U.S. AIR FORCE

USSF

AFRL

AN OVERVIEW OF AFRL/AFOSR AND ITS BASIC RESEARCH INVESTMENTS

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Air Force Office of Scientific Research

November 2024

Air Force Research Laboratory (AFRL) Overview

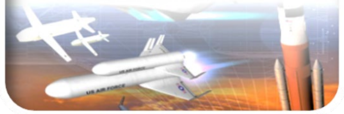
AFRL

AF Office of Scientific Research (AFOSR)

- Aerospace, Chemical, & Material Sciences
- Physics & Electronics
- Mathematics, Information, & Life Sciences
- Education & Outreach

Aerospace Systems (RQ)

- Air Vehicles
- Control, Power, & Thermal Management
- High Speed Systems
- Space & Missile Propulsion
- Turbine Engines

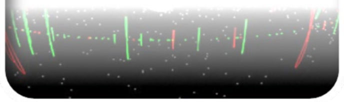


Directed Energy (RD)

- Directed Energy & EO for Space Superiority
- High Power Electromagnetics
- Laser Systems
- Weapons Modeling & Simulation

Information (RI)

- Autonomy, C2, & Decision Support
- Connectivity & Dissemination
- Cyber Science & Technology
- Processing & Exploitation



Human Systems (RH)

- Bio-Effects
- Decision-Making
- Human-Centered ISR
- Training

Munitions (RW)

- Ordnance Sciences
- Fuze Technology
- Munitions AGN&C
- Terminal Seeker Sciences
- Munitions System Effects Science

Sensors (RY)

- Advanced Devices & Components
- Layered Sensing Exploitation
- Advanced Sensing (RF/EO)
- Spectrum Warfare

Space Vehicles (RV)

- Space Electronics
- Space Environmental Impacts & Mitigation
- Space EO/IR
- Space Experiments
- Platforms & Ops Technology

Materials and Manufacturing (RX)

- Functional Materials & Applications
- Manufacturing & Industrial Technology
- Structural Materials & Applications
- Support for Operations

- We lead, discover, develop and deliver science, technology and innovation for Warfighters.
- AFRL supports the Science & Technology needs of two services: the **Air Force** and the **Space Force.**
- **Workforce: ~11,200** employees
  Military, Government civilians, and Contract positions
- **Locations** in **10** States
  California, Florida, Hawaii, Nevada, New Mexico, New York, Ohio, Tennessee, Texas and Virginia.
- International Sites in **5** Countries
  The United Kingdom, Japan, Brazil, Australia and Chile.

AFRL/AFOSR Mission & Span of Influence

AFOSR's Mission is to Discover, Shape, Champion, and Transition High Risk Basic Research to profoundly impact the future Air and Space Force

Core Mission - With a broad, long-term perspective, we identify areas for investment and collaboration to advance the Department of the Air Force's (DAF) research and development enterprise across the full spectrum of air, space, and cyber operations. We build bridges to the world's most prestigious universities and talented researchers to enhance partnerships and provide revolutionary science and technology discoveries to the Warfighter.

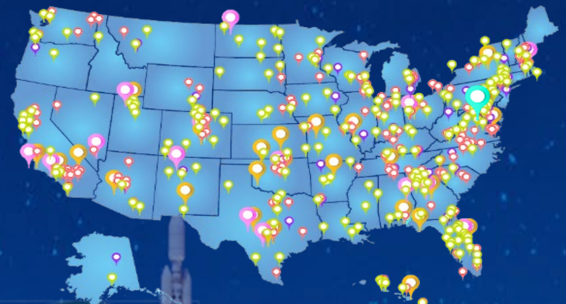
Span of Influence - 60+ World-class Subject Matter Experts manage 1,600+ grants at over 300 leading academic institutions across 50 states and 65 countries, 150 industry-based contracts, and more than 230 internal AFRL research efforts.

Inherent in our mission, we strive to strengthen and shape the Science and Engineering talent pipeline through targeted outreach, research, internships, and fellowship programs to include a focus on Historically Black Colleges and Universities and Minority Serving Institutions. Fund DAF's K-12 STEM Outreach at 30+ bases supporting 500+ competitions!

DAF Link to Academia

Global Footprint and Reach

STEM Outreach Impact



Strategic Partnerships are Vital to Basic Research Success

It is the teaming of diverse areas of science that enables the next generation of technology advancements.

Department of Defense

Academia

Other Gov't Offices

Distribution A: Approved for Public Release (AFRL-2024-6414)

S&T Portfolios

Engineering and Complex Systems
- High-Energy Solid State Physics
- GHz-THz Electronics
- Energy, Combustion, and Thermodynamics
- Aerodynamic Sciences
- High-Speed Aerodynamics
- Aerospace Composite Materials
- Multiscale Multifunctional Structures & Systems
- Propulsion and Power
- Agile Science of Test and Evaluation (T&E)

Mathematics and Information Sciences
- Computational Cognition and Machine Intelligence
- Computational Mathematics
- Dynamical Systems and Control Theory
- Dynamic Data and Information Processing
- Information Assurance and Cybersecurity
- Mathematical Optimization
- Science of Information, Computation, Learning, and Fusion
- Trust and Influence
- Complex Networks
- Cognitive and Computational Neuroscience

Physical Sciences
- Aerospace Materials for Extreme Environments
- Atomic and Molecular Physics
- Electromagnetics
- Condensed Matter Physics
- Optoelectronics and Photonics
- High Energy Radiation-Matter Systems
- ***Quantum Information Sciences***
- Physics of Sensing
- Space Physics
- Ultrashort Pulse Laser-Matter Interactions
- Astrodynamics

Chemistry and Biological Sciences
- Biophysics
- Human Performance and Biosystems
- Space Biosciences
- Molecular Dynamics and Theoretical Chemistry
- Natural Materials and Systems
- Organic Materials Chemistry

International Office
- Asian Office of Aerospace R&D Tokyo
- European Office of Aerospace R&D London
- Southern Office of Aerospace R&D Santiago
- North America - Arlington

Legend
- High Physics Content
- Partial Physics Content
- Portfolios Spanning most Domestic Technical Areas; similar mix of Physics Content

Broad Agency Announcement for the Air Force

An official website of the United States government Here's how you know

GRANTS.GOV℠
FIND. APPLY. SUCCEED.℠

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Search site content

Home | Learn Grants | Search Grants | Applicants | Grantors | System-To-System | Forms | Connect | Support

SEARCH GRANTS

?

Search Tips Export Results

BASIC SEARCH CRITERIA:

Keyword(s): AFOSR

Opportunity Number:

Assistance Listings:

Search

SORT BY: Relevance (Descending) Update Sort

DATE RANGE: All Available Update Date Range

Opportunity Number	Opportunity Title	Agency	Opportunity Status	Posted Date	Close Date
FA9550-23-S-0001	Research Interests of the Air Force Office of Scientific Research	DOD-AFOSR	Posted	01/30/2023	
PD-23-1406	Thermal Transport Processes	NSF	Posted	04/05/2023	
PD-23-1407	Combustion and Fire Systems	NSF	Posted	04/14/2023	
FOAAFRLAFOSR20240006	FY24 DEFENSE ESTABLISHED PROGRAM TO STIMULATE COMPETITIVE RESEARCH (DEPSCoR) CAPACITY BUILDING (CB)	DOD-AFOSR	Posted	03/28/2024	11/25/2024
FOAAFRLAFOSR20240007	FY24 DEFENSE ESTABLISHED PROGRAM TO STIMULATE COMPETITIVE RESEARCH (DEPSCoR) – RESEARCH COLLABORATION (RC)	DOD-AFOSR	Posted	03/28/2024	11/25/2024

OPPORTUNITY STATUS:

- [x] Forecasted (0)
- [x] Posted (11)
- [ ] Closed (8)
- [ ] Archived (232)

How We Accomplish Our Mission

Technology Transition

- Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) Program
- Partnerships for Transition

Basic Research Traditional Grants

All qualified, responsible organizational applicants from academia, the non-profit sector, and industry are eligible to submit research proposals.

Strengthening Academic Research Capabilities

- Multidisciplinary University Research Initiative (MURI) Program
- Defense University Research Instrumentation Program (DURIP)
- Presidential Early Career Award for Scientists and Engineers (PECASE)

Strengthening Air & Space Force Research Capabilities

- US Air Force Academy Program
- Summer Faculty Fellowship Program (SFFP)/Science & Technology Fellowship Program (STFP)

Workforce Development

- Awards to Stimulate and Support Undergraduate Research Experiences (ASSURE)
- National Defense Science and Engineering Graduate Fellowship Program (NDSEG)
- Pre K-12 STEM

Expanding Air & Space Force Academic Reach

- Young Investigator Program (YIP)
- Historically Black Colleges & Universities/Minority Serving Institutions (HBCU/MSI) Program
- AFRL Basic Research National Science Portals (NSPs)

Diversified investment strategy for maximum discovery potential

Grant Process

Initial Contact
- Email to contact listed in Broad Agency Announcement on **grants.gov**

White Paper
- Submit by email
- 1-3 pages

Initial Review
- Determine Air/Space Force interest
- Adjust proposal

Full Proposal
- Once requested by program officer
- Formal submission on grants.gov

Full Review and Acceptance
- Formal technical review
- ~3 months for review & award

Conduct Research
- Annual reports
- Optional collaboration

Publish Results
- Open-source journals
- Final report

Atomic and Molecular Physics: Technical Focus Areas

Dr. Boyan Tabakov
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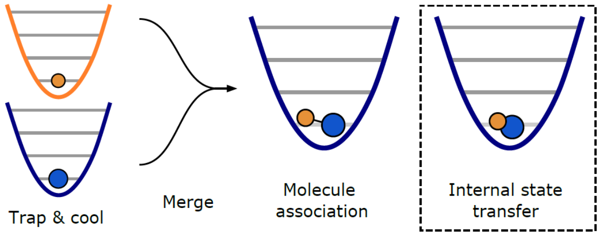
Enhance a broad spectrum of critical Air Force and Space Force capabilities through exploiting the quantum nature of atoms, molecules, and their interactions. Applications include improvements in timing and sensing for ground, air, and space operations; atom and molecule-based simulators to create novel materials; predictive models for controlling chemical reactions for fuel production and energy transport and storage; and providing platforms enabling quantum information science.

Novel Phenomena

Discover and understand new correlated behavior

- Strong interactions
- Quantum correlations, new phases of matter (topological states) and phase transitions
- Exotic matter/phenomena

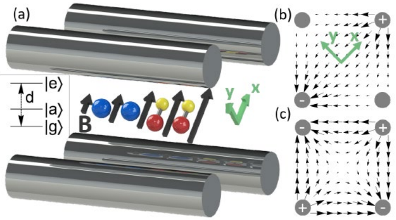


Cairncross *et al.*, arXiv: 2101.03168
Phys. Rev. Lett. **126**, 123402 (2021)

Coherent Control

Exquisite control of single particles and ensembles

- Quantum state preparation (e.g. cooling, trapping, protocols)
- Manipulation of states and interactions
- Non-destructive readout of final or intermediate states

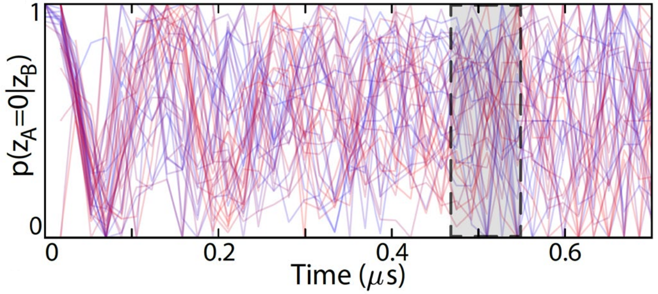


Hudson and Campbell, arXiv: 2011.08330
Phys. Rev. A **104**, 042605 (2021)

Many-body Dynamics

Investigate time-dependent behavior of large systems

- Many-body localization and thermalization
- Driven-dissipative systems
- Energy transport and storage



Choi *et al.*, arXiv: 2103.03535
Nature **613**, 468 (2023)

Electromagnetics: Technical Focus Areas

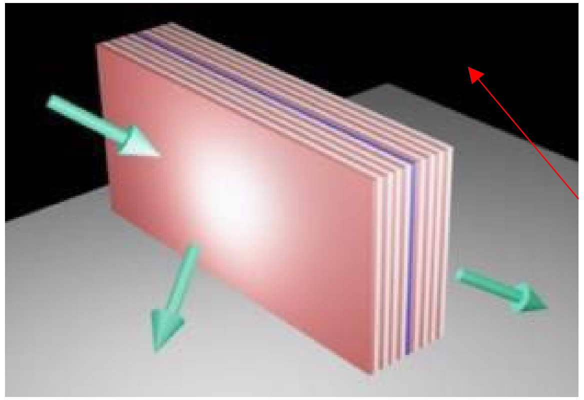
Dr. Arje Nachman
Electromagnetics@us.af.mil

Electromagnetics Portfolio Objectives:

Interrogate (Model/Simulate) Linear/Nonlinear Maxwell's Equations together with Signal Processing

Wave Propagation Through Complex Media

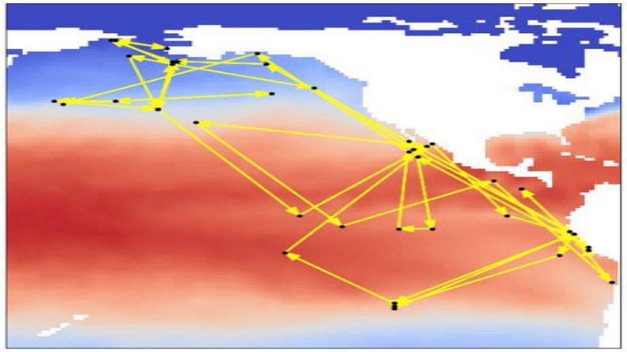
- random/turbulent media
- dispersive/conductive media
- cluttered surfaces (multipathing)
- metamaterials



Dr Ilya Vitebsky (AFRL/RYDHC)
AFOSR Lab Task
Metamaterial Nonsacrificial Sensor Protector

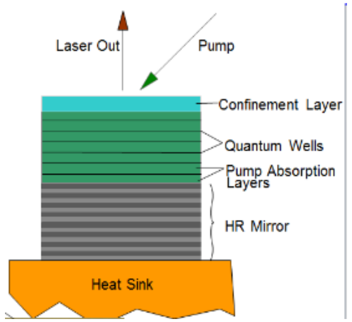
Signal Processing

- correlation-based radar processing
- moving sensor methods (SAR and drones)

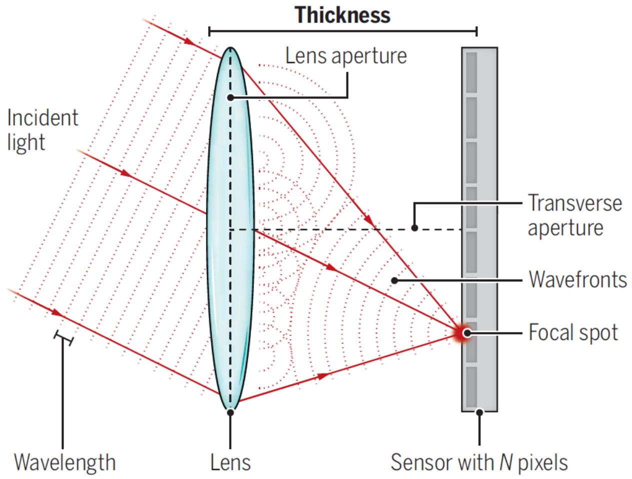


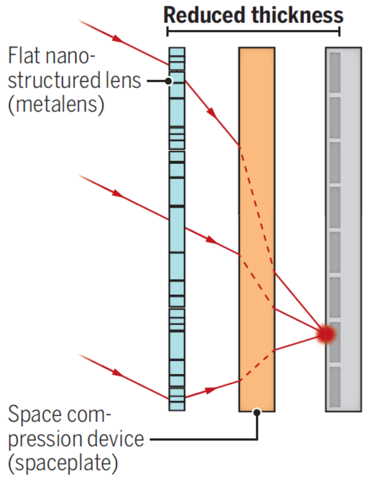
Theoretical Nonlinear Optics

- First-principles design of semiconductor lasers
- propagation of ultrashort, intense laser pulses

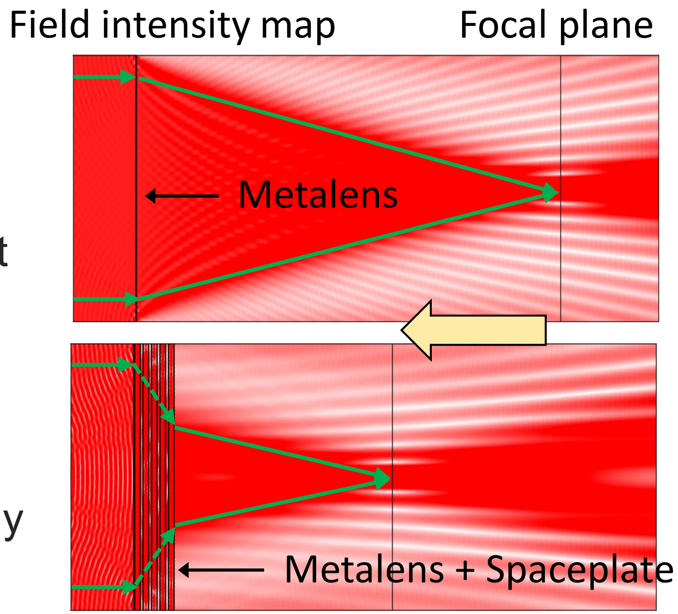


Electromagnetics: Toward the ultimate thickness limits of optics





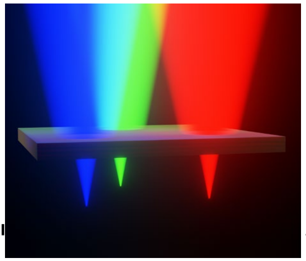
How thin can an optical system get? In a lens-sensor imaging system (left), a certain area and a certain distance between the focusing lens and the sensor are needed. A combination of new optical elements (right) allows a reduction in thickness. This may lead to the miniaturization of a wide range of optical systems, approaching their ultimate thickness limits dictated by wave physics.

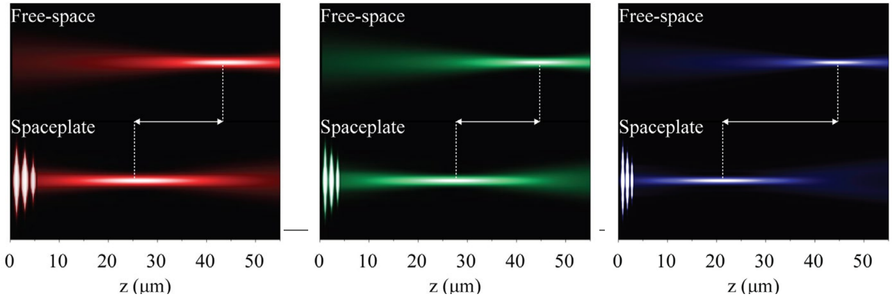


Spaceplates are new thin, planar, optical elements designed to mimic the way that light propagates and spreads in empty space but over a shorter distance. With a spaceplate, light effectively experiences more space than what actually exists.

PI Monticone designed and theoretically/computationally demonstrated optimal single-color and multi-color spaceplates, and studied some of the fundamental limits of these devices.

Some of the spaceplate designs proposed by the PI have been shown in [D. A. B. Miller "Why optics needs thickness," Science 379, 41-45 (2023)] to be nearly optimal to reach the minimum possible thickness of an imaging system





F. Monticone, "Toward Ultrathin Optics," Science 379, 30-31 (2023).

K. Shastri, and F. Monticone, "Nonlocal Flat Optics," Nature Photonics, vol. 17, pp. 36-47, 2022.

M. Pahlevaninezhad, and F. Monticone, "Multi-Color Spaceplates in the Visible," ACS Nano 18, 28585-28595 (2024).

A. Chen, and F. Monticone, "Dielectric Nonlocal Metasurfaces for Fully Solid-State Ultrathin Optical Systems," ACS Photonics 8, 5, 1439–1447 (2021).

Condensed Matter Physics: Technical Focus Areas

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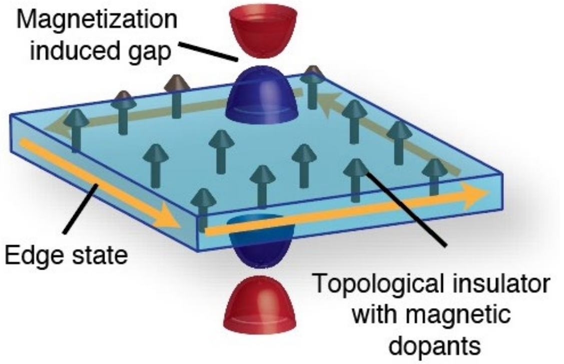
This program seeks to investigate modern directions in the fundamental physics of condensed matter. The ultimate goal is to lead discoveries of new states of matter and understanding of fundamental phenomena towards exploitation and engineering of extraordinary quantum mechanical properties.

Topological phases and states

Discovery of topological materials, characterization of topological states, topological defects, and high temperature topological orders



Strongly correlated systems

Control and modulation of electronic correlation, probing of emergent phenomena with advanced metrology

Quantum phase transition

Can we exploit quantum fluctuation as a tool to control and design material properties?

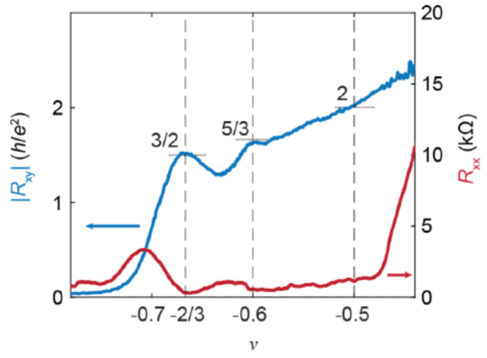
1879: **Hall Effect**
- Edwin Hall

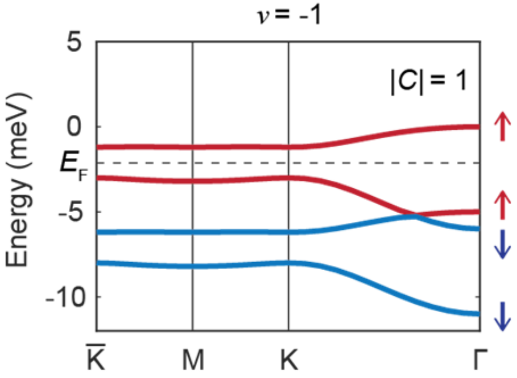
1980: **Quantized Hall Effect**
- Klause von Klitzing (1985 Nobel Prize)

2013: **Quantized Anomalous* Hall Effect**
- Qikun Xue
(Anomalous = zero magnetic field)

2023: Discovery of Fractional Quantized Anomalous Hall Effect (FQAH)

Twisted bilayer MoTe2





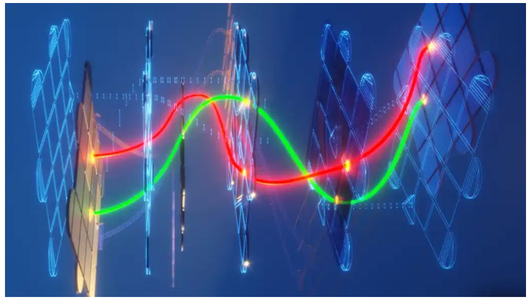
- **Robust ferromagnetism**
- **Electric tunability of magnetism & topology**

2023 June: Signatures of fractional quantum anomalous Hall states in twisted $MoTe_2$, Nature 622, 63–68 (2023);
2023 August: Observation of fractionally quantized anomalous Hall effect, Nature 622, 74–79 (2023)

FA9550-21-1-0177: CMP traditional
FA9550-19-1-0390: FY19 MURI, PO: Dr. Goretta

2023 September: Observation of Integer and Fractional Quantum Anomalous Hall Effects in Twisted Bilayer MoTe2, Phys. Rev. X 13, 031037
2024 February: Fractional quantum anomalous Hall effect in multilayer graphene, Nature, 626, 759–764 (2024)
2024 March: Evidence of the fractional quantum spin Hall effect in moiré $MoTe_2$, Nature (2024) (**FA9550-20-1-0219: PECASE**)

Non-abelian anyon: topological qubit ?



https://www.sciencenews.org/article/quantum-computers-braided-anyons-quasiparticles-memory

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Optoelectronics & Photonics: Technical Focus Areas

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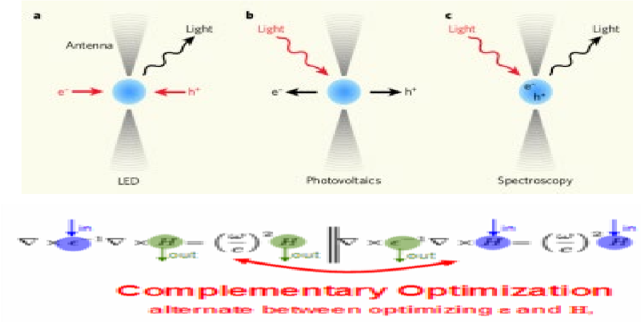
This program seeks to explore: 1. Light-matter interactions at the subwavelength- and nano-scale between metals, semiconductors, semi-metals & insulators (nanophotonics), 2. The role of nanotechnology, metamaterials, topological science & quantum behavior in photonics and optical systems and 3. Optoelectronic information processing, integrated photonics, novel sensors, optical & photonic device components for air and space platforms to transform AF capabilities in computing, communications, storage, sensing and surveillance.

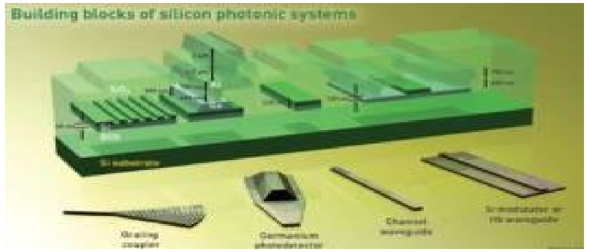
Natural Phenomena & Theory

Plasmonics, Novel Architectures, Strain-engineering, Chiral Engineering, fundamental light-matter interactions, photonics at subwavelength and nanoscale



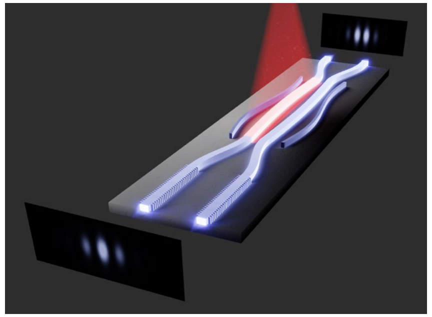
Materials & Devices

Photonic Crystals, Meta-Materials, 2D-materials, Opto-Mechanics, Optical Components, CMOS-leveraged Photonics, Modulators, Photodiodes, Quantum-dots, etc



Optical Information Processing

Ultra-Low power, Reconfigurable Networks, Architectures, Neuro-mophic Computing, quantum memories, Edge Detection, Optical Logic, Optical analog computing



High Energy Radiation-Matter Systems (HERMeS)

Dr. Joel Bixler
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HERMeS is focused on the **controlling** the nonlinear/multi-scale/multi-physics phenomena that occurs at high energy density. This allows the **production of useful work** in the electromagnetic spectrum for a variety of missions:

- Directed Energy Attack/Counter-DE Defense
- Electronic Warfare
- Radar, LIDAR, Remote Sensing
- Communications
- Radiation Damage Simulators
- EM/Biophysics Safety

Image from Wikipedia

High-Energy/Power Lasers

- Production of coherent "short-wavelength" high power laser light with good beam quality and high efficiency
- Typically quantum physics

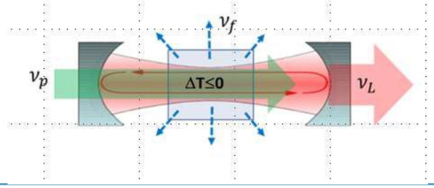


Image from Sheik-Bahea

Laser/RF-Matter Interaction

- Fundamental EM-matter interaction
- Critical for high-power/energy optics and beam propagation

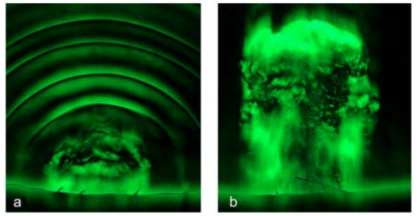


Image from Vogel

High-Power EM (HPEM)

- Production of coherent "long-wavelength" high-power electromagnetic signals
- Typically classical physics

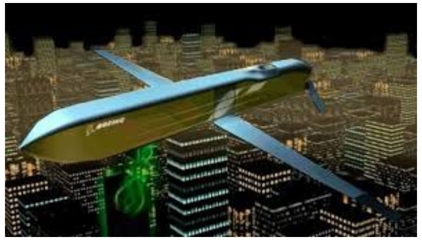
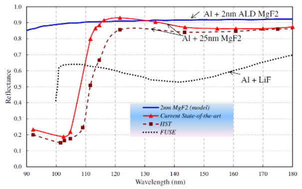


Image from Wikipedia

Non-equilibrium Thermodynamics

- Track the flow of energy, charge, and information through a system
- Coupling of light with neutral and charged matter



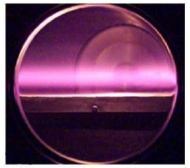


Image from Walton

Basic Science Enabling Directed Energy and Communication

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Novel Optical Fiber Theory

Theory of Stimulated Brillouin Scattering in Fibers for Highly Multimode Excitations

WISAL, WARREN-SMITH, CHEN, CAO, and STONE PHYS. REV. X **14**, 031053 (2024)

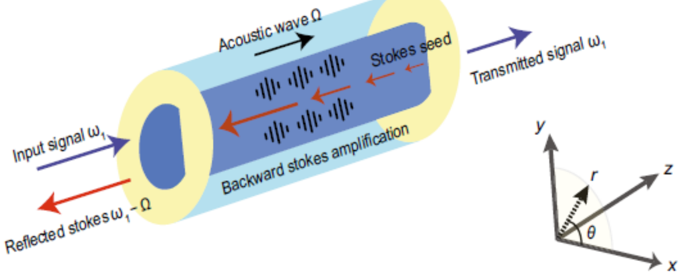
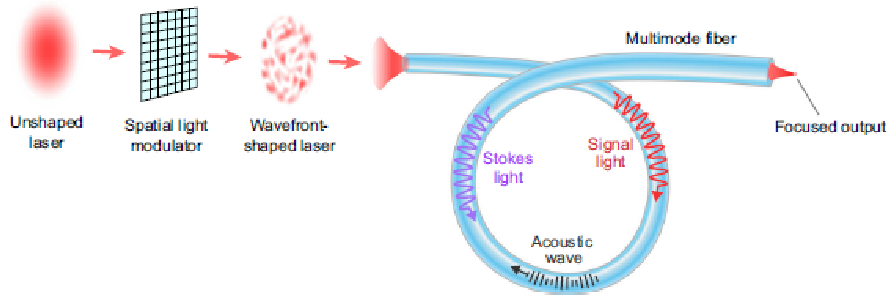


FIG. 1. Schematic of SBS in a multimode fiber with arbitrary core shape (here, D-shaped). Stokes-shifted backward-traveling light (seeded by spontaneous Brillouin scattering) experiences amplification due to the scattering of the forward-going signal by the acoustic phonons, which are generated by electrostriction. This process can take away significant power from the signal and limits the transmitted power.

PHYSICAL REVIEW X 14, 031053 (2024)
FA9550-20-1-0129
FA9550-20-1-0160
FA9550-24-1-0182

High Energy Fiber Amplifiers for DE Applications

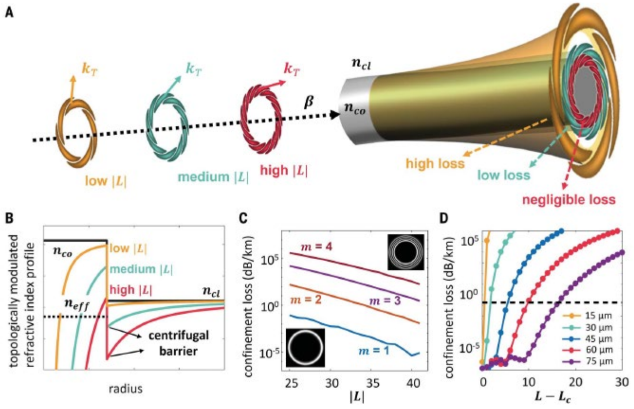


Mitigating stimulated Brillouin Scattering in fiber amplifiers

Nature Communications (2023)14:7343

FA9550-20-1-0129
FA9550-20-1-0160

Multi-Mode for Communication for Space



Scaling information pathways in optical fibers enabling advanced quantum computer networks

Science 380, 278–282 (2023)

FA9550-14-1-0165

Basic Science and Future Communications: Selected Examples

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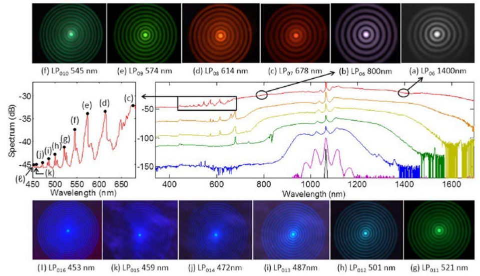
Novel Optical Communication Channels

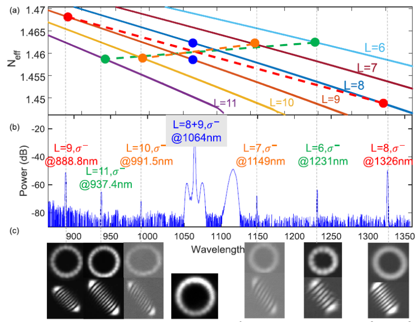
Higher order modes allow wavelength diversity via FWM



Optica, **2**, 14 (2015)

Exploit novel laser technology to produce new channels and links with wavelength diversity and/or OAM channels via four-wave mixing in a single fiber (significant SWaP-C savings exploiting nonlinear optics)

Channel selectivity and diversity via SAM/OAM conservation



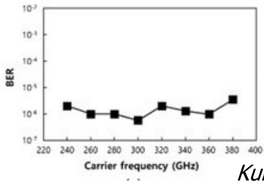
APL Photon., **5**, 010802 (2020)

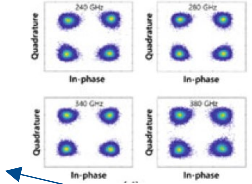
Director's Research Initiative: Leaky THz Waveguide for Channel Discovery and Creation

THE challenge for optical communications is acquisition of the target

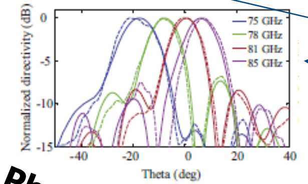
Chilton, Mitchell Institute Policy Paper (2022)

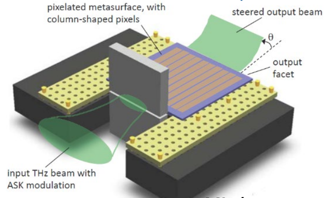
Combine high-power sources, metamaterial- and carbon-nanotube-based electronic control, and detailed analysis of the resulting spatio-temporal waveforms to study the competing requirements of power, bandwidth, polarization, and directivity



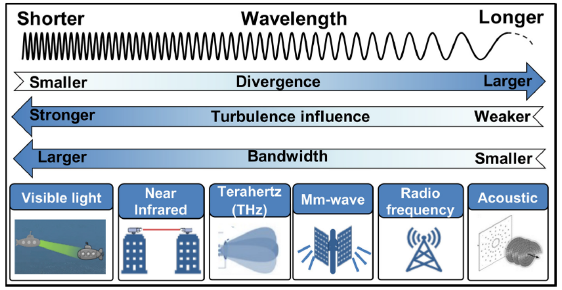


Kurner





Mittleman



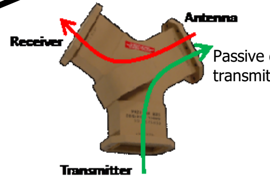
Opt. Photonics, **32**, 34 (2021)

HERMES (AFRL/AFOSR PO: John Luginsland)

/ Physics of Sensing / GHz – THz Electronics (AFRL/AFOSR PO: Michael Yakes) (AFRL/AFOSR PO: Ken Goretta)

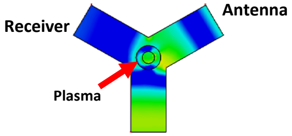
High Energy Radiation-Matter Systems (HERMES) (AFRL/AFOSR PO: John Luginsland)

Magnetized Plasma-based Tunable Circulators

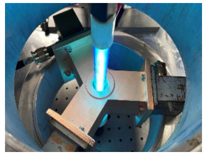


Passive device, signals transmit one direction

Microwave Circulators-used to separate transmitting and receiving waves



Exploit gyrotropic properties of magnetized plasmas



Proven asymmetric scattering

Phys. Plasmas, **29**, 112114 (2022)

Construction and successful demonstration of prototype

Propulsion and Power (AFRL/AFOSR PO: Mitat Birkan)

AFOSR rapid response: COVID Modeling/UV Light

BASIC RESEARCH

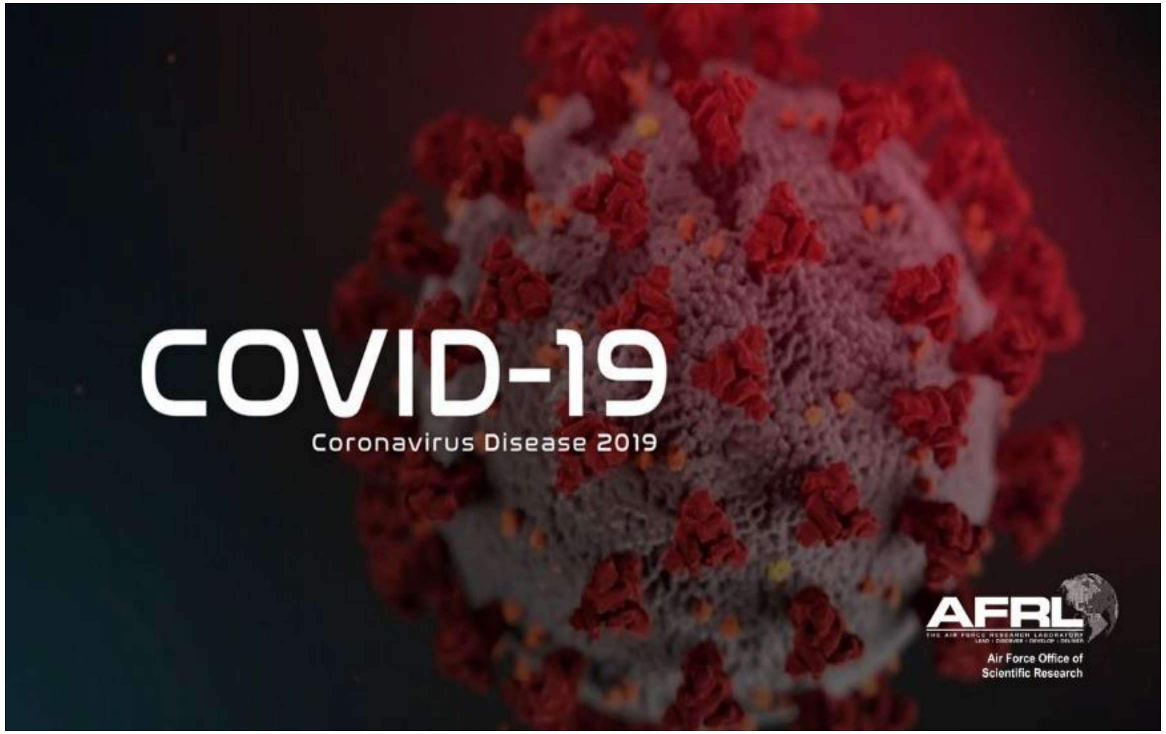
Funding Dr. Eden since 1978

Eden's focus changes from lasers to micro-discharge arrays

Discovery: arrays produce UV light useful to disinfect surfaces and penetrate human tissue

Research led to Eden Park's Far-UVC lamp

Partners wih Cygnus Photonics to manufacture deep-ultra violet light

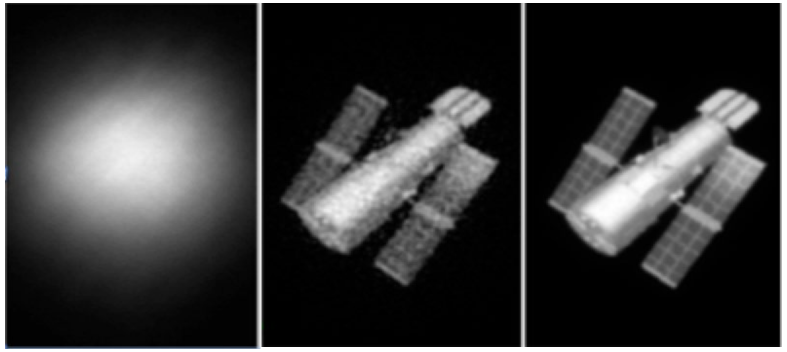


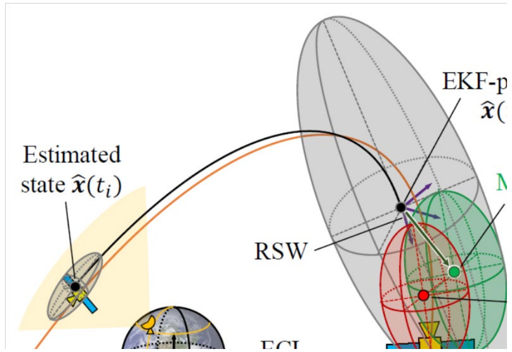
Prof J. Gary Eden at the University of Illinois together with Cygnus Photonics began manufacturing deep-ultraviolet lamps — lamps developed under AFOSR support — that a can rapidly kill dangerous virus cells and disinfect densely populated spaces. Amid threats like COVID-19, it's a science-backed solution for returning our communities to a new, safer normal. The research led to Eden Park's Far-UVC lamp. The lamp has the ability to rapidly kill virus cells, including COVID-19, and disinfect densely populated spaces and was deployed thought out the **White House in 2020**. What began with small AFOSR grant in the late seventies on conversion lasers has, with enabling funding and agile support from AFOSR, grown into a significant technological advance in today's fight against COVID-19

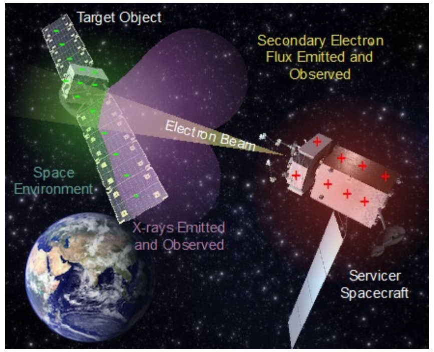
Physics of Sensing: Technical Focus Areas

Dr. Michael Yakes
remote.sensing@us.af.mil

This portfolio seeks to understand the fundamental scientific limits of sensing and to develop revolutionary concepts for detection with improved accuracy, sensitivity, and robustness.







Imaging and Beam Propagation

- Discovering fundamental limits to restrictions such as limited aperture size and imperfections in the optics, and techniques to approach or circumvent these limitations.
- Understanding irregularities in the optical path including imaging though obscured, degraded, and non-line of sight conditions and developing novel methods for imaging in these conditions.

Space Domain Awareness (SDA) / Astrodynamics

- Understanding and predicting dynamics of space objects as it relates to identification and space domain awareness.
- Innovating techniques for on-orbit characterization, including radiation tolerant optical and non-optical sensors such as electrostatic field measurements, accelerometers and radiation dosimeters.

Physics for Sensors

- Researching detection phenomena and the physics of ideal and real sensor systems including multimodal, hyperspectral, and hypertemporal, sensors.
- Creating new techniques, systems, and materials to approach the fundamental detection limits.

Ultra-broadband speckle imaging for space domain awareness

AFRL

Goal:

To detect and characterize satellites over a broader range of sizes, distance from Earth, and satellite classes than is possible with current AF assets

Research Objective(s):

Use high-fidelity, tomographic, wavefront measurements to enable snapshot hyperspectral imaging via broadband speckle images.

Impact to AF:

- ***Characterization of satellites***
- ***Detection of faint closely spaced objects***
- ***Health monitoring***

Funding and Duration:

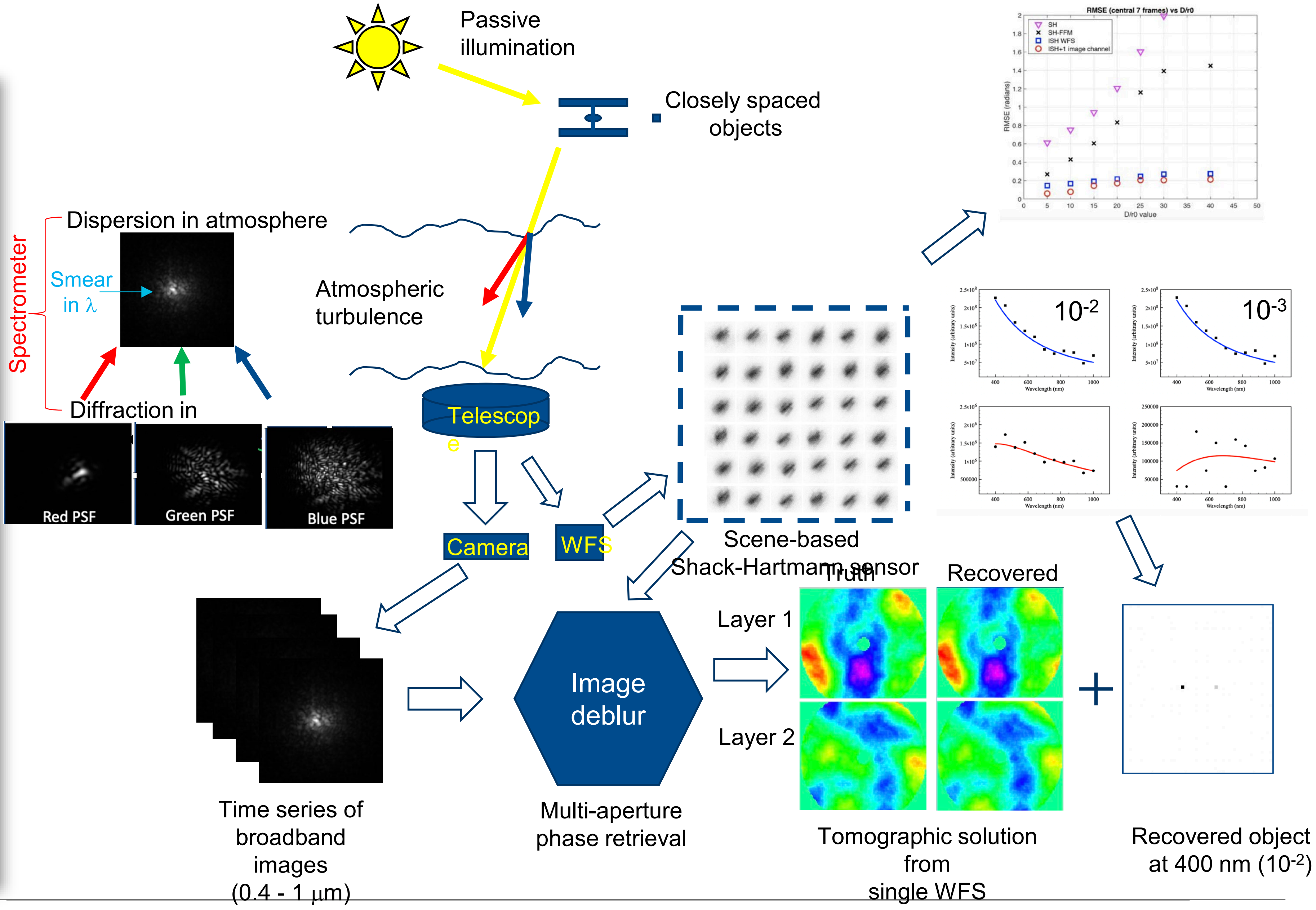
Grant type: Traditional

Duration: 09/21 – 08/24

Collaborator(s)

Georgia Tech Research Inst., AFRL

PI: Stuart M. Jefferies (sjefferies@gsu.edu)



Space Physics: Technical Focus Areas

Dr. Julie Moses
Space@us.af.mil

Fund basic research to enable Air Force space weather needs.

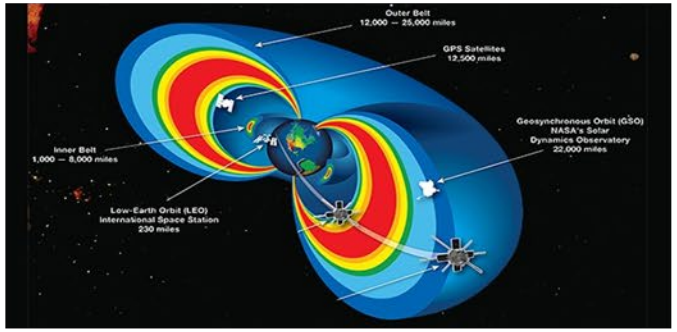
- Fund basic research to support the National Space Weather Strategy and Action Plan (March 2019)
- Increase fundamental knowledge of the Heliosphere, Magnetosphere, Ionosphere, Thermosphere, and Mesosphere

Ionosphere/Thermosphere/ Mesosphere

- Gravity Waves, Traveling Ionospheric Disturbances (TIDs)
- Topside and bottomside ionosphere, ITM coupling.
- Adversely affects OTHR, Communications, and GPS

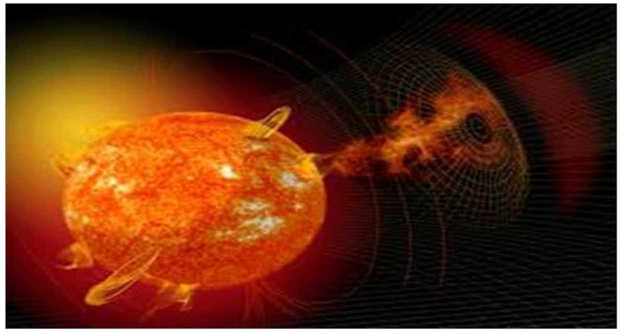
Magnetosphere

- Radiation Belt physics
- Killer electrons and energetic ions kill satellite electronics.
- Changing radiation belt fluxes age spacecraft electronics.



Solar

- Improving forecast of Interplanetary Magnetic Field Z-component IMF Bz.
- Solar flares cause disruption to communications, damage satellites, and affect radiation belt fluxes.



Ultrashort Pulse Laser-Matter Interactions: Technical Focus Areas

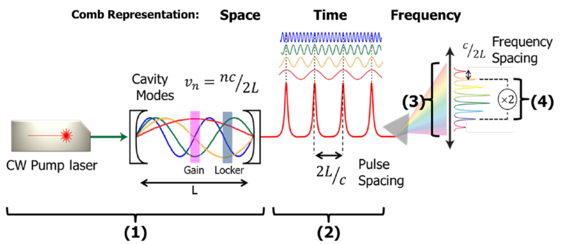
Andrew Stickrath
Short.Laser@us.af.mil

Program Objective: explore and understand the broad range of physical phenomena accessible via the interaction of ultrashort pulse lasers with matter in order to further capabilities of interest to the U.S. Air Force and Space Force, including directed energy, remote sensing, communications, diagnostics, and materials processing

The portfolio explores research opportunities accessible by means of the three key distinctive features of USP laser pulses: **large spectral bandwidth**, **high peak power**, and **ultrashort temporal duration**.

Optical Frequency Combs

Exploring the *precision* broadband

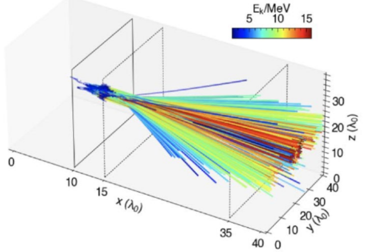


- Metrology / PNT
- Material Science

High-field Laser Physics

Exploring the *precision* intense

Nature Comm., 13, 54 (2022)

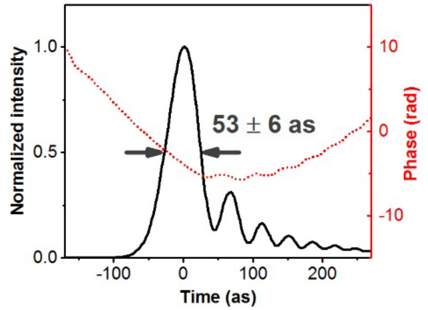


- Particle Acceleration
- Secondary Radiation Sources
- Propagation in Media

Attosecond Science

Exploring the *precision* ultrashort

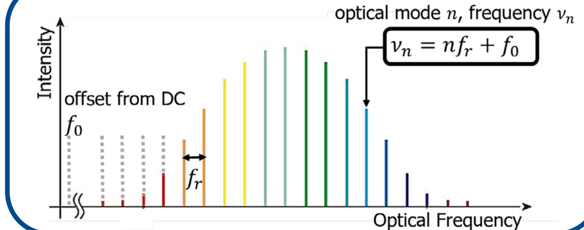
Nature Comm., **8**, 186 (2017)



- Materials Science
- Metrology

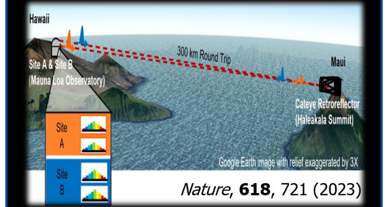
Precision control of laser-matter interactions represents an enabling technology for Air and Space Force applications.

Optical Frequency Combs: Extending Metrology to Applications and Out of the Lab



Andrew Stickrath
Ultrashort Pulse Laser-Matter Interactions
andrew.stickrath@us.af.mil

Time and Frequency Transfer

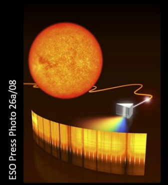


Nature, **618**, 721 (2023)

*Altimetric Score: 139 (top 5% of all research outputs)

Laura Sinclair, NIST/CU
laura.sinclair@nist.gov

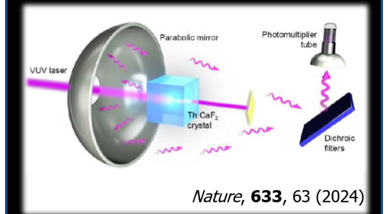
Optical Interferometric Imaging



New MURI: Kickoff Dec 2024

David Burghoff, UT
burghoff@utexas.edu

Nuclear Clock

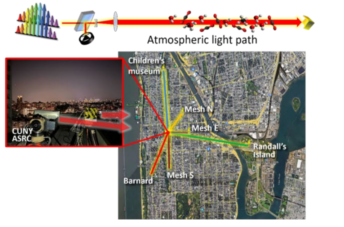


Nature, **633**, 63 (2024)

*Altimetric Score: 684 (top 5% of all research outputs)

Jun Ye, CU/NIST/JILA
Ye@JILA.colorado.edu

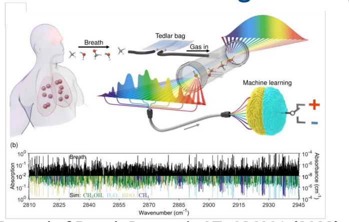
Atmospheric Sensing



Active experiment: Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas (AEROMMA) consortium

Ian Coddington, NIST
ian.coddington@nist.gov

Breath Sensing

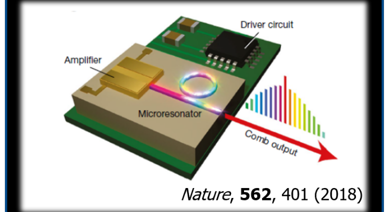


Journal of Breath Research, **17**, 036001 (2023)

*Altimetric Score: 346 (top 5% of all research outputs)

Jun Ye, CU/NIST/JILA
Ye@JILA.colorado.edu

Integrated (chip-scale) Optical Frequency Combs

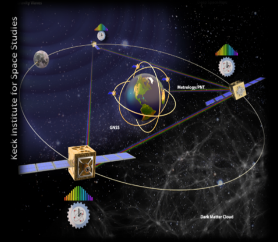


Nature, **562**, 401 (2018)

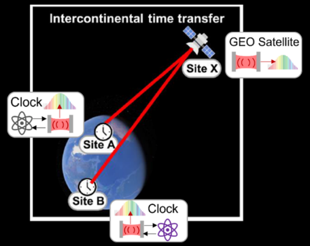
*Altimetric Score: 92 (top 5% of all research outputs)

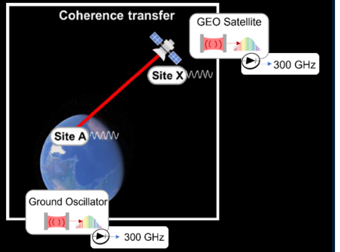
Alex Gaeta, Columbia
alg2207@columbia.edu

Enabling the future of PNT



From motivating vision to real systems – *exploring* and *controlling* the underlying basic science





APL Photonics, **9**, 016112 (2024)

- The Ultrashort Pulse Laser-Matter Interactions Portfolio is exploring basic science to enable DOD applications with both broad and specific impact.
- Resulting technical developments enable both applications and the exploration of more basic science – this dual use is heavily leveraged to guide the community toward DOD challenges.
- Frequency Comb Thrust is driven by a grand vision to enable space-based metrology, PNT, and sensing – *with many off-ramps.*

Astrodynamics: Technical Focus Areas

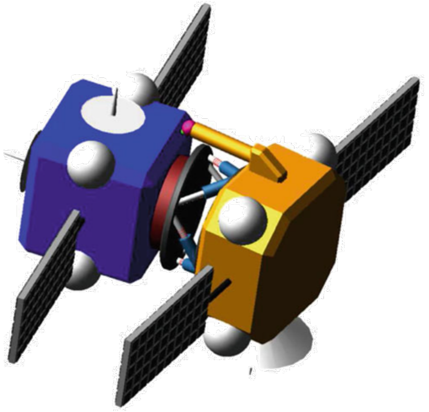
Dr. Andrew Sinclair astrodynamics@us.af.mil

Benefit to Warfighter: The USSF requires new flexible orbits (LEO, XGEO) that require breakthroughs to provide accurate predictions of performance. Planned ISAM missions still require fundamental advances to be realized. This portfolio covers relevant missions including space domain awareness/control, on-orbit servicing, and constellation design.

Challenge: The needs for the space domain are under active development. Command signal is often focused for near-term needs. Actual requirements, specifications, and missions are under active development in real time with multiple stakeholders at a time when adversaries are dramatically developing new capability.

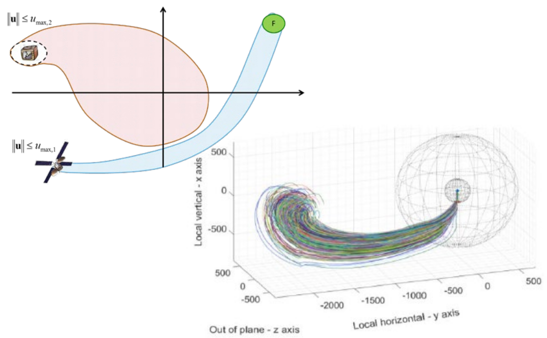
Spacecraft Guidance, Navigation, Control, and Autonomy

- Deterministic-time computation
- Precision navigation and timing in Cislunar space.
- Formal verifiability
- Risk-adverse and fault robust algorithms
- Adaptivity and resilience.
- Computationally Constrained



Celestial Mechanics with emphasis of XGEO/Cislunar Space

- 3 to n-body problems, restricted and unrestricted.
- Accurate prediction and estimation of possible orbit trajectories in the presence of chaos.
- Stochastic uncertainty propagation under partial, corrupted, and infrequent information.



Reachability for GEO: Computationally manageable but will need more study for extension to cis-lunar and deep space

In-Space Logistics

- Offline and online optimization of constellation design.
- Long-term propagation and planning of single and multi-satellite systems.
- Resilient and robust capabilities on-orbit.

Biophysics: Technical Focus Areas

Dr. Sofi Bin-Salamon
biophysics@us.af.mil

Objective

Seek transformative fundamental multidisciplinary research that elucidates biophysics of *critical non-classical* processes ranging from quantum behavior to collective dynamics in human molecular and cell biology. These discoveries can be used to develop breakthrough operational solutions in contested multi-domain environments under intense cognitive workloads.

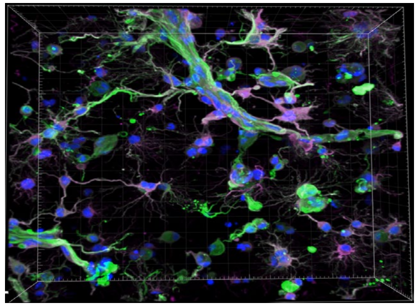
Quantum Sensing in Living Systems

- Novel quantum techniques to observe biological processes
- New approaches to elucidate the properties of non-classical biological behavior and processes

- **DOD National Defense Strategy**
  - Joint lethality in contested environments
  - Advanced autonomous systems
- **USAF 2030 Science and Technology Strategy**
  - Resilient Information Sharing
  - Rapid, Effective Decision-making
  - Complexity, Unpredictability and Mass
  - Speed and Reach of Disruption and Lethality
- **DAF Operational Imperatives**
  - Space order of battle
  - Tactical air dominance
  - Moving target engagement
  - Resilient basing

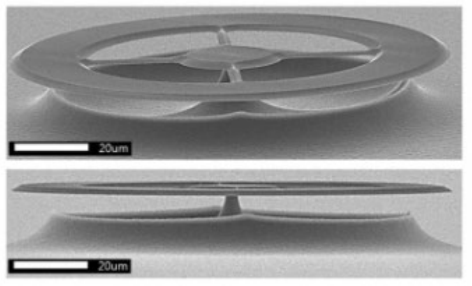
3D Cell Systems

- Engineered cellular networks



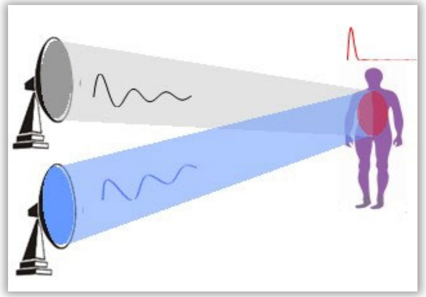
Bioimaging

- Novel bioimaging techniques



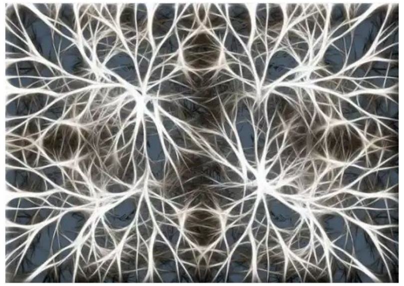
EM-tissue Interactions

- Electromagnetic biophysical interactions in living systems



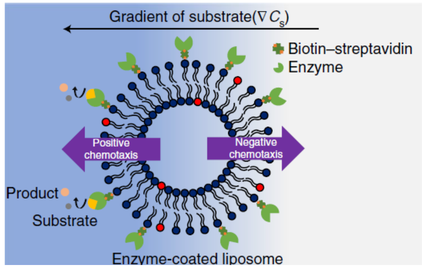
Neuro-glial Networks

- Neuro-glial signaling in biological processes



Collective Dynamics

- Multiscale properties of collective behavior



GHz-THz Electronics: Technical Focus Areas

Dr. Kenneth Goretta; ghz.thz@us.af.mil

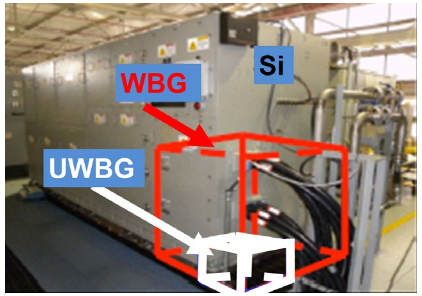
Objective: Understanding fundamental processing/structure/property relations; **direct observations of well-made** materials, structures, and devices, coupled with study of properties and theory and modeling/simulation for electronics relevant to USAF and USSF missions.

Approach: (1) Focus portfolio to a handful of topics → 70% turnover of subjects since 2016; (2) build confederated teams across AFRL, various agencies, and selected countries.

Major decisions made 2015-2023: (1) **retain** semiconductor basics, 2-D materials, magnetics, THz sciences, reconfigurability, and fundamental studies; (2) **discard** sensors/detectors; (3) **add** ultrawide-bandgap semiconductors and superconductors; **expand** radiation damage.

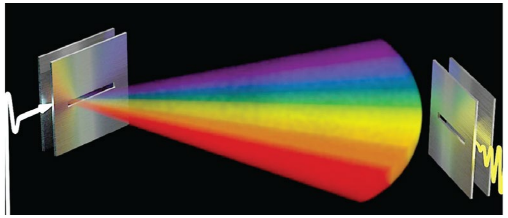
Science and Engineering for High Power

- Ultrawide-bandgap (UWBG) semiconductors/prototype devices
- Thermal properties



Science and Engineering for Low Power, Very High Speed

- 2-D devices & 2-D/3-D integration
- New spin- or valley-based devices
- Novel THz-speed devices
- Superconductors



Fundamental Science and Engineering for Electronics

- Electromagnetic surfaces
- Fundamentals, including defects, interfaces, and radiation damage

Continuous and Lasting Impact of AFOSR Basic Research on QIST

- **Start of AFOSR/JSEP investments facilitating creation of QIS field** (*e.g.*, masers/lasers, atomic laser cooling and trapping)
- **AFOSR supports research in materials now leveraged by QIS** (*e.g.,* quantum dots, quantum wells, spintronics)
- **AFOSR supports critical breakthroughs enabling quantum memories and interfaces** (*e.g.*, Electromagnetically Induced Transparency, slowed and stopped light, quantum frequency conversion)
- ***First DARPA quantum computing program**
- **Focus on early quantum computer architectures** (*e.g.*, NMR, superconductors, optics) and **quantum algorithms** (by DOD/IC)
- **AFRL-AFOSR Type II Quantum Computing** (classical/quantum hybrid systems)
- **First programs on quantum simulation of condensed matter** (AFOSR/ONR MURI, DARPA), helped seed DARPA ONISQ
- **Spurs creation of Ultracold Molecules field** (AFOSR MURIs)
- **Quantum transduction to enable hybrid systems** (AFOSR/ARO/LPS MURIs)
- **Continuously seed new efforts (*e.g.*, Quantum Programming Languages, Dissipation Engineering, Quantum Holography, QRAM, Quantum Phononics, Hot Solid-State Qubits, N-Qubit Gates, Materials Science for QIS, *etc.*** (various AFOSR MURIs and programs)

1950 1980 1990 2000 2010 2020

Quantum Computing first appears on Gartner Hype Cycle

Shor's algorithm published

Feynman proposes *quantum computer* concept to simulate and understand science of quantum mechanical systems

Continuous and Lasting Impact of AFOSR Basic Research on QIST

AFRL

AFOSR PIs leading current major Industry and Academic programs, *e.g.*,

- Dana Anderson (University of Colorado), Founder of ColdQuanta (now Infleqtion)
- Jeremy O'Brien (University of Bristol), Founder/CEO of PsiQuantum
- Ian Walmsley and Josh Nunn (University of Oxford), Founders of ORCA Computing
- Chris Monroe (Duke University), Founder of IonQ
- Oskar Painter (Caltech), Head of Quantum Hardware at Amazon Web Services
- Bob Coecke (University of Oxford), Chief Scientist at Quantinuum
- Mikhail Lukin, Markus Greiner (Harvard University) and Vladan Vuletic, Dirk Englund (MIT), Founders of QuEra Computing;
- Michel Devoret (University of California Santa Barbara), Chief Scientist at Google Quantum AI
- NSF National Quantum Initiative (NQI) Center Leads
    - Jun Ye (University of Colorado/JILA/NIST) 2002 Breakthrough Prize, AFOSR support started in early 1990's for graduate student studies
    - Brian DeMarco (University of Illinois), Director of Illinois QIST Center, part of Quantum Microelectronics Park
    - Dan Stamper-Kurn (University of California Berkeley)
- DOE NQI Center Leads
    - David Awschalom (University of Chicago), Director of Chicago Quantum Exchange
- MacArthur "Geniuses" (3 of last 7 physicists supported by AFOSR early on): Monika Schleier-Smith (Stanford, 2020), Ana Maria Rey (U Colorado, 2013), Markus Greiner (Harvard, 2011)
- New Horizons Prize Laureates: many are AFOSR-funded; *e.g.* in 2023, 4 out of 8 laureates previously received AFOSR YIP

Partnerships in broader QIST Ecosystem

International

AUKUS
NATO
US-EU
US-Korea, Taiwan Initiatives

White House

NSTC Subcommittee on QIS
OSTP Quantum WGs
National Quantum Initiative Act

Intelligence Community (IC)

OSD

OUSD(R&E) Principal Director Quantum Science, Basic Research Office
CAPE Quantum Issue Team, ARAP programs

Other Gov't Agencies

Air Force

Air Mobility Command (Dr. Lowas), AF Global Strike Command (Dr. Senft), AF Technical Applications Center (Dr. DeForest), SAF/AQ, AFRL, Space Systems Command (Dr. Ewart)

Army

Navy

Key Recent Activities

- Interagency WGs: OSTP, OUSD(R&E), AUKUS, US-EU
- Develop People: Advise new USAFA QIS Minor program
- **Chair Interagency QIS Coordinating Group**
  - intentionally informal, resurrected in 2018
  - DAF, Army, Navy, DARPA, LPS, IARPA, NSF, and DOE
  - Guest speakers (*e.g.*, OUSD, OSTP, FBI, State Dept.)
- Evaluator for DOE, NSF, Army, Navy, DARPA, IARPA, DIU, LPS

Technology Transition Opportunities

- Constant dialog w/ AFRL TDs, AFWIC, MAJCOMS, OSD 6.2+ (*e.g.,* DIU Quantum Sensors in Air/Space), Industry (*e.g.,* QED-C, Google, start-ups)
- Key Role as **Honest Brokers**
  - Accurate representation of state-of-the-art
  - Ensures DAF maintains realistic expectations

AFOSR QIST Team: Vision and Strategy

Dr. Grace Metcalfe
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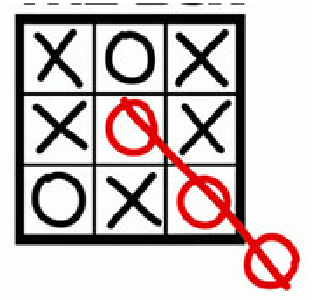
Redefine the Boundaries

- ***Unconventional* research to seed *Disruptive* Capabilities**
  - FY18 YIP /FY19 MURI Dissipation Engineering
  - Ultracold Molecules (created new field!)
  - Quantum Phononics MURI
  - *N*-qubit Gates MURI



- *Broad* impact sphere research *underpinning multiple* Quantum S&T areas to advance DAF missions

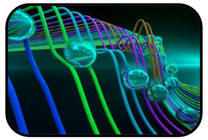
➢ Scientific landscape – Newest science breakthroughs, inspiration from other disciplines

➢ Funding landscape – Assessment/coordination with other QIST stakeholders

- Fault-tolerant quantum computing (LPS, IARPA)
- Quantum computing hardware (industry, DOE)
- Clocks and sensors (DARPA, ONR, industry)
- Quantum benchmarking (DARPA)

AFOSR QIST: Basic Research Focus Areas

- **Unconventional Quantum Resources**
  - Discover, understand, control and leverage *non-traditional* quantum resources (*e.g.*, dissipation, phonons, cold molecules, synthetic fields, synthetic dimensions, *etc*.)
    - including physical resources for “unconditional security” (can’t be guaranteed by today’s cryptography) for long-term information storage, communications, computation
  - Re-examine conventional assumptions (*e.g.*, von Neumann architecture, qubits, 1 and 2 qubit gates, *etc.*)



- **Quantum Information Distribution**
  - Understanding and optimizing configurations for routing quantum information across multiple quantum elements (*e.g.*, between information processor and memory)
  - Interfacing between disparate quantum systems (*e.g.*, transduction, switches, etc.) and between quantum and classical systems (*e.g.*, for end-to-end security, quantum/classical data processing, *etc*.)
- **Certification**
  - Verification and validation of quantum information processing and communication devices and systems (from theory to experiment) → Establish reliability and protection of realistic quantum systems
- **Quantum Components and Materials for QIS**
  - Devices uniquely required for Quantum S&T: repeaters, memories, integrated photonics
  - “Smart” design of materials with exquisite behavior for quantum technologies

AFOSR QIST Highlight: Dissipation Engineering

Objective: Tailor dissipation channels to steer quantum system towards desired target state(s) or process

Impact: Seeded *unconventional* approaches to controlling quantum systems, shifting paradigm in broader community

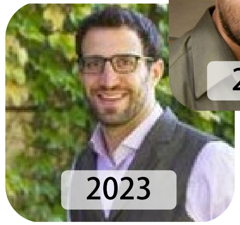
- ❖ Autonomous Quantum Error Correction
- ❖ Manipulated disorder to extract information from many-body states → compressed quantum measurement! [1]

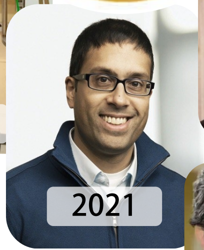
Numerous publications and accolades…

2024 NAS member

NATIONAL ACADEMY OF SCIENCES

APS physics FELLOW





FY19 MURI Team: Publications

*Analysis & image from Web of Science of pubs that cite MURI award #

FY18 AFOSR YIP Awardee → 2020 DOE Early Career Award

[1] *arXiv*:2309.05727

DARPA launches FY24 MeasQuIT (*Measurement-based Quantum Information and Transduction*)

*"MeasQuIT… will demonstrate novel approaches to scalable quantum control of qubits, sensors and other quantum circuits using techniques of quantum measurements and **dissipation engineering**"*

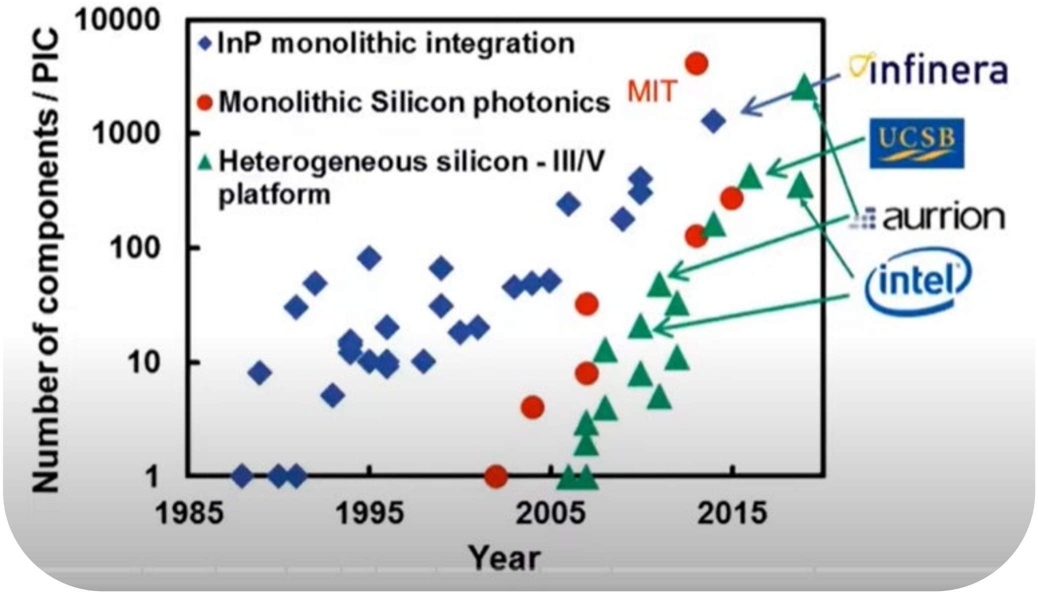
*"seeks to demonstrate… new forms of **autonomous error correction** that may require substantially lower overhead for fault-tolerant performance"*

- ➢ Two Dissipation Engineering MURI PIs (Monroe, Jiang) and YIP PI (Wang) leading MeasQuIT teams
- ➢ Five other AFOSR QIS PIs leading or supporting teams under MeasQuIT

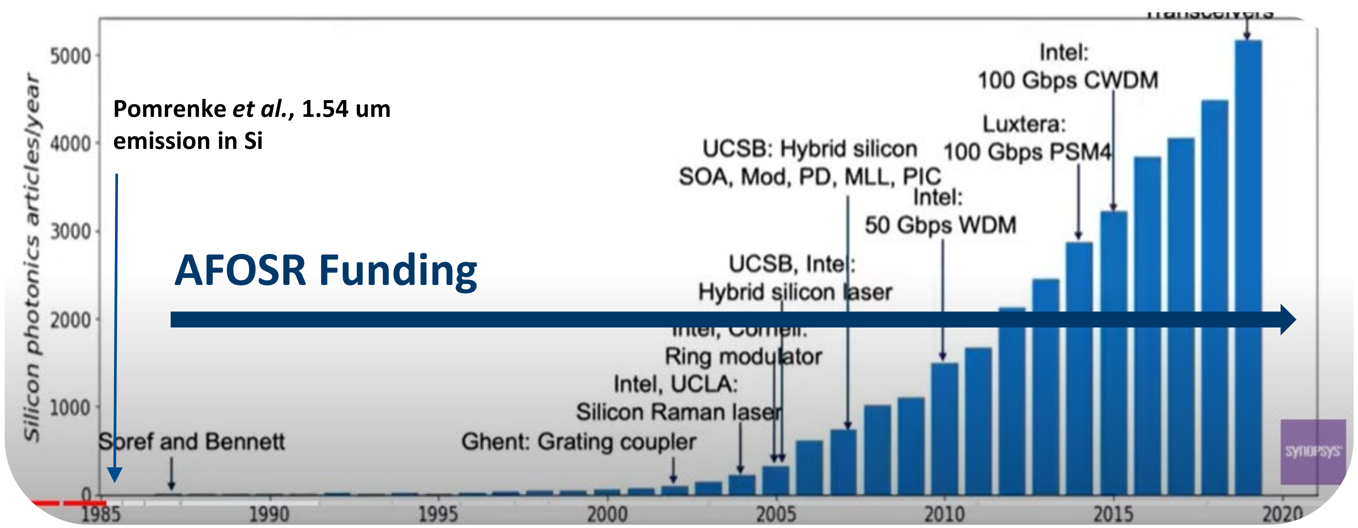
AFOSR QIST Highlight: Integrated Photonics

Dr. Gernot Pomrenke
AFOSR Program Officer 1989-2023

Developing New Fabrication & Processing Capabilities

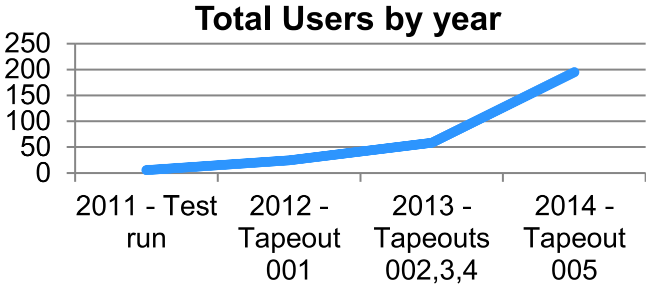


John Bowers https://www.youtube.com/watch?v=2PptAPCN8IE



AFOSR program OpSIS

American Institute for Manufacturing (AIM) Photonics

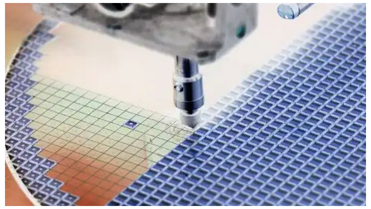


195 global users signed NDA's for PDK access.
~Half corporate, half academic

Luminous Computing names Michael Hochberg (AFOSR FY08 YIP, Director of OpSIS) President

- Established in 2015 to secure robust U.S. silicon photonics ecosystem
- Secured $321M in new seven-year cooperative agreement in Oct. 2021 with AFRL & Research Foundation of the State University of New York
- Enables continued development of silicon photonics for critical defense applications and other advanced photonics capabilities, including *quantum technologies* (see slide7 and AFRL talk)

AIM PHOTONICS



AFOSR Highlight: Quantum Networking

AFRL

Challenge: Limited flexibility of current networks for space systems

Approach: Share entanglement between networked assets to provide ultraprecise sensing, distributed computing, and communications

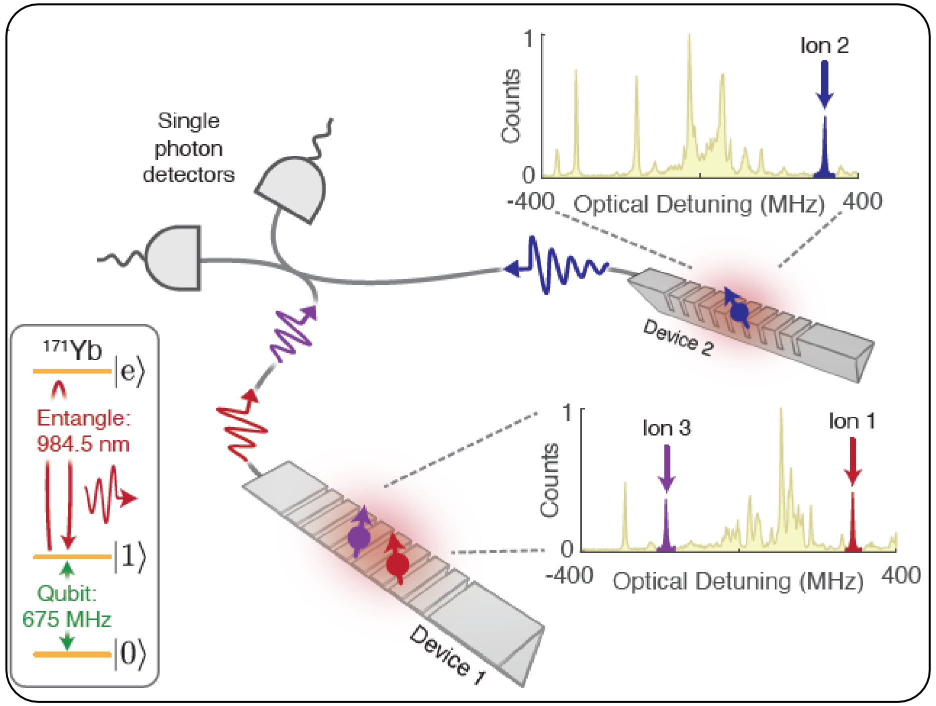
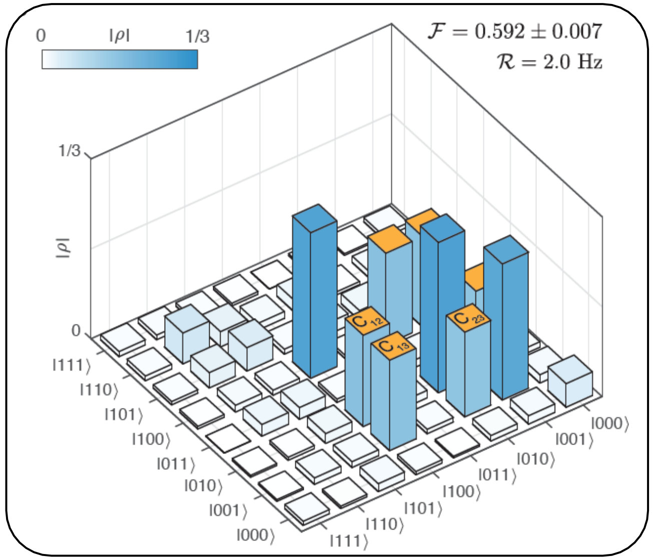


Figure shows schematic of shared entanglement between three quantum bits across physically separated devices. The quantum bits can serve as communication nodes, information processors, or sensors. Image from Ref [1].

Result: First demonstration of entanglement across three quantum bits in the U.S. Researcher overcomes the typical limitation of distinguishability for entanglement using clever real-time measurement-conditioned feedforward technique.

PI: Prof. Andrei Faraon, Caltech

Impact: Solid-state platform and telecommunications wavelength compatibility provides practical path towards scalable, long-distance, multi-mode quantum networks



Experimental data showing entanglement between three distinguishable quantum bits (i.e., creation of tripartite W state). W states are relevant for advanced quantum networking applications [2, 3]. Image from Ref [1].

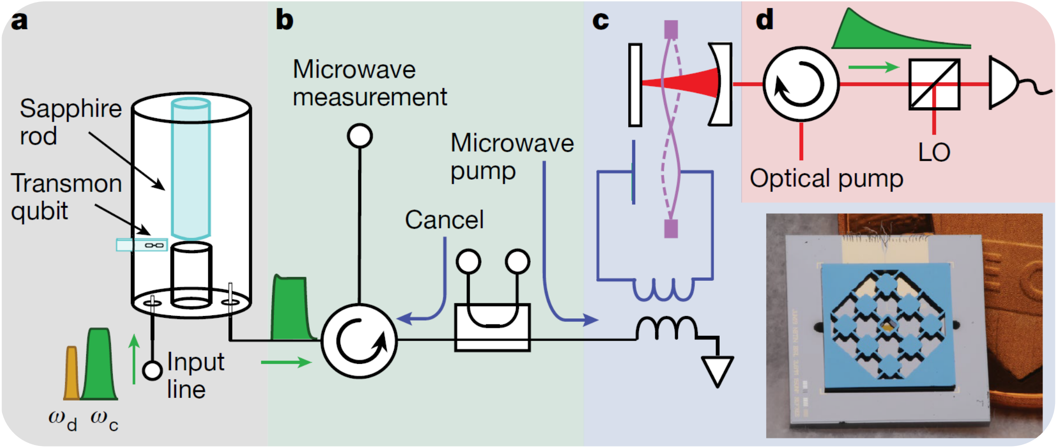
[1] Ruskuc *et al.*, "Scalable Multipartite Entanglement of Remote Rare-earth Ion Qubits," *arXiv*:2402.16224. Submitted to *Nature*.
[2] D'Hondt *et al.*, "The computational power of the W and GHZ states," *Quantum Inf. Comput.* **6**, 173 (2005)
[3] Lipinska *et al*, "Anonymous transmission in a noisy quantum network using the W state," *Phys. Rev. A* **98**, 052320 (2018)

AFOSR QIST Highlight: Quantum Transduction

Coherent interface between disparate quantum systems (*e.g.*, superconductor-based qubits to photons) → needed for scaling quantum computing and networking

- FY14 Quantum Transduction MURI (inherited from Drs. Weinstock and Curcic in 2018)
  - Leveraged early AFOSR investment in superconducting-based* quantum computing (2001 DURINT**)
  - Co-sponsored with LPS and ARO → enabled two MURI teams
  - CII extended (2019-2022) sub-effort on "Dynamically Reconfigureable Networks"
    - Yielded general purpose bus capable of transferring quantum information between diverse media (*e.g.*, electronics, photonics, and phononics)

Dr. Harold Weinstock
(1934-2024)
AFOSR Program Officer 1984-2018



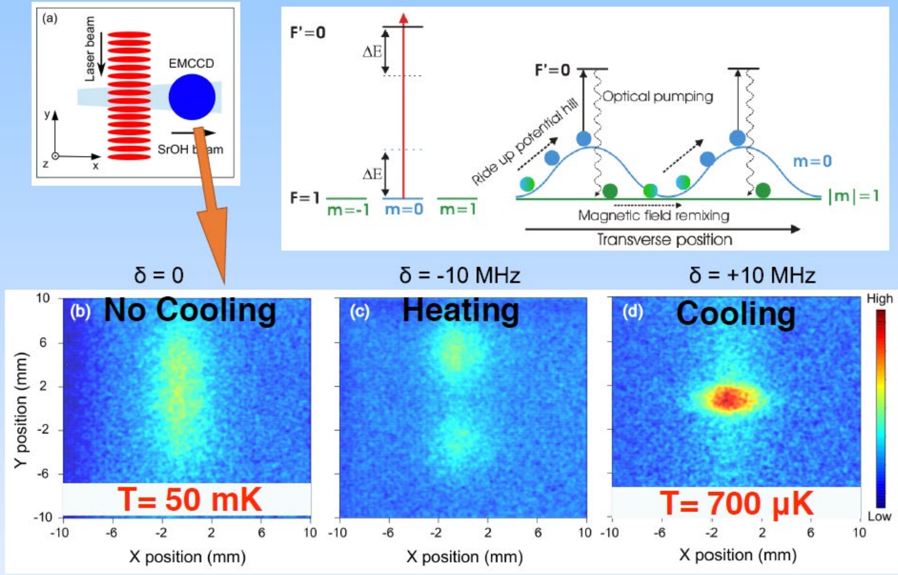
Apparatus for readout of a superconducting qubit via electro-optic transduction. Image from Ref [1].

- **Example follow-on programs**
  - LPS FY17 Cross Quantum Technology Systems (CQTS)
  - LPS FY22 Quantum Computing in the Solid State with Spin and Superconducting qubit Systems (QCS^5)
  - NSF 2019 Quantum Leap Challenge Institute
  - NSF 2021 Quantum Interconnect Challenges for Transformational Advances in Quantum Systems (QuIC-TAQS)
  - FY23 MURI topic on Quantum Phononics
  - AFRL/RI quantum transduction program

*Many industrial quantum computers today are based on superconductors (*e.g.*, IBM, Google, Rigetti, Atlantic Quantum)
**DURINT =Defense University Research Initiative on NanoTechnology
[1] *Nature* **606**, 489 (2022)

AFRL

First laser cooling of polyatomic molecule (Doyle, Harvard)

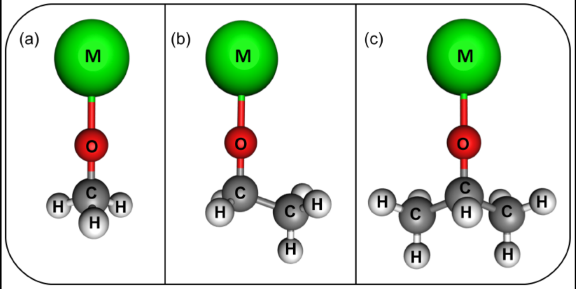


Sisyphus Laser Cooling SrOH

~ 200 Photons

I. Kozyryev, L. Baum, K. Matsuda, B. L. Augenbraun, L. Anderegg, A. Sedlack, and J. M. Doyle. PRL 118 (17) 2017

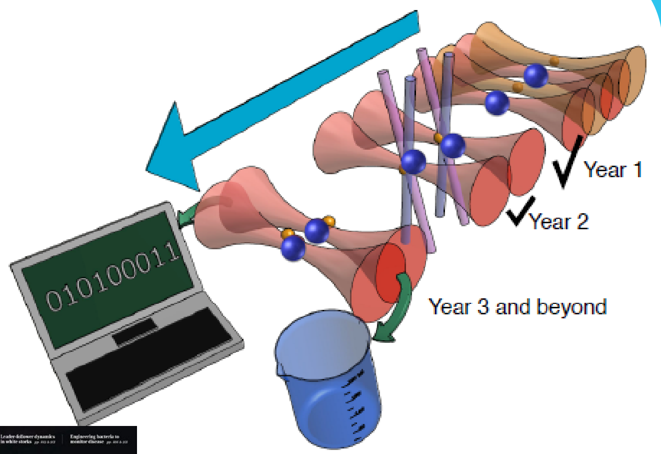
Generalizable to much larger polyatomics… control over larger and more complex molecules



Proposal for Laser Cooling of Complex Polyatomic Molecules
Kozyryev, L. Baum, K. Matsuda, and JMD, *PCCP* **17**, 3641(2016)

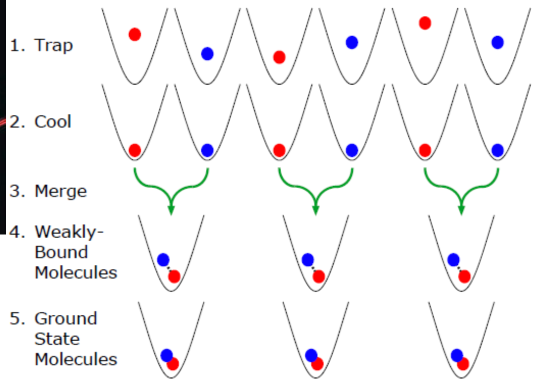
First to build single molecules atom-by-atom using optical tweezers (Ni, Havard)

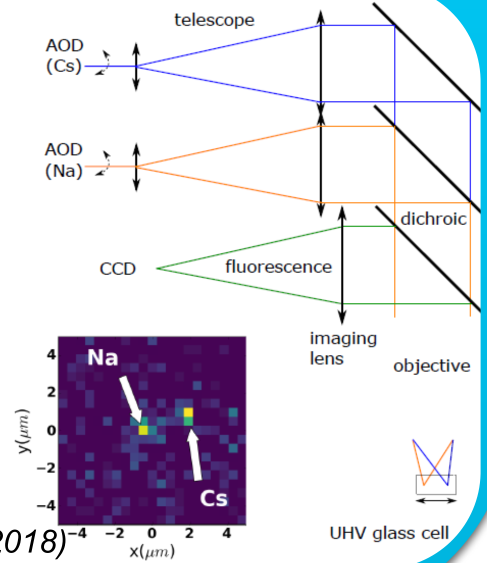
Ultracold Molecular Assembler



2015 YIP, 2023 New Horizons Prize

Represents new level of precision and control for molecules



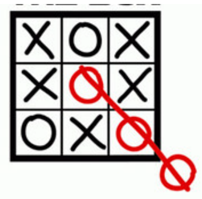


*Liu, Hood, Yu, Zhang, Hutzler, Rosenband, Ni, **Science** 360, 900 (2018)*

Summary

- Lasting impact of AFRL/AFOSR in QIST
  - Seed ground-breaking innovation (and QIST leaders), executed mostly through single investigator awards and OSD MURIs
  - Create new fields of science (like QIS, Ultracold Molecules, and Materials Research for QIS)
  - Down-select most promising high-risk approaches for both Air and Space Force at early, lowest cost stage → demonstrated transitions to larger programs (*e.g.*, AFRL, DARPA, IARPA, other DoD Labs, *etc.*)

- Partnerships throughout larger ecosystem
  - Cultivate close connections with AFRL researchers and other agency stakeholders
  - Resource of advisors or subject matter experts (honest brokers) for policy, research directions, people development, etc.



- AFRL/AFOSR S&T focuses on *unconventional* basic research with largest impact sphere
  - ➢ Where it takes you hard to predict, and thus can create *Disruptive* capabilities

Connect with AFRL

Student & Faculty Opportunities

Grants.Gov

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AFresearchlab

Air Force Research Laboratory - AFRL

AFResearchLab

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Announcements and Highlights

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