POSTER SESSION / BREAK	
	Session chair: Zhenhuan Yi	
10:40 – 11:20 AM	Norbert Kroo *Wigner Research Center*	High field plasmonics and potential nanoplasmonic laser fusion
11:20 – 12:00 PM	Zhedong Zhang, *City University of Hong Kong*	Monitoring electronic coherence of molecules by quantum-light spectroscopy (Zoom)
12:00 PM	**LUNCH**	Tobin Cafeteria
	Afternoon recreational activities	
6:15 – 7:00 PM	**DINNER**	Outside PS 103
PS103		
7:00 – 7:50 PM	Ed Fry, *TAMU*	Recent Nobel Prize and the Bell Inequality
7:50 – 8:20 PM	POSTER SESSION / BREAK	
8:20 – 9:10 PM	Hamza Patwa *Howard University*	Quantum Gravity: An Introduction

Saturday, July 22, 2023 Sunday, July 23, 2023

8:00 – 9:00 AM	**BREAKFAST**	Dorm kitchen
12:00 PM	**LUNCH**	Dorm kitchen
July 22, 5:00 PM **Barbecue on the yard (under pavilion tent outside Tobin Cafeteria)**		July 23, 6:00 PM **Dinner,** Dorm kitchen

Monday, July 24, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria (bottom floor UU Bldg.)
PS103	Session chair: Dawei Wang	
8:10 – 8:50 AM	Wolfgang Schleich *Universität Ulm*	The wave functional of the vacuum in a resonator
8:50 – 9:30 AM	Yanhua Shih *University of Maryland*	Nonlocal interference of photon pair at distance
9:30 – 10:10 AM	Truell Hyde, *Baylor*	Complex Plasma
10:10 – 10:40 AM	POSTER SESSION / BREAK	
	Session chair: Truell Hyde	
10:40 – 11:20 AM	Dmitri Voronine *Univ. of South Florida*	Raman autopsy of cancer cells
11:20 – 12:00 PM	Cleo Bentley, *Prairie View A&M University*	The Lithium atom fine structure energy levels from electron average-path elliptical orbits and spin
12:00 PM	**LUNCH**	Tobin Cafeteria (bottom floor UU Bldg.)
Afternoon recreational activities		
6:15 – 7:00 PM	**DINNER**	Outside PS 103
PS103	Session chair: Philip Kurian	
7:00 – 7:40 PM	Muriel Medard, *MIT*	An introduction to Forward Error Correction and Guessing Random Additive Noise Decoding
7:40 – 8:20 PM	Ken Duffy *Northeastern University*	Leveraging channel knowledge with GRAND – ORBGRAND-AI
8:20 – 8:50 PM	POSTER SESSION / BREAK	

Tuesday, July 25, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
PS103		
8:10 – 9:50 AM	Suhail Zubairy, *TAMU*	Quantum communication with invisible photons
9:50 – 10:20 AM	POSTER SESSION / BREAK	
PS103	Session chair: Dmitri Voronine	
10:20 – 11:00 AM	Olga Kocharovskaya, *TAMU*	Coherent control of ultra-narrow nuclear transitions
11:00 – 11:40 AM	Yury Shvyd'ko, *Argonne National Laboratory*	Resonant X-ray excitation of the long-lived ultra-narrow nuclear isomeric state in ^{45}Sc
11:40 – 12:00 PM	Xiwen Zhang, *TAMU*	Nuclear quantum memory for hard X-ray photons
12:00 PM	**LUNCH**	Tobin Cafeteria
Afternoon recreational activities		
6:15 – 7:00 PM	**DINNER**	Outside PS 103
PS103		
7:00 – 7:50 PM	Roland Allen, *TAMU*	The deepest mysteries of our quantum universe
7:50 – 8:20 PM	POSTER SESSION / BREAK	
8:20 – 9:10 PM	Philip Kurian *Howard University*	Computational Capacity of Life and the Observable Universe

Wednesday, July 26, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
PS103	Session chair: Arash Azizi	
8:10 – 8:50 AM	Marlan Scully, *TAMU*	Entanglement in Unruh and Hawking radiation from a quantum optical perspective
8:50 – 9:30 AM	Robert Mann *University of Waterloo*	Quantum superpositions of black holes (Zoom)
9:30 – 10:10 AM	Eduardo Martin-Martinez *University of Waterloo*	When do quantum effects matter in the interface of gravity, quantum information and quantum optics? (Zoom)
10:10 – 10:40 AM	POSTER SESSION / BREAK	
PS103	Session chair: Carlos Ordonez	
10:40 – 11:20 AM	Bill Unruh, *Univ. of BC*	LIGO is Quantum (Zoom)
11:20 – 12:00 PM	Philip Stamp, *Univ. of BC*	Is the LIGO mirror a macroscopic quantum object? Current theory and future experiments (Zoom)
12:00 PM	**LUNCH**	Tobin Cafeteria
Afternoon recreational activities		

5:00 – 6:00 PM, Dinner, Tobin Cafeteria (bottom floor UU Bldg.)

7:00 PM (to be confirmed)**, Movie “Oppenheimer”** (directed by Christopher Nolan)
Studio City Digital Cinemas, 5020 E. Second St., Casper

Thursday, July 27, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
PS103	Session chair: Wolfgang Schleich	
8:10 – 8:50 AM	Frank Narducci *Naval postgraduate school*	Novel atom interferometer
8:50 – 9:30 AM	Carlos Ordonez *University of Houston*	Quantum scaling anomalies in 2D and 1D systems
9:30 – 10:00 AM	POSTER SESSION / BREAK	
10:00 – 10:30 AM	Jonathan Ben-Benjamin *TAMU*	General relativity for the unwashed
10:30 – 11:20 AM	James Murray *Howard University*	From Plants and Photosynthesis to Solar Panels: A Quantum Biology Unit of Study for 4th and 5th Graders
11:20 – 12:10 PM	Suzy Lidström, *TAMU*	A quantum perspective on consciousness
12:10 PM	**LUNCH**	Tobin Cafeteria
Afternoon recreational activities		
6:15 – 7:00 PM	**DINNER**	Outside PS 103
PS103		
7:00 – 8:00 PM	**Presentations by high-school students**	
8:00 – 8:30 PM	POSTER SESSION / BREAK	
8:30 – 9:30 PM	**Presentations by high-school students**	

Friday, July 28, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
PS103	Session chair: Wenzhuo Zhang	
8:10 – 8:30 AM	Barnabas Kim, *TAMU*	What's next in quantum heat engines
8:30 – 9:10 AM	Nara Altangerel, *TAMU*	Sinclair pig as an animal model in both cancer and diet related research studies
9:10 – 9:30 AM	Alma Fernandez, *TAMU*	Study of nitrate uptake in roots with Raman microscopy
9:30 – 10:00 AM	POSTER SESSION / BREAK	
10:00 – 10:50 AM	Suzy Lidström and Roland Allen, *TAMU*	Quantum physics in medicine
10:50 – 11:40 AM	Alexei Sokolov, *TAMU*	Ultrafast Lasers and Quantum Sensing in Biophotonics
11:40 – 12:00 PM	**Concluding remarks**	
12:00 PM	**LUNCH**	Tobin Cafeteria
Afternoon recreational activities		

Friday evening, July 28, 2023

6:00 – 7:00 PM: Dinner, Tobin Cafeteria (bottom floor UU Bldg.)

8:00 PM: Snack food is being delivered to the Residence Hall kitchen (1st floor)

Saturday morning, July 29, 2023

5:30 AM Breakfast is set in the Residence Hall kitchen (1st floor)

Posters:

1. Sahar Delfan, TAMU, *Biosensor design and fabrication*
2. Zhi Gao, TAMU, *High-spatially resolved probing local field distribution of optical antennas for enhancing OAM Light*
3. Guillermo Gonzalez, University of Texas at San Antonio, *Quantum edge detection*
4. Ayla Hazrathosseini, TAMU, *Taking Upconversion to Lase in Microcavity*
5. Tuo Jia, TAMU, *Aspects of Hawking temperature*
6. Zhenfei Jiang, TAMU, *Applications of quantum light sources in bioimaging*
7. Yiyun Li, TAMU, *Optical multiband polarimetric modulation sensing for the identification of gender and species of native solitary pollinators in flight*
8. Ankang Liu, TAMU, *Manifestation of magnon vacuum entanglement*
9. Jiru Liu, TAMU, *Conservation of Gaussian states nonclassicality in linear optical networks*
10. Pablo Lopez-Duque, University of Houston, *Entanglement in bipartite systems involving finite-lifetime observers*
11. Hamza Patwa, Howard University, *Single photon superradiance and radiation trapping: Comparison of analytical, discrete, and numerical approaches for the cylindrical case*
12. Riva Salzman, TAMU*, High resolution imaging of soil aggregate pore space and microbial activity using optical coherence and multiphoton microscopy*
13. Yanli Shi, TAMU, *Origin of the transparency resonances in ensemble of germanium vacancy centers*
14. Nusrat Zahan Tanwee, Baylor, *Photoreaction studies with photoluminescence ghost imaging: Leveraging structured light and benefits of ghost imaging*
15. Sanjib Thapa, Baylor, *Plasmonic resonance measurement of metals and transparent conducting films using the Kretschmann configuration*
16. Sijmon Verhoef, Wildwood Secondary, *Radio waves in World War II*
17. Charles Wallace, TAMU, *Weak coherent state localization*
18. Xingqi Xu, Zhejiang University, *Floquet Superradiance Lattices in Room-Temperature Atoms*
19. Fan Yang, TAMU, *Whispering gallery modes in a wormhole*
20. Chaofan Zhou, TAMU, *Decay of single photon in cavity with atomic mirrors*
21. Wenzhuo Zhang, TAMU and Zia Harrison, Furman University, *Atom response to quantum chaos of a black hole*

Summer School is organized by:

Bob Brick, Marlan Scully, Anatoly Svidzinsky, Zhenhuan Yi

Quantum Science Camp

Casper College, Casper, Wyoming, July 17-28, 2023

Sunday, July 16, 2023

3:00 PM: Snack food is being delivered to the Residence Hall kitchen (1st floor)

6:00 PM: Dinner is set in the Residence Hall kitchen (1st floor) and stored in fridge for late arrivals

Monday, July 17, 2023

Lectures will be in Loftin Life Science Center, Room 206 (**LS 206**) and Wold Physical Science Center, Room 103 (**PS 103**). Labs are in Wold Physical Science Center, Rooms 201-210 (**PS 201-210**)

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria on bottom floor of Union/University (UU building)
PS 103		
8:10 – 8:20 AM	Marlan Scully, *Quantum Camp & Symposium*	**Overview and Welcome**
8:20 – 8:30 AM	Darren Divine, *Casper College*	
8:30 – 8:40 AM	Szymon Suckewer, *Princeton*	
8:40 – 8:50 AM	John Junkins, *TAMU*	
8:50 – 9:00 AM	BREAK	
LS 206		
9:00 – 10:30 AM	Suhail Zubairy *TAMU*	Birth of Quantum Mechanics: Planck, Einstein, Bohr, De Broglie, black body radiation, photoelectric effect, atomic models
10:30 – 10:50 AM	BREAK	
LS 201-210		
10:50 – 12:30 PM	Lab	Photoelectric effect
12:30 PM	**LUNCH**	Tobin Cafeteria (bottom floor UU Bldg.)
Afternoon recreational activities		
6:15 – 7:00 PM	**DINNER**	Outside PS 103
LS 206		Moderators:
7:00 – 8:00 PM	Video 1	Anatoly Svidzinsky, *TAMU*
8:00 – 8:20 PM	BREAK	
8:20 – 9:20 PM	Video 2	

Tuesday, July 18, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
LS 206		
8:10 – 9:40 AM	Suhail Zubairy, *TAMU*	Quantum interference, Heisenberg uncertainty relations, wave-particle duality, double slit experiment
9:40 – 10:00 AM	BREAK	
LS 201-210		
10:00 – 12:20 PM	Lab	Radio waves
12:20 PM	**LUNCH**	Tobin Cafeteria
Afternoon recreational activities		
6:15 – 7:00 PM	**DINNER**	Outside PS 103
PS 103		
7:00 – 8:00 PM	**Poster presentations by graduate students**	
8:00 – 8:30 PM	BREAK	
8:30 – 9:30 PM	**Poster presentations by graduate students**	

Wednesday, July 19, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
LS 206		
8:10 – 9:40 AM	Suhail Zubairy, *TAMU*	Simple quantum systems: Polarizers and beam splitters, photons
9:40 – 10:00 AM	BREAK	
LS 201-210		
10:00 – 12:20 PM	Lab	Polarization of microwaves and visible light
12:20 PM	**LUNCH**	Tobin Cafeteria
Afternoon recreational activities		
6:15 – 7:00 PM	**DINNER**	Outside PS 103
PS 103		
7:00 – 7:40 PM	Marcelo Terra Cunha *University of Campinas*	The Hardy argument for quantum contextuality
7:40 – 8:30 PM	Robert Nevels, *TAMU*	Radio and the Science of Wireless Transmission
8:30 – 8:50 PM	BREAK	
8:50 – 9:30 PM	Aart Verhoef & Alma Fernandez, *TAMU*	Identification of Molecules using Raman Spectrometer

Thursday, July 20, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
LS 206		
8:10 – 9:40 AM	Suhail Zubairy, *TAMU*	Coherent superposition, quantum entanglement, Schrodinger cat paradox, Quantum teleportation
9:40 – 10:00 AM	BREAK	
LS 201-210		
10:00 – 12:20 PM	Lab	Young’s double slit experiment
12:20 PM	**LUNCH**	Tobin Cafeteria
Afternoon recreational activities		
5:00 PM	Dinner, Hamburgers & hot Dogs, Gateway Center (GW) 221/225	
7:00 – 9:00 PM	Nationwide Eclipse Ballooning Project presentation Paul Marquard, *Casper College*	

Friday, July 21, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
8:10 AM – 12:10 PM	**Nationwide Eclipse Ballooning launch,** meet at Dorm lobby	
12:10 PM	**LUNCH**	Tobin Cafeteria
LS 206		
1:30 – 3:00 PM	Suhail Zubairy, *TAMU*	Einstein-Podolski-Rosen (EPR) paradox, Complementarity and Bell's inequalities
3:00 – 3:20 PM	BREAK	
LS 201-210		
3:20 – 5:20 PM	Lab	SPDC and Bell Inequality measurement
6:15 – 7:00 PM	**DINNER**	Outside PS 103
PS 103		
7:00 – 7:50 PM	Ed Fry, *TAMU*	Recent Nobel Prize and the Bell Inequality
7:50 – 8:20 PM	BREAK	
8:20 – 9:10 PM	Hamza Patwa *Howard University*	Quantum Gravity: An Introduction

Saturday, July 22, 2023

8:00 – 9:00 AM	**BREAKFAST**	Dorm kitchen
PS 103		Moderators:
9:10 – 10:00 AM	Video 3	Marcelo Terra Cunha, *Unicamp* Rafael Quintero-Torres, *CAPAT* Hamza Patwa, *Howard University*
10:00 – 10:10 AM	BREAK	
10:10 – 11:00 AM	Video 4	
11:00 – 11:10 AM	BREAK	
11:10 – 12:00 PM	Video 5	
12:10 PM	**LUNCH**	Dorm kitchen
3:00 PM	**Snacks, Dorm kitchen**	
5:00 PM	**Barbecue on the yard (under pavilion tent outside Tobin Cafeteria)**	

Sunday, July 23, 2023

8:00 – 9:00 AM	**BREAKFAST**	Dorm kitchen
PS 103		Moderators:
9:10 – 10:00 AM	Video 6	Carlos Ordonez, *University of Houston* Hamza Patwa, *Howard University* Tuo Jia, *TAMU*
10:00 – 10:10 AM	BREAK	
10:10 – 11:00 AM	Video 7	
11:00 – 11:10 AM	BREAK	
11:10 – 12:00 PM	Video 8	
12:10 PM	**LUNCH**	Dorm kitchen
6:00 PM	**Dinner, Dorm kitchen**	

Monday, July 24, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
LS 206		
8:10 – 9:40 AM	Suhail Zubairy, *TAMU*	Quantum secure communication, Quantum cryptography, BB-84 protocol, Quantum money
9:40 – 10:00 AM	BREAK	
LS 201-210		
10:00 – 12:20 PM	Lab	Quantum Eraser
12:20 PM	**LUNCH**	Tobin Cafeteria (bottom floor UU Bldg.)
Afternoon recreational activities		
6:15 – 7:00 PM	**DINNER**	Outside PS 103
LS 206		Moderators:
7:00 – 8:00 PM	Video 10	Kaden Hazzard, *Rice University* Rafael Quintero-Torres, *CAPAT*
8:00 – 8:20 PM	BREAK	
8:20 – 9:20 PM	Video 11	

Tuesday, July 25, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
PS 103		
8:10 – 9:50 AM	Suhail Zubairy, *TAMU*	Quantum communication with invisible photons
9:50 – 10:10 AM	BREAK	
LS 201-210		
10:10 – 12:20 PM	Lab	BB-84 protocol
12:20 PM	**LUNCH**	Tobin Cafeteria
Afternoon recreational activities		
6:15 – 7:00 PM	**DINNER**	Outside PS 103
PS 103		
7:00 – 7:50 PM	Roland Allen, TAMU	The deepest mysteries of our quantum universe
7:50 – 8:20 PM	BREAK	
8:20 – 9:10 PM	Philip Kurian *Howard University*	Computational Capacity of Life and the Observable Universe

Wednesday, July 26, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
LS 206		
8:10 – 9:40 AM	Suhail Zubairy, *TAMU*	Quantum Computing I: Quantum logic gates, Deutsch algorithm, Quantum dense coding and shell game
9:40 – 10:00 AM	BREAK	
LS 201-210		
10:00 – 12:20 PM	Lab	Online Quantum Computer programming
12:20 PM	**LUNCH**	Tobin Cafeteria
Afternoon recreational activities		
5:00 – 6:00 PM, Dinner, Tobin Cafeteria (bottom floor UU Bldg.)		
7:00 PM (to be confirmed), Movie "Oppenheimer" (directed by Christopher Nolan) Studio City Digital Cinemas, 5020 E. Second St., Casper, WY		

Thursday, July 27, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
LS 206		
8:10 – 9:40 AM	Suhail Zubairy, *TAMU*	Quantum Computing II: Shor and Grover’s Algorithms
9:40 – 10:00 AM	BREAK	
PS 103		
10:00 – 10:30 AM	Jonathan Ben-Benjamin *TAMU*	General Relativity for the unwashed
10:30 – 11:20 AM	James Murray *Howard University*	From Plants and Photosynthesis to Solar Panels: A Quantum Biology Unit of Study for 4th and 5th Graders
11:20 – 12:10 PM	Suzy Lidström, *TAMU*	A quantum perspective on consciousness
12:10 PM	**LUNCH**	Tobin Cafeteria
Afternoon recreational activities		
6:15 – 7:00 PM	**DINNER**	Outside PS 103
PS 103		
7:00 – 8:00 PM	**Presentations by high-school students**	
8:00 – 8:30 PM	BREAK	
8:30 – 9:30 PM	**Presentations by high-school students**	

Friday, July 28, 2023

7:00 – 8:00 AM	**BREAKFAST**	Tobin Cafeteria
LS 206		
8:10 – 9:40 AM	Suhail Zubairy, *TAMU*	Schrodinger equation, interpretation of the wavefunction, Hydrogen atom, particle in a box
9:40 – 10:00 AM	BREAK	
PS 103		
10:00 – 10:50 AM	Suzy Lidström and Roland Allen, *TAMU*	Quantum physics in medicine
10:50 – 11:40 AM	Alexei Sokolov, *TAMU*	Ultrafast lasers and quantum sensing in Biophotonics
11:40 – 12:00 PM	**Concluding remarks**	
12:00 PM	**LUNCH**	Tobin Cafeteria
Afternoon recreational activities		
6:00 – 7:00 PM	**DINNER**	Tobin Cafeteria

Saturday, July 29, 2023

5:30 – 8:30 AM	**BREAKFAST**	Dorm kitchen

Videos:

Video 1:

Models of Atom: Plum pudding model, Rutherford model, Bohr model
Matter waves, de Broglie wavelength
Quantum mechanical picture of Atoms and Chemical bonding

Video 2:

Heisenberg Uncertainty Principle
Structure of Atoms according to Quantum Mechanics
Crystals
Superconductivity
Solar Cells

Video 3:

Quantum Entanglement
Double-slit experiment and measurement in quantum mechanics
Delayed choice quantum eraser experiment
Why don't quantum effects occur in large objects

Link to Videos

Video 4:

EPR paradox and Bell's inequality
How quantum mechanics produces reality
Copenhagen vs many worlds interpretation of quantum mechanics
Free will, consciousness, and quantum mechanics

Video 5:

Standard Model of Elementary Particles
Fundamental Forces of Nature
Strong Nuclear Force, Quantum Chromodynamics
Higgs boson and Higgs field
Electroweak force, Higgs mechanism of mass generation

Video 6:

Where particles come from? Big Bang
Where do all the elements ultimately come from?
Where does mass of atoms come from?
Physics of the Sun
Neutron Stars and Pulsars

Link to Summer School Program

Video 7:

Minkowski Spacetime and Special Relativity
General Theory of Relativity
Black holes and Hawking radiation
Problems with General Relativity
String Theory

Video 8:

Quantum Fields
Dark matter in the Universe
Theory of Everything
Supersymmetry

Video 9:

Cosmic Microwave Background Radiation
Dark Matter and Dark Energy in the Universe

Video 10:

Quantum Computer
How does a computer CPU work: classical vs quantum
What is Qubit made from
Superconducting Qubit
Quantum world of diamonds
Quantum computer algorithms
Quantum cryptography: the BB84 protocol

Video 11:

Origin of Life
How does smell work - Quantum connection
How quantum mechanics helps birds navigate
Quantum Mechanics in Photosynthesis
Quantum brain, Quantum mind and Consciousness

Video 12:

Inertial confinement nuclear fusion
Lithium-ion battery
Wormhole as a connector between entangled particles

Talk Abstracts

(Listed Alphabetically by Presenter’s Last Name)

The deepest mysteries of our quantum universe

Roland Allen
Texas A&M University

Our deepest current understanding of Nature is that it consists entirely of quantum fields (even though we are still working on quantization of the gravitational field). This picture is so accurate that the agreement between its predictions and experiment are equivalent to predicting the distance between New York City and Los Angeles to within a millimeter. Remarkably, this highest level understanding of all forces and particles is essentially equivalent to a grand extension of the quantized harmonic oscillator, in which particles are just the quanta of fields. The fact that quantum fields are even more fundamental than particles is of central importance in understanding Hawking radiation from black holes and the related Unruh effect. Here we will discuss the deepest mysteries of our quantum universe, from the Big Bang to the origin of high-temperature superconductivity. Related articles are listed below.

Roland E. Allen and Suzy Lidström, “Life, the universe, and everything – 42 fundamental questions”, Physica Scripta **92**, 012501 (2017).

G. Agarwal et al., “Light, the universe, and everything — 12 Herculean tasks for quantum cowboys and black diamond skiers”, Journal of Modern Optics **65**, 1261 (2018).

Roland E. Allen and Suzy Lidström, “Your Higgs number — how fundamental physics is connected to technology and societal revolutions”, Physica Scripta **90**, 028002 (2015).

Suzy Lidström and Roland E. Allen, “Their Higgs numbers – inspiration for young people around the world”, Proceedings of the European Physical Society Conference on High Energy Physics (22-29 July 2015, Vienna, Austria).

Roland E. Allen, “From crystallography to life”, Physica Scripta 89, 068005 (2014).

Roland E. Allen, “The Higgs bridge”, Physica Scripta **89**, 018001(2014).

Roland E. Allen, “The London-Anderson-Englert-Brout-Higgs-Guralnik-Hagen-Kibble-Weinberg mechanism and Higgs boson reveal the unity and future excitement of physics”, Journal of Modern Optics **61**, 1 (2014).

Sinclair pig as an animal model in both cancer and diet related research studies

Narangerel Altangerel[1], Ayla Hazrathosseini[1], Robert Brick[1], Duane Kraemer[1], Philip Hemmer[1] and Marlan Scully[1,2,3]

[1]Texas A&M University, [2]Baylor University, [3]Princeton University

The Sinclair pig, also known as the Göttingen minipig, is a highly regarded and extensively utilized animal model in biomedical research. This breed has gained significant recognition due to its close anatomical, physiological, and genetic resemblances to humans. With similar organ sizes and functions, Sinclair pigs have proven to be invaluable in the study of human diseases and the testing of new therapeutic interventions. In the field of melanoma research, the Sinclair pig model has played a crucial role in providing valuable insights into this aggressive form of skin cancer.

In our study, we employed Raman microscopy to investigate melanoma and normal skin tissues obtained from Sinclair pigs. By analyzing the Raman spectra obtained from these samples, we were able to gain valuable insights into the molecular changes associated with melanoma development, comparing them to normal skin tissue. One significant finding in our Raman microscopic analysis of melanoma samples was the observed alteration in the composition of biomolecules. These changes provided important information about the molecular transformations linked to the progression of melanoma.

Furthermore, we conducted a dietary study with Sinclair pigs, dividing them into two groups with distinct diets. We collected their feces daily and utilized Surface Enhanced Raman spectroscopy (SERS) to extract detailed information about the microbiota present in their fecal samples. Our analysis revealed that the gut bacterial profiles of the pigs underwent changes as a result of slight modifications in their diet.

Overall, the utilization of the Sinclair pig model in our Raman microscopic study of melanoma and the subsequent dietary investigation has provided valuable insights into the molecular changes associated with melanoma development, as well as the impact of diet on gut bacterial profiles. These findings contribute to our understanding of melanoma and its potential treatment strategies, as well as shed light on the intricate relationship between diet and gut microbiota in the context of Sinclair pigs.

Kappa vacua: Enhancing the Unruh temperature

Arash Azizi

The Institute for Quantum Science and Engineering,
Texas A&M University, College Station, TX 77843, USA

We uncover an infinite number of vacua in two-dimensional quantum field theory, the Klein-Gordon field for simplicity, by conceiving a new mode that is classified by a real positive parameter κ. We show each mode has a distinct vacuum, say κ-vacuum. This new mode is a generalization of the Unruh mode. Moreover, the Minkowski and Rindler vacua are special cases of the κ-vacuum for $\kappa = 1$ and $\kappa \to 0$, respectively [1].

Furthermore, we establish a relation among different kappa vacua, resembling the thermofield double state. However, the energy of a kappa photon no longer exhibits a linear dependence on its frequency, unless the limit of $\kappa \to 0$ (the Rindler vacuum) is taken into account. In other words, a kappa vacuum can be expressed in terms of the Rindler vacuum as the conventional thermofield double state, with the usual energy for a photon. However, it features a modified Unruh temperature given by $T_\kappa = \frac{\hbar a}{2\pi c k_B}\kappa$. Consequently, when a uniformly accelerated observer with an acceleration a is immersed in a κ-vacuum, they perceive a thermal bath. However, the temperature experienced by the observer is a modified Unruh temperature denoted as T_κ. Remarkably, the Unruh temperature can be enhanced by an arbitrary factor of κ. [2].

References

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[2] A. Azizi, *Kappa vacua: Enhancing the Unruh temperature*, arXiv:2301.13672, (*to appear in Journal of High Energy Physics)*.

Rabi sideband emission from excitation gratings in filament wake channels in a dense argon gas*

Suyash Bajpai,[1, 2] Dmitri A. Romanov,[1, 4] and Robert J. Levis[3, 4]

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[2]*Quantum Biology Laboratory, Howard University, Washington DC, 20060, USA*
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Temple University, Philadelphia, PA 19122, USA.

When femtosecond laser filamentation takes place at a crossing of two laser beams, it is affected by the transient intensity grating (Fig. 1) caused by interference in the crossing area, which leads to transverse modulation of the filament wake channel. We consider this process to occur in a relatively dense gas, where the interatomic distances are comparable with the ponderomotive radius, so that electron-collisional processes lead to copious excitation of neutral atoms during the laser pulse. In this situation, a finite grating of excited-atom density is left in the pulse wake. Using a kinetic model of the system evolution during the pulse, we theoretically obtain the characteristics of this grating, controlled by the spatial and temporal characteristics of the crossing pulses (Fig. 2). These excitation gratings manifest themselves in a hallmark Rabi sideband emission when probed by a picosecond laser pulse of the standard 800 nm carrier wavelength. This Rabi sideband radiation emitted by the grating lines interferes constructively to form a characteristic spatial-spectral pattern on a remotely placed screen. These patterns (see Fig. 3) are considerably modified by the beam crossing angle, inter-beam phase delay, and distance between the screen and the excitation grating. We also demonstrate how the characteristics of the Rabi sideband patterns are quantitatively associated with the grating characteristics.

*This work was supported by the National Science Foundation under Grant No. PHY1806594 and by the Office of Naval Research under Award No. N00014-15-1-2574.

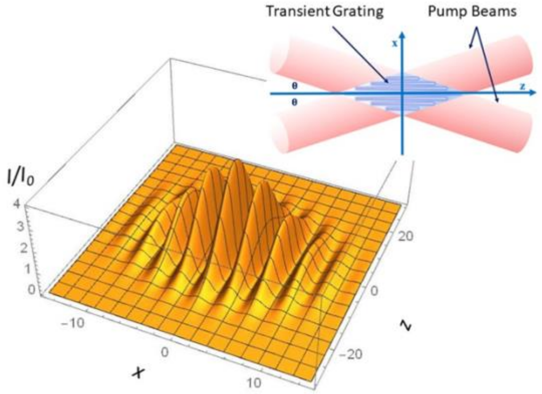

Fig 1. A snapshot of the transient intensity grating in the crossing area of two identical laser beams. **Inset**: the crossing-beam scheme for the excitation grating formation.

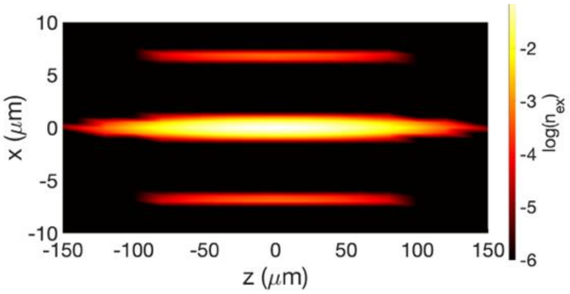

Fig 2. Simulated excitation grating at crossing angle of 0.057 Rads.

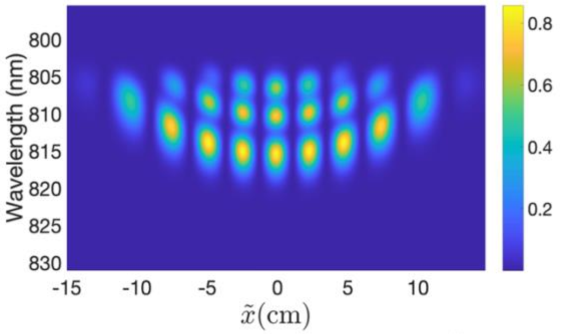

Fig 3. A typical spatial-spectral pattern from the excitation grating.

General Relativity for the Unwashed

J. S. Ben-Benjamin
IQSE

We present a conceptual tutorial to Einstein's theory General Relativity. Our goal is to motivate and give an idea of the theory while minimizing the use of mathematics.

We start from Newtonian physics, and use arguments of Einstein and Schild to demonstrate that Special Relativity cannot account for gravity.

Notwithstanding our guiding principle, we showcase some important equations conceptually, and otherwise – using simple examples.

CLIP ART INC

The Lithium atom fine structure energy levels from electron average-path elliptical orbits and spin

By

Cleo L. Bentley, Jr.

Prairie View A&M University

Abstract: If one takes the average path of the valence electron in a lithium atom to be elliptical around a spherical force-field porous barrier at a Bohr radius r_n from a proton-source diffraction pattern, improvement in precision of theoretical fine-structure energy values is observed over that found in Schrodinger Quantum Electrodynamics (QED.)

Manipulating physical properties toward quantum information application through phase control and Moiré patterns in mixed phase 2M-2H WS_2

TeYu Chien

Department of Physics and Astronomy, University of Wyoming

The topological superconducting phase is considered to be one of the candidates of realizing topological qubits, which can tolerate environmental noise. 2M phase WS_2 has been identified to be a topological superconductor with superconducting transition temperature of 8.8 K. WS_2 is a van der Waals (vdW) material which can be manipulated with phase change and the Moiré patterns. 2M phase of WS_2 is meta-stable while 2H phase is a more stable form. On the other hand, Moiré patterns in vdW materials can be formed by stacking dissimilar materials or by twisting two layers of same materials. The Moiré patterns in vdW materials have been demonstrated to exhibit strongly correlated nature which can host a variety of quantum states.

In this talk I will talk about our scanning tunneling microscopy (STM) studies of the 2M and 2H phases of WS_2. In particular, I will talk about various Moiré patterns found on the mixed phase 2M-2H WS_2 flakes. I will also talk about the close inspection of the laser heating induced phase change from 2M to 2H phase WS_2. The understanding of these detail phase change and interactions will provide important insights toward the achievement of topological qubit using WS_2.

Short Bio:

TeYu Chien is an Associate Professor of Physics at the University of Wyoming. He obtained his BS in Physics degree from National Taiwan Normal University in Taiwan in 2001. He received his Ph. D degree from University of Tennessee, Knoxville in 2009 working with Prof. Ward Plummer on electron-phonon coupling on Be (0001) surface using angle-resolved photoemission spectroscopy (ARPES). He then worked as postdoctoral research in Argonne National Lab (2009-2011) on developing cross-sectional scanning tunneling microscopy (XSTM) for oxide interfaces and in Northwestern University (2011-2013) on studying functionalizing graphene using chemical modifications. He joined the University of Wyoming as an assistant professor in 2013 to establish his own STM group. He was promoted to associate professor in 2019.

The Hardy argument for quantum contextuality

Marcelo Terra Cunha

Departamento de Matemática Aplicada
Universidade Estadual de Campinas (Unicamp), Brazil

Hardy has given an argument that is considered the simplest introduction to quantum nonlocality: a small sequence of propositions that imply one impossibility of the last of them to be true, while quantum theory allows for a positive probability of obtaining the correspondent truth value. Quantum contextuality is, in some sense, even simpler than nonlocality, since it does not require spacial separation. In this talk we show a Hardy argument for introducing quantum contextuality in terms of a game with some rules which make impossible a classical winning, while quantum theory allows for a positive probability of winning. There are, also, interesting connections of these ideas to "negative probabilities" of joint events, which we can also discuss.

Adán Cabello, Piotr Badziag, Marcelo Terra Cunha, and Mohamed Bourennane (2013), Simple Hardy-Like Proof of Quantum Contextuality, Phys. Rev. Lett. 111, 180404.

Bárbara Amaral and Marcelo Terra Cunha (2018), On Graph Approaches to Contextuality and their Role in Quantum Theory, SpringerBriefs in Mathematics.

Title: Leveraging channel knowledge with GRAND – ORBGRAND-AI

Speaker: Ken Duffy (Northeastern University) and Muriel Médard (MIT)

Abstract:

Having introduced Forward Error Correction (FEC) and Guessing Random Additive Noise Decoding (GRAND), we explain how – uniquely – GRAND can readily use statistical and realization-based information to improve its decoding performance.

Almost all FEC decoders are code-book centric and their decoding algorithms are built assuming that each bit is independently hit by noise, yet noise usually has a strong temporal correlation component. So that reality conforms with decoder expectations, in practice bits in data are coded and then well-separated before being communicated via a process called interleaving. At the receiver, bits are reassembled through deinterleaving before being decoded. Interleaving results in unwanted latency, but – more crucially – provably reduces channel capacity by destroying information contained in noise correlation.

With its focus on noise effects, GRAND is uniquely positioned to ditch the interleaving step and leverage noise characteristics to improve its decoding. Here we explain how ideas first introduced in thermodynamic probability theory can be incorporated into GRAND to create a practical decoding algorithm that is more precise and less computationally complex than existing decoders.

K. R. Duffy, M. Grundei & M. Médard. Using channel correlation to improve decoding – ORBGRAND-AI. *arXiv*, 2023.

A. Riaz, A. Yasar, F. Ercan, W. An, J. Ngo, K. Galligan, M. Médard, K. R. Duffy & R. T. Yazicigil. A sub-0.8 pJ/bit, 16.3 Gbps/mm2 universal soft-detection decoder using ORBGRAND in 40 nm CMOS. *Proceedings of IEEE ISSCC*, 2023.

K. R. Duffy, W. An & M. Médard. Ordered reliability bits guessing random additive noise decoding. *IEEE Transactions on Signal Processing*, 70, 4528–4542, 2022.

Further information about GRAND, including links to papers and a tutorial given at the International Symposium on Information Theory in 2022, can be found here: https://www.granddecoder.mit.edu/

Study of Nitrate Uptake in Roots with Raman Microscopy

Alma Fernández, Dipankar Sen, Ze Tian Fang, Brian Henrich, Alexei Sokolov,
Marlan Scully, Sakiko Okumoto, Aart Verhoef
Texas A&M University, College Station, TX 77843, USA

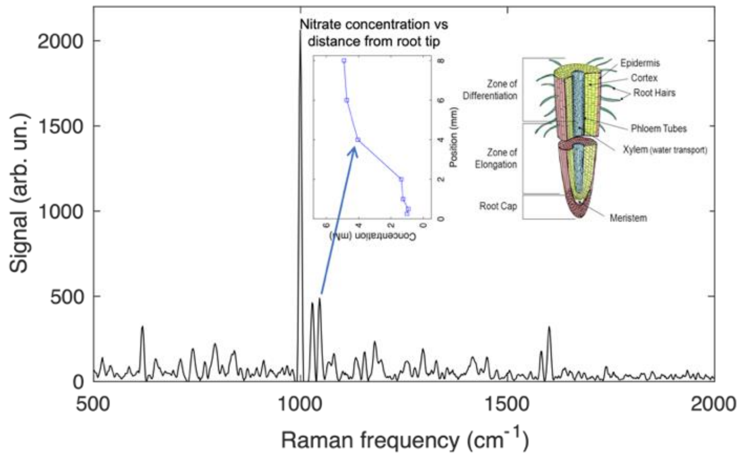

Figure 1: Raman spectrum of Arabidopsis root grown on agar plate medium. The peak at 1046 cm^{-1} scales linearly with the nitrate concentration. Inset: Measured concentration vs distance from the root tip. For details see text.

Many different techniques exist to optically study physiologically relevant parameters in biological samples. Fluorescence microscopy coupled with fluorophores that change their behavior depending on certain environmental (physiological) parameters has allowed to make many important discoveries. Such fluorescent biosensors can be introduced in cells in different ways, for example by genetic encoding or allowing exgenous fluorophores to diffuse int the tissue. However, such biosensors may not be available for every physiologically relevant molecule. Another means to study such molecules is Raman micro-spectroscopy. As Raman spectra reveal molecular vibrational signatures of the samples under study, it is an attractive tool to detect and quantify the distribution of relevant molecules. As it is especially challenging to introduce biosensors in plant tissues (plant cell walls are much less permeable to such molecules than animal cell membranes), Raman microscopy is especially relevant to plant studies. In this work, we use a portable Raman spectrometer coupled to a home-built microscope to study the uptake and distribution of nitrate molecules in plant roots. Roots grow new cells at the root tip, and with increasing distance from the end of the root, the function and maturity of cells change [1]. While growing and dividing cells require (consume) nitrate as a nitrogen source to make proteins and other cellular components, maturated cells, that have their cell walls completed require much less nitrogen. The first few mm of a root consists of dividing and growing cells, which differentiate into cells with different functions when the root has grown a few mm. As cells in different phases of their life cycle have different nitrogen demands, it can be hypothesized that nitrate concentrations in the cells differ as a function of position. However, with conventional methods it is impractical to measure nitrate concentrations with a high spatial resolution as the amount of sample is very low and destructive analysis is required. Raman microscopy can overcome that limitation [2]. Our experimental results show that the nitrate concentration in root tissue is lowest at the root tip and increases to a maximum value at about 4-6 mm from the tip, and then levels off or decreases. This trend is consistent under different growth media conditions. We also observe that under nitrogen-starved conditions, the roots accumulate nitrate to several times the media concentration. Under more nitrogen-rich conditions, the accumulation of nitrate levels off, and turns into inhibition of nitrate to the tissue. These observations will allow us to perform more detailed studies of gene-regulation and understanding of plant responses to variations in nitrogen availability.

References

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Recent Nobel Prize and the Bell Inequality

Edward S. Fry

Department of Physics and Astronomy
Texas A&M University, College Station TX 77843-4242

Abstract

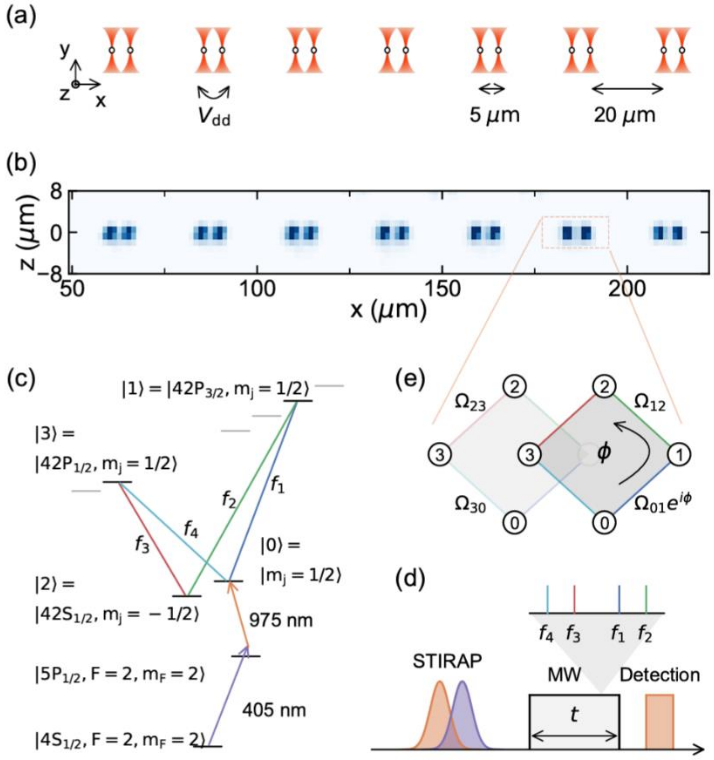
The Nobel prize in 2022 was awarded to John Clauser, Alain Aspect and Anton Zeilinger for their experimental tests of the Bell Inequalities. The conceptual foundations of quantum mechanics and Bell Inequalities will be discussed. And the decades long history of the contentious problem will be reviewed together with some of the associated quotes; *e.g* Einstein believed that quantum mechanics was an incomplete theory and is famously quoted from a letter he wrote to Max Born in 1944: “You believe in God playing dice and I in perfect laws in the world of things existing as real objects . . .” A breakthrough analysis by John Bell in 1964 and the resulting Bell Inequality that made it possible to experimentally test these heretofore philosophical arguments will be discussed. Results of many experimental tests of the Bell inequalities will be presented and one surprising result is that Einstein was wrong. Results (agreement or not with QM) of the five earliest experiments, and the Zeilinger experiment will be provided:

1) 1972: **Clauser** (& Freedman); QM-Yes; data collection ~200 hours
2) 1973: Holt (& Pipkin); QM-No; data collection ~200 hours
3) 1976: **Clauser**; QM-Yes; data collection ~200 hours
4) 1976: Fry (&Thompson); QM-Yes; data collection ~60 minutes
5) 1981: **Aspect** (& Grangier, Roger) QM-Yes; data collection ~13 minutes
6) 1998: **Zeilinger** (& 4 others) QM-Yes; data collection ~10 seconds

Programmable Ultracold Quantum Matter

Kaden R. A. Hazzard
Rice University

Physicists’ ability to measure and control quantum matter has grown from manipulating the quantum motion of single atoms in the 1990s to coherently controlling thousands of them, atom-by-atom. This has led to insights into interacting quantum matter, and new phases of matter and dynamical phenomena. I will discuss our recent progress advancing this frontier, in which we (theorists) have partnered with experimentalists to create and understand programmable matter in both real space and in so-called synthetic dimensions. One approach uses optical potentials in real space to program arbitrary lattice geometries for fermions, allowing experiments to perform “quantum simulations” of models and regimes that have never before been accessible. Another, perhaps more surprising, approach uses *synthetic dimensions*, systems with degrees of freedom that behave in a way that can mimic motion in space. I will focus on Rydberg atom and molecule synthetic dimensions, describing recent experiments that observed topological edge states and how interactions can lead to novel phenomena such as quantum strings and membranes, and to parastatistical quasiparticles, a type of particle beyond fermions and bosons (and beyond anyons).



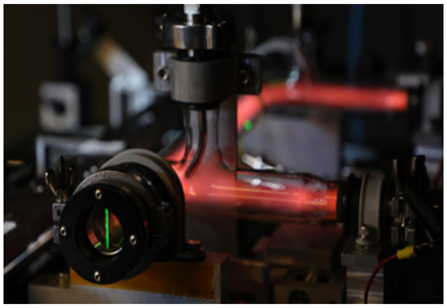
Adapted from T. Chen, C. Huang, I. Velkovsky, K. R. A. Hazzard, J. P. Covey, and B. Gadway, arxiv:2306.00883

Complex Plasma

Truell W. Hyde

CASPER / Department of Physics, Baylor University

ABSTRACT



A large percentage of the visible matter in the Universe is in a complex plasma state. Within this parameter space, the nanometer to micron size particles comprising the ‘solid’ component of this complex plasma can act as either a probe of the environment and/or an integral component of the complex plasma itself. When the particles act as probes, they provide the ability to ‘map’ the electric and magnetic fields within the plasma as well as help identify plasma / particle interactions, even those not easily observed or measured in any other manner. When the particles act as an integral component of the complex plasma, they produce entirely new physics resulting in the formation of symmetric or asymmetric structural ‘states’ and even at times, the formation of systems obeying non-Hamiltonian physics. This talk will discuss each of these employing data collected at the Hyde lab at Baylor University and the PK-4 on the International Space Station.

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Support from NASA / JPL Contract Numbers 1571701 and 1647194, NASA Contract numbers EW-2962-LDRM, DOE DE-S0021334, DOA 76943-SM and NSF Grant numbers PHY 1740203, PHY 1707215 and PHY 2008493 is gratefully acknowledged.

Credits: Dust and magnetic fields image: NASA/SOFIA / Star field image: NASA/Hubble Space Telescope

Characterization of optical vortex beam in free space and optical fiber

Rohil Kayastha[1], Blake Birmingham[1], Alexei V. Sokolov[2], and Zhenrong Zhang[1]

[1]Department of Physics, Baylor University, Waco, TX
[2]IQSE, Department of Physics and Astronomy, Texas A&M University, College Station, TX

Optical vortex beam has been used in many applications such as nanoscale imaging, telecommunication, sensing, and so on due to its unique azimuthal phase distribution. Many of these applications make use of optical fibers as a sensor or to propagate the beam for the transfer of data and information. The vortex beam has a phase singularity which gives the doughnut intensity profile for the beam as shown in Figure 1a. These beams can carry both spin angular momentum and orbital angular momentum (OAM). Because of the helical wavefront nature, the vortex beam carrying OAM can also be used to distinguish the enantiomers of the chiral molecule. However, coupling efficiency remains a problem due to the size mismatch of the beam and the molecule. In our work, we will make use of vortex fibers with plasmonic nanostructures to focus the vortex beam to the nanoscale which can enhance the coupling between the light and matter. To achieve this goal, we will first characterize the vortex beam in free space and through the vortex fiber, a polarization-maintaining ring core optical fiber that can support doughnut beams.

Generation and propagation of two different types of vortex beams, cylindrical vector beam and OAM beam, have been characterized in free space and through a vortex fiber. These vortex beams were generated in free space with a spatially variant λ/2 waveplate called S-waveplate and quarter waveplates. S-waveplate converts a linearly polarized Gaussian beam to a cylindrical vector beam with radial or azimuthal polarization. Circularly polarized OAM beams ($l = \pm 1$ and $s = \pm 1$) were generated in free space with the combination of a quarter waveplate and an S-waveplate. A circularly polarized OAM beam can also be converted into linearly polarized OAM ($l = \pm 1$ and $s = 0$) using another quarter waveplate. The helical phase fronts in the OAM beam can twist in a counterclockwise ($l = +1$) or clockwise ($l = -1$) direction as shown in Figures 1b and 1c respectively. To determine the helicity, a reference Gaussian beam of the same polarization interfered with a vortex beam. Two different interference patterns were studied experimentally; coaxial interference to observe a spiral interference pattern and off-axis interference for a fork-shaped fringe pattern. The characterization and analysis of the polarization of the beams were performed using a linear polarizer.

The transmission of cylindrical vector beams and the circularly polarized OAM through the ring core vortex fiber has been studied. The free space beam was coupled to the fiber and the purity and consistency of the output beam after the transmission were characterized. Nano-focusing of the vortex beam was tested by the fabrication of a nanostructure on the core of the vortex fiber facet. The structure could enhance the coupling efficiency of the beam with chiral molecules.

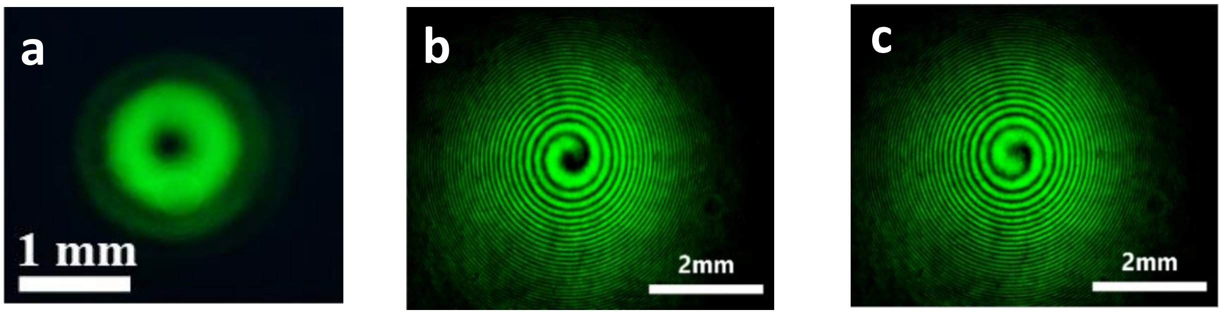

Figure 1: a) Vortex beam with doughnut intensity profile. Interference of circularly polarized OAM with circularly polarized Gaussian beam showing the spiral pattern; b) Counterclockwise ($l = +1$) c) Clockwise ($l = -1$)

What's next in Quantum Heat Engines

Barnabas Kim
IQSE, Texas A&M University, College Station, TX, USA 77843

To elude the Carnot efficiency in quantum heat engines, quantum weirdness is required. Using the imbalance in the emission and absorption caused by the quantum coherence, it might be possible to get efficiency over the canonical Carnot efficiency; it might be possible to get useful work from a single reservoir using the quantum coherence [1]. In photonic quantum heat engine, the efficiency could be almost unity, so that the "almost" input energy can be converted to the work using the superradiance [2, 3]. To implement this feature at least in laboratory, investigations on experimental reality are conducted for several different models of heat engines [4,5]. With theoretical understanding on quantum thermal systems [6], we will review the experimental implementations on several kinds of quantum heat engine modes and their applications.

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Coherent Control of Ultra-Narrow Nuclear Transitions

Xiwen Zhang[1], Yuri Shvyd'ko[2], and Olga Kocharovskaya[1]

[1]*Institute for Quantum Science and Engineering & Department of Physics and Astronomy, Texas A&M University, College Station, Texas, USA*

[2]*Argonne National Laboratory, Lemont, Illinois, USA*

Narrow optical resonances corresponding to quantum transitions in atoms, molecules, quantum dots, rare-earth ions and color centers constitute the basis of quantum optics with numerous applications in sensing, imaging, computation, communication, etc. Very high-quality atomic resonances with Q-factor ~10^{15}-10^{20} are on demand for atomic clocks, chronometric geodesy and gravimetry, search for time variation of the fundamental constants and dark matter [1]. Their realization requires low atomic density, vacuum environment, laser cooling below 100 nK temperature, and magnetic traps or optical lattices.

Nuclear resonances with similar high-quality factor can be achieved at solid density and even at room temperature, as the nuclei are naturally trapped in a crystal lattice. The major advantage of nuclear vs atomic transitions is a smaller sensitivity to frequency shifts caused by electric and magnetic fields perturbations. Besides, the Mössbauer effect makes it possible to effectively eliminate thermal-motion broadening. Thus, nuclear transitions offer an appealing platform for a new precision metrology capable, for example, of detecting a gravitational red shift with a sub-mm displacement. However, with the only known exceptions of ^{229m}Th and ^{235m}U, all the nuclear transitions lay in the hard x-ray range. Their resonant excitation, coherent control and interfacing with the resonant x-ray photons is challenging due to absence of the bright coherent sources and high-quality cavities in the hard x-ray range.

In this talk we will review recent progress in this field including resonant excitation with a train of x-ray pulses from the European XFEL of the 12.4 keV long-lived (0.46 s) nuclear transition in ^{45}Sc [3], recent realizations of quantum nuclear memory [4] and experimental demonstrations of the coherent waveform shaping of the x-ray photons [5], acoustically induced transparency [6] and slow light [7].

We will discuss also the prospects for potential applications of the super-narrow ^{45}Sc nuclear resonance (such as realization of nuclear clocks, super-dense quantum nuclear memory and super-resolution nuclear coherent forward scattering spectroscopy [4]) opened by this experimental breakthrough as well as the further experimental and theoretical studies which are required for implementation of these prospects.

This work is supported by NSF (Grant No. PHY-2012194).

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MEDIUM HIGH FIELD PLASMONICS AND ONE OF ITS SPECIAL APPLICATION

Norbert Kroo

Wigner Research Center of Physics, Hungary

Surface plasmon polaritons are the light of the nanoworld, with a broad spectrum of special properties. These properties open the field for a high number of applications, both in the fields of low and high intensities. This lecture summarizes those plasmonic properties both of propagating (SPP) and localized (LSPP) plasmons, which play a role in medium high field (up to 10^{12} W/cm^2 exciting laser intensities) applications.. For a special application our results are described in some detail. The SPP-s are enhancing electron emission, furthermore are localized on irregularities of the surface and can be detected by a near field scanning tunneling microsope (STM), as seen in the figure below. Three sets of experiments are presented in this lecture, using the near field microscope and an electron time-of-flight spectrometer, which are proving the existence of 2 dimensional superconductivity in gold films. This conclusion is based on the anomaly found in the laser intensity depence of the surface plasmon near field STM signal, furthermore on the time-of-flight analysis of the spectrum of electrons, emitted from the gold surface.It has been found, that the Meissner effect is observable and simultaneous emission of two electrons are found, indicating the presence of Cooper-pairs, which are bound not by phonons, but by SPP-s.

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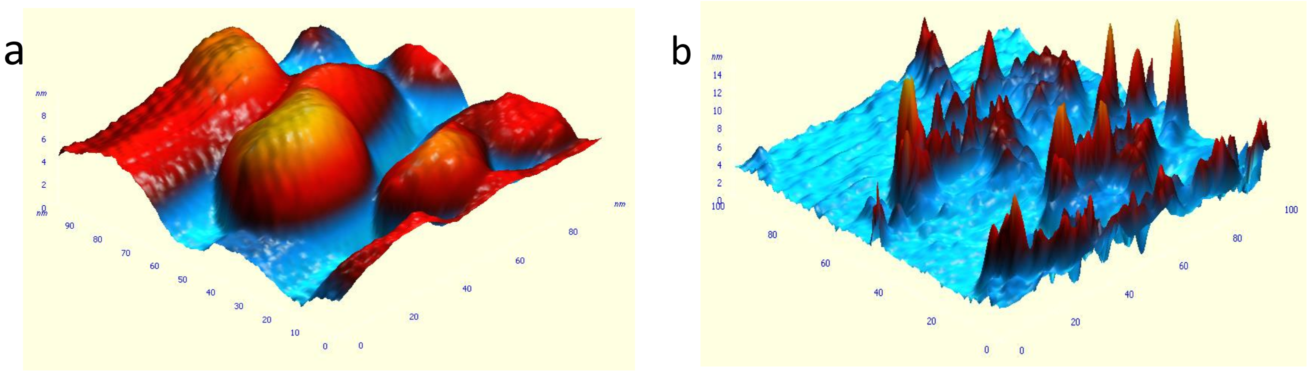

Overlapping scanning tunneling microscope images (100x100nm) of the topology (a) and the near field surface plasmon polariton field (b) of a gold film. The SPP-s were excited ont he film via a prism, in the Kretschman geometry.

ON HIGH FIELD PLASMONICS AND POTENTIAL NANOPLASMONIC LASER FUSION

Norbert Kroo

Wigner Research Center of Physics, Hungary

Surface plasmon polaritons are the light of the nanoworld, with a broad spectrum of special properties. These properties open the field for a high number of applications, both in the fields of low and high intensities. The present lecture summarizes th plasmonic properties of localized (LSPP) plasmons, comparing them also with those of propagating plasmons (SPP). LSPP-s play a role in many high field applications.. In this lecture 1 example of the role of localized surface plasmons is presented. These plasmons have been resonantely excited by ultrashort (n.10fs), high intensity (up to n.10^{17} W/cm^2) pulses of a Ti:Sa laser on gold nanoparticles, implanted into a transparent polymer, creating craters in the studied samples. The volume of these craters, produced by the laser pulses in clean and gold nanoparticles implanted polymers has been studied as the function of the exciting laser intensity. Simultaneously the C-H and C-D oscillation Raman scattering lines were also measured on the crater surfaces. Preliminary data indicate energy production and nuclear trasmutation (hydrogen to deuterium) in the nanoparticle seeded samples already at these „relatively low" laser intensities, clearly proving the decisive role of different properties of the LSPP-s in both observed phenomena. One of the effects, namely the volume of the craters produced by the laser shots is shown in the figure below, clearly demonstrating the influence of the resonant nanoparticles on the crater volume .The roughness of the crater surface is also analized in the lecture. Preliminary data of other techniques (optial and mass spectrometry and some nuclear methods) are also shown.

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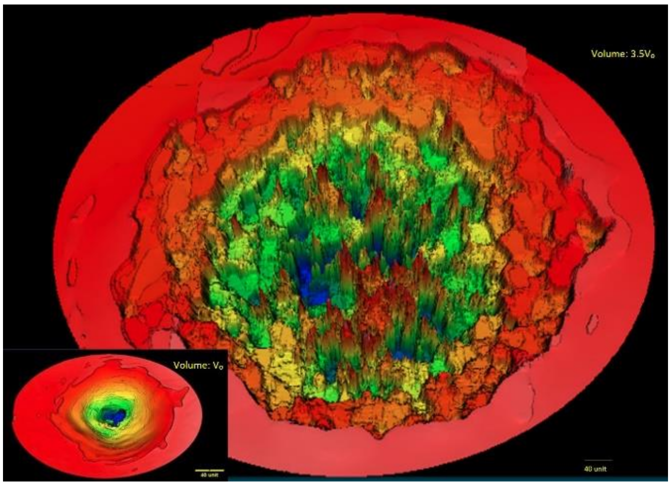

White light interference microscope images of 2 craters, the results of 25mJ (2.10^{17} W/cm^2) laser shots on the polymer samples without (small image) and with resonant gold nanorods (large image).

Quantum optical mega-networks in biological architectures, and the computational capacity of life and the observable universe

P. Kurian

Quantum Biology Laboratory, Howard University
https://quantumbiolab.com

***Abstract* – In this talk I will present an overview of our work [1] analyzing mega-networks of tryptophan in biological architectures with numerical simulations and steady-state ultraviolet spectroscopy, providing opportunities for control of light-matter interactions in cellular organelles and neuronal bundles. I will then, based on these insights and fundamental physical considerations, consider the computational limits of living systems and all matter in the observable universe. The implications for development of artificial intelligence(s) will also be discussed.**

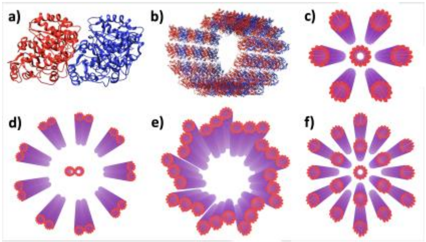

Fig. 1: Hierarchical mega-networks of quantum emitters form in protein architectures of functional biological significance, enhancing observed measurements of fluorescence quantum yield even in the presence of significant disorder [1].

Networks of tryptophan – an aromatic amino acid with strong fluorescent response – are ubiquitous in biological systems, forming diverse architectures in transmembrane proteins, cytoskeletal filaments, sub-neuronal elements, photoreceptor complexes, virion capsids, and other cellular structures. We analyze the cooperative effects induced by ultraviolet (UV) excitation of several biologically relevant tryptophan mega-networks, thus giving insight into novel mechanisms for cellular signalling and control. Our theoretical analysis in the single-excitation manifold predicts the formation of strongly superradiant states due to collective interactions among organized arrangements of up to more than 100,000 tryptophan UV-excited transition dipoles in microtubule architectures, which leads to an enhancement of the fluorescence quantum yield that is confirmed by our experiments. We demonstrate the observed consequences of this superradiant behavior in the fluorescence quantum yield for hierarchically organized tubulin structures, which increases in different geometric regimes at thermal equilibrium before saturation – highlighting the effect's persistence in the presence of significant disorder. Our results motivate a revisiting of conventional assumptions about the computing limits of cytoskeletal and neuronal architectures, which are generally considered to signal via Hodgkin-Huxley action potentials (millisecond timescale). It is shown that these biosystems can harness superradiant effects (picosecond timescale) in tryptophan lattices to process orders of magnitude more information than exascale supercomputers, at significantly lower power consumptions, by operating extremely close to the Landauer bound for logically irreversible operations. The robustness of single-photon-excited superradiant states paired with subradiant states (second timescale) in biology thus offers a novel paradigm for understanding large collectives of quantum emitters and their quantum information processing limits in warm, wet, and wiggly environments.

ACKNOWLEDGEMENT

The project was supported by The Guy Foundation Family Trust. This research used resources of the Argonne Leadership Computing Facility, which is a DOE Office of Science 24 User Facility supported under Contract DE-AC02-06CH11357. This research used molecular graphics and analyses performed with UCSF Chimera, developed by the Resource for Biocomputing, Visualization, and Informatics at the University of California, San Francisco, with support from NIH P41-GM103311.

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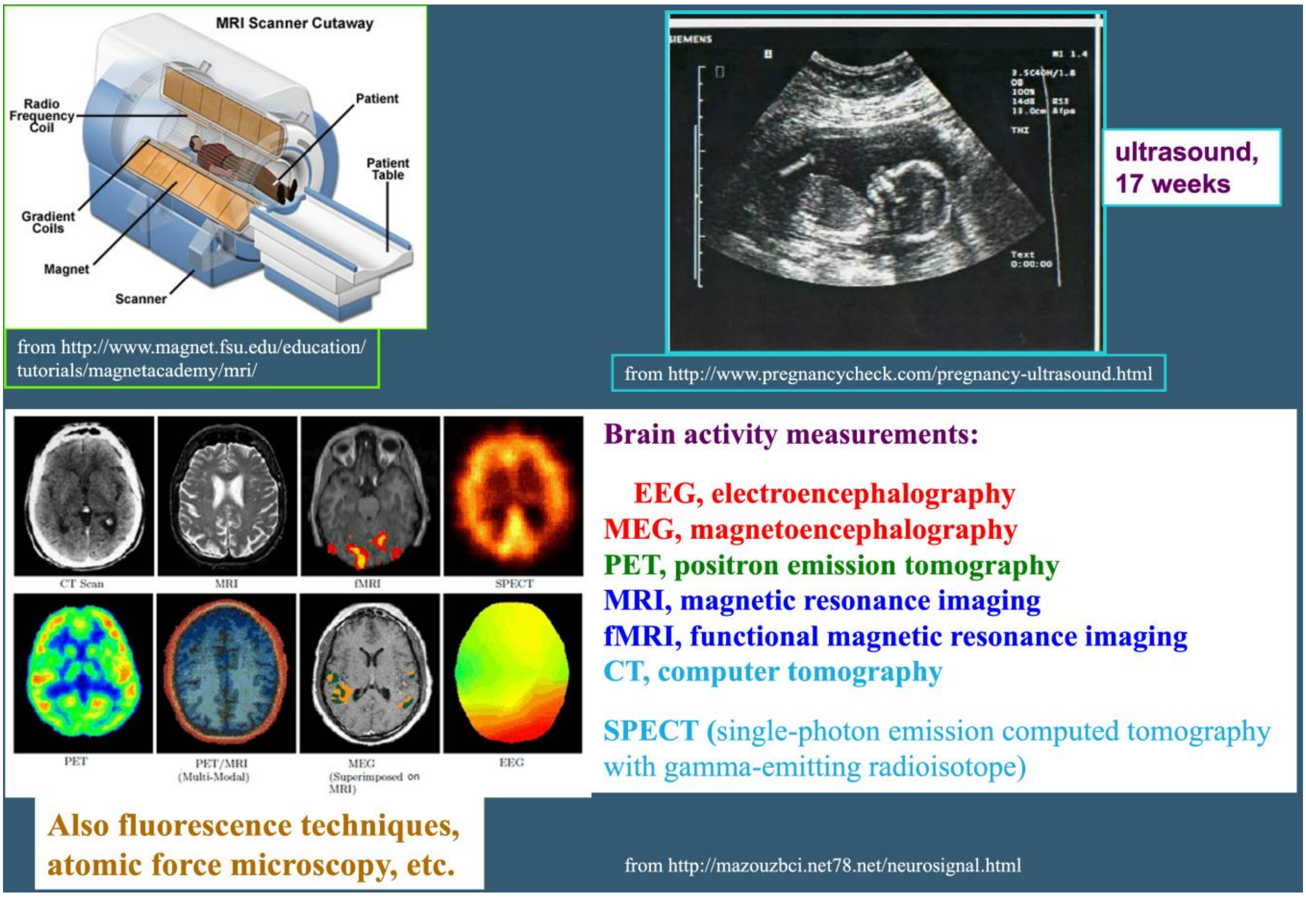
Quantum physics in medicine

Suzy Lidström and Roland Allen
Texas A&M University

We will discuss a very large number of important instruments and techniques in medicine which have originated in (quantum) physics, from x rays to functional magnetic resonance imaging. A few are indicated in the accompanying images, and many more are currently under development. We will mention the use of Raman spectroscopy to detect anthrax spores and study other biological systems, and how tip enhanced Raman scattering was used to study DNA in the context of a COVID related research program at Texas A&M.



from http://www.magnet.fsu.edu/education/tutorials/magnetacademy/mri/

ultrasound, 17 weeks

from http://www.pregnancycheck.com/pregnancy-ultrasound.html

Brain activity measurements:

EEG, electroencephalography
MEG, magnetoencephalography
PET, positron emission tomography
MRI, magnetic resonance imaging
fMRI, functional magnetic resonance imaging
CT, computer tomography

SPECT (single-photon emission computed tomography with gamma-emitting radioisotope)

Also fluorescence techniques, atomic force microscopy, etc.

from http://mazouzbci.net78.net/neurosignal.html

A quantum perspective on consciousness

Suzy Lidström
Texas A&M University

In the spirit of previous ideas in the neuroscience community, but with a more physics-oriented perspective, we interpret consciousness as the collective excitation of a brainwide web of neural cells. This picture is inspired by the fact that, in all major areas of physics, a collective excitation has just as much physical reality as a particle or other localized object. The brainwide web extends into those regions (neuronal and glial networks) where processed information is received from the senses, memories, etc. (emerging out of unconscious processes in prior networks). It unifies those regions (plus motor control regions) via the vast complexity of the neural interactions that it spans.

At the most fundamental level, all physical phenomena result from excitation of quantum fields (since, in current physics, these fields are the bedrock of reality). It follows that, in the present picture, quantum physics solves the old combination (or binding) problem of consciousness, since the experience of consciousness requires coherent excitation of only a single hybrid electron-electromagnetic field.

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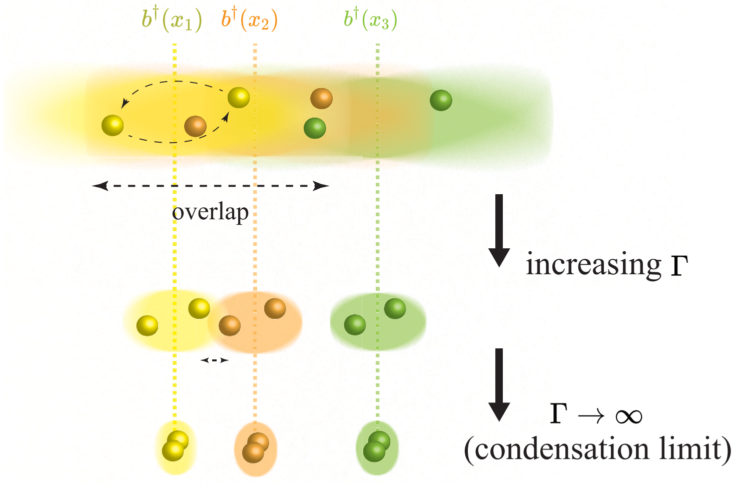
Coherent States of Photonic Dimers

Qihang Liu, Yao Zhou, and Jung-Tsung Shen
Department of Electrical and Systems Engineering,
Washington University in St. Louis

To date, laser remains the dominant coherent many-photon light source. As many nonlinear optical processes with laser light are very inefficient, if inter-photon correlations could be created, nonlinear process efficiency can be improved by orders of magnitude. In this presentation, I will discuss a new type of coherent quantum light source that, instead of independent photons, outputs a coherent state of the photonic dimers [1]. Photonic dimer is a pair of entangled photons that exhibit a strong bunching correlation, which has been shown to improve the performance of two-photon microscopy [2]. We show that an optical cavity can shape the spectrum of spontaneous parametric down-conversion (SPDC) photon pairs to create coherent states of photonic dimers. The correlation functions are shown to exhibit a BEC-BCS crossover behavior when the two-photon pairing correlations (i.e., the size of photonic dimers) are comparable to the average spacing between the dimers. The strong inter-photon correlations make it possible to transform many nonlinear processes into linear ones, opening up new possibilities in quantum imaging, and advancing our understanding of the collective behaviors of many-photon systems.



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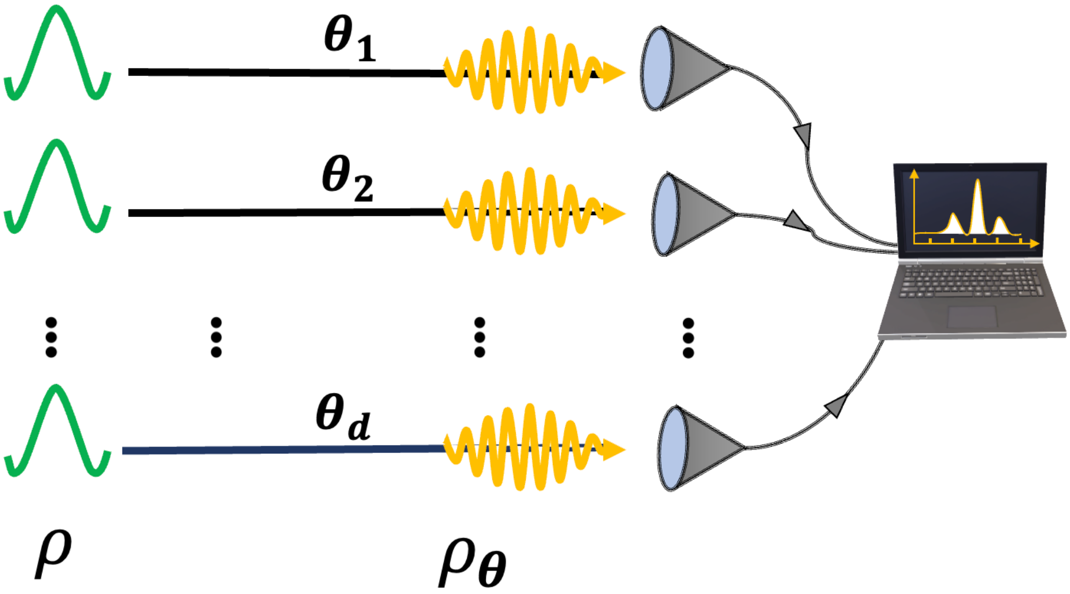
Quantum Networked Sensors and Distributed Phase Estimation Metrology

Yusef Maleki

Institute for Quantum Science and Engineering (IQSE) and Department of Physics and Astronomy,
Texas A&M University, College Station, TX 77843-4242, USA

Quantum sensors offer unprecedented sensing and imaging capabilities that surpass the limits of classical devices and provide the tools to explore a wide range of new technologies from atomic clocks and quantum microscopy to quantum-enhanced gravitational wave detection. In this talk, I present the performance of multi-mode quantum probes for the quantum networked sensors. I introduce analytical expressions for the metrological bound of quantum networked sensors and introduce quantum probes with the ultimate limit (the so-called Heisenberg Limit) of performance within these classes of quantum systems. This enables us to shed light on the scaling of the sensor performance and find a criterion for enhancing the sensitivity in quantum networked sensors.



Quantum Superpositions of Black Holes

Robert Mann

University of Waterloo, Waterloo, Ontario N2L 3G1, Canada

ABSTRACT

If relativistic gravitation has a quantum description, it must be meaningful to consider a spacetime metric in a genuine quantum superposition. But how might such a superposition be described, and how could observers detect it? I will present a new operational framework for studying "superpositions of spacetimes" via model particle detectors. After presenting the general approach, I show how it can be applied to describe a spacetime generated that is a superposition of two expanding spacetimes. I will then move on to show how black holes in two spatial dimensions can be placed in a superposition of masses and how such detectors would respond. The response exhibits signatures of quantum-gravitational effects reminiscent of Bekenstein's seminal conjecture concerning the quantized mass spectrum of black holes in quantum gravity. I will provide further remarks concerning the meaning of the spacetime metric, and on distinguishing spacetime superpositions that are genuinely quantum-gravitational, notably with reference to recent proposals to test gravitationally-induced entanglement.

Classical vs Quantum theories in optics and information: when do quantum effects matter in the interface of gravity, quantum information and quantum optics?

Eduardo Martín-Martínez[1, 2, 3]

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[3] *Institute for Quantum Computing, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada*

Abstract.– A full formulation of quantum gravity is among the most coveted theories in physics. However, we lack experimental testbeds to probe gravity in the quantum regime. Recently, exciting proposals for tabletop experiments combining quantum mechanics and gravity have been put forward by Bose et. al [1] and Marletto and Vedral [2] (the so-called BMV experiment). These proposals have captured the eye of the community for their alleged potential to provide proof of the quantum nature of gravity.

The experiment consists of two particles, each prepared in a superposition of two different trajectories. The two particles interact only gravitationally. The rough idea is that the different superposed paths generate different gravitational fields, which can entangle the particles. Despite the inherent experimental challenges to isolate the particles while shielding them from decoherence, we are close to having technology that will allow the experiment in the near future [1–8]. Although it is exciting to have an experiment that can explore aspects of gravity when quantum theory is relevant, some possible objections to the fact that the BMV experiment can reveal the quantum nature of gravity exist in the literature [9–14]. This indicates that the conclusions that can be drawn from the experiment require careful analysis. For example, it has been claimed that if the gravitational field is capable of entangling the masses, then either we must abandon the principle of locality, or the gravitational field must be quantum [15, 16]. In this letter we present a series of arguments why this is not exactly the case. Instead, we discuss that while the experiment, as proposed, can prove that gravity can establish a quantum channel between the particles, it cannot decide whether gravity has quantum degrees of freedom. Furthermore, we propose a modification to the experiment so that it can demonstrate the fundamental quantum behaviour of gravity.

It is well-known that the coupling of classical and quantum systems is *theoretically* inconsistent (see, e.g., [17, 18]). This prevents theories where matter is quantum and gravity is classical from being fundamental. However, the theoretical argument alone cannot be used to claim that gravity is quantum. Instead, for an experimental claim of quantumness, one requires observing specific markers of quantum behaviour. While different authors may disagree on what conditions are sufficient to prove that a system is quantum, there are some uncontroversial properties of a system that, if observed, would prove its quantumness. For example, observing Wigner negativity, or violations of Bell inequalities.

In this talk 1) we will discuss whether the *current* proposals of the BMV experiment can witness indisputably quantum behaviour of the gravitational field. That is, we will see what the observation that two masses (in a quantum superposition of trajectories) get entangled through the gravitational interaction can tell us about the existence of gravitational quantum degrees of freedom. 2) we will also identify in which regimes a BMV-like experiment could uncontroversially reveal quantum aspects of gravity in a tabletop experiment.

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Title: An introduction to Forward Error Correction and Guessing Random Additive Noise Decoding

Speaker: Muriel Médard (MIT) and Ken Duffy (Northeastern University)

Abstract:

This talk introduces the principles of Forward Error Correction (FEC) through the lens of Guessing Random Additive Noise Decoding (GRAND), a recently developed approach to error correction decoding that has been demonstrated in chips and is being considered for use in quantum systems.

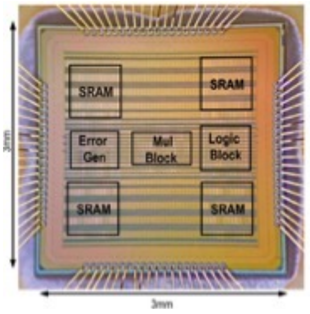
All digital data can be subject to corruption that results in the received information differing from the original. The solution to this problem is to code the data, which adds redundancy. One fruitful way of thinking about that redundancy is to take original data and append a hash of it. This additional redundancy can inform the receiver about the integrity of the data and enable them to correct errors.

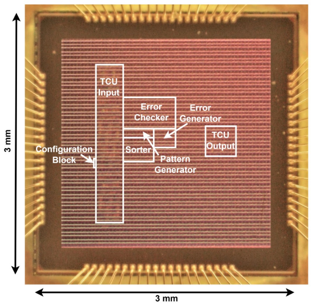
There are a wide variety of codes - rules for the creation of that hash - and they were all co-designed with specific decoders that use the code-book structure, the hash structure, to try and infer what the original data was based on what was received. In some circumstances, no side information is available to the receiver, called a hard detection situation. In others, it bits are received with a reliability measure, which is called the soft detection situation.

Most codes are individually only suitable for the hard or soft detection setting because they only have a hard or soft detection decoder suitable for them. Because the decoder is entirely coupled to the code structure, this typically means one needs a distinct implementation to decode each of these codes and often, when done in hardware, even distinct pieces of hardware for different levels of redundancy.

GRAND is a methodology based on an innovative paradigm. It is agnostic to the code structure as it aims to identify the noise effect that has impacted the data, solely using the codebook for what it is: a hash of that data. This talk introduces principles of FEC through the lens of GRAND and explains why it .

Further information about GRAND, including links to papers and a tutorial given at the International Symposium on Information Theory in 2022, can be found here: https://www.granddecoder.mit.edu/





Quantum Multiphoton Rabi Oscillations in Waveguide QED

Debsuvra Mukhopadhyay[1,*] and Jung-Tsung Shen[1]

[1]*McKelvey School of Engineering, Washington University in St. Louis, MO 63130, USA.*

One of the foremost processes underpinning quantum photonic technologies is the phenomenon of Rabi oscillations that is observed when a qubit is irradiated by a strong coherent laser source. In contrast to thE most protoypical semiclassical setting [1], we expound on the more general, quantum theoretic case in waveguide QED, where the optical excitation is the multiphoton Fock state and the qubit is coupled to a continuum of frequencies. By employing the real-space formalism in waveguide QED, we analytically explore the scattering dynamics of the photonic Fock state as it interfaces with a two-level emitter (c.f. Fig. 1). The derived wavefunction features a linear superposition of various independent scattering events that are engendered by the possibility of sequential photon absorptions and emissions, as the atom is bombarded by a host of flying photons. The lowest-order excitation event, brought to bear by the stochastic scattering of any one of the multiple photons in the field, quite accurately describes the overall dynamics in the weak-field approximation. Alternatively, any higher-order scattering event is stimulated by the repeated interaction of the atom with the radiation source and embodies the indelible signatures of photon-photon correlations induced by the scattering dipole. The temporal evolution of the qubit excitation in our configuration shows canonical correspondences with the semiclassical predictions, particularly in the strong-pumping limit. In a nutshell, our analysis extends the existing results on quantum Rabi oscillations pertinent to single-mode cavity QED [2], to the multimode, waveguide-QED configurations wherein flying photons are the information carriers [3]. For completeness, we also closely scrutinize the scattering dynamics of pulsed wave packets and educe the possibility of dramatically increasing the excitation efficiency even in the few-photon regime. Considering the burgeoning scientific interest in harnessing nonclassical Fock states for quantum networking protocols as well as correlated multiphoton sources, such as photonic bound states [4], which arise organically in waveguide-based platforms, we believe that our detailed formulation for predicting multiphoton dynamics would find vital applications in the empirical world.

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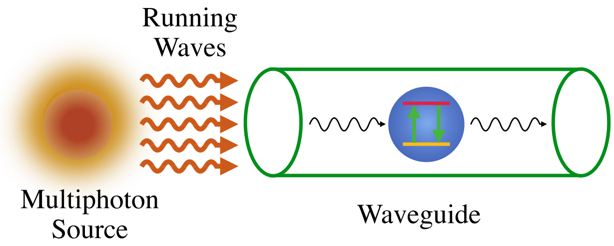

FIG. 1: Schematic of a two-level atom embedded in a waveguide and excited by a multiphoton radiation field.

From Plants and Photosynthesis to Solar Panels: A Quantum Biology Unit of Study for 4th and 5th Graders

Quantum Science Camp Abstract

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Quantum information science (QIS) is one of ten priority research areas promoted by the National Science Foundation that will revolutionize life, work, and thought in the years to come. The challenge for this next technological revolution is the creation of a quantum-smart workforce to meet current and future demands. Embedded in this challenge is the dearth of diverse professionals in the quantum sciences, especially among women and people of color. While the data on the percentage of women and people of color in the quantum sciences are limited, there is ample data on the underrepresentation of these groups in STEM fields. As a strategy for creating a quantum-smart workforce, the national strategic overview for QIS calls for quantum science education at an early stage, including elementary, middle, and high schools. This strategy demands the development of new standards, curricula, and learning objects in QIS. Moreover, K-12 teachers will need to be developed to meet this challenge.

Through partnership with the Quantum Biology Laboratory (QBL) at Howard University, Rowen Elementary School in Philadelphia, Pennsylvania, dedicated in March 2022 the Quantum STEAM Laboratory focused on teaching students about the mysteries of the quantum world. Howard University scientists in the QBL serve as expert consultants to support the development of learning materials aligned with QIS objectives. These materials consist of digital tools, exploratory virtual environments, laboratory experiences, and performance-based tasks that provide educators and students with robust opportunities to maximize deep, accessible, and interactive learning.

Dr. Murray, K-12 Liaison in the QBL, will discuss a unit of study for upper elementary students to investigate how photosynthetic organisms capture photons from sunlight for chemical energy conversion and storage. Using virtual and augmented reality, field experiments at a local arboretum, and laboratory experiments, students are introduced to the possibility that photosynthetic efficiency may be caused by a weird effect called quantum coherence. Students are challenged through a performance-based task to create a diagram that displays all the different parts of the system that allows people to obtain electricity from solar energy. Finally, students design and print operable solar panels using 3D scanners and 3D printers.

Novel atom interferometer

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Atom interferometers form the basis for extremely high precision measurements of quantities of both fundamental and applied interest. As an example, after the demonstration of the first atom interferometers, scientists were able to put bounds on the so-called “alpha-dot” parameter using atom interferometers. Nowadays, the technology has matured to the point where these devices can be used in more applied settings, such as providing acceleration and rotation measurements to aid in the navigation of a ship in GPS-denied environments. In this talk, I will begin discussing the physics underlying an atom interferometer, beginning with the use of light pulses [1] to form the atom optics. Next, I will highlight the origins of the scaling of the sensitivity of an atom interferometer to T^2, where T is the time between light pulses. I will take a brief excursion to describe an atom interferometer we are currently developing which is focused on inertial navigation applications. Most of the talk will focus on my group’s efforts to develop a novel atom interferometer with high scaling (T^3) [2] [3]. The higher scaling leads to a greater sensitivity without increasing the physical size of the atom interferometer. Finally, I will provide a glimpse into the construction of an extremely tall atomic tower and its potential uses.

This work was funded by the Office of the Secretary of Defense, the Army Research Office and the Office of Naval Research

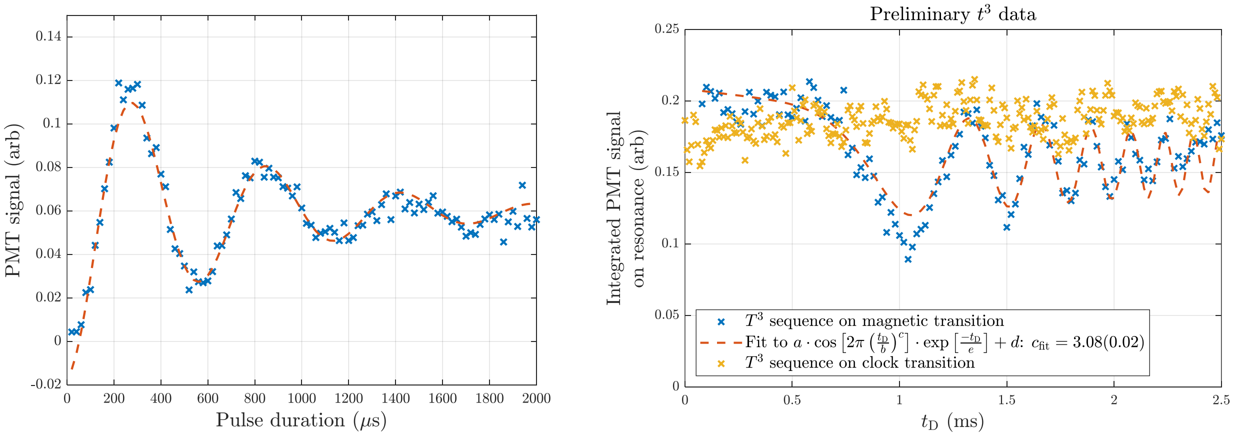

Figure 1: (Left) Rabi cycling on a magnetically sensitive transition in a magnetic field gradient. (Right) The first demonstration of a T3 interferometer using atoms in free-fall.

References:

[1] M. Kasevich and S. Chu, "Atomic interferometry using stimulated Raman transitions," *Phys. Rev. Lett.*, Bd. 67, Nr. 2, pp. 181-184, Jul 1991.

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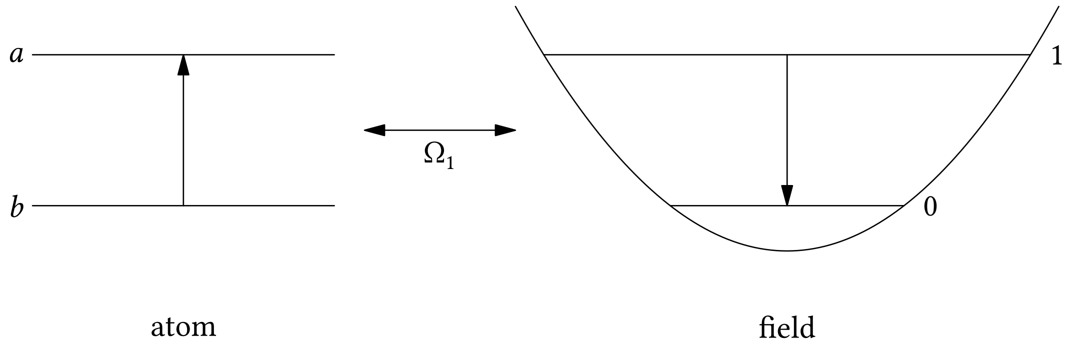
Jittering the photon distribution

Reed Nessler

IQSE, Texas A&M University, College Station TX 77843

The treatment by Jaynes and Cummings[1] of atom–field interaction, introduced six decades ago, furnishes a fundamental exactly solvable model system in quantum optics. It entails the celebrated revival of Rabi oscillations following their collapse, which is a pure quantum phenomenon, i.e. depends for its explanation on quantizing the electromagnetic field.

The theory of the Jaynes–Cummings model is a well-trodden path.[2] We present some of its mathematical aspects, and we report for the first time the capacity of local time-averaging to mimic a change of parameter in the initial field state. This effect is distinct from, though reminiscent of, the uncertainty due to phase fluctuations (originating from spontaneous emission) when using two-level atoms as a spectrometer to measure laser frequency following Scully and Lamb.[3]



Two-level atom coupled to a single-mode field, represented as a quantum harmonic oscillator (figure after Shore and Knight[2])

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[1] E. T. Jaynes and F. W. Cummings, *Proc. IEEE* **51**, 89 (1963)

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[3] J. Gea-Banacloche, M. O. Scully, and D. Z. Anderson, *Opt. Commun.* **57**, 1 (1986)

Radio and the Science of Wireless Transmission

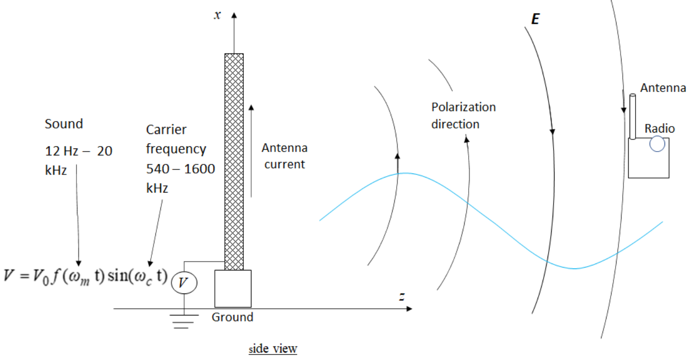
Robert Nevels

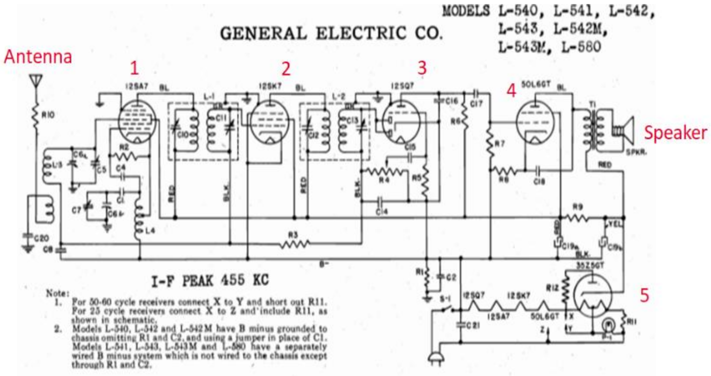
Texas A&M University, College Station, TX

Radio transmission brought great changes to society. First to ships at sea that prior to the 20th century were completely isolated from land contact for months at a time. Then to people on land in a world where news previously spread slowly to a population mostly living on farms. But radio brought some serious challenges to science including, a need understand what electrical current is made of on a fundamental level, how electrical components could control current, how the current interacted with the electromagnetic field inside these components, how the field could be efficiently launched and received by the antenna and what form the signal itself should take. In this presentation we will see how a sinusoidal field gains its polarization, and how information is impressed on the field. We then look at how the field propagates and is received by the radio and finally how the radio circuit pulls the information off the signal, amplifies it and sends it to the speaker.

The figure on the right shows a generator sending an amplitude modulated (AM) signal into an antenna tower which launches an electromagnetic wave traveling in the z-direction and polarized in the direction of the curved lines. The blue line shows the amplitude of the wave as it travels in the z-direction and excites a current on the receiving antenna.

AM Antenna Tower





Note:
1. For 50-60 cycle receivers connect X to Y and short out R11. For 25 cycle receivers connect X to Z and include R11, as shown in schematic.
2. Models L-540, L-542 and L-542M have B minus grounded to chassis omitting R1 and C2, and using a jumper in place of C1. Models L-541, L-543, L-543M and L-580 have a separately wired B minus system which is not wired to the chassis except through R1 and C2.

On the right is the schematic for a General Electric L-542 radio made in 1942. The circles are vacuum tubes, which are labeled according to their function. In the order they interact with the input signal: Antenna, (1) Variable frequency oscillator, (2) Mixer, (3) Detector, (4) Audio amplifier, (5) Rectifier, and Speaker. The property of each tube will be explained in the presentation which will conclude with a schematic and explanation of the transistor radio receiver you will construct.

Title: Quantum Scaling Anomalies in 2D and 1D systems

Author: Carlos R. Ordonez

Affiliation: University of Houston

Summary of findings:

A pedagogical review will be given on quantum scaling anomalies and its consequences in 2D and 1D systems. The emphasis will be in the concepts and the basic logic of the main applications of these ideas to the study of ultracold, diluted Fermi systems. The impact of these developments in other areas will be presented.

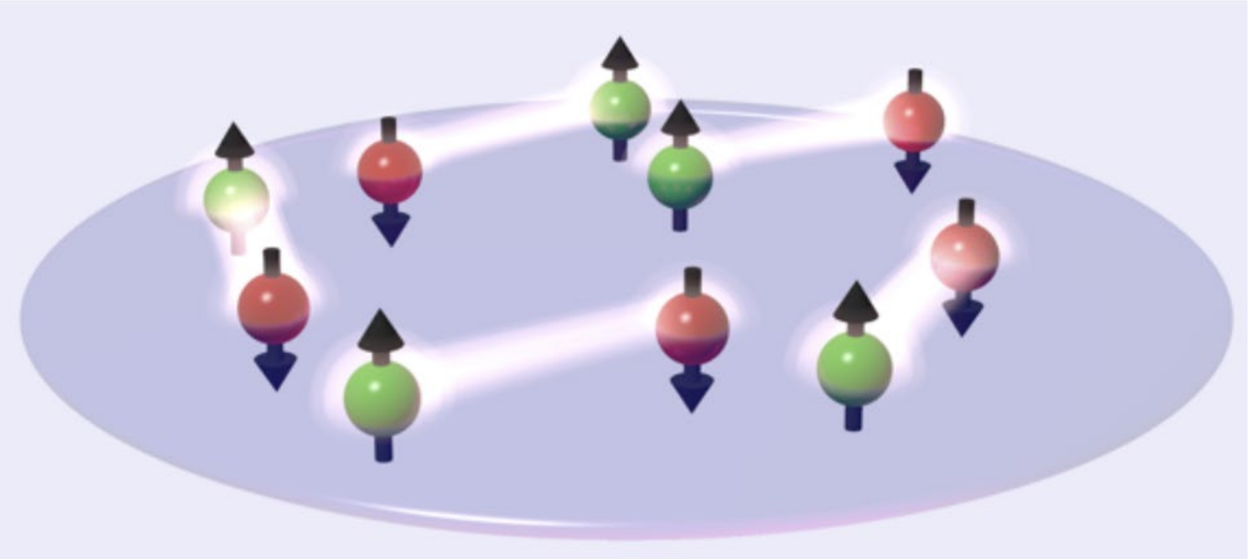


Figure 1: 2d Fermi dilute gas of ↑ and ↓ fermions with contact interaction given by:

$$\mathcal{H} = \int d\mathbf{x} \sum_{\sigma=\uparrow,\downarrow} \psi^\dagger_\sigma \Big(-\frac{\hbar^2\nabla^2}{2m} - \mu_\sigma\Big)\psi_\sigma + g_0 \psi^\dagger_\uparrow \psi^\dagger_\downarrow \psi_\downarrow \psi_\uparrow$$

(Fig. 1 from N. Defenu. Quantum anomaly and scaling dynamics in the 2D Fermi gas (2018)).

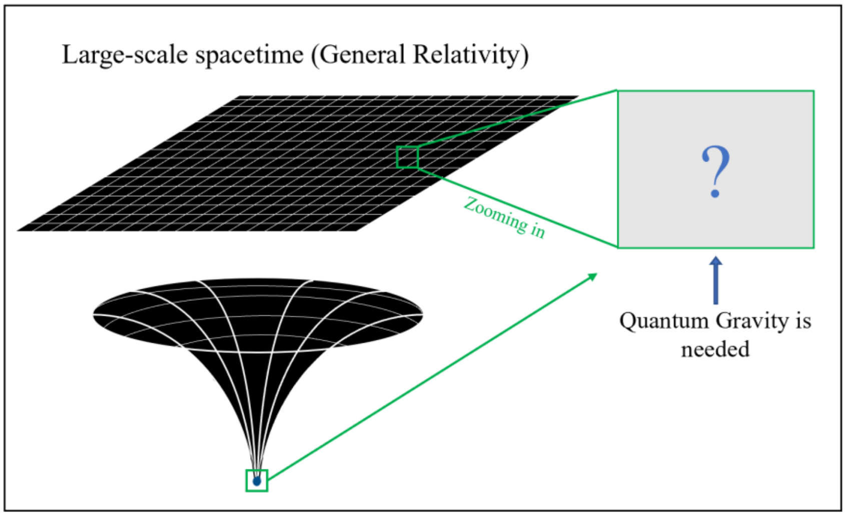
Quantum Gravity: An Introduction

Hamza Patwa[1] and Philip Kurian[1]

[1]*Quantum Biology Laboratory*, Howard University, Washington, D.C.* https://quantumbiolab.com

A self-consistent theory of quantum gravity (QG) would unify the two major physical theories that we have today: quantum mechanics and general relativity. Currently, quantum mechanics and general relativity are inconsistent with one another, for many conceptual reasons. One example is that in general relativity, time is dynamical and relative to one's reference frame and gravitational potential, while in standard quantum mechanics, time is just a global parameter. Another is that general relativity is a fully deterministic (though highly nonlinear) theory, while quantum mechanics includes uncertainties in non-commuting observables, superposition states, and nondeterministic measurements (in the Copenhagen interpretation, so-called "collapse"). Also, at tiny length scales on the order of the Planck length, where the discrete graininess of spacetime becomes apparent, neither general relativity nor quantum theory can provide a good description of how gravity behaves. So, we still are unable to fully describe what happens at the singularity of a black hole, or at the beginning of the big bang, which are both phenomena governed by laws at the Planck scale or beyond. If we *can* obtain a self-consistent theory of QG, we expect it to provide insights into these phenomena, as well as to reveal a truer picture of space and time.

In this talk, I will give a brief overview of what QG is, why we need it, and attempts to create a theory of QG, such as string theory and loop quantum gravity. Also, I will discuss the relational interpretation of quantum mechanics, which describes observables as interactions *between* systems and measuring instruments/observers, not facts about systems in isolation, giving rise to a perspectival rather than objectivist view of the wavefunction. Specifically, I will state how this interpretation of quantum mechanics enables us to gain a cleaner conceptual understanding of QG, including how concepts of space and time *emerge* from this view. I will conclude with my thoughts on the future outlook of this field.



Schematic depicting why quantum gravity is needed. Image created by Hamza Patwa.

Relativistic nanophotonics: creating extreme plasma conditions and fields with ultra- intense, ultrafast lasers

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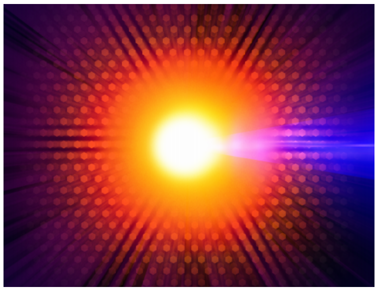
Ultra-high-energy-density (UHED) matter. characterized by energy densities > 1 x 10^8 J cm^{-3} and pressures greater than a gigabar, is encountered in the center of stars but is difficult to create in the laboratory. We show that the irradiation of high aspect-ratio aligned nanowire arrays with ultra-high contrast femtosecond laser pulses of only Joule-level energy provides a unique combination of nearly complete optical absorption and drastically enhanced light penetration into near-solid density targets that allows to volumetrically heat materials deep into the UHED regime [1]. Using ALEPH (Advance Laser for Extreme Photonics), a Petawatt-class laser developed at CSU, we demonstrate that femtosecond laser pulses of relativistic intensity can volumetrically heat near-solid density plasmas to multi-keV temperatures, reaching pressures that are only surpassed in the laboratory in the central hot-spot of highly compressed thermonuclear fusion plasmas. The physics of relativistic laser pulse interactions with nanostructures and promising applications will be reviewed. Electron densities more than 100 times greater than the critical density are achieved. We observed extraordinarily high degrees of ionization (e.g. 72 times ionized Au^{+72}) at solid densities using laser pulses of < 10 Joule energy [2]. The laser pulses induce return currents through the nanowires that create quasi-static Giga-Gauss magnetic fields [3]. The large electron density combined with the large plasma volume results in record 20 percent conversion efficiency into picosecond x-ray pulses. In a different set of experiments the acceleration of deuterons from deuterated nanowire arrays to multi-MeV energies resulted in quasi-monochromatic fusion neutron production 500 times larger than that obtained irradiating flat solid targets of the same material [4]. 3-D particle-in-cell simulations that aid the understanding of the physics of relativistic laser pulse interactions with nanostructures will be discussed.



Work supported by the U.S. Department of Energy, Fusion Energy Sciences, and a DOD Vannevar Bush Faculty Fellowship, using facilities supported by LaserNet US.

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4. A. Curtis, et al. "Micro-scale fusion in dense relativistic nanowire array plasmas", Nature Communications **9,** 1077, (2018)

The Wave Functional of the Vacuum in a Resonator

Wolfgang P. Schleich

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The standard approach towards the quantization of the electromagnetic field is straightforward: decomposition of the field into modes and quantization of the resulting harmonic oscillator amplitudes by the canonical commutation relations. The wave functional of the vacuum proposed by John Archibald Wheeler does not rely on a mode expansion but involves the complete electromagnetic field. We outline the road [1] to the wave functional shown in Fig. 1 and demonstrate that despite the fundamentally different situations, the wave functional of the vacuum in a resonator is identical to that of free space.

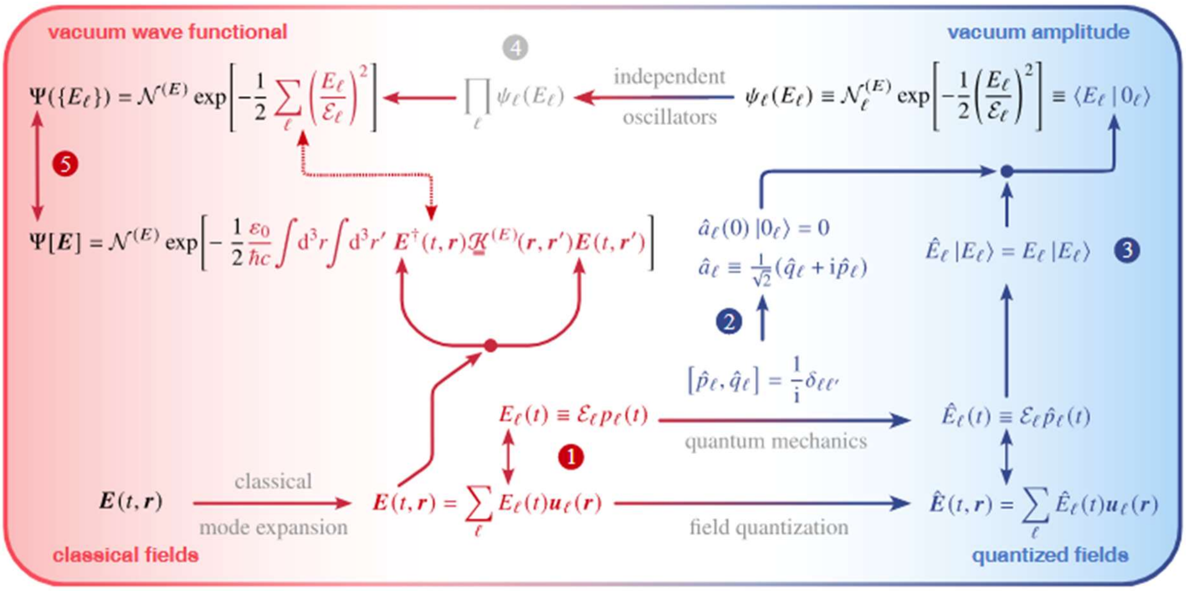


Fig. 1. Road to the wave functional of the vacuum in a resonator.

Reference:

[1] A. Friedrich, D. Moll, M. Freyberger, L. Plimak , and W.P. Schleich, *The Wave Functional of the Vacuum in a Resonator*, Act. Phys. Pol. A (to be published on June 14, 2023)

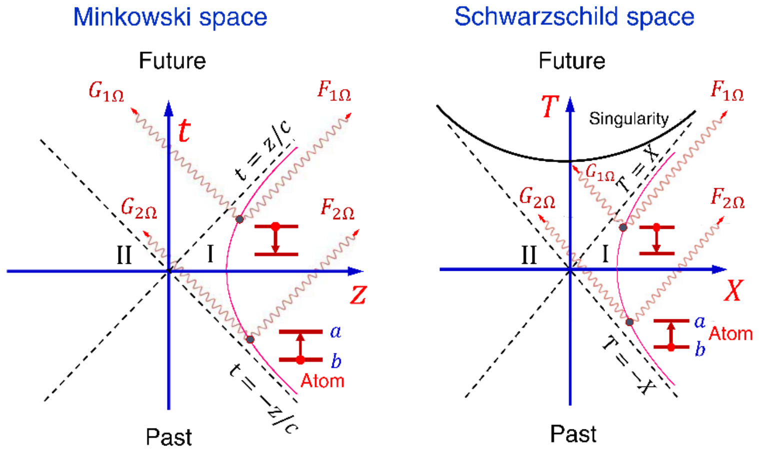
Entanglement in Unruh and Hawking Radiation from a Quantum Optical Perspective

Marlan Scully

Texas A&M, Princeton and Baylor Universities

In this talk simple arguments and a little algebra will show that a uniformly accelerated atom in Minkowski space-time emits entangled photon pairs in a squeezed state which mimics entanglement of the Minkowski vacuum. Similar emission of photon pairs occurs if an atom is held above the black hole event horizon. Namely, a ground-state atom becomes excited by emitting a “negative” -energy photon under the horizon and then spontaneously decays back to the ground state by emitting a positive-energy photon outside the horizon, which propagates away from the black hole.

Ref: M. O. Scully, A. A. Svidzinsky and W. Unruh, Phys. Rev. Res. **4**, 033010 (2022)



(a) (b)

Figure: (a) A ground-state atom accelerated in wedge I goes to the excited state $|a\rangle$ while emitting a photon into a right-propagating Unruh-Minkowski (UM) mode $F_{2\Omega}$, which is mostly located in the “future” wedge and wedge II by the ratio of the Boltzmann factor for temperature $a/(2\pi c)$, and a left-propagating mode $G_{2\Omega}$, which is mostly localized below the $t = -z/c$ horizon. Subsequently, the atom spontaneously decays to the ground state $|b\rangle$ emitting a photon into the UM modes $F_{1\Omega}$ and $G_{1\Omega}$, which are mostly located in the same wedge as the atom. (b) A ground-state atom held fixed above the horizon of a Schwarzschild black hole goes to the excited state while emitting a photon into the Unruh-Schwarzschild (US) mode $F_{2\Omega}$ which exists mostly in the “future” wedge below the event horizon and mode $G_{2\Omega}$, which is mostly localized under the $T = -X$ line. Subsequently, the atom spontaneously decays to the ground state emitting a photon into the US modes $F_{1\Omega}$ and $G_{1\Omega}$, which are located mostly above the horizon.

Title:

Dark Soliton Qudits: A Novel Quantum Information Platform

Abstract:

We study the possibility of using dark-solitons in quasi one-dimensional Bose-Einstein condensates to produce two or three-level systems (qudits) by exploiting the intrinsic nonlinear and the coherent nature of the matter waves. More precisely, we intend to create the dark soliton qudits by using trapped impurities. The decoherence induced by the quantum fluctuations (phonons) produces a finite lifetime due to their intrinsic slow-time dynamics. Remarkably, the qubit lifetime is estimated to be of the order of a few seconds, being only limited by the dark-soliton death due to quantum evaporation. Further, we explore the spontaneous generation of phononic entanglement between dark soliton qubits in the dissipative process of spontaneous emission. Moreover, we derive the analytical expression of the linear susceptibility to demonstrate the phenomenon of acoustic transparency based on matter wave phononics. The dark-soliton qutrit with unique properties of transmission and dispersion revealing the possibility of slowing down the speed of acoustic pulse. Our results suggest that dark-soliton qudits are a good candidates for quantum information protocols based purely on matter-wave phononics.

Author:

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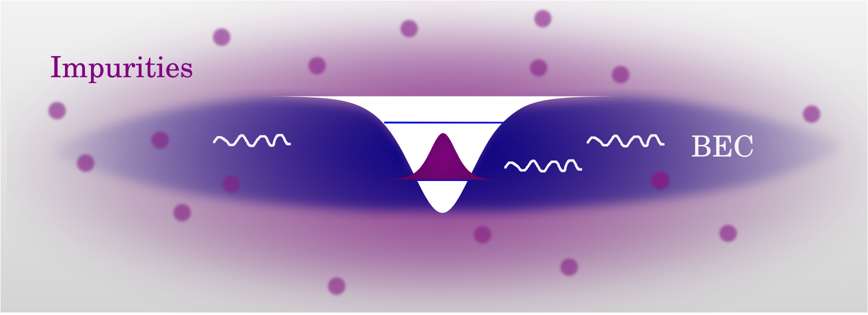
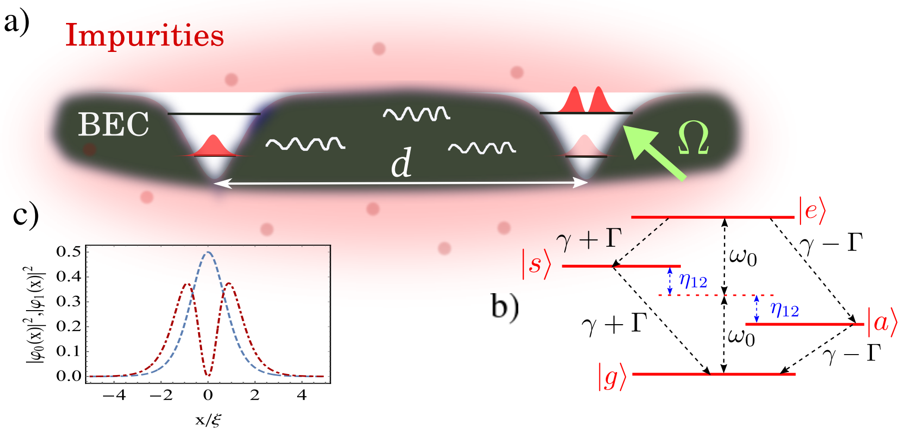
Model:1



Schematic representation of BEC contains a dark soliton which acts as a potential to the impurity particles

Model:2



(a) Two dark-soliton qubits placed at distance d in a quasi 1D BEC. b) Collective states of dark-soliton qubits. c) Ground (dashed) and Excited (dotted-dashed) state profile.

Nonlocal Interference of Photon Pair at Distance

Yanhua Shih
Department of Physics
University of Maryland Baltimore County, MD 21250

In the last a few years of his life, Einstein posed his students a question: suppose a photon of energy $\hbar\omega$ is created from a point source, such as an atomic transition; how big is the photon after propagating one year? This question seems easy to answer for his students. Since the photon is created from a point source, it would propagate in the form of a spherical wave and its wavefront must be a sphere with a diameter of two lightyears after one year propagating. Einstein then asked again: suppose that photon is annihilated by a point-like photon counting detector located on the surface of the big sphere, how long does it take for the energy on the other side of the big sphere to arrive at the detector? Two years? Bohr provided a famous answer to this question: the "wavefunction collapses" instantaneously! Why does the wavefunction need to "collapse"? Bohr did not explain. Nevertheless, Bohr confirmed the NONLOCALITY of the wavefunction.

Einstein began to question the nonlocal "problem" of quantum theory from the beginning of quantum mechanics. In 1935, Einstein-Podolsky-Rosen proposed an entangled two-particle system, and a momentum-momentum and position-position correlation measurement at distance. The wavefunction of the EPR system is a superposition of infinite number of two-particle wavefunctions in continuous space-time variables. In 1950s, Bohm simplified the EPR state to 2-D in spin variables

$$|\Psi\rangle = \frac{1}{\sqrt{2}} \left[\, |\uparrow\rangle_{(\mathbf{r}_1,t_1)} |\downarrow\rangle_{(\mathbf{r}_2,t_2)} - |\downarrow\rangle_{(\mathbf{r}_1,t_1)} |\uparrow\rangle_{(\mathbf{r}_2,t_2)} \,\right], \tag{1}$$

representing a two-particle interference at distance: a pair of spin-1/2 particles interference with the pair itself. Emphasizing the nonlocal superposition and measurement, we labeled the space-time coordinates of the two measurement events. Does this nonlocal interference take time? It might not take time for superposition to occur in a point particle source, but how long would it take if the two measurements were two lightyears apart?

Interestingly, two-particle interference even occurs with two randomly created and randomly paired photons at distance. Figure 1 is a schematic setup of a two-photon interference experiment of 2015. In this experiment Peng and Shih observed EPR-Bohm-Bell type polarization correlation from randomly paired photons in thermal state.

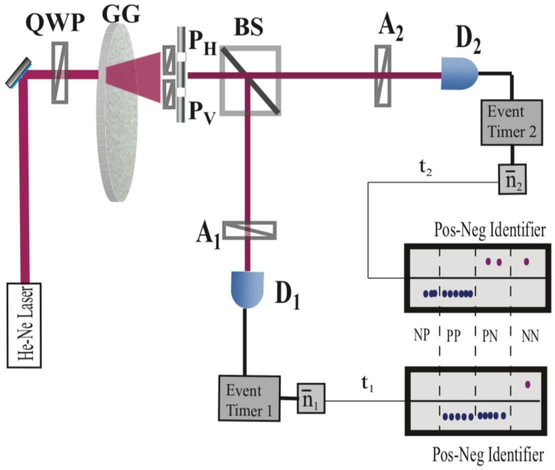


Figure 1: Schematic setup of the 2015 experiment of Peng and Shih: EPR-Bohm-Bell correlation of thermal fields in photon-number fluctuations as well as two-photon anti-correlation and correlation.

A pair of photons, either in entangled state or thermal state, is able to interference with the pair itself at distance: how long does it take for the two-photon interference to complete?

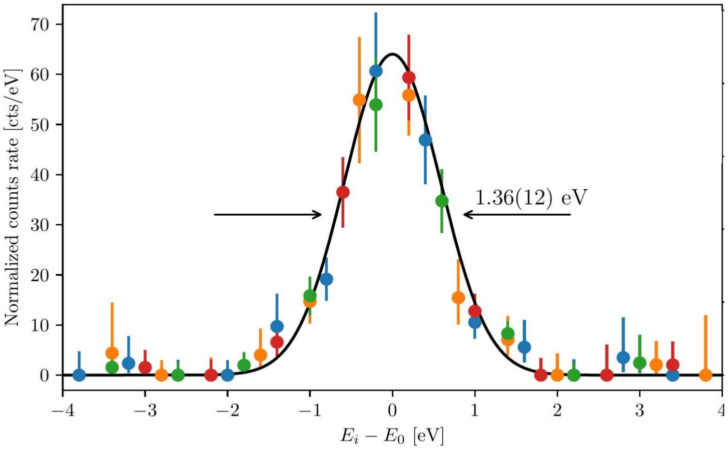
RESONANT X-RAY EXCITATION OF THE LONG-LIVED ULTRA-NARROW NUCLEAR ISOMERIC STATE IN ^{45}SC

Yuri Shvyd'ko
Argonne National Laboratory, Lemont, Illinois, USA (shvydko@anl.gov)

Resonant oscillators with stable frequencies and large quality factors determine our ability to keep track of time with high precision. Examples span from ubiquitous quartz crystal oscillators in hand-wrist watches to atomic oscillators in atomic clocks that are presently our most precise time measurement devices. Search for more stable and convenient reference oscillators is ongoing [1-2].

Nuclear oscillators surpass their atomic counterparts by their naturally higher quality factors and higher resilience against external perturbations. One of the most promising cases is an ultra-narrow nuclear resonance transition in ^{45}Sc between the ground and the 12.4-keV isomeric state with a long lifetime of 0.46 seconds [3] and a natural linewidth of 1.4 femto-eV. The scientific potential of the ^{45}Sc resonance together with the possibility of its resonant excitation by photons from modern accelerator-based sources of hard X-rays (no radioactive parent isotope is available for ^{45}Sc) was identified more than 30 years ago [4]. However, earlier attempts of its resonant excitation at synchrotron radiation sources were not successful, mostly due to the lack of sufficient spectral flux. This flux constraint was overcome only recently with the advent of narrow-band x-ray free-electron lasers (XFELs) working with a high repetition rate.

In this talk, I will provide an overview of the field and present results of a recent experimental studies performed at the European XFEL in Hamburg (Germany) by an international team [5], in which the first resonant excitation of the long-lived ultra-narrow 12.4-keV nuclear isomeric state of ^{45}Sc was observed by irradiation of a Sc metal foil with 12.4-keV XFEL photon pulses and subsequent detection of nuclear decay products. In this experiment, the ^{45}Sc resonance energy was determined with a more than hundred times higher accuracy than known before. In addition, we could obtain new estimates for the resonance cross section, and for the coefficients of internal conversion. The high average spectral flux of the incident X-rays together with a very low background noise in detection of the nuclear decay products were crucial for the success of the experiment.



These advancements break new ground for extreme metrology, nuclear clock technology, ultra-high precision spectroscopy, and other applications. The next immediate step towards these goals will be discussed: observation of the time dependence of the coherent nuclear forward scattering to measure the actual width of the ^{45}Sc resonance.

References

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Quantum Sensing in Biophotonics

Alexei V. Sokolov

Institute for Quantum Science and Engineering, Departments of: Physics and Astronomy, Electrical and Computer Engineering, Texas A&M University, College Station, TX 77843-4242, USA

Abstract

Quantum coherence is the central feature of multiple techniques and corresponds to a situation where atoms or molecules of a sample are prepared in a coherent superposition state. High degree of coherence can lead to remarkable results. Atomic coherence has earlier been used in electromagnetically induced transparency, ultraslow light propagation, and lasing without inversion. Molecular coherence enables a variety of applications, including, for example, a technique termed molecular modulation, which produces a coherent optical bandwidth spanning infrared, visible, and ultraviolet spectral regions, allowing arbitrary ultrafast space- and time-tailored sub-cycle optical field synthesis. Building upon these ideas, we have shown that an increased and cleverly manipulated molecular coherence enables astonishing improvements in optical detection and sensing, including video-rate coherent vibrational micro-imaging. In another approach, laser spectroscopy is aided by plasmonic nanoantennas, and shows promise for nondestructive label-free bioimaging with single molecule -level sensitivity. In my talk, I will review our recent advances toward ultrasensitive vibrational spectroscopic probing and imaging of various bio-molecules, cells and organisms.

Noise induced coherence, manifestations of vacuum entanglement and efficiency of quantum heat engines

Anatoly Svidzinsky
Texas A&M University, College station, TX 77843, USA

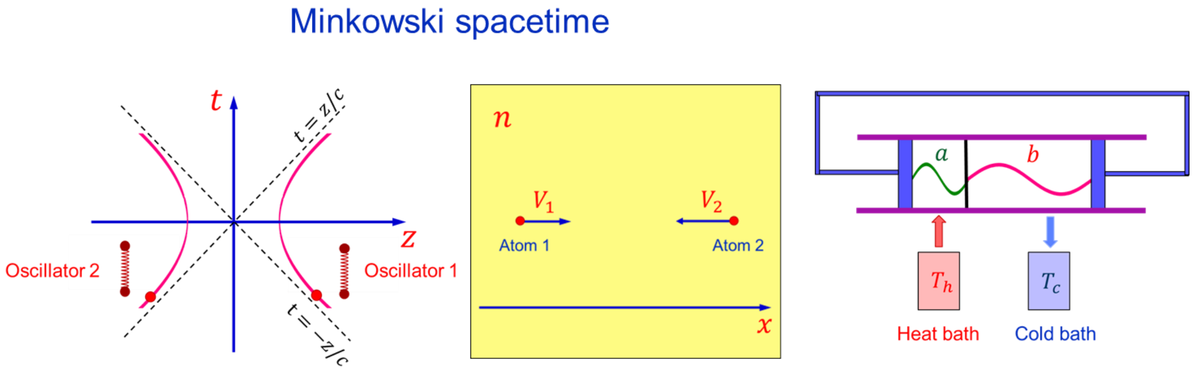
If we choose Rindler modes to describe electromagnetic field, Minkowski vacuum is filled with Rindler photons whose number in different space regions is correlated. This property yields observable effects. For example, two ground-state oscillators uniformly accelerated in causally disconnected regions (Fig. 1a) become excited in a correlated fashion by absorbing Rindler photons, so that state vector of the system evolves as

$$|\psi(\tau)\rangle = \sqrt{1-\gamma^2}\, e^{\gamma(cos(g\tau)\hat{b}_1^+ - isin(g\tau)\hat{\sigma}_1^+)(cos(g\tau)\hat{b}_2^+ - isin(g\tau)\hat{\sigma}_2^+)}|0_R\rangle\,|0\rangle,$$

where $\hat{b}_{1,2}^+$ are Rindler photon creation operators, $\hat{\sigma}_{1,2}^+$ are oscillator's raising operators, g is the oscillator-photon coupling constant, and τ is the oscillator's proper time. For time instances for which $\cos(g\tau) = 0$ the state reduces to

$$|\psi\rangle = \sqrt{1-\gamma^2}\, e^{-\gamma\hat{\sigma}_1^+\hat{\sigma}_2^+}|0_R\rangle\,|0\rangle,$$

which is a two-mode squeezed state for oscillators, and field is in the Rindler vacuum $|0_R\rangle$. Thus, entanglement of Minkowski vacuum is transferred to oscillators. A similar effect takes place when causally disconnected ground-state atoms are moving with a constant velocity through a medium and become excited in a correlated fashion by emitting Cherenkov radiation (Fig. 1b). We discuss connection of this effect with the noise induced coherence and efficiency of quantum heat engines (Fig. 1c). In particular, we consider heat engines with quantum working substance that use hot and cold reservoirs in thermal equilibrium as the energy source and the entropy sink respectively. We show that Carnot formula yields limiting efficiency for such engines under general assumptions.



(a) (b) (c)

Figure 1: (a) Oscillators are uniformly accelerated in causally disconnected regions through Minkowski vacuum and become excited in correlated fashion. (b) Ground-state atoms 1 and 2 are moving through a medium with refractive index n in the opposite directions with uniform velocities $V_{1,2} > c/n$ and become excited in correlated fashion by emitting Cherenkov radiation. (c) Photonic quantum heat engine.

Investigation of the thermal transport and magnetic properties of potential quantum materials

Jinke Tang

Department of Physics and Astronomy, University of Wyoming

I will talk about our investigation of the thermal conductivity and thermal Hall effect of topological superconductors that have potential applications as fault tolerant qubits. I will also talk about some other materials that may be considered as potential platforms for qubits development including skyrmion based qubits and rare earth doped solid state systems. Lastly, I will talk about our NSF Innovation Engines Development Award: *Advancing quantum and supporting technologies in the Northern Intermountain States (MT, WY, ID).*

Short Bio:

Jinke Tang is a Professor of Physics at the University of Wyoming. He taught at the University of New Orleans for 17 years before he moved to Laramie 16 years ago. He has a PhD in Physics and MS in Metallurgy, both from Iowa State University. He came to the US in 1984 to pursue graduate study via CUSPEA (China-US Physics Exams and Applications) organized by Nobel Laureate T.D. Lee. He obtained his BS degree in Physics from Jilin University in China in 1982.

Two-dimensional topological superconductors for future fault-tolerant quantum computing

Jifa Tian
Department of Physics & Astronomy, University of Wyoming

Quantum computers are an exciting frontier in modern technology, with the power to solve problems that are out of the capability of today's computers. One of the challenges of current quantum computers (such as superconducting qubit-based) is sensitive to disruptions. That's where topological quantum materials, including a special group called topological superconductors,[1,2] come in. These materials have unique properties that make them ideal for building more stable quantum computers. In this talk, I will first give a brief introduction about topological superconductivity. Then, I will focus on our team's experiments with a promising topological superconductor candidate known as 2M-WS_2, which is composed of tungsten and sulfur.[3] I will first look at the intrinsic properties of 2M-WS_2, such as how it's made and how its electrical properties change with thickness. Plus, I will show how 2M-WS_2 can be made to switch between a superconducting state (where it lets electricity flow freely) and a semiconducting state (where it restricts the flow somewhat). Our research is an important step towards harnessing the potential of topological superconductors for building robust quantum computers.

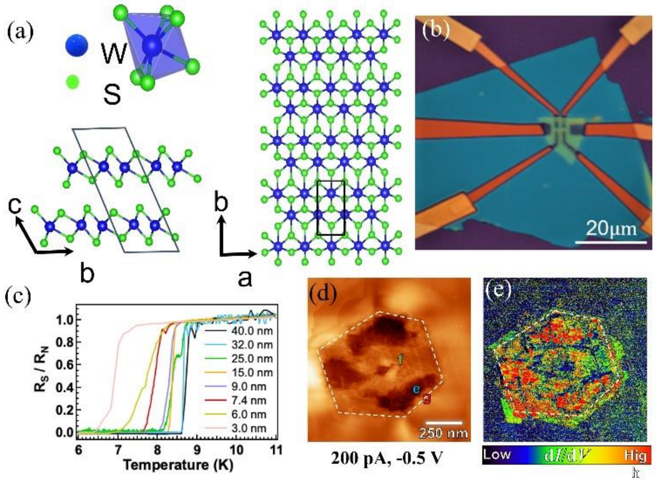


Figure1 (**a**) schematic of the crystal structure of 2M phase WS_2; (**b**) optical image of a Hall-bar device of 2M-WS_2 thin layer; (**c**) Thickness dependence of superconductivity in 2M-WS_2 layers. (**d**, **e**) Locally induced superconducting to semiconducting phase transition in a 2M-WS_2 thin layer.

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Short Bio:

Jifa Tian is currently an Assistant Professor of the Department of Physics & Astronomy at University of Wyoming (UW). In 2009, he received his PhD from the Institute of Physics & the University of Chinese Academy of Sciences (UCAS), CAS, China. Before joining UW in 2018, he did his postdoctoral work at Purdue University and worked as a guest researcher at the National Institute of Standards and Technology (NIST, Gaithersburg). His research field is experimental condensed matter physics, nanophysics, and nanotechnology. His current research interest focuses on studying the novel electronic properties of quantum materials (including topological superconductors, 2D magnets and other novel 2D materials and their heterostructures) and exploring their potential applications in advanced computing technology and energy harvesting.

Laser-induced thermal profile in liquids and self-induced diffraction patterns.

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Centro de Física Aplicada y Tecnología Avanzada
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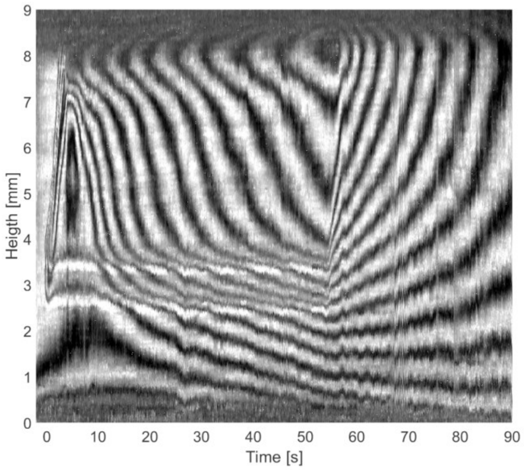
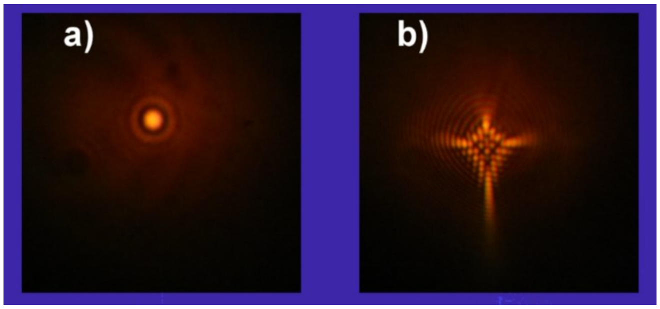
Laser propagation through a fluid can produce temperature changes in the liquid defined by the properties of the fluid and the boundary conditions, which can show very symmetrical thermal profiles at low intensity, or even thermal oscillations like those observed in the Rayleigh-Bernard cells at large intensity. Here we will present a detailed numerical study [1] to describe the thermal profile of the fluid and its interaction with the laser, obtained by the measurement of the phase in a Michelson interferometer (see the image at the left). In addition, we evaluate the far-field diffraction images [2] produced by the pumping beam impinging on the fluid (see the image al the right for water and methanol) and the interferometric pattern obtained normal to the direction of propagation to further detail the thermal profile. The direct comparison between experimental results and numerical simulation allows a complete understanding of the transfer of energy from laser to liquid and the subsequent effect on laser propagation. Spatial phase self-modulation and propagation control from small-phase diffraction, aberration-controlled diffraction at medium intensity, and diffraction oscillation are observed and can be explained. The study of diffraction patterns with a simple analog problem using an axicon and Zernike polynomials further helps to understand the physical processes and even be used as a probe for fluids analysis.





Left image: Isophase lines produced with a Michelson interferometer. The horizontal axis represents the time, and the laser-ON ranges from 0 to 55 s. The vertical axis is the cell height. The link between phase and temperature is the refractive index sensitivity $S = dn/dT$. Right image: Photographs of the diffraction patterns observed at similar conditions for a) water and b) methanol.

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LIGO is Quantum

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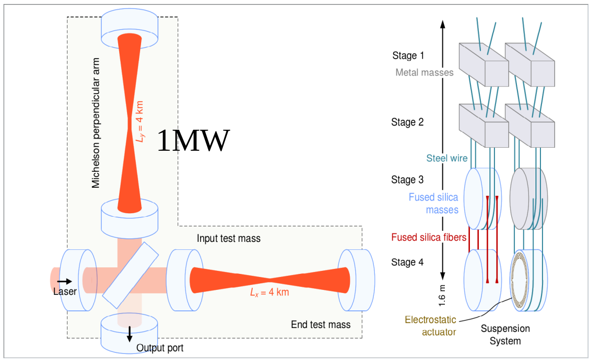
IQSE, Texas A&M Univ, USA

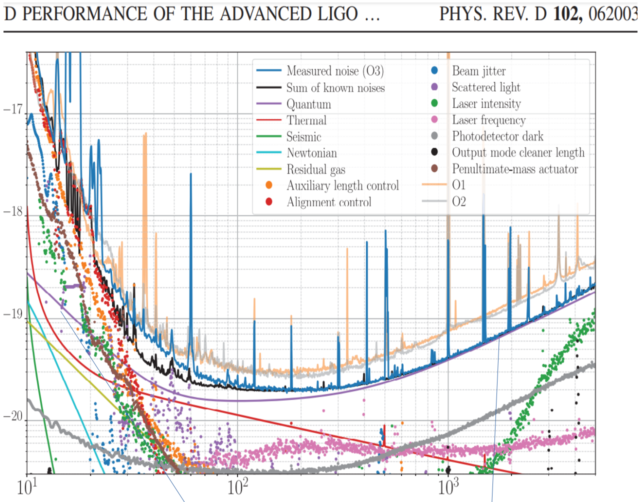
Are large objects Quantum? This question has loomed over the field for the last 100 years. LIGO, the Laser Interferometer Gravitational-wave Observatory, has 40kg mirrors, which are certainly macroscopic. 40 years ago, I argued that using frequency dependent squeezing of the light entering the “dark port” of the interferometer, one could reduce both the short noise due to the photon detection at the output and the radiation pressure fluctuations on the mirrors, even though they are complementary quantum observables, if the mirror’s centre of mass motions are quantum. Using a model of the interaction of quantum light with a classical system, they cannot be cancelled. It is a quantum interference phenomenon. Recent experiments with a LIGO test bed has shown that they do interfere, just a quantum Mechanics predicts, and thus frequency dependent squeezing has now been implemented in the LIGO detectors to improve their sensitivity.



1MW

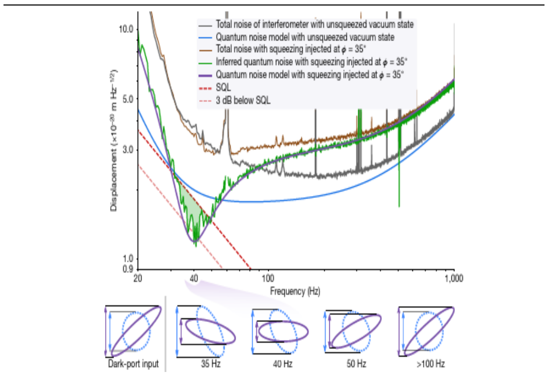
40W

1mW



Detector shot noise

Pressure shot noise



Squeezed input

Radio waves in World War II

Sijmon Verhoef, *Wildwood Secondary*

In the year of 1865, a Scottish mathematician and one of the greatest scientists who have ever lived, James Clerk Maxwell posited the existence of electromagnetic waves, in his theoretical work “A Dynamical Theory of the Electromagnetic Fields” [1]. In that work he predicted that electromagnetic fields travel through space at the speed of light, in the form of waves. Maxwell work was based on experiments done years before by Michael Faraday. Maxwell’s work stating that electromagnetic energy, including light, consisted of waves propagating through space remained strictly theoretical for a while. Years after Maxwell´s dead, a brilliant German Physicist, Heinrich Rudolf Hertz demonstrated the existence of the electromagnetic waves predicted by James Clerk Maxwell, in a series of experiments conducted between 1886 and 1889. At the time, Hertz stated that his work was simply a demonstration of Maxwell´s theory of electromagnetic wave propagation, with no practical application [2] . Few years later, in 1896, Guglielmo Marconi, an Italian physicist invented a successful “wireless telegraph, or “radio”. The history of using of radio waves to detect objects beyond the range of sight was first developed into a practical technology by British scientists and engineers in the 1930s. This new equipment, known as radar ('radio detection and ranging'), would play a major role during the World War II and in subsequent conflicts. In 1909 Hertz received the Nobel Prize for Physics. In this work we explore the role of radio waves during the second world war, where radio waves play a decisive role in the outcome of World War 2. I will give clear examples to illustrate the relevance of the radar during World War II: radars were the main warning system for the British when Nazi Germany was sending their air force to attack them. Radars that warned the British could detect aircrafts from up to 80 miles away. Despite British being the inventors of the radar, the science behind it was discovered in 1922 by A. Hoyt Taylor, Leo C. Young and the Us Navy Aircraft Radio Laboratory when a ship that was crossing a transmission path of a radio link was causing a fading in-and-out signal. This was reported as a Doppler-beat interference. In 1930 Laurence A. Hyland observed the same affect with an airplane. The Italians had a radar prototype developed in 1935 and Nazi Germany having their first functioning radar in 1939. In the 1930s when the berlin Tempelhof Airport opened, Lufthansa (a German airline) has developed the Lorenz system which assist aircrafts for landing during heavy storms and at night. Later in the war, when Germany annexed France they wanted to bomb Britain. The Germans modified the Lorenz system for bombing Britain at night. In addition, a **poster presentation** in Memoriam of Dr. Nelson Duller, a Texas A&M Physicist and a World War II veteran, who was a HAM radio enthusiast and passionate teacher will be presented as well.

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Multiphoton super-resolution microscopy

Aart Verhoef, Anton Classen, Ajithamithra Dharmasiri, Reed Nessler, James T. Florence,
Aleksei Zheltikov, Alexei Sokolov, Girish Agarwal, Marlan Scully, Alma Fernández
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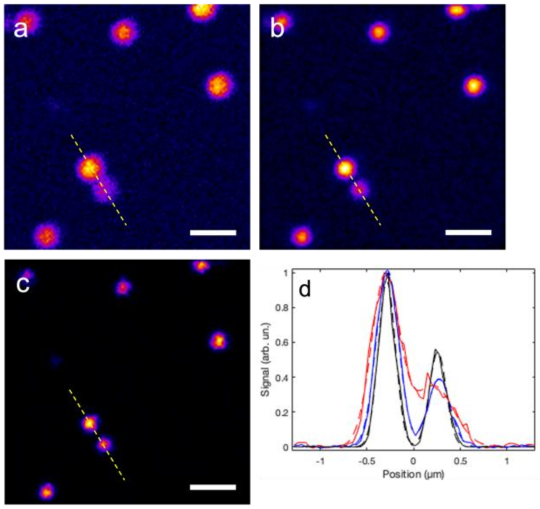

Fig. 1. Resolution enhancement of multi-photon microscopy by using different super-resolution techniques. Image taken with (a) standard 2-photon microscopy, (b) ISM enhanced 2-photon microscopy, and (c) SOFI+ISM (SOFISM) enhanced 2-photon microscopy. (d) Profile along yellow line in the images, showing the consecutive enhancement of ISM and SOFISM.

Imaging biological samples with sub-cellular precision is important for our understanding of fundamental processes governing biological processes. Standard optical techniques allows to resolve structures as small as $0.51\lambda/\mathrm{NA}$, where λ is the wavelength of the light used, and NA is the numeric aperture of the imaging objective lens. A better resolving power can be achieved with advanced techniques referred to as super-resolution microscopy. When coupled with single photon excitation, super-resolution techniques are limited in imaging depth by absorption and photo-darkening. Photo-darkening is especially detrimental when acquiring image stacks, i.e. to obtain a 3-dimensional image. An elegant way to avoid out-of-focus photodarkening is to illuminate the imaging plane from the side, a technique called light-sheet microscopy [1]. However, this technique is not compatible with the use of ultra-high NA objectives as the short working distance does not allow access for the excitation optics to illuminate from the side. As the optical sectioning inherent to multiphoton imaging [2] relies on the nonlinear confinement of the excitation to the focus, out-of-focus photo-darkening is dramatically reduced compared to single photon excitation microscopy. As the illumination is done through the imaging objective, ultra-high NA optics can be naturally used with multiphoton excitation. Compared to single photon microscopy, the resolution that can be achieved with multiphoton microscopy is less good, because the effect of taking the excitation point spread function to the n-th power (for n-photon excitation) is more than offset by the n times longer wavelength needed. Nonetheless, the loss in achievable resolution can be re-gained by combining multiphoton excitation with super-resolution techniques.

I will present recent results we have obtained demonstrating the combination of 3-photon excitation with image scanning microscopy (ISM) [3], which allowed us to obtain sub-diffraction limited images with a resolution of $\lambda/8$. Combining different super-resolution techniques allows to further improve the imaging resolution. We demonstrate 2-photon excitation with super-resolution optical fluctuation imaging (SOFI) [4] and ISM [5], which allows us to achieve an imaging resolution better than 100 nm, i.e. better than $\lambda/10$. We apply 3P ISM to image samples to a depth greater than 100 μm, where confocal imaging is limited to just a few μm due to photodarkening.

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Raman Autopsy of Cancer Cells

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ABSTRACT

Recent advances in high-resolution biomedical imaging have improved cancer diagnosis, focusing on morphological, electrical, and biochemical properties of cells and tissues, scaling from cell clusters down to the molecular level. We present new insights from the complex multidimensional analysis of cancer cells focusing on the plasma membrane and inner cellular molecular composition, using a variety of imaging techniques, including atomic force microscopy (AFM), kelvin probe force microscopy (KPFM), tip-enhanced fluorescence (TEF) and tip-enhanced Raman scattering (TERS).

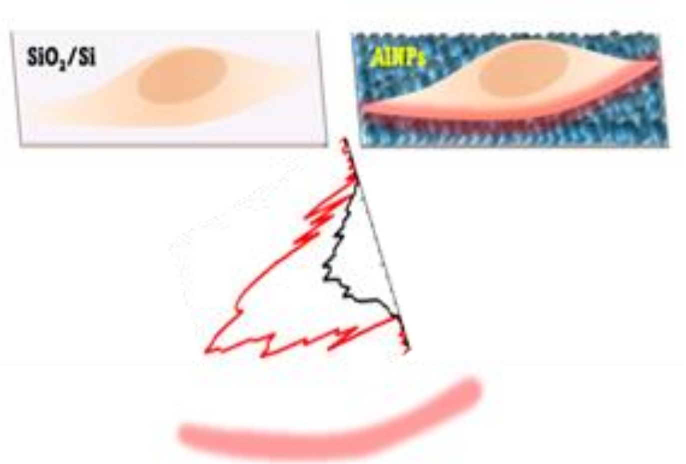


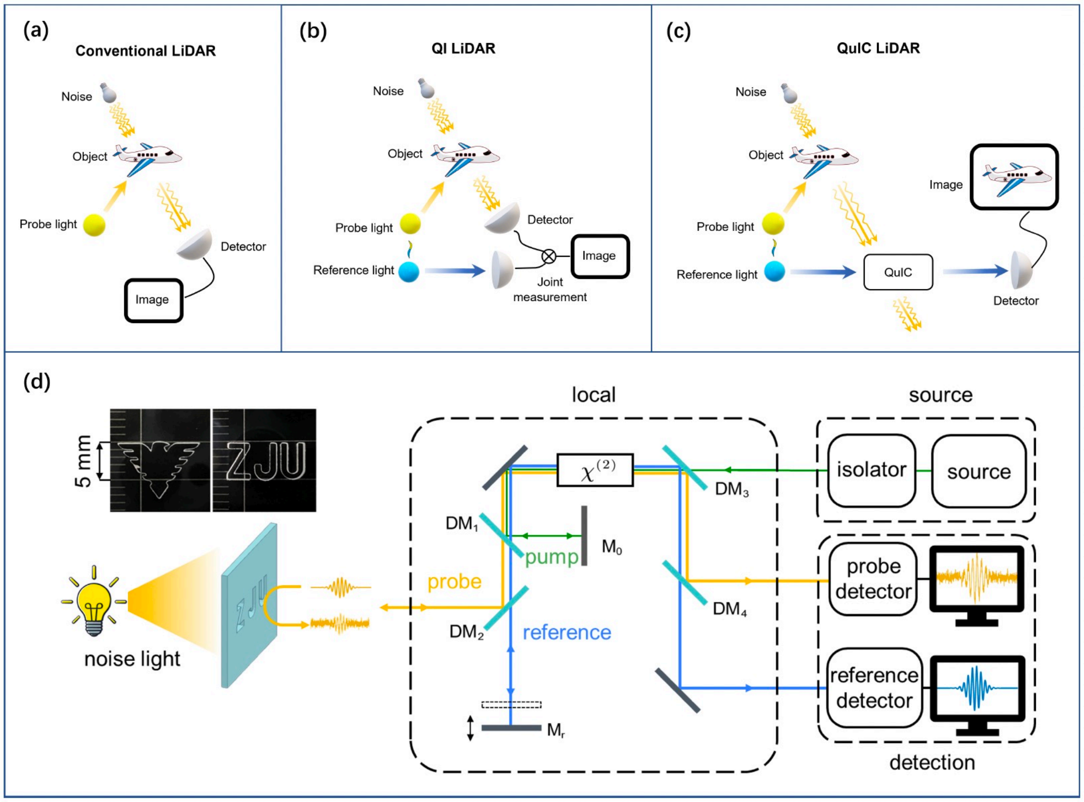
Figure. Surface-enhanced Raman imaging of intact cell membranes of normal and cancer cells on rough aluminum substrates reveals molecular differences.

Quantum Induced Coherence Light Detection and Ranging

Da-Wei Wang, Gewei Qian and Xingqi Xu

School of Physics, Zhejiang University

Abstract: Quantum illumination has been proposed and demonstrated to improve the signal-to-noise ratio (SNR) in light detection and ranging (LiDAR). When relying on coincidence detection, such a quantum LiDAR is limited by the response time of the detector and suffers from jamming noise. Inspired by the Zou-Wang-Mandel experiment, we design, construct and validate a quantum induced coherence (QuIC) LiDAR which is inherently immune to ambient and jamming noises. In traditional LiDAR the direct detection of the reflected probe photons suffers from deteriorating SNR for increasing background noise. In QuIC LiDAR we circumvent this obstacle by only detecting the entangled reference photons, whose single-photon interference fringes are used to obtain the distance of the object, while the reflected probe photons are used to erase path information of the reference photons. In consequence, the noise accompanying the reflected probe light has no effect on the detected signal. We demonstrate such noise resilience with both LED and laser light to mimic the background noise and jamming attack. The proposed method paves a new way of battling noise in precise quantum electromagnetic sensing and ranging.



Label-free Wide-Field Imaging with High Spatial Resolution Enabled by Infrared-Resonant Third-Order Sum-Frequency Technique

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Infrared (IR) spectroscopy can provide molecular selectivity based on intrinsic molecular features, which makes it ideal for label-free imaging. We recently developed a wide-field label-free microscope based on infrared-resonant third-order sum-frequency (ITS) technique [1]. The energy scheme is shown in Fig 1(a). In this experiment, a femtosecond pulse train is used to resonantly excite C-H vibrational modes (2900 cm^{-1}) while another probe pulse train centered at 1.55 µm probe the coherence at a certain time delay. The signal light, which contains the information of C-H modes, is emitted by sum-frequency-generation process at around 633 nm and used for imaging.

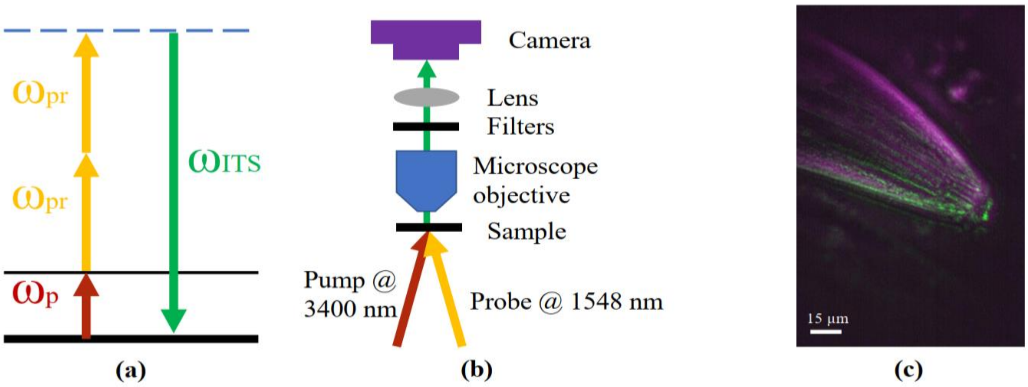

Fig. 1. (a) Energy diagram of ITS spectroscopy. (b) Schematic drawing of the wide-field ITS microscope. (c) ITS image of the head area of a Caenorhabditis elegans worm.

By adapting the ITS spectroscopy in a microscope, it can image the chemical distribution of a biological sample without labeling. The schematic diagram of the ITS imaging setup is illustrated in Figure 1(b). In Figure 1(c), an ITS image of an alive Caenorhabditis elegans worm is displayed, captured using a 1.0 NA water immersion objective. The green color is the four-wave-mixing background that contains structural information, while the purple color corresponds to the resonant CH vibrational signal.

This method overcomes several issues that traditional IR microscopy has. (1) It can image samples in aqueous conditions. (2) The spatial resolution is determined by the visible signal. In this experiment, we achieved a minimum resolution of 0.5 µm. (3) Video-rate wide-field imaging enables real-time imaging of bio-samples. (4) The signal collection only needs a Si-based camera, which is more efficient, less cost, and faster than IR detectors.

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Brillouin microscopy: seeing life in a new light

Vladislav Yakovlev, TAMU

The progress of biomedical sciences depends on the availability of advanced instrumentation and imaging tools capable of attaining the state of biological systems in vivo without using exogenous markers. Mechanical forces and local elasticity play a central role in understanding physical interactions in all living systems. We demonstrate a novel way to image microscopic viscoelastic properties of biological systems using Brillouin microspectroscopy [1], which was named by The Guardian as one of the top 10 science stories of 2022.

In my talk, I will discuss the ways how an old spectroscopic tool can be used for real time microscopic imaging and provide possible solutions to long standing problems in Life Sciences and Medicine [2-4]. At the end, I will outline the most recent advancements in instrumentation utilizing quantum light excitation [5] and will review future applications of this new technology.

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Atomic Coherence, Cooperative Emission and some Applications

Zhenhuan Yi[1]**, M. O. Scully**[1,2,3]

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ABSTRACT

Quantum coherence has been an import resouce for many facinating effects, e.g, Electromagnetically Induce Transparency (EIT), Laser Without Inversion (LWI), Stopped light, etc. In extended sytems, atoms act coherently and produce cooperative emission such as superfluorescence and superradiance. Atomic coherence and cooperative emissoin are also the bases of induced Rabi oscillation effect and quantum beat spectroscopy [1].

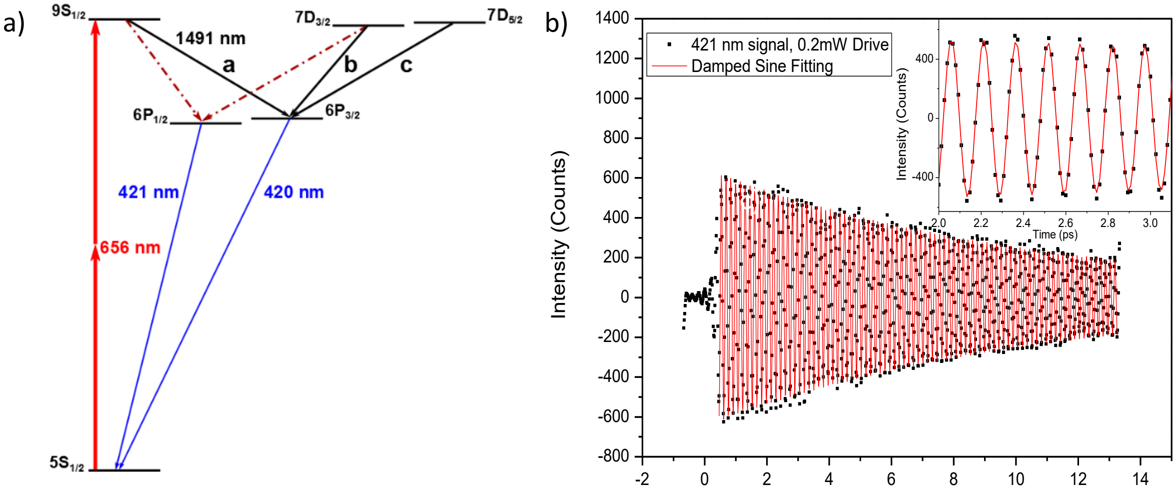

Figure: a) ^{87}Rb levels involved in experiment; b) Beating signal at wavelength of 421nm (black dots) and the damped sinusoidal fitting (red solid curve), the fitting gives a 6.5643THz ±0.16GHz for energy splitting between $9S_{1/2}$ and $7D_{3/2}$, which is close to theoretical value of 6.5630THz ±0.3GHz [2].

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Nuclear quantum memory for hard X-ray photons

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Quantum memories are essential elements in complex quantum computing and communication networks for reliably storing and retrieving quantum information. While several protocols of quantum memories have been developed for optical photons, storing X-ray photons has remained an open challenge. Here we report, for the first time, quantum memories of 14.4 keV (wavelength 0.86 Å) hard X-ray photons for 28 ns at the single photon level, with efficiency 8.5% and fidelity 67% (Fig. 1). The demonstrated protocol [1] is based on the formation of a comb-like structure in the nuclear resonant absorption spectrum due to the Doppler effect, by using a set of 3.2 μm-thick moving ^{57}Fe foils. Such tunable, robust, and highly flexible system offers a promising platform for compact solid state, room temperature quantum memory in the hard X-ray range, and paves the way for X-ray quantum information.

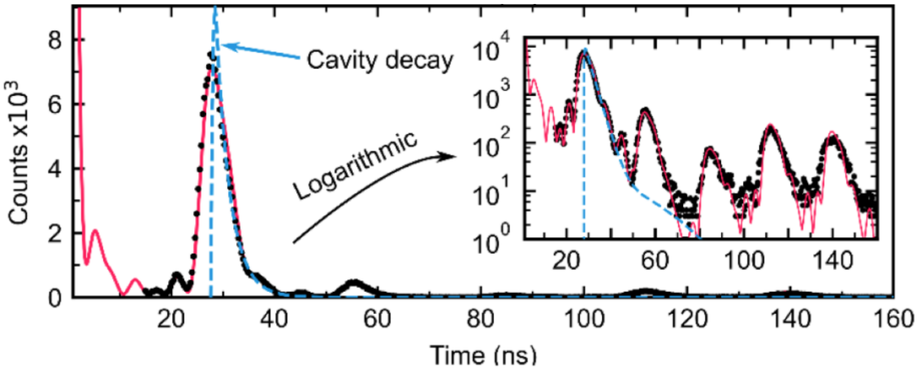

Figure 1. Experimental data (black) and numerical simulation (red) of storing 14.4 keV exponential cavity-decay single photons (blue) for 28 ns by moving 7 ^{57}Fe foils with velocity spacing 3.1 mm/s.

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Monitoring Electronic Coherence of Molecules by Quantum-Light Spectroscopy

Zhedong Zhang[1]

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Quantum states of the light, e.g., single photons, entanglement and squeezing, open up a new avenue for spectroscopy by utilizing the parameters of quantum optical fields as novel control knobs and through the variation of photon statistics. With the advancements of cavity quantum electrodynamics and light source technology, imaging and controlling the electron and vibrational motions of molecules can be achieved, towards unprecedented resolution and precision, not accessible by the classical light pulses. Two key issues emerge at nanoscale: quantum states of photons and strong matter-light interaction. The underlying physics is still an open issue for molecules and spectroscopy.

In this talk, I will present an overview of our recent work on multidimensional spectroscopic probes for nonequilibrium dynamics of complex molecules. Several spectroscopic signals will be covered: multidimensional coherent probe, photon-coincidence counting, and Raman spectra with entangled photons [1,2]. Microscopic models for molecular polaritons using density matrix and Heisenberg-Langevin approach will be incorporated for a unified understanding of the spectroscopic signals [3].

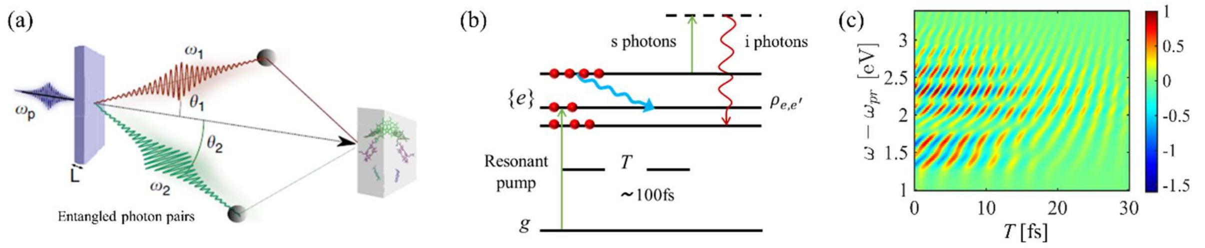

Figure: (a) Entangled photon pairs as ultrafast probe for molecules where nonlinear medium and photon-coincidence counting are presented. (b) Level scheme of the microscopic model of molecular relaxation interacting with two entangled photons that induce the Raman scattering. (c) Femtosecond Raman signal with entangled photons as probe, for time-evolving electronic coherence of molecular complexes, versus time delay *T* between entangled photons and resonant pump.

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Laser-Printed Plasmonic Structural Coloration on TiN Substrate

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ABSTRACT

Plasmonic structural color generation has been investigated for sustainable color printing. Among the various printing methods, laser-induced metasurfaces hold the promise of mass production in comparison to e-beam lithography and focused ion-beam lithography. Most of the laser-printed metasurfaces utilize traditional noble metal plasmonic thin films. Here, we report the laser-induced coloring on an alternative plasmonic material, TiN thin film, which has a high melting temperature and high chemical stability. TiN films were deposited through magnetron sputtering on different substrates. Various TiN patterns were written using a 532 nm laser with a lab-built confocal Raman microscope (Figure 1a). Our investigations show that laser irradiation induces nanocrystal aggregation of TiN. The plasmonic absorption of these aggregates with various sizes results in different colors. Laser power is the determining factor in laser-induced colorization. The color of patterns varies from purple to blue, to green then golden as the laser power increased from 6 mW to 30 mW (Figure 1b). These colored structures with a spatial resolution of down to a submicrometer can be used in various photonic applications, including tunable perfect absorbers, surface decoration, optical data storage, and sensors.

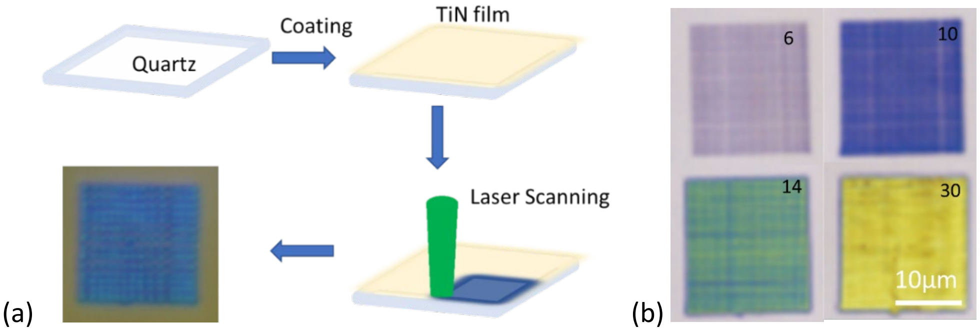


Figure 1 a: Sketch of laser-written pattern on TiN substrate. b: Optical images of 20 μm × 20μm patterns of different colors written with different laser power. The number on each photo is the laser power in milliwatts.

From quantum interference to quantum simulation

Shiyao Zhu and Da-Wei Wang

School of Physics, Zhejiang University

In this talk, we will introduce the basic concept of quantum interference and its applications in lasing without inversion, spontaneous emission cancellation, quantum dynamics in photonic crystals and superradiance lattices. The quantum interference in three-level systems is the key mechanism leading to lasing without inversion and spontaneouos emission cancellation, which can be further modified in engineered vacuum. Quantum interference and superradiance can be combined to construct superradiance lattices, providing a new platform to simulate exotic quantum matter at room temperature.

Poster Abstracts

(Listed Alphabetically by Presenter’s Last Name)

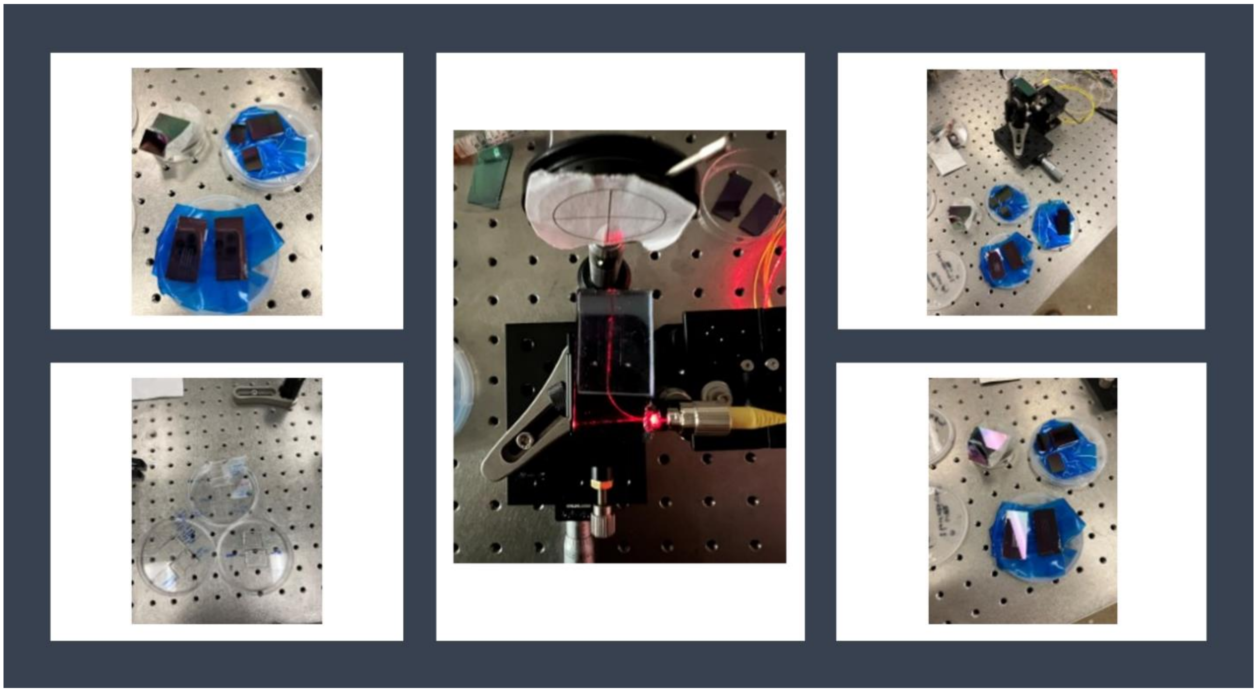
Biosensor Design and fabrication

Sahar Delfan

Institute for Quantum Science and Engineering, Texas A&M University, College Station, TX 77843

A sensor is a device that converts the value of a non-electrical parameter, into an electrical signal. Inspired from one of Dr. Scully's works 30 years ago [1] and a recent work on single virus detection with integrated Young Interferometer [2], we propose to build biosensors, an integrated waveguide system to have a sensitive detection of SARS-CoV-2 antibody and microfluidic channel. The working principle of waveguide based detection was well known, however we did not have any experience on waveguide fabrication and those biological aspects at that moment.

We spent about 9 months to develop the basic techniques for dielectric waveguide fabrication and microfluidic channel. We open a sensing window by etching away the upper cladding layer and expose the waveguide core to the environment. The test sample containing different concentrations of target antibody is then put into the sensing region (through the microfluidic system). By change in concentration, refractive index (including real and imaginary parts) will change. The resultant phase shift or intensity attenuation serves as a good characterization of antibody concentration in the sample.



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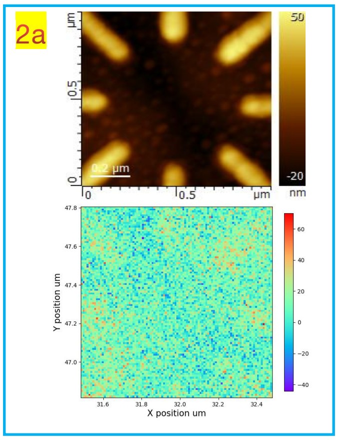
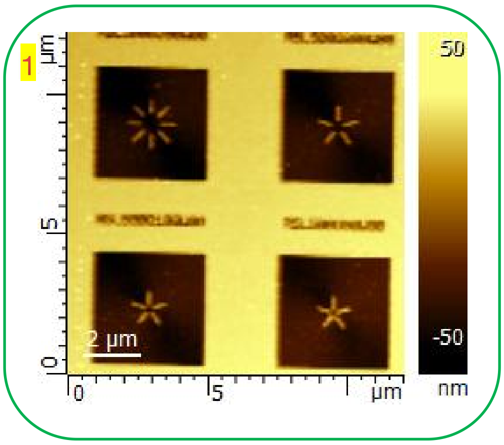
High-spatially resolved probing local field distribution of optical antennas for enhancing OAM Light

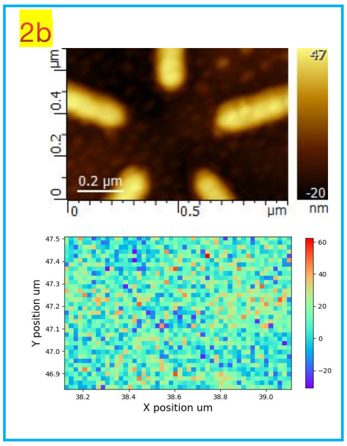
Zhi Gao[1], Alexei Sokolov[1], Rohil Kayastha[2], Zhenrong Zhang[2], Wei Zhang[2], Jonathan Hu[2]
[1]Department of Physics and Astronomy, Texas A&M University, College Station, TX, USA 77843
[2]Baylor University, Waco, TX, USA 76706

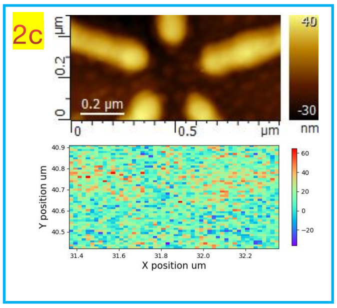
Introduction and results

Light with internal orbital angular momentum (OAM) is called an optical vortex, which has a clockwise and counterclockwise twisted wavefront and can distinguish left and right handed media instead of using the polarization of light. Suitable optical antennas can enhance OAM light by breaking diffraction limit and focusing such light to nanoscale. And it will contribute to studying the handness of single particle or even single molecule. The local field distribution and the enhancement factor of such antennas determines their functionality, which will also guide such optical antenna design and application. Different techniques have been used to study the spatial confinement and field enhancement around nanoantennas and in antenna gaps. Here we combine the lateral resolution of atomic force microscopy (AFM) with the chemical specificity of Raman spectroscopy to achieve this goal. From initial results we can identify the local field of antennas with the resolution of tens of nanometers although the contrast is low.









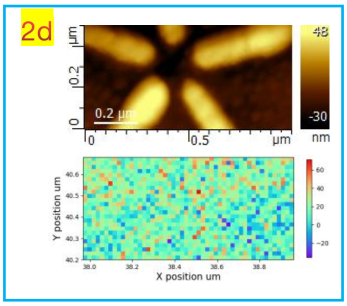


Fig. 1, AFM images of antenna samples on the borocilicate glass substrate; the number of rods and the diameter of central circles are variable.

Fig. 2a), 2b), 2c) and 2d) are partially magnified AFM images of the samples in Fig. 1 and their respective near-field maps.

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Quantum Edge Detection

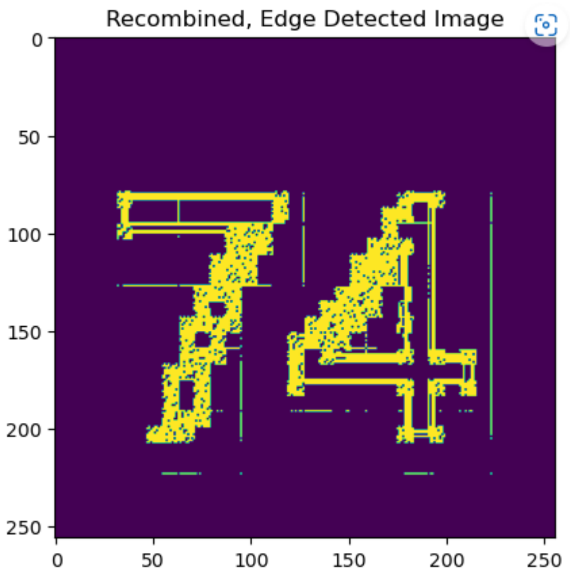
Guillermo Gonzalez - University of Texas at San Antonio, Quantum Realm Computing

Abstract

Quantum Image Processing (QImP) is an emerging field of quantum computing that can strengthen capacity for storing, processing, and retrieving information from images and video. While not as popular as other surging quantum topics (encryption, optimization, quantum internet), QImP has the potential to advance emerging deep tech fields like autonomous vehicles, medical imaging, and security applications such as facial recognition, gait analysis, "DeepFake" video and image manipulation detection. Existing research shows QImP offers significant advantages over current classical methods of image processing by leveraging the unique computational power of quantum computers to make processing tasks faster and more efficient. This effort will utilize existing quantum image processing algorithms combined with classical pre- and post-processing techniques to determine if a processing pipeline can be developed from beginning to end. Comparisons will be made between running the quantum computer-based portions on simulators and on real quantum computers to compare results.

Findings

Current implementations of quantum image processing algorithms do not provide usable results at this time, but advancements are being made every day. Many of the advancements come in the form of error correction. In addition, new types of quantum computers are being created with better gate fidelity and coherence times which will improve results.



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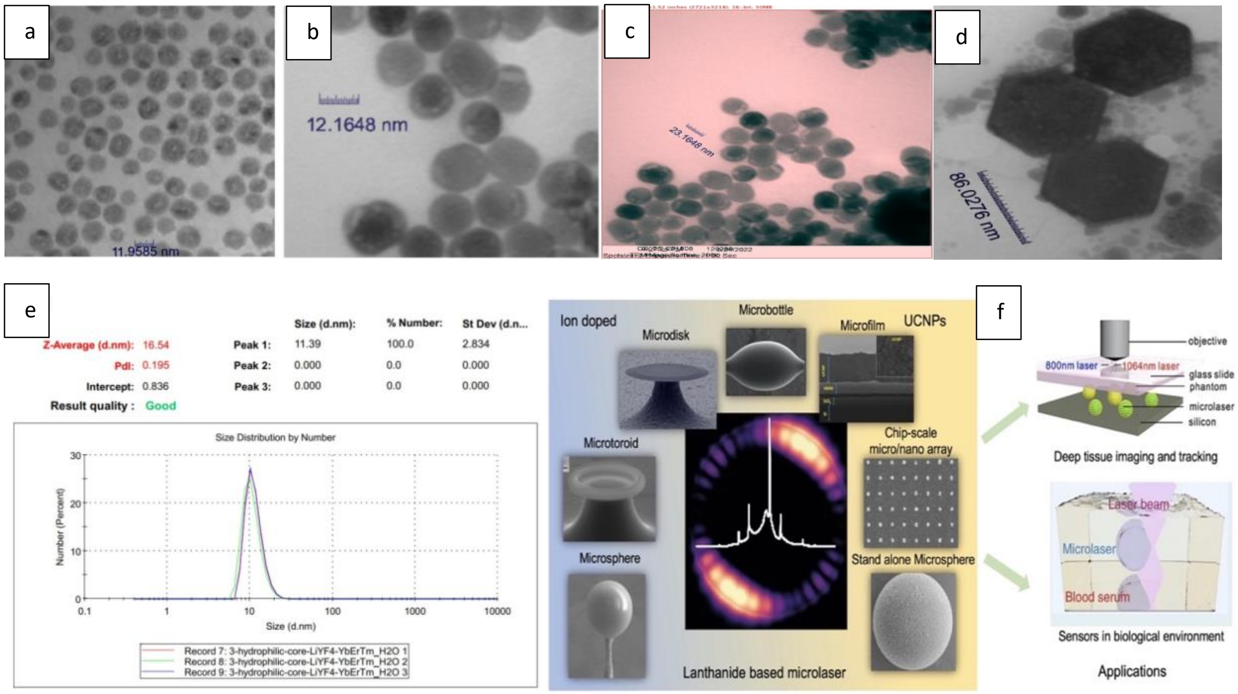
The Qiskit Team. Quantum Edge Detection - QHED Algorithm on Small and Large Images. 2021 URL: https://qiskit.org/textbook/ch-applications/quantum-edge-detection.html

Taking Upconversion to Lase in Microcavity

Ayla Hazrathoseyni, Shahriar Esmaeili, Navid Rajil, Philip R. Hemmer and Marlan O. Scully
Texas A&M University, IQSE, College Station, TX 77840, USA

Despite large size of lasers that limits their applications in biosensing, lanthanide-base micron-size upconverted microlasers show great advantages for biological applications owing to their tunable excitation and emission characteristics and excellent environmental stability. In this work we synthesized some Lanthanide-based biocompatible upconverting nanoparticles (UCNP) LiYF$_4$:Yb(%18),Er(%1.5),Tm(%0.5) and NaGdF4:Yb/Er@NaYb$_{0.9}$F$_4$:Nd(10%) with solvothermal method. Structural characterization of these materials was performed by means of transmission electron microscopy (TEM) as well as dynamic light scattering (DLS), and the upconversion luminescence (UCL) studies. In the next step, we try to fabricate upconversion microlasers with UCNPs that could make a strategy for highly smooth whispering gallery mode (WGM) resonators with small size and high-quality factor.



Z-Average (d.nm): 16.54
PdI: 0.195
Intercept: 0.836
Result quality : Good

	Size (d.nm):	% Number:	St Dev (d.n...
Peak 1:	11.39	100.0	2.834
Peak 2:	0.000	0.0	0.000
Peak 3:	0.000	0.0	0.000

Figure 1. (**a,b**) TEM images of LiYF4:Yb(18%), Er(1.5%), Tm(0.5%) UCNPs before (a) and after (b) EBAA ligand exchange. Image (a) is captured at 100k magnification, and image (b) is captured at 200k magnification using TEM JEOL 1200. (**c,d**) TEM images of the core-shell particles NaGdF4:Yb/Er@NaYb$_{0.9}$F$_4$:Nd (10%) (respectively spherical: 23 nm & hexagonal: 86 nm). (**e**) DLS data for hydrophilic LiYF4:Yb(18%), Er(1.5%), Tm(0.5%) in H_2O. (**f**) General concepts of the structures and applications of Lanthanide-based microlasers, https://doi.org/10.1007/s12274-023-5848-y.

Aspects of Hawking Temperature

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Black holes are amongst the most enigmatic objects in our universe, they are of great interest to almost all physicists, gravity theorists, quantum physicists, string theorists, condensed matter physicists and so on. Black holes are not entirely black, they radiate, they have temperatures. In this presentation, I am going to introduce several ways to derive the Hawking temperature of black holes.

Standard Thermodynamic Point of View. First, we review the ordinary laws of thermodynamics, namely,

$$T\mathrm{d}S = \mathrm{d}E - \Omega\mathrm{d}J - \phi\mathrm{d}Q,$$

and

$$\Delta S \geq 0.$$

Then we apply them to black holes. Since the degrees of freedom of black holes are holographically presented on their surfaces, they have entropies which are proportional to the surface areas. By reading off the coefficients in front of the differentials, we can easily obtain the Hawking Temperature of different kinds of black holes.

Thermal-field-theoretic Point of View. Our slogan for thermal field theory (TFT) is "Imaginary Time = Inverse Temperature". By doing the correct near-horizon expansion of a black hole and reading off the thermal Green's function or the density matrix of the thermal ensemble, we can readily get the Hawking temperature of a black hole.

Surface Gravity Point of View. At the black hole horizon, the surface gravity κ is defined as

$$\xi^{\mu}\nabla_{\mu}\xi^{\alpha} = \kappa\xi^{\alpha},$$

where ξ^{α} is the Killing vector. I will illustrate the physical meaning of the surface gravity. The Hawking temperature T_{BH} is calculated by

$$T_{BH} = \frac{\kappa}{2\pi}.$$

And More. Finally, we will briefly talk about obtaining Hawking temperature by considering a quantum mechanical reflection problem. We will discuss the discrepancies between the quantum mechanical reflection method and the aforementioned methods.

Applications of Quantum Light Sources in Bioimaging

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Quantum light sources are essential for the development of quantum technologies, as they provide the necessary building blocks for quantum communication, quantum metrology, quantum sensing, and quantum computing. As a crucial type of quantum light sources, squeezed light has a lower level of quantum noise in one of its properties (such as intensity or phase) than what would be expected for a classical light source. Stimulated Raman scattering (SRS) microscopes are a standard technique to image cells, tissues or track the uptake of drugs[1]. An increase of sensitivity in these devices is directly linked to the increase of laser power. Therefore, the photodamage of targets is challenging and squeezed light offers a solution to this challenge. Recently squeezed light has been used to enhance the sensitivity of continuous-wave and pulsed SRS[2,3] setups and stimulated emission spectroscopy[4]. In this review, we focus on the different experimental schemes, discussing the most recent and general results for the quantum noise squeezing. With this basic background in place, we then review emerging applications of quantum light sources in bioimaging. Along with the state of the art, we also explore open issues and potential next steps.

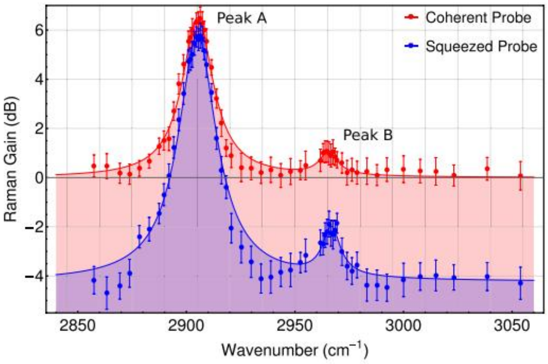

Figure 1 SRS spectrum of Polydimethylsiloxane (PDMS). The pump beam is scanned around the C-H stretching region with pump and probe powers of 28 and 1.3 mW, respectively. The traces are normalized to the shot-noise level [2].

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Manifestation of magnon vacuum entanglement

Ankang Liu and Anatoly Svidzinsky

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We study the Cherenkov-like effect in a magnetically ordered system. We first consider a spin-$1/2$ particle, prepared in its lower-energy state, moving along a 1D antiferromagnetic spin chain. We calculate the probability of the spin flip of the particle by emitting a spin wave propagating in the chain when this particle is traveling faster than the spin-wave velocity. In addition, we calculate the probability of the joint spin flip of two causally disconnected spin-$1/2$ particles, initially prepared in their lower-energy states with antiparallel spins and moving in opposite directions along the spin chain (see Fig. 1). We find that, under the resonance condition, the joint-spin-flip probability is greater than the product of the two individual single-spin-flip probabilities, which is a manifestation of entanglement of the antiferromagnetic ground state.

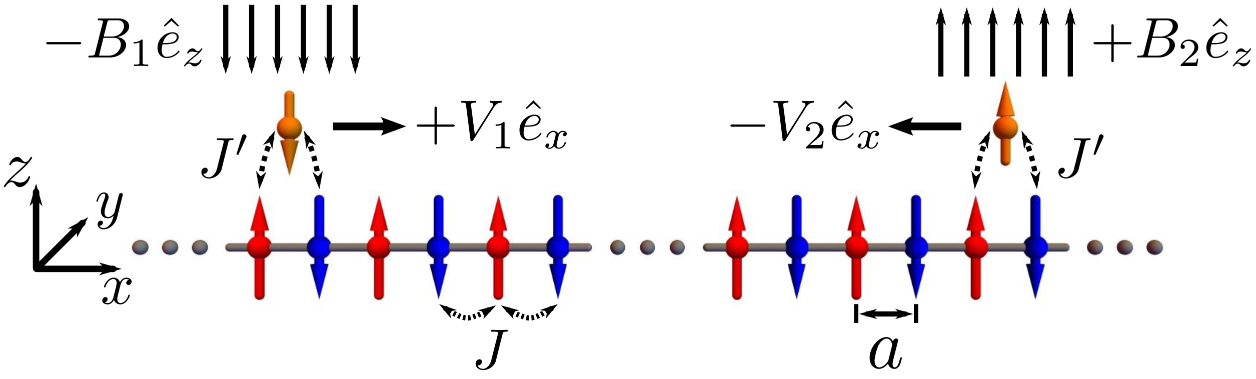

FIG. 1. Two spin-$1/2$ particles (the orange arrows) are traveling in opposite directions along a 1D antiferromagnetic spin chain (the red and blue arrows). The spin chain with lattice constant a is oriented along x direction. Each spin on the chain is coupled to its nearest neighbors through the short-range exchange interactions with strength $J > 0$. Under the equilibrium, all spins on sublattice A (the red arrows) are directed along positive z direction, whereas all spins on sublattice B (the blue arrows) are pointed along negative z direction. The two spin-$1/2$ particles are moving oppositely along the spin chain with velocities $+V_1\hat{e}_x$ and $-V_2\hat{e}_x$. These two particles only interact with the two closest spins in their vicinity on the chain through the exchange couplings $J' > 0$. The first spin-$1/2$ particle traveling with velocity $+V_1\hat{e}_x$ is subjected to a uniform magnetic field $-B_1\hat{e}_z$. It was initially spin-down, i.e., in its lower-energy state. On the other hand, the second spin-$1/2$ particle moving with velocity $-V_2\hat{e}_x$ is under a magnetic field $+B_2\hat{e}_z$. It was initially prepared in a spin-up state, which also corresponds to its lower-energy state.

Conservation of Gaussian states nonclassicality in linear optical networks

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[2]*Department of Physics, University of Rhode Island, Kingston, Rhode Island 02881, USA*

Nonclassical Gaussian states are important resources for quantum information processing due to their nonclassical properties such as squeezing and entanglement. Quantification of these properties in multi-mode Gaussian states has been an elusive task. Here we propose quantifiers for single mode nonclassicality, which captures the squeezing property of quantum states, and bipartite entanglement in a multi-mode Gaussian state. We show that the sum of these quantifiers is invariant under arbitrary linear-optical transformations for any two-mode and three-mode Gaussian states. Our findings contribute to a novel quantification of nonclassicality and offer valuable insights into the structure of entanglement within quantum networks.

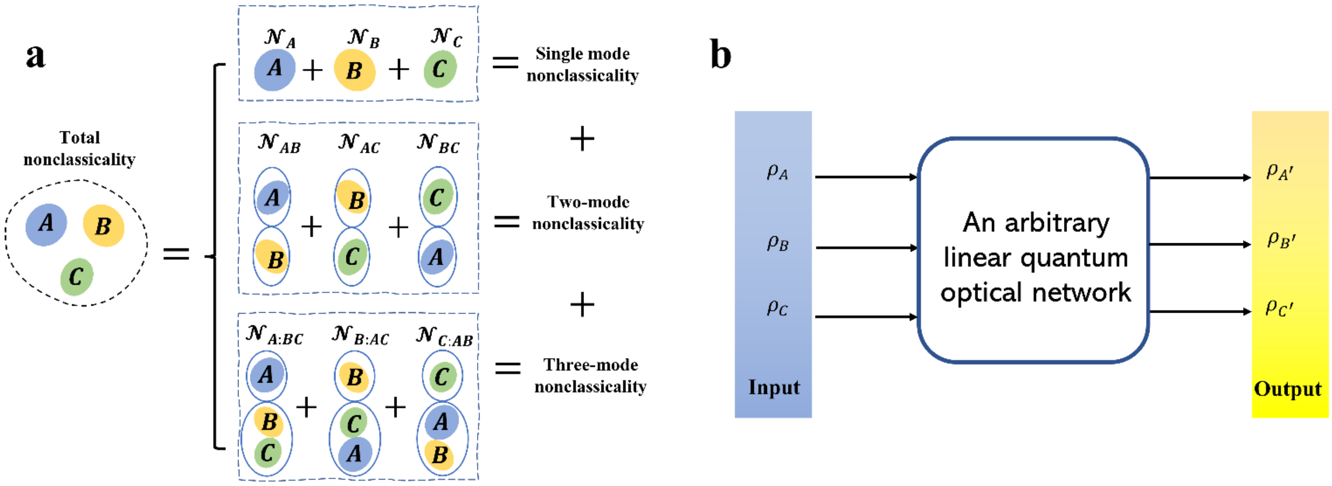

Figure 1: a. Total nonclassicality of three-mode Gaussian state. b. The conservation relation in an arbitrary linear quantum optical network.

Optical multiband polarimetric modulation sensing for the identification of gender and species of native solitary pollinators in flight

Yiyun Li[1, *], Zehua Han[1], Reed Nessler[1], Zhenhuan Yi[1], Philip Hemmer[1, 2], Robert Brick[1], Alexei V. Sokolov[1, 3], and Marlan O. Scully[1, 3]

[1]Institute for Quantum Science and Engineering, Department of Physics and Astronomy, Texas, A&M University, College Station, TX 77843–4242, USA

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Abstract

Native pollinators are crucial to local ecosystems but are under threat with the introduction of managed pollinators like honeybees (*Apis mellifera*) [1]. We explored the feasibility of employing the entomological lidar technique in native pollinator abundance studies. This study included individuals of both genders of three common solitary bee species, *Osmia californica*, *Osmia lignaria*, and *Osmia ribifloris*, native to North America. Properties like optical cross-section, degree of linear polarization, and wingbeat power spectrum at all three wavelengths have been extracted from the insect signals collected by a compact close–range remote sensing system. These properties are then used in the classification analysis. For species with temporal and spatial overlapping, our method achieved overall accuracies of 89% (*O. ribifloris* & O. *lignaria*) and 84% (*O. lignaria* & *O. californica*). The benefit of employing the habit information in enhancing identification accuracy has been emphasized [2].

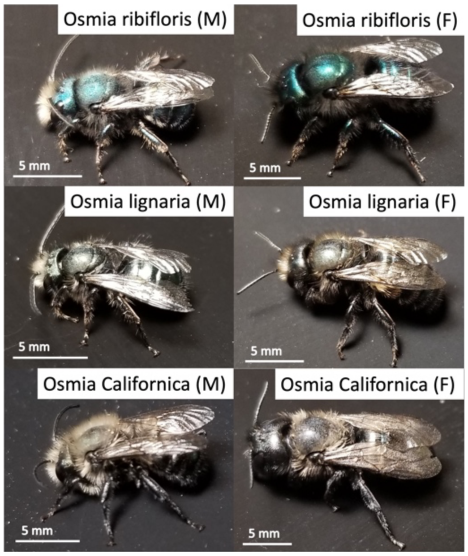

Fig. 1. Image of insects measured in the study. Images of the solitary pollinators used in the study: *O. ribifloris*, *O. lignaria*, and *O. californica*. The scale bar is shown at the bottom left of each image.

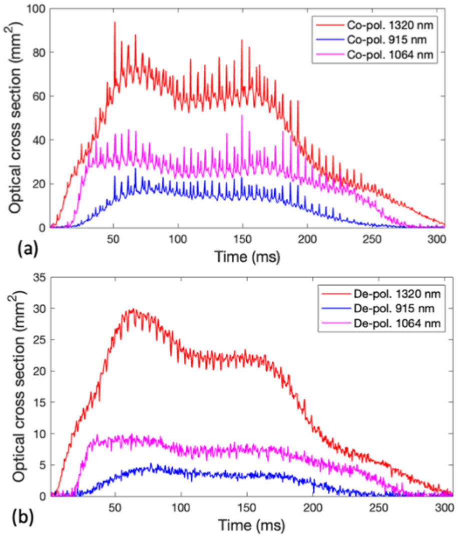

Fig. 2. Multiband polarimetric signals of a flying *O. californica* male. Signals at three wavelengths in the co–polarization channel are shown in (a) while the signals in the de–polarization channel are shown in (b).

Reference

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2. Li, Y., Han, Z., Nessler, R., Yi, Z., Hemmer, P., Brick, R., Sokolov, A.V. and Scully, M.O., Optical multiband polarimetric modulation sensing for the identification of gender and species of native solitary pollinators in flight (submitted to iScience)

Title: Entanglement in bipartite systems involving finite-lifetime observers.

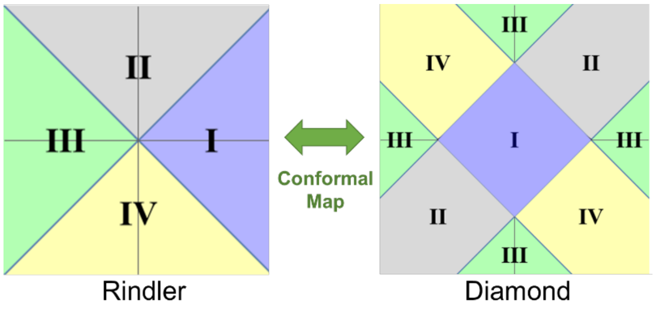
Authors: Horacio Camblong[1], Abhijit Chakraborty[2,3], Pablo Lopez-Duque[2], Carlos R. Ordonez[2].

Affiliation: University of San Francisco[1], University of Houston[2], University of Waterloo[3].

Summary of findings:

A bipartite system consisting of an inertial observer and an accelerated observer has been used in previous studies to show a connection between entanglement degradation and the Unruh effect. The degradation in entanglement between two modes of a non-interacting scalar field appears as a consequence of the relative acceleration between the observers. In this work, we analyze a bipartite system where one observer has finite lifetime and the other is inertial. The observer with finite lifetime is restricted to move in a causal diamond. This allows us to use a conformal transformation to establish a connection with the case for a constantly accelerated observer. The system is initially in a maximally entangled state if observed form the perspective of inertial observers, and it becomes less entangled from the perspective of finite lifetime observers. We argue that this effect is due to the presence of causal horizons.

Figure 1: Conformal mapping that connects the case for observers with constant acceleration and the case for observers with finite lifetime.



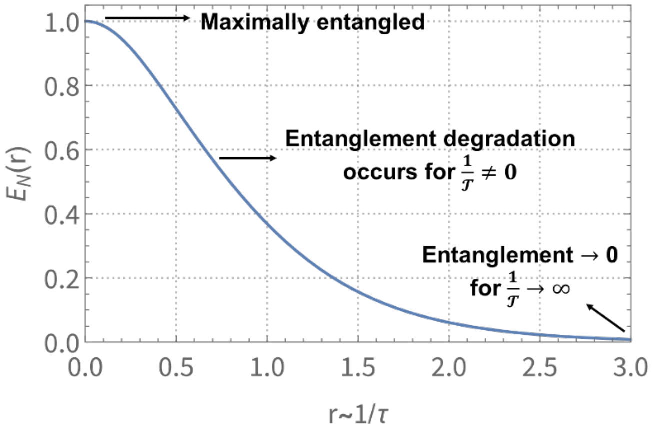


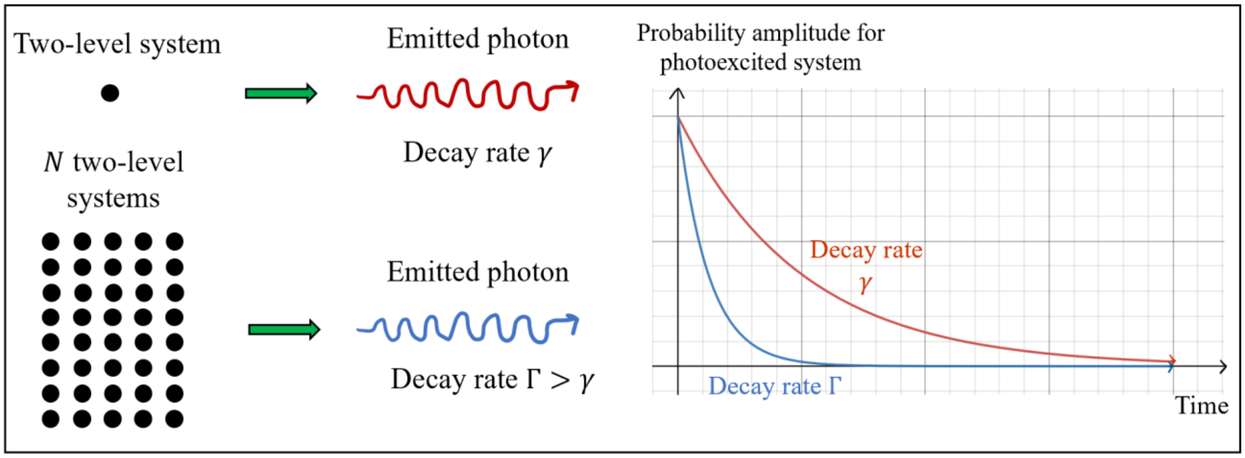
Figure 2: Logarithmic negativity for an inertial maximally entangled state when one observer has finite lifetime and the other is inertial. The negativity is unaffected for infinite lifetime, and it is degraded for finite lifetimes.

Single-photon superradiance and radiation trapping:
Comparison of analytical, discrete, and numerical approaches for the cylindrical case

Hamza Patwa[1], Nathan Babcock[1], Philip Kurian[1]

[1]*Quantum Biology Laboratory, Howard University, Washington, D.C.* https://quantumbiolab.com

Single-photon superradiance is a quantum mechanical phenomenon that results from many identical systems emitting a photon collectively at a higher decay rate than any one of those systems individually. This phenomenon has been studied analytically in idealized, continuous distributions of two-level systems [1], as well as numerically in photosynthetic nanotubes and also more recently in cytoskeletal architectures [2,3]. We study the phenomenon of superradiance from both an analytical and a numerical perspective, specifically in networks of tryptophan molecules, which are strongly fluorescent amino acids treated as two-level systems and found in many proteins. Our analytical study of superradiance consists of solving for the decay rates of a collective eigenstate of a shell with two-level systems distributed continuously on its surface. Our approach is based on [1], in which the infinite cylinder case is solved. We particularize the results in [1] by using discrete Fourier transforms to solve the eigenvalue equation and obtain decay rates for a finite cylinder. Our numerical study follows [2,3], where we apply a non-Hermitian Hamiltonian to the open quantum system of tryptophan molecules, organized in a native cylindrical geometry, to compare results with the problem solved analytically. Our results will aid future studies on the role of collective phenomena such as superradiance for the functionality of biological systems.



Schematic of superradiance. Image created by Hamza Patwa.

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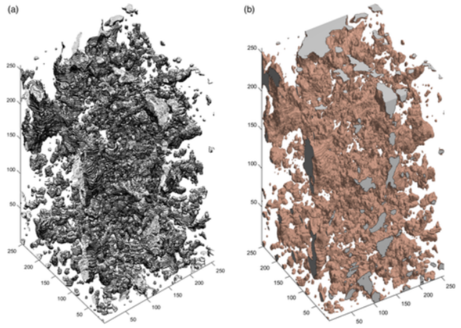
High Resolution Imaging of Soil Aggregate Pore Space and Microbial Activity using Optical Coherence and Multiphoton Microscopy

Riva Salzman[1], Alma Fernandez[1], Peyton Smith[1], Aart Verhoef[1]
[1]: Texas A&M University, College Station TX 77843, USA

One major asset in soil science is the ability to obtain a detailed understanding of soil structure from any sample. The soil pore space is perhaps the most physically relevant feature of soil structure because it determines how a soil behaves under physical stresses, permits gas and water transport, and makes up the major surfaces and pathways upon which biological and chemical processes take place[2]. We present a method of using optical coherence tomography (OCT) as a means of gathering 3D structural information of the interior of a soil aggregate so it can be analyzed for porosity and pore size distribution (PSD) characteristics. Potential benefits of OCT include faster imaging times and better spatial resolution for more accurate pore characterization (as compared with X-ray CT, the current standard method for imaging porosity[3]). Our current Fourier Domain Optical Coherence Microscopy (FD OCM) setup[1] can achieve a lateral resolution of down to 2.5 um. This ability to extract pore features of soil samples can help us understand and predict how soils will respond to environmental or agricultural stress.

A central process in soils related to pore space is the activity of microbes upon organic matter in soil. More information is needed on the precise spatial distribution of microbial enzyme activity in aggregates. Having this knowledge will assist in the development of mechanistic models that explain several soil processes in which microbial metabolism plays a key role, including aggregate formation and breakdown, and carbon storage and release in soils[4]. In this study we use multiphoton fluorescence imaging to generate high resolution images of hotspots of microbial activity. The location of these hotspots with respect to soil pore structure will also be documented, by using the fluorescence hotspot images in conjunction with OCT images of the same aggregates containing pore structure information.



Example of a 3D reconstruction of soil pore space.[5]

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Origin of the Transparency Resonances in Ensemble of Germanium-Vacancy Centers

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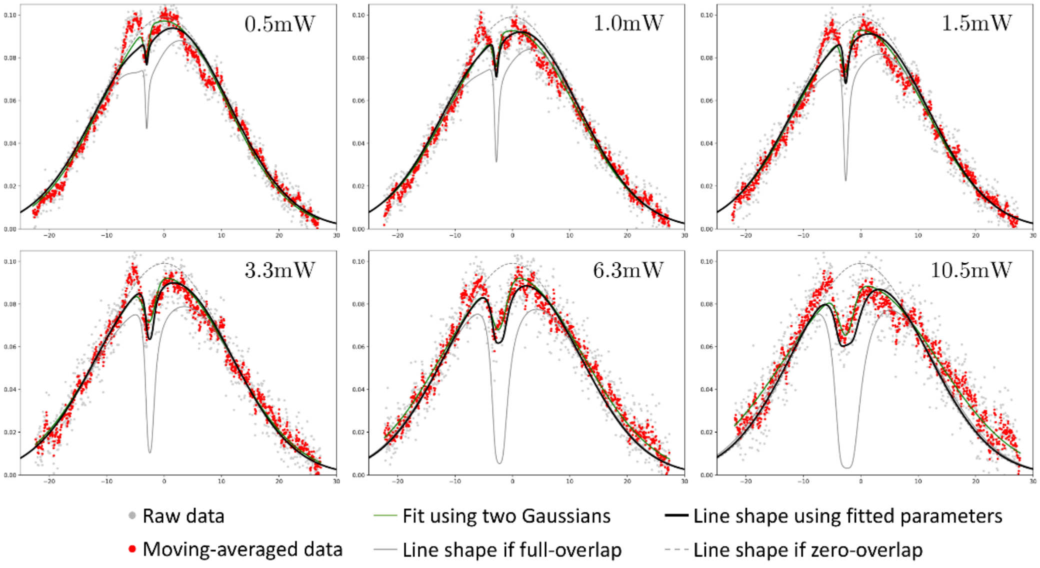
Recently, germanium-vacancy centers in diamond (GeVD) have attracted much attention. Like nitrogen-vacancies in diamond (NVD) they have 2-3 orders of magnitude higher dipole moment of the optical transition as compared to the rare-earth doped crystals. At the same time, as compared to NVD, they have about 20 times stronger zero-phonon line. Other advantage of GeVD is a presence of polarization selection rules at the optical transition forming the lambda system and large (160 GHZ) energy levels splitting in the ground state. The last advantage allows for orders of magnitude larger storage bandwidth compared to typically several MHz bandwidth in the rare-earth doped solids. The disadvantage of this vacancy center is rather fast decay of the atomic coherence on the order of 100ns.

Individual GeVD have been widely studied in view of their promising potential applications for quantum memories, quantum gates, quantum thermometry, etc. Some of these applications could benefit from using ensembles of GeVD. However, while individual vacancies have been widely studied less research was done with the ensembles. The experimental investigation undertaken by the group of P. Hemmer and A. Akimov at TAMU (including J.-W. Fan, I. Cojocaru, L. Jiang, A. Alajlan‖) had shown rather broad inhomogeneously broadened optical lines about 26GHz, through still much smaller compared to NVD. At the same time, relatively narrow and quite deep transparency resonances were observed.

The goal of this work was to clarify the physical origin of these resonances and to extract the information about the inhomogeneous broadening of the low-frequency caused the spin-orbital splitting. The presented analysis led to conclusion that the physical origin of the observed transparency resonances was an Autler-Townes splitting in each homogenously broadened sub-ensemble. It is shown that the summation of those resonances well mimicked an EIT resonance in the whole inhomogeneously broadened ensemble. As a result of the theoretical fitting of the experimental data the inhomogeneous broadening at the LF transition was estimated at 133 MHz.



Photoreaction Studies with Photoluminescence Ghost Imaging: Leveraging Structured Light and Benefits of Ghost Imaging

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Ghost imaging, utilizing correlation measurements between a reference beam and object-scattered or transmitted light, demonstrates versatility across fields like remote sensing, astronomy, and biomedical imaging. However, the imaging process faces limitations due to environmental disturbances, including optical path fluctuations and the requirement for a strong correlation between reference and object beams. These challenges can affect ghost imaging systems' practicality and image quality, highlighting the need for ongoing research. To address these issues, structured beams have been introduced to improve the temporal resolution of samples in scattered media [1,2]. Photoluminescence Ghost Imaging (PLGI) technique combines photoluminescence and ghost imaging principles to improve the understanding of complex photoreactions. In this work, our goal is to unravel the underlying structure-reactivity relationship involved in the TiO_2 reaction by monitoring the change of photoluminescence (PL) spectra. Our approach is to combine ghost imaging with structured beams and then with photoluminescence effect to study photoreaction. We utilize the PLGI system that utilizes structured light patterns using a digital micromirror device (DMD) to overcome the effects of light scattering on scattered media. Temporal resolution enables the observation and measurement of time-dependent changes.

Our experimental setup consists of a 532 nm laser beam directed towards the digital micromirror device (DMD), which spatially modulates the laser beam and generates structured illumination patterns matching the input monochrome patterns. The scaled beam passes through a liquid media and interacts with a TiO_2 sample, and then the beams are captured by a detector. Firstly, the setup for PLGI using the structured beams has been tested using a test sample (single crystal TiO_2) in both air and liquid media and the impact of scattered media on the imaging process has been observed. Then a real-time photoluminescence imaging experiment will be conducted for the TiO_2 sample to visualize and analyze the temporal changes and dynamics occurring with a high spatial resolution during the photoluminescence process. Using a PLGI system with structured light and a DMD will hold great promise for advancing our understanding of complex photoreactions in photochemistry and materials science.

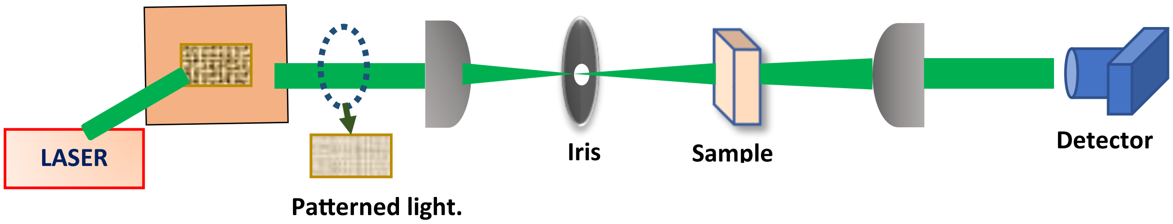

Figure: Experimental setup for Photoluminescence Ghost Imaging

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Plasmonic Resonance Measurement of Metals and Transparent Conducting Films Using the Kretschmann Configuration

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Gold (Au) and silver (Ag) are renowned for their ability to exhibit surface plasmon resonance (SPR) in the visible range of the electromagnetic spectrum, making them ideal choices for enhancing photo reactivity using sunlight. However, gold can be prohibitively expensive for practical applications, and silver tends to tarnish when exposed to air containing sulfur compounds. As an alternative, transparent materials like titanium nitride (TiN) and indium tin oxide (ITO) offer stability, cost-effectiveness, and photocatalytic capabilities.

In this study, we aimed to investigate and compare the plasmonic properties of metal films (gold) and transparent conducting materials (TiN and ITO) coated on various substrates, including titanium dioxide (TiO_2), silicon dioxide (SiO_2), silicon, and optical fiber and study the potential application to the photocatalysis. Thin surface coatings, with thicknesses below 100 nm, were deposited using a high-vacuum magnetron sputtering system. To measure the plasmonic resonance, we employed the Kretschmann configuration, a prism coupling method known for its simplicity and efficiency in determining the plasmonic resonances of metal films and transparent conducting films.

In our experimental setup, a supercontinuum broadband light source was directed through the air-prism interface, and the reflected light beam was collected by a spectrometer. By investigating the incident angles across a range of wavelengths, we were able to obtain distinct resonance angles where plasmonic resonances occurred. These resonance angles corresponded to different wavelength ranges, leading to the generation of surface plasmons.

This research investigation offers valuable insights into the plasmonic properties of the studied materials and aims to identify an efficient material that can facilitate plasmonic-enhanced photo-reactivity. Furthermore, the comprehensive understanding of the optical characteristics of metal and transparent conducting films derived from this study contributes significantly to the design and optimization of plasmonic-based devices and systems.

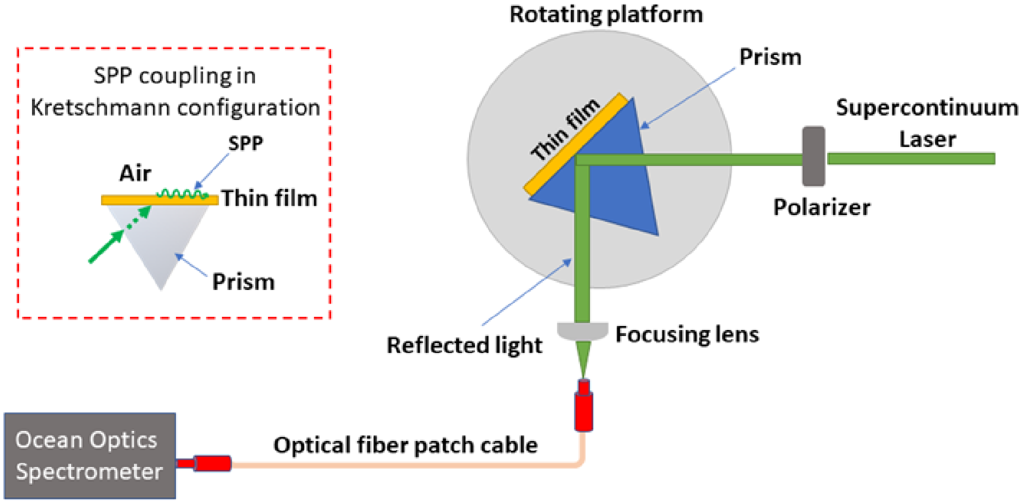

Figure: Experimental diagram for the measurement of surface plasmonic resonance. The reflected light from the prism-film combination is collected by the spectrometer. No light will be collected at the resonance angle.

Weak Coherent State Localization

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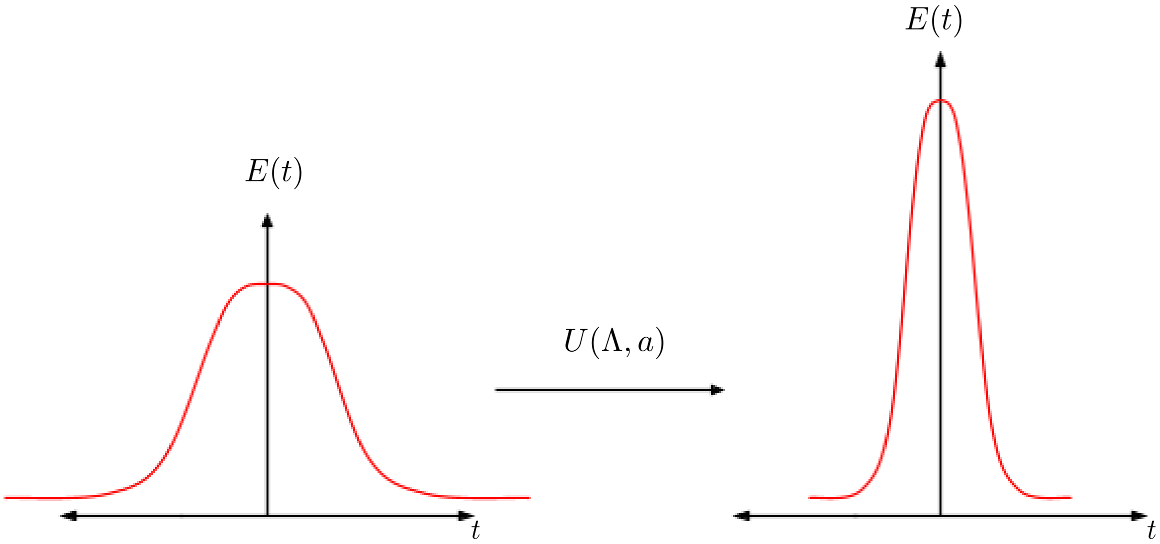
It is well known that single photon states cannot be arbitrarily localized according to the constraints of the Paley-Wiener Theorem. However, coherent states suffer no constraints from the Paley-Wiener Theorem and can be localized to an arbitrary degree. Given this, a weak coherent state with small mean photon number can be made to approximate a single photon state while at the same time being able to be arbitrarily localized. After describing a pulse that approximates a single photon in terms of a superposition of weak coherent states, the properties of Poincaré transformations can be used to arbitrarily reduce the duration of the pulse in order to localize the pulse to an arbitrary degree. It is then demonstrated that the localization of the pulse can lead to an arbitrarily large increase in the magnitude of the electric field of the pulse without changing the average photon number of the pulse. This therefore demonstrates theoretically that the weak coherent state can be made to have an arbitrarily large electric field through the localization of the pulse while maintaining the small mean photon number necessary for the weak coherent state to approximate a single photon. This can pave the way for nonlinear single photon optics since the weak coherent state can achieve the electric field necessary to make the nonlinear effects of a medium appreciable.



Floquet Superradiance Lattices in Room-Temperature Atoms

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Floquet modulation is a wide-spread technique in optical lattices for coherent control of quantum devices, in particular for synthesizing artificial gauge fields and simulating topological matters. However, such modulation can always overwhelm the signal of quantum dynamics in ultracold atoms. Here we report that thermal motion, instead of being a noise source, provides a new control knob in Floquet modulated superradiance lattices, which are momentum-space tight-binding lattices of collectively excited states of atoms in room temperature. The Doppler shifts combined with Floquet modulation provide effective forces along arbitrary directions in a lattice in frequency and momentum dimensions. Dynamic localization, dynamic delocalization, and chiral edge currents have been observed from a single transport spectrum of superradiance lattices. This work paves a way for simulating Floquet topological matters in room-temperature atoms and facilitates their applications in photonic devices. This work is supported by National Natural Science Foundation of China (Grants No. U21A20437, 11874322, and 11934011).

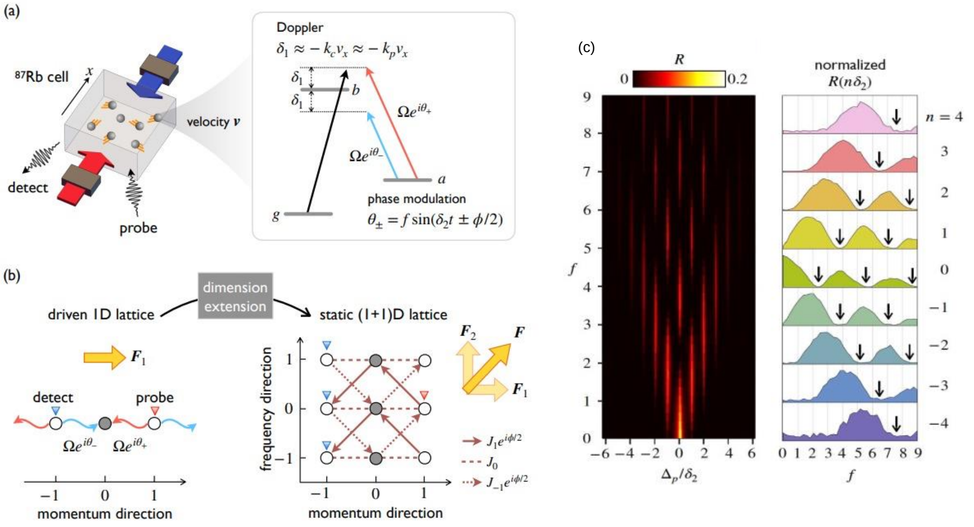

Figure. (a) The experimental setup. (b) principle of Floquet modulated Superradiance lattices. (c) the results of dynamic localization in Superradiance lattices.

Reference: Xu X, Wang J, Dai J, *et al.* Floquet superradiance lattices in thermal atoms. Physical Review Letters, 2022, 129(27): 273603.

Whispering Gallery Modes in Wormhole

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We theoretically show the existence of trapped states with discrete frequencies and exponentially small decay rate for a massless scalar field in the wormhole geometry that connects two asymptotically flat spacetime regions with finite and infinite volumes respectively. These states are like the Whispering gallery modes (WGM) of a spherical dielectric known in optics. The WGMs analogy appears because the wormhole throat plays the role of an effective potential barrier for photons and massive particles.

We consider a "modified" exponential metric in the following form:

$$ds^2 = e^{-r_s/(r+r_0)}c^2dt^2 - e^{r_s/(r+r_0)}(dr^2 + r^2(d\theta^2 + sin^2\theta d\varphi^2)) \tag{1}$$

The metric has a throat for small enough r_0, and the wormhole interior has a finite volume if $r_0 > 0$, see Fig.1(a). We investigate field evolution in the wormhole spacetime by solving the wave equation (Eq.2) in the wormhole geometry.

$$\frac{\partial^2\chi_{(r)}}{\partial r^2} + \left(\nu^2 e^{2r_s/(r+r0)} - \frac{l(l+1)}{r^2}\right)\chi_{(r)} = 0 \tag{2}$$

As shown in Fig.1(b)(c), the presence of the throat leads to the effective potential barrier which can trap particles and waves with low energy in the interior region. Although classically particles cannot surpass the barrier, in quantum consideration they can tunnel through the barrier. We find the discrete frequencies of the field modes and their decay rates as a function of the orbital quantum number l using the WKB approximation, see Fig.1(d)(e).

We show that for a general spherically symmetric metric with a throat and finite interior volume, the potential barrier does exist, and so do the WGMs. Having connected the presence of the "barrier" with the throat, we argue that for a wormhole connecting two infinite asymptotically flat regions, the trapped states can exist only if there are two throats and one anti-throat, thus the effective potential forms an "M" shape.

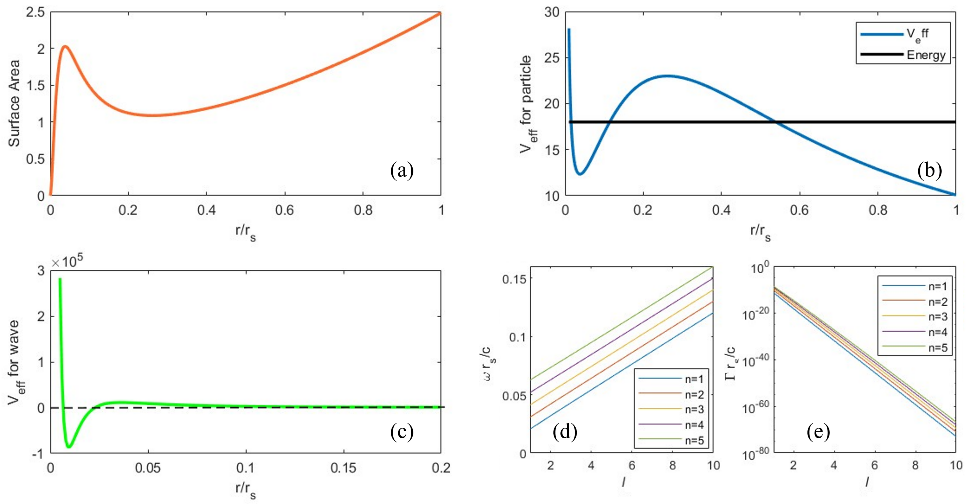

Figure 1: (a):wormhole surface area. (b)-(c):effective potential barrier for particle and wave. (d)-(e):WGMs frequencies and the decay rate for different l and resonance numbers.

Atom response to quantum chaos of a black hole

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Some models of quantum gravity predict that black holes are quantum chaotic systems [1]. A statistical indicator of a quantum chaotic behavior is level repulsion. The paper aims to use two-level atoms as probes of the chaotic level statistics of black holes by studying atom’s evolution as open quantum systems. We attempt to obtain insights on this problem by adopting quantum information calculation.

Based on the description of level repulsion [2], we find a complete temporal evolution of a probe system composed of a single or multiple atoms. Via computing the Quantum Fisher Information (QFI) [3] of the system, we examine several detection approaches to address the quantum chaos. Indirect detection by extracting chaotic characters from the time or frequency domain behavior is investigated. Evolution of the atom and QFI are depicted in Fig. 1.

Our results show that the response to the chaotic background is rather distinct compared to the nonchaotic case of classical gravity. At the initial stage of evolution, the chaotic properties of the field induce significant growth and subsequent attenuation of QFI. We also clarify the influence of entanglement on chaos detection and find that it can be advantageous under certain coupling conditions. The probable difficulties of such an application are discussed as well.

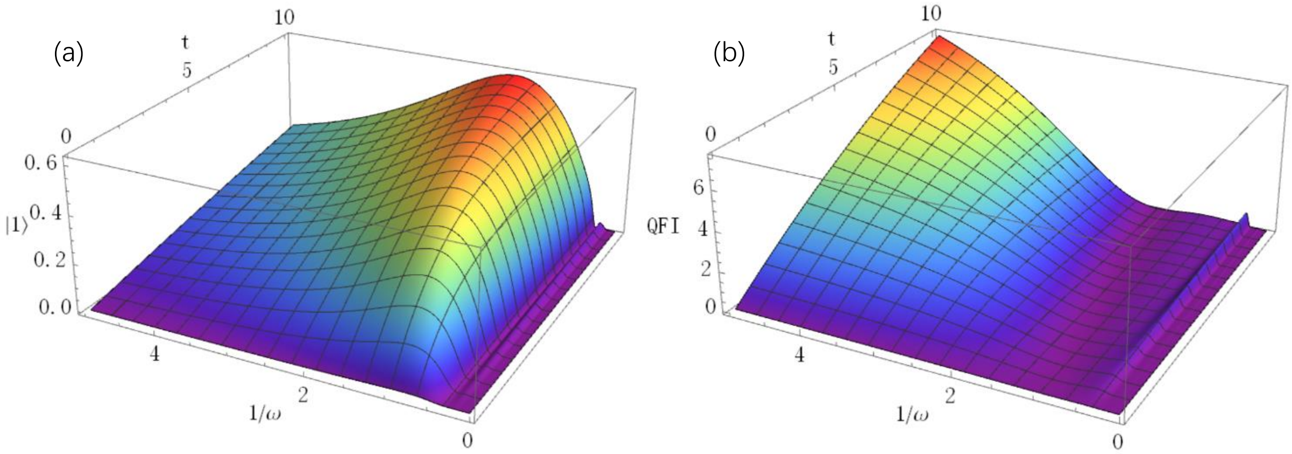

Figure 1. Evolution of a single-atom detector influenced by the quantum chaos near the horizon of a 2-D black hole and the corresponding QFI. Atomic excitation (a) and QFI (b) as a function of time and frequency. |1⟩ refers to the excited state population of the two-level atom. QFI indicates the credibility of estimate of the Unruh temperature and level repulsion.

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Decay of single photon in cavity with atomic mirrors

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ABSTRACT

We explore the dynamics of single-photon pulses and their emission within a cavity comprising of two atomic mirrors coupled to a one-dimensional waveguide. Our study illuminates how the decay rate of a single-photon pulse within the cavity is influenced by several factors, including coupling strength, cavity length, spontaneous decay rate, and atomic separation. We reveal that proper selection of these parameters, alongside spectrum width and detuning considerations, can lead to significant enhancement in the cavity's finesse and reduction in the photon pulse loss rate. Our findings extend the potential storage duration of a single-photon pulse within the cavity. In addition, we investigate single-photon emission in the atomic cavity under the influence of collectively enhanced coupling. By adjusting atomic separations, we enable phenomena like frequency comb generation, spectrum narrowing, and unidirectional spectrum narrowing. We further observe the control of the central frequency of narrowed spectra within a specific atomic separation range. Our study also identifies the sudden birth and revival of bipartite entanglement during photon propagation. Our results hold potential for the engineering of high-quality, micro-scale cavities useful in integrable quantum devices and high-resolution waveguide-QED-based spectrometers.