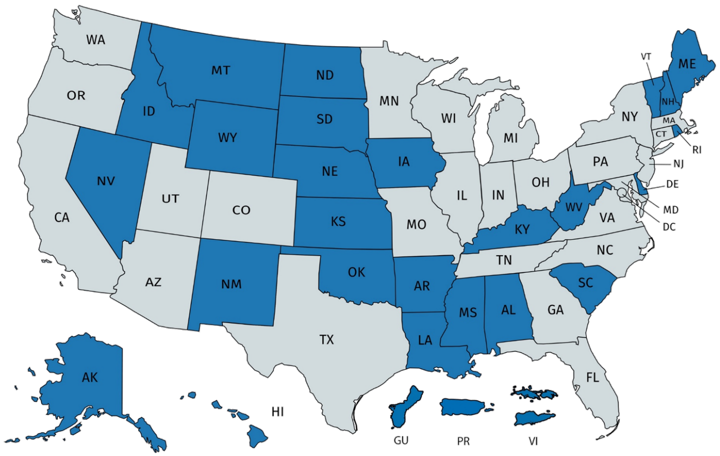
# EPSCoR Jurisdiction Research Programs
*aligned with*
# NASA Langley Research Center Priorities

A Companion Booklet created for NASA Langley Researchers in conjunction with the "NASA EPSCoR Research for LaRC" Virtual Meeting held on Thursday, January 27, 2022, 3 pm EST

NASA EPSCoR



# NASA EPSCoR Research for LaRC

## Thursday, January 27, 2022 | 3:00 pm – 4:30 pm Eastern

**Virtual participation via Microsoft Teams**

**Meeting Link**

# Agenda

*All times are EASTERN U.S. time zone*

| | | |
|---|---|---|
| **3:00 pm** | **Welcome and Summary of Meeting Objectives** | **T. G. Guzik** |
| **3:02 pm** | **Welcome and Introduction to LaRC Research Priorities** | **N. M. Abreu** |
| **3:07 pm** | **Introduction to EPSCoR and the NASA EPSCoR Program** | **T. G. Guzik** |

## EPSCoR Researcher Flash Presentations

**3:20 pm** **Intelligent Flight Systems & Trusted Autonomy:**
*Smart cities, automation, robotics*

Robotic In-Situ Resource Utilization **Orion Lawlor (AK)**

Decentralized Formation Control of Teams of Autonomous Agents
**Marcio de Quieroz (LA)**

Scalable and Robust Multiagent Reinforcement Learning for Robot Swarms
**Chuangchuang Sun (MS)**

Q&A (4 minutes)

**3:30 pm** **Systems Analysis and Concepts:**
*Air transportation system architectures and vehicle concepts*

Conceptual Design and Analysis of Aerobot for Long-Endurance Mission on Venus **Andreas Gross (NM)**

Multiphase High Voltage Electrified Propulsion for Spacecrafts/Aircrafts
**Omid Beik (ND)**

Q&A (4 minutes)

**3:38 pm** **Advanced Materials & Structural Systems:**
*Advanced manufacturing*

Enhanced Planetary Protection via Additive Manufacturing of Internal Structures with Integrated Mechanical and Energetic Properties for End-of-Mission Sterilization **Travis Walker (SD)**

Robotic Walking Machines for Automated Additive Manufacturing, Surface Exploration & ISRU **Pierre Larochelle (SD)**

Laboratory for Advanced Materials **Jihong Ma (VT)**

Stochastic Modeling for Advanced Manufacturing: Machine Learning and Statistical Modeling **Pejman Tahmasebi (WY)**

Soft Robotics and Advanced Manufacturing **Kwang Kim (NV)**
Q&A (4 minutes)

**3:52 pm** Ten-minute break in virtual meeting.
Resume at 4:02 pm eastern.

**4:02 pm** **Entry, Decent & Landing:**
*Robotic mission entry vehicles*

Modeling, Learning, and Control for Autonomy and Human-Robot Collaboration Systems **Yue Wang (SC)**

Experimental Aerodynamics Laboratory **Vibhav Durgesh (ID)**
Q&A (4 minutes)

**4:10 pm** **Terrestrial and Planetary Atmospheric Sciences:**
*Air quality, properties of clouds, winds, aerosols, water vapor, trace gases, climate change*

Measuring Aerosol Chlorides for Atmospheric Corrosion Studies in Arctic Climate **Raghu Srinivasan (AK)**

Clemson Air Quality Lab **Andrew Metcalf (SC)**
Q&A (4 minutes)

**4:18 pm** **Innovative Concepts for Earth and Space Science Measurements:**
*LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement*

Deep Learning-Based Super Resolution of Satellite Gravity Data for Geophysical Exploration **Jyotsna Sharma (LA)**

Active Remote Sensing with a Space-borne Imaging Radiometer **Ashanthi Maxworth (ME)**

Ultra-Compact Plasma Spectrometer **Earl Scime (WV)**

Topographic Correction of Broadband Snow Albedo Measured from an Uninhabited Aerial Vehicle (UAV) **Eric Sproles (MT)**

Q&A (4 minutes)

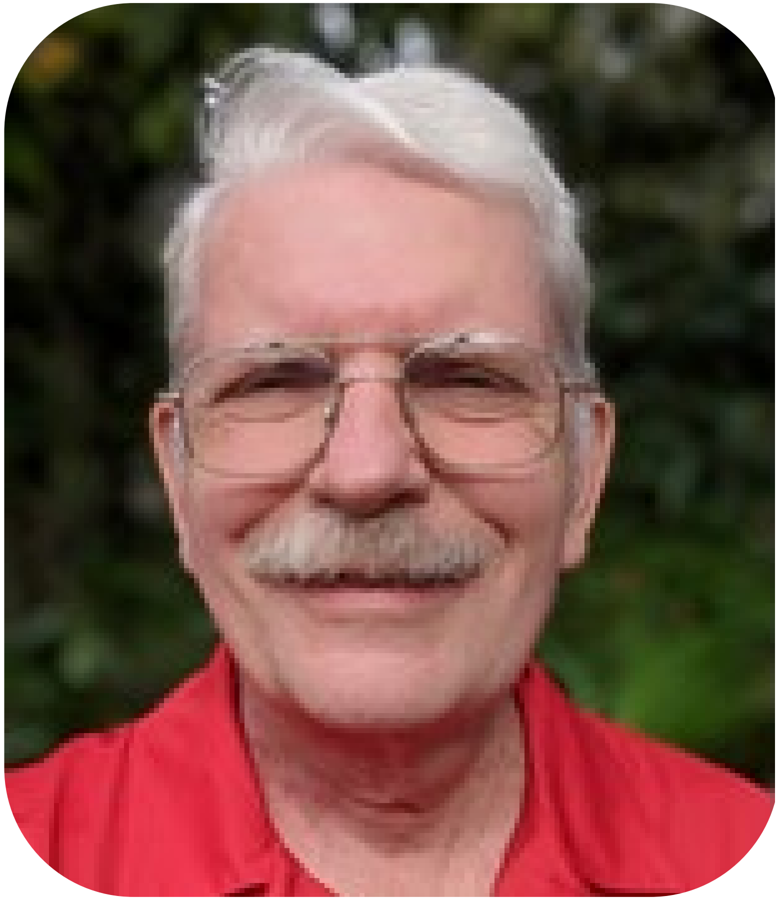
## 4:30 pm Adjourn Meeting

# Introductions

## T. Gregory Guzik

Louisiana Space Grant / NASA EPSCoR Program
Department of Physics and Astronomy
Louisiana State University
tgguzik@lsu.edu

T. Gregory Guzik is the Director of the Louisiana Space Grant / NASA EPSCoR program. His scientific career has focused on astrophysical energetic particles including large class cosmic ray balloon instruments launched as long duration balloon flights in Antarctica, heavy ion particle accelerator experiments, cosmic ray instruments on-board satellites, and is part of an international collaboration working with the CALET high energy cosmic ray instrument on-board the International Space Station. Dr. Guzik has been directly involved with Space Grant and NASA EPSCoR for close to 20 years including developing and managing both entry-level and advanced experiential student ballooning programs. Dr. Guzik currently serves as the Chair of the NASA EPSCoR Caucus.



# A Brief Summary of the NASA EPSCoR Program

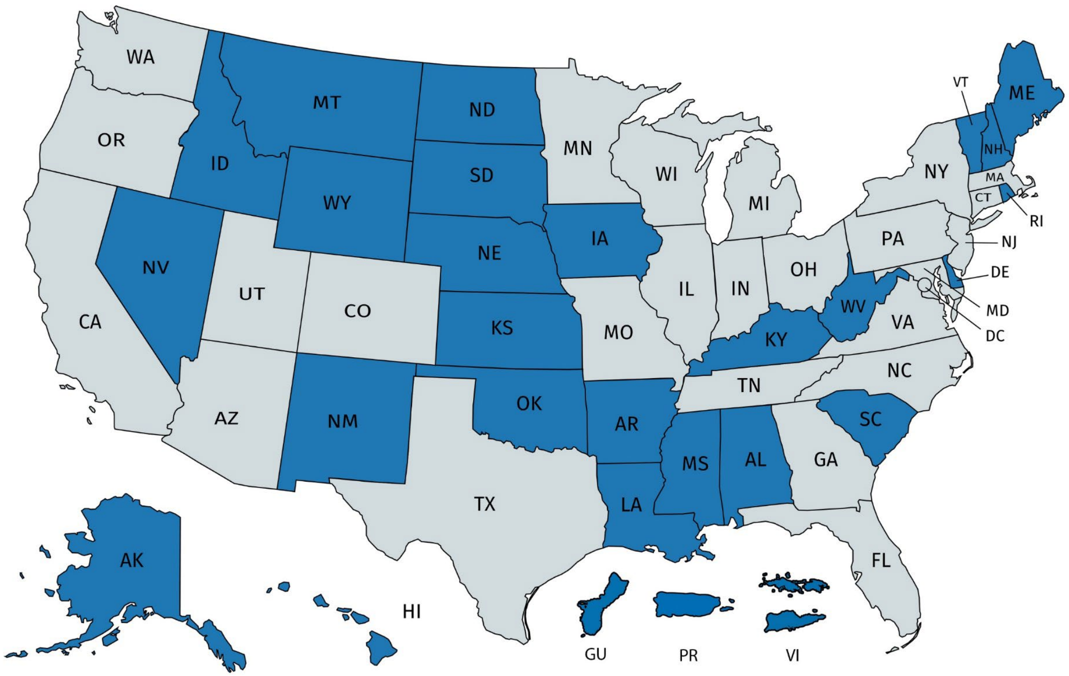
**T. Gregory Guzik,** Chair and Director
NASA EPSCoR Caucus, Louisiana NASA EPSCoR & Space Grant
Department of Physics & Astronomy
Louisiana State University, tgguzik@lsu.edu

# EPSCoR was established in 1988

- Congress formally established the *"Experimental Program to Stimulate Competitive Research (EPSCoR)"* in 1988 in order to help address a major discrepancy in the distribution of competitive research awards.
- Eligible jurisdictions receive less than 0.75% of the total NSF Research and Related Activities budget.
- The 28 EPSCoR states receive just 13.6 percent of all NSF research funds. A larger portion – 15% – went to just eight of the nation's research universities.
- The 1988 statute stipulated that the program was to increase research and infrastructure capacity, thereby improving the ability of institutions in EPSCoR states to compete for non-set-aside federal R&D funding.
- Participating states were required to demonstrate a commitment to the program by establishing science and technology governing committees to ensure NSF funding was sensitive to the state's overall strategy for research. Congress also required significant cost sharing between states and the federal government.
- In 2017 (P.L. 114-329) the program was reaffirmed and renamed to the *"Established Program to Stimulate Competitive Research."*

# EPSCoR Jurisdictions and Agencies

- Jurisdictions are currently eligible if their most recent 5-year funding level of NSF research support is equal to or less than 0.75% of the total NSF Research and Related Activities budget.  This amount excludes EPSCoR funding from the count.



# NASA EPSCoR was established in 1992

- Established in 1992 (P.L. 102-588) to enable jurisdictions to develop an academic research enterprise directed toward capability in aerospace and aerospace-related research and to contribute, in turn, to the jurisdiction's economic viability.
- Management function at NASA assigned to Office of Education (now Office of STEM Engagement).
- Established linkage between National Space Grant College & Fellowship Program and the NASA EPSCoR program.
  - Some similar research and workforce development goals
  - Require jurisdiction Space Grant Director to also be PI on all NASA EPSCoR projects
- The National NASA EPSCoR Caucus was organized by the jurisdiction Directors in 2012 to create an effective network of persons and institutions to support the NASA EPSCoR program.
  - The Caucus took the initiative to organize and conduct this meeting

# NASA EPSCoR Objectives

- Contribute to and **promote the development of research capability in NASA EPSCoR jurisdictions** in areas of strategic importance to the NASA mission.
- Improve the capabilities of the NASA EPSCoR jurisdictions, including minority serving institutions, to **gain support from sources outside the NASA EPSCoR** program.
- **Develop partnerships** among NASA research assets, academic institutions, other agencies, and industry.
- Contribute to the overall **research infrastructure, science and technology capabilities of higher education, research faculty diversity, and economic development of the jurisdiction.**

# NASA EPSCoR Program Opportunities

**Research Infrastructure Development (RID):** This “base” funding is awarded to all jurisdictions. Used for jurisdiction management, travel support for jurisdiction researchers to NASA centers, seed money research projects.

**Research Implementation:** Three-year research project support, focused on a major NASA interest area, and addressing jurisdiction needs.

**ISS Flight Opportunity:** Awarded only to Science-Is who have developed an instrument under NASA EPSCoR research that could be tested on the ISS. Funds only for travel and review support.  No instrument development.

**Suborbital Flight Opportunity:** Open to all researchers in a jurisdiction to develop and fly a NASA relevant payload on a suborbital balloon, sounding rocket, aircraft, or reusable rocket vehicle.

**Rapid Response Research (R3):** In third year of implementation. More focused on specific tasks identified at the NASA centers or mission directorates rather than innovative research in a general area of interest. Offers an opportunity for developing a close working relationship with NASA researchers.

**NSF / NASA EPSCoR FAST:** Joint NSF / NASA EPSCoR pilot to engage MSI and NASA researchers, establish strategic collaborations, and build experiences and know-how across respective communities.

# NASA EPSCoR Program Opportunities

**Research Infrastructure Development (RID):** This "base" funding is awarded to all jurisdictions. Used for jurisdiction management, ***travel support for jurisdiction researchers to NASA centers***, seed money research projects.

**Research Implementation:** Three-year research project support, ***focused on a major NASA interest area***, and addressing jurisdiction needs.

**ISS Flight Opportunity:** Awarded only to Science-Is who have developed an instrument under NASA EPSCoR research that could be tested on the ISS. Funds only for travel and review support. No instrument development.

**Suborbital Flight Opportunity:** Open to all researchers in a jurisdiction to develop and fly a NASA relevant payload on a suborbital balloon, sounding rocket, aircraft, or reusable rocket vehicle.

**Rapid Response Research (R3):** In third year of implementation. More focused on ***specific tasks identified at the NASA centers*** or mission directorates rather than innovative research in a general area of interest. Offers an opportunity for developing a close working relationship with NASA researchers.

**NSF / NASA EPSCoR FAST:** Joint NSF / NASA EPSCoR pilot to engage MSI and NASA researchers, establish strategic collaborations, and build experiences and know-how across respective communities.

# NASA EPSCoR Components

## 01 Research

3 years
$750,000
Matching funds

## 02 Research Infrastructure Development (RID)

5 years
$1,000,000
Matching funds

## 03 International Space Station

3 years, $100,000

**Suborbital**

3 years, $250,000

## 04 Rapid Response Research (R3)

1 year
$100,000

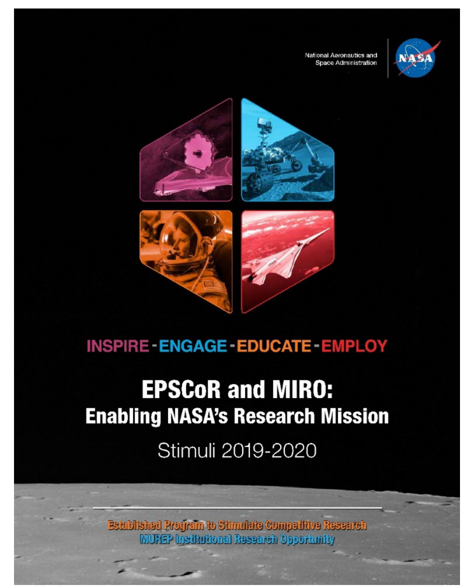
## 05 NASA and NSF PILOT

2 years:
NSF $300,000
NASA $30,000

# NASA EPSCoR research examples

- The NASA EPSCoR Stimuli document provides success stories that illustrate how state interests meet NASA interests. See file "Example NASA EPSCoR Research Projects 2020.pdf" and link below to the complete listings for 2017 through 2020.
  - https://www.nasa.gov/stem/epscor/home/EPSCoR_Stimuli.html





# Diversity and Inclusion

- **NASA EPSCoR Opportunities are open to ALL institutions in each jurisdiction**
  - Includes HBCU, Tribal Colleges, Community Colleges, and other MSI
  - There are more that 859 MSI in the EPSCoR states
- **NASA EPSCoR focus is on research infrastructure development in jurisdictions that are NOT heavily funded by federal agencies**
  - MSIs in such jurisdictions are resource poor and usually can not develop independent research programs without assistance
- **NASA EPSCoR is a federal / state partnership program and, consequently, jurisdiction as well as NASA needs must be addressed**
  - For most jurisdictions improving diversity in research and economic development is a priority
- **Some jurisdictions have implemented programs to encourage majority / minority collaborations within the state as part of the evaluation of pre-proposal for limited submission NASA EPSCoR opportunities**

# NASA EPSCoR is focused on research

- **NASA EPSCoR is a higher education program focused on aerospace research**
  - Relevant to research and technology development in all NASA Mission Directorates and at all NASA Centers
  - Graduate student training useful for research infrastructure development but is not the primary goal of the program
- **Primary goal of NASA EPSCoR is to develop infrastructure for aerospace research in jurisdictions**
  - Institutions in EPSCoR jurisdictions are an under-utilized resource for NASA to advance science and technology development
  - For 2019-2020 there are more than 125 different NASA EPSCoR research projects across 28 jurisdictions
- **Later in this meeting jurisdiction researchers will provide "flash" presentations on research interest / capabilities directly relevant to LaRC priorities**
- **Plan over next several months is to explore possible collaborative efforts in preparation for face-to-face meeting at LaRC in June 2022**

# Introductions

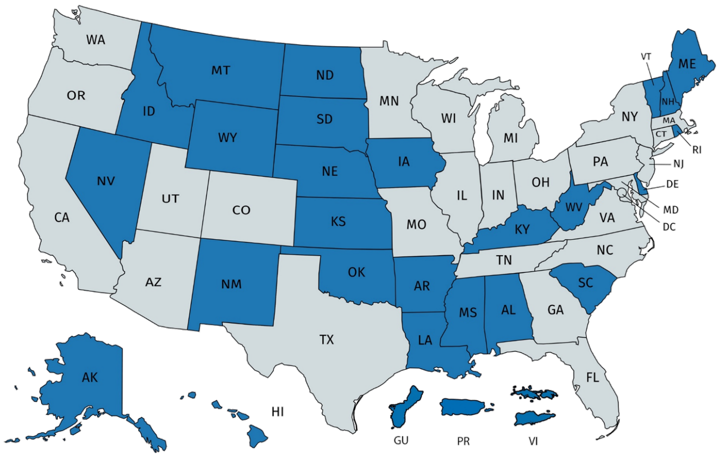
## Neyda Abreu

Senior Advocate for Science and Research
NASA Langley Research Center
Hampton, VA 23681-2199
neyda.m.abreu@nasa.gov

Neyda Abreu is the Senior Advocate for Science and Research at NASA Langley Research Center. Dr. Abreu aims at supporting scientists and researchers to do their best work. Experienced Scientist with a demonstrated history of working in Earth and Planetary Sciences and Materials. Interested in Sustainable Exploration of Space and Strategy.

# Topic Area 1:

# Intelligent Flight Systems and Trusted Autonomy: Smart cities, automation, robotics



# Intelligent Flight Systems and Trusted Autonomy: Smart cities, automation, robotics

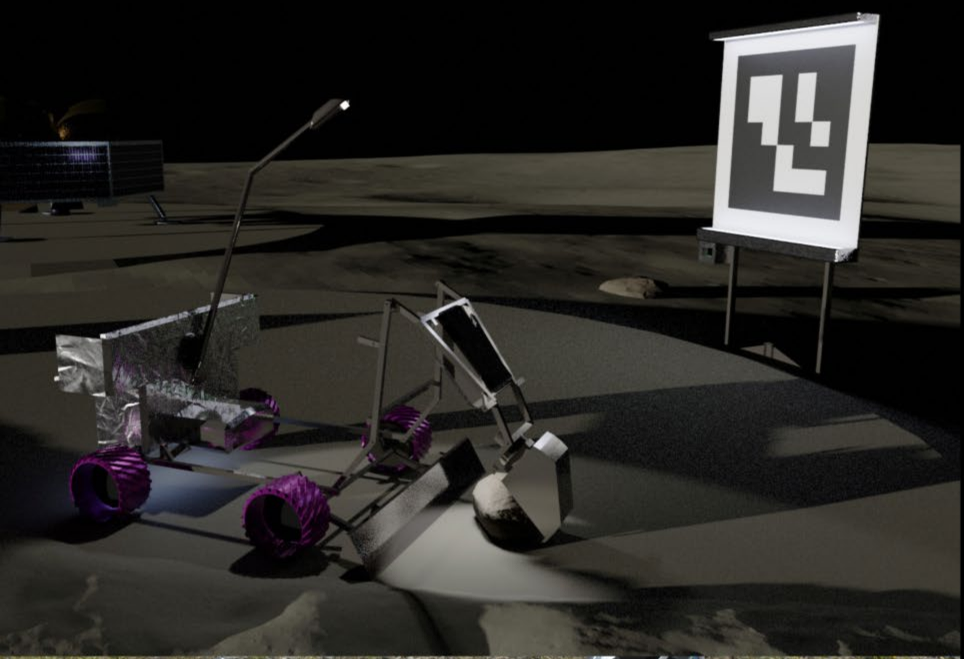
## Robotic In-Situ Resource Utilization (ISRU)

Dr. Orion Lawlor

University of Alaska Fairbanks (UAF)
Computer Science Department
lawlor@alaska.edu

Dr. Orion Lawlor is an associate professor of computer science at the University of Alaska Fairbanks, with research interests spanning autonomous robotics, computer graphics, ISRU manufacturing, and smart geospatial data to support autonomous robotic construction and maintenance in remote places. Dr. Lawlor has won cash prizes at the NASA Break The Ice lunar permafrost mining challenge (Phase 1), NASA 3D Printed Habitat Challenge (Phases 1 & 2), Mars Society city-state design competition with Nexus Aurora, and has participated regularly in the NASA Robotic Mining Contest

# Robotic In-Situ Resource Utilization (ISRU)



Vision: build multi-function, multi-mission robots with interchangeable tools for:

- Landing pads & berms
- Foundations & utilities
- Resource excavation
- Hauling ore and products
- Surface logistics

Operational needs:

- Local positioning system
- Ground truth remote sensing datasets
- Online terrain modeling
- Inspection and repair

Earth analog testing is key:

- Build full-size prototypes
- End-to-end full-up testing
- Test interchangeable *tools*
- Test long term robotic ops
- Test on real permafrost
- Test on *snow* (like regolith with gravity offload)

Aurora
**ROBOTICS**

Dr. Orion Lawlor

lawlor@alaska.edu

@AlaskaLawlor

University of Alaska Fairbanks

NASA Challenge prize winner:
Break The Ice phase 1, 2021
3D Printed Habitat Challenge phase 1 & 2, 2017

NASA Robotic Mining Contest:
Judges' Innovation Award, 2014
Lightest robot, 2019
National finals, 2013-2019

We built a dual-pin tool coupler with mass 400g/tool (1/20th of FRGF!)

Regolith density * lunar gravity
≈ Snow density * Earth gravity

Robotics should also be useful i remote areas like Alaska village & mines

## Intelligent Flight Systems and Trusted Autonomy: Smart cities, automation, robotics

### Decentralized formation control of teams of autonomous agents


# Dr. Marcio de Queiroz

Louisiana State University
Department of Mechanical & Industrial Engineering
Innovation in Control & Robotics Engineering (iCORE) Laboratory
mdeque1@lsu.edu; (225) 578-8770


Marcio de Queiroz is a Professor of Mechanical Engineering at LSU. He's the director of the iCORE Lab and coordinator for the Robotics Engineering minor. His research expertise is at the intersection of systems theory, control engineering, and robotics. Since 2011, Dr. Queiroz's primary area of activity has been coordination control of multiple autonomous robotic vehicles. Such systems are intrinsic to missions that involve air traffic management, search and rescue, area coverage, perimeter protection, or co-transportation of large objects. The iCORE Lab is home to TIGER Square, an experimental testbed for multi-agent systems, which uses small, low-cost, custom-built, differential-drive robots as the mobile robot platform. The testbed can be operated in both centralized and decentralized modes of sensing, communication, and control.

# Decentralized Formation Control of Teams of Autonomous Agents

## Motivation

### Nature

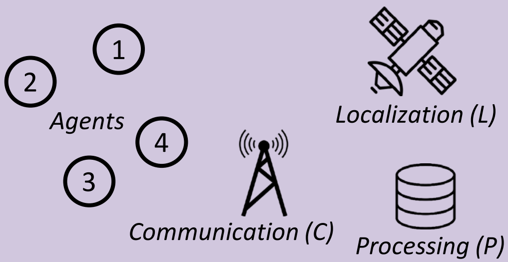
**Inspiration**

### Engineered Systems


- Air traffic management
- Search and rescue
- Area coverage
- Perimeter protection
- Co-transportation of large objects

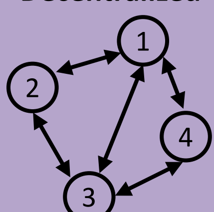
## Autonomy Modes

### Centralized




- Unified L/C/P
- ***Critical points-of-failure***

### Decentralized




- Distributed, onboard L/C/P
- ***Robust and versatile (e.g., GPS-denied environments)***

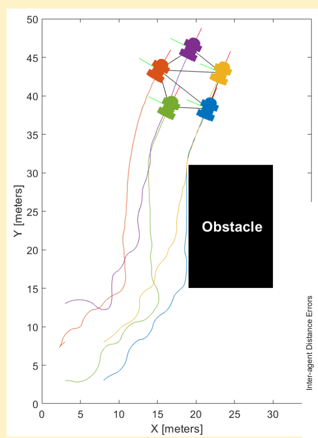
## Our Research

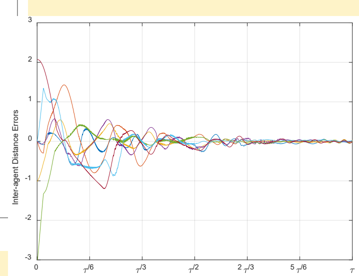
**Tools**
- Rigid graph theory
- Nonlinear systems theory
- Distance-based control

**Applications**
- Formation maneuvering
- Target interception
- Splitting and merging

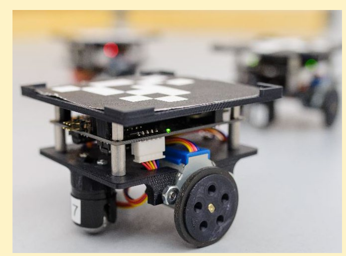
**Outcomes**
- Switched autonomy
- Stability guarantees
- Collision/obstacle avoidance

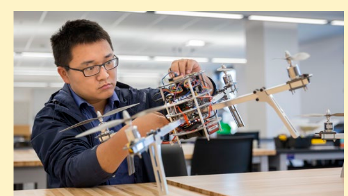
**Computer Simulation**

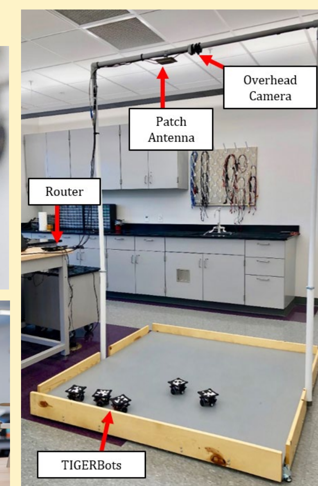



**Experimentation**










iCORE Innovation in Control and Robotics Engineering Lab
Dr. Marcio de Queiroz
LSU College of Engineering
Department of Mechanical & Industrial Engineering

NASA EPSCoR Research for LaRC
January 27, 2021

# Intelligent Flight Systems and Trusted Autonomy: Smart cities, automation, robotics

New Unified Framework for Scalable, Risk-Aware, and Resilient Estimation and Control of Satellite Swarms


## Dr. Hamid Ossareh

University of Vermont
Department of Electrical and Biomedical Engineering
Hamid.Ossareh@uvm.edu


Dr. Ossareh is an Assistant Professor of Electrical Engineering. Previously, he was a Research Engineer at Ford Motor Company, where he worked on advanced automotive control systems. He earned his Ph.D. in electrical engineering systems (control theory) from the University of Michigan and his B.A. Sc. from the University of Toronto. His expertise areas include systems and control theory, constrained and predictive control, applications of control theory to automotive and power systems. Jurisdictional research capabilities associated with this research include dynamical systems, control theory, estimation theory, formation control, fault detection, satellite swarms, CubeSats, orbital mechanics, simulation.

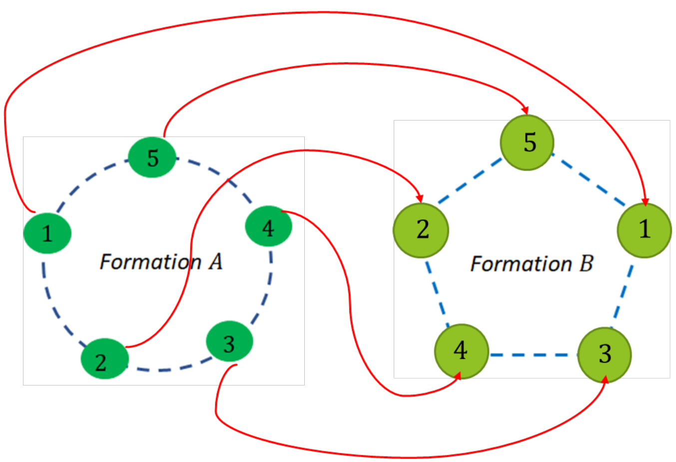
**Dr. Hamid Ossareh**
*Electrical Engineering*
*University of Vermont*

# Areas of research

- Dynamical systems and control
  - Constraint management of dynamical systems
  - Control of automotive fuel cells
  - Control of grid edge devices
  - Formation flight of satellite swarms

## Recent NASA EPSCoR-funded project (NASA partner: JPL)

**Formation planning, estimation, and real-time control of satellite swarms (100s of satellites)**




**Objectives:**

- Optimal formation planning
- Optimal thruster profiles
- Real-time collision-free control
- Real-time estimation
- Fault detection and controller reconfiguration

**Key focus:** computational efficiency and scalability of the algorithms, no communication with ground, low communication overhead between satellites

NASA EPSCoR Research for LaRC
January 27, 2021

Intelligent Flight Systems and Trusted Autonomy: Smart cities, automation, robotics

## Soft and Continuum Robots for Space Applications


# Hunter B. Gilbert, Ph.D.

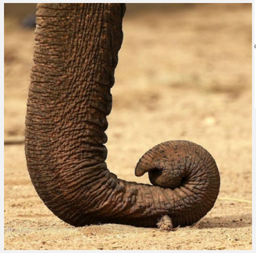
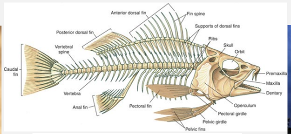
iCORE Lab
Department of Mechanical and Industrial Engineering
Louisiana State University
hbgilbert@lsu.edu

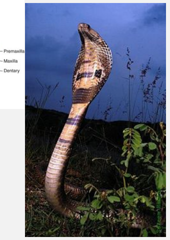
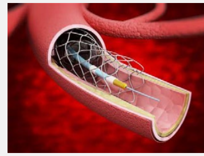

Hunter Gilbert is an Assistant Professor of Mechanical Engineering at Louisiana State University and Co-Director of the iCORE Lab. His research is focused on the intersection of mechanics and robotics, discovering the ways in which mechanical compliance enables robust and safe operation of robotic systems in uncertain and challenging environments. Applications range across healthcare, industrial, field, and space systems. Research and development expertise and capability includes robot design, control, prototyping, and evaluation; embedded and mechatronic systems development; mechanics-based modeling; and telemanipulation systems.

# Soft Robots for Physically Intelligent, Safe, Uncertain Interaction

## Inspiration

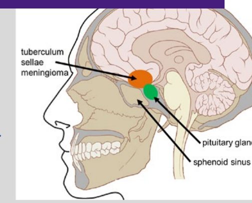
***Beneficial Mechanical Compliance***
*(Natural & Engineered)*

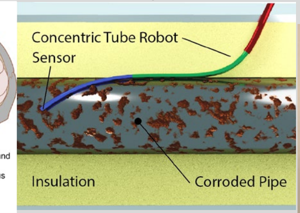



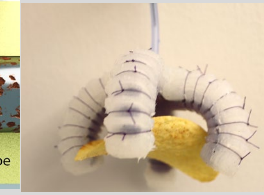





## Application Domains

***New Capabilities***





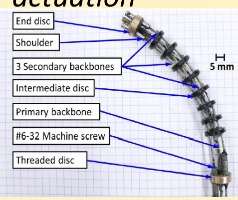


- Minimally invasive surgery
- Assistive technologies
- Agriculture / plant handling
- Inspection & maintenance
- Exploration
- Manufacturing & construction

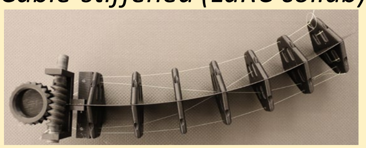
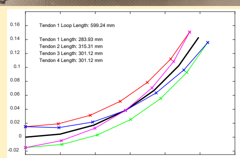
## Novel Designs

**Novel actuation strategies**

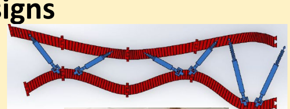
*Screw-based actuation*




*Lightweight Cable-stiffened (LaRC collab)*

**Hybrid rigid/soft designs**

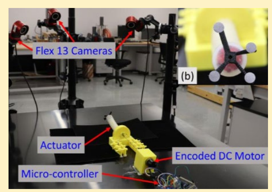

*Endoskeleton*

*Robot-inspired C-collar*

## Soft Mechanism Theory

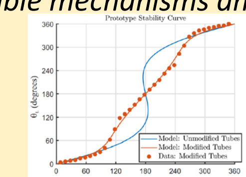
**Kinematic and dynamic analysis**

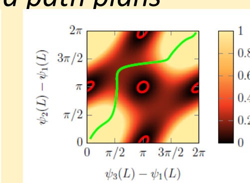
*Simulation and experimental validation*



**Bifurcation & stability analysis**

*Stable mechanisms and path plans*

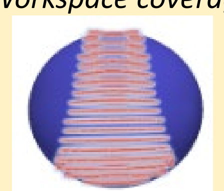
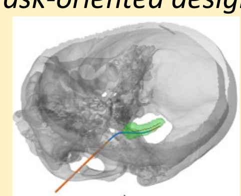




**Computational design optimization**

*Workspace coverage*

*Task-oriented design*

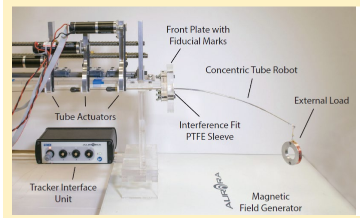



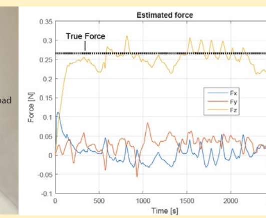
## Computational Intelligence

**Mechanics-based telemanipulation**

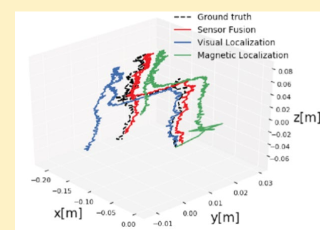
Realtime Mechanics Models


**Proprioceptive force sensing**

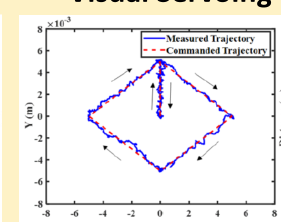





**State estimation**




**Visual Servoing**



NASA EPSCoR Research for LaRC
January 27, 2021

## Intelligent Flight Systems and Trusted Autonomy: Smart cities, automation, robotics

SCOPE the Future with South Carolina Org. for Power and Energy

# Kristen (Garcia) Booth

University of South Carolina
Department of Electrical Engineering
Assistant Professor
kristen.booth@sc.edu
(803) 777-8966

Kristen (Garcia) Booth is an Assistant Professor in Electrical Engineering at the University of South Carolina. She previously held a postdoctoral position at the Ohio State University and was a recipient of the NSF Graduate Research Fellowship (NSF GRFP) during her doctoral studies at North Carolina State University. Kristen's research interests include resiliency and reliability of power electronics converters, AI-integrated power electronics, optimization of power systems, and digital twins for grid modernization and electric aviation.

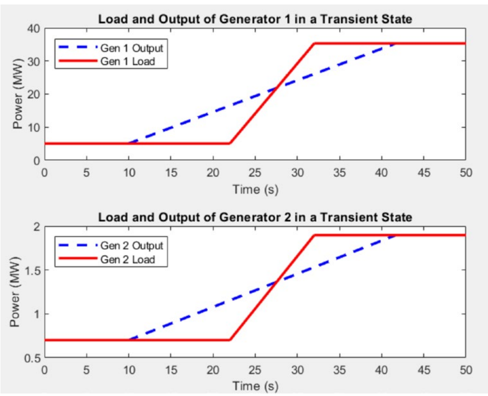
EOL
Energy Optimization Laboratory

# Kristen Booth

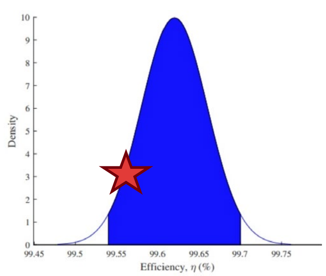
SCOPE
South Carolina Org. for Power & Energy

# DIGITAL TWINS FOR POWER & ENERGY

## Current Research:



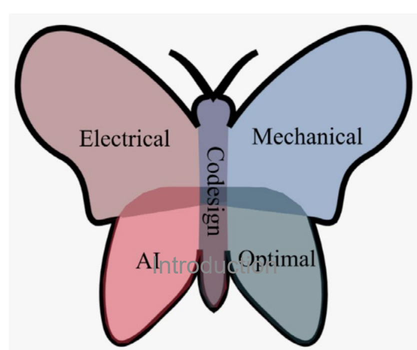

Consolidated generation and ES management.†




Co-design tolerance and variation.

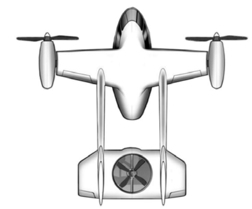
## Future Opportunities:

- Enable advanced integration of subsystems.
- Co-design elements of a system.
- Reduce timeline for Engineering Design Process (EDP).

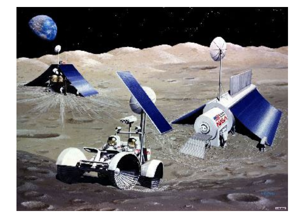



## Applications:

Electric Aviation



Artemis Base Camp*

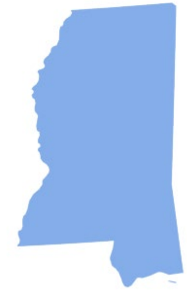


Mars Base*

UofSC Engineering and Computing

† Distribution Statement A. Approved for Public Release, Distribution Unlimited.

* Image credit: NASA



# Intelligent Flight Systems and Trusted Autonomy: Smart cities, automation, robotics

Scalable and robust multiagent reinforcement learning for robot swarms

## Dr. Chuangchuang Sun

Department of Aerospace Engineering
Mississippi State University
email: csun@ae.msstate.edu
Phone: 662-325-7288

Dr. Chuangchuang Sun is an assistant professor in the aerospace engineering department at Mississippi State University since August 2021. Prior to that, he was a postdoctoral associate at MIT (2019-2021) and Boston University (2018-2019). He received his Ph.D. in August 2018 from the Ohio State University and a B.S. degree from the Beijing University of Aeronautics and Astronautics, China in 2013, both in Aerospace Engineering. His research interests focus on control, optimization, reinforcement learning with applications in robotics and aerospace systems.

# Scalable and robust multiagent reinforcement learning for robot swarms

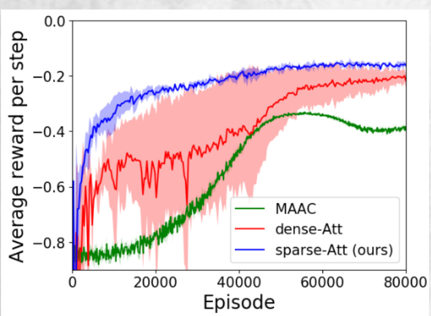
Chuangchuang Sun, Department of Aerospace Engineering

## Learn Adaptive Sparse Communication Graph for Scalability

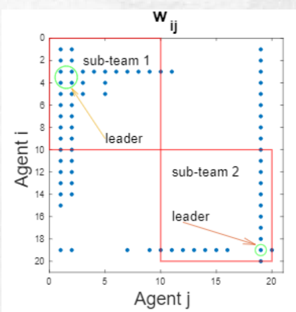
- Key observations:
  - Interactions between agents are often **sparse** at a certain time instance, such as soccer
  - Interchangeability exists among homogeneous agents, which can enable **parameter-sharing**
- Learn communication graph via dot-product attention mechanism [Vaswani17], in a **principled** way without handcraft metrics or prior knowledge.
- New sparsity-induced activation function: adaptive projection onto a probability simplex [Sun20]

## Address Non-stationarity via Considering Peer Learning for Robustness

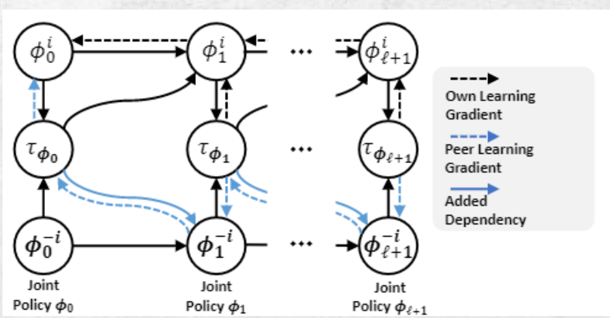
- Mitigate non-stationary effect by modeling gradient updates to directly consider both an agent's own non-stationary policy dynamics and the non-stationary policy dynamics of other agents [Kim20]



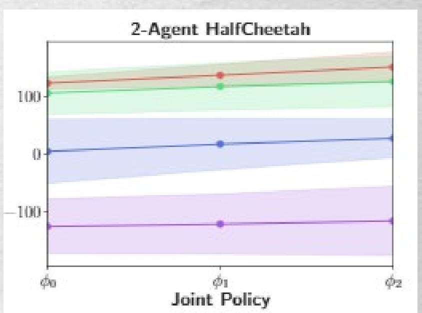

Reward comparison. Baselines: MAAC[Iqbal19], Dense-Att[Agarwal19]




Our learned sparse communication graph



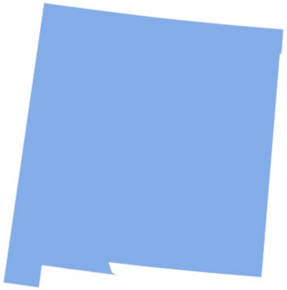

New terms enable Meta-MAPG to actively influence the future policies of other agents as well through the peer learning gradient




Results show that Meta-MAPG (red) successfully adapts to new and learning peer

MISSISSIPPI STATE UNIVERSITY

Chuangchuang Sun
(csun@ae.misstate.edu)



# Intelligent Flight Systems and Trusted Autonomy: Smart cities, automation, robotics

## Predictive Intelligent Guidance and Control for Energy-Efficient Urban Air Mobility and Safe On-Orbit Satellite Servicing


## Hyeongjun Park

Assistant Professor, Department of Mechanical and Aerospace Engineering,
New Mexico State University
Jett Hall 226, Las Cruces, NM 88001
Tel: (575) 646-2024, E-mail: hjpark@nmsu.edu


Dr. Park received the B.S. and M.S. degrees in aerospace engineering from Seoul National University, South Korea, in 2003 and 2008, respectively, and the Ph.D. degree in aerospace engineering from the University of Michigan in 2014. From 2015 to 2017, he was a Post-Doctoral Research Associate of the U.S. National Research Council at Naval Postgraduate School, Monterey, CA. He is currently an Assistant Professor at the Department of Mechanical and Aerospace Engineering, New Mexico State University. His research interests include real-time optimal control of unmanned aircraft systems with consideration of guaranteed stability, high-fidelity flight dynamics model, control surface limitations, path constraints, aerodynamic heating constraints, and real-time computation of the milli-second range. He also has research experiences on guidance and control of spacecraft proximity operations, satellite attitude determination and control, and autonomous aerial manipulation for interaction with the environment.

# Predictive Intelligent Guidance and Control for Energy-Efficient Urban Air Mobility and Safe On-Orbit Servicing

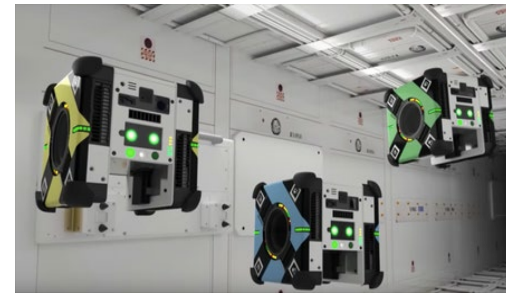
**Dr. Hyeongjun Park, Assistant Professor**

Department of Mechanical and Aerospace Engineering, New Mexico State University

SNL Hypersonic Glider


Northrop Grumman CubeSat Docking

NASA VTXO Mission



NASA Astrobee Robots in ISS

**Contact Information:** Dr. Hyeongjun Park
Email: hjpark@nmsu.edu
**Personal Web Page**: https://wordpress.nmsu.edu/hjpark

**Description/Objectives:** Real-time guidance and control algorithms will be developed based on a deep reinforcement learning method with robust nonlinear model predictive control. The flight environment and operational constraints are directly considered for autonomous systems such as urban air mobility and spacecraft on-orbit servicing applications.

**Strategy/Approach:** We propose using a robust, optimization-based control scheme to replace the current guidance and autopilot layers for aerospace vehicle control. This technique will improve the adaptability of aerospace vehicles to unexpected situations by directly incorporating nonlinear dynamics and operational constraints when calculating control actions.

**Rationale/Need:** Real-time optimal and robust guidance and control algorithms are required to handle complex and reconfigurable constraints, disturbances, and uncertainties for aerospace vehicles.

**Recent/Pertinent Funding Sources**: NASA, NSF, SNL, Northrop Grumman

**Archival Publications (sampling):**

1) G. Cervettini, S. Pastorelli, H. Park, Dae Young Lee, Marcello Romano, Development and Experimentation of a CubeSat Magnetic Attitude Control System Testbed, *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 57, No. 2, pp. 1345-1350 (2021).

2) M. Mammarella, M. Lorenzen, E. Capello, H. Park, F. Dabbene, G. Guglieri, M. Romano, and F. Allgöwer, An Offline-Sampling SMPC Framework with Application to Automated Space Maneuvers, *IEEE Transactions on Control Systems Technology*, Vol. 28, No. 2, pp. 388-402 (2020).

2) K. Lee, H. Park, C. Park, and S. Park, Sub-Optimal Cooperative Collision Avoidance Maneuvers of Multiple Active Spacecraft via Discrete-Time Generating Functions, *Aerospace Science and Technology*, Vol. 93, pp. 105298 (2019).

3) R. Zappulla, H. Park, J. Virgili-Llop, and M. Romano, Real-Time Autonomous Spacecraft Rendezvous and Docking Using an Adaptive Artificial Potential Field Approach, *IEEE Transactions on Control Systems Technology*, Vol. 27, No. 6, pp. 2598-2605 (2019).

NASA EPSCoR Research for LaRC
January 27, 2021

# Intelligent Flight Systems and Trusted Autonomy: Smart cities, automation, robotics

Energy and Emission Aware Autonomy for Safe and Efficient Operation of Unmanned Aerial

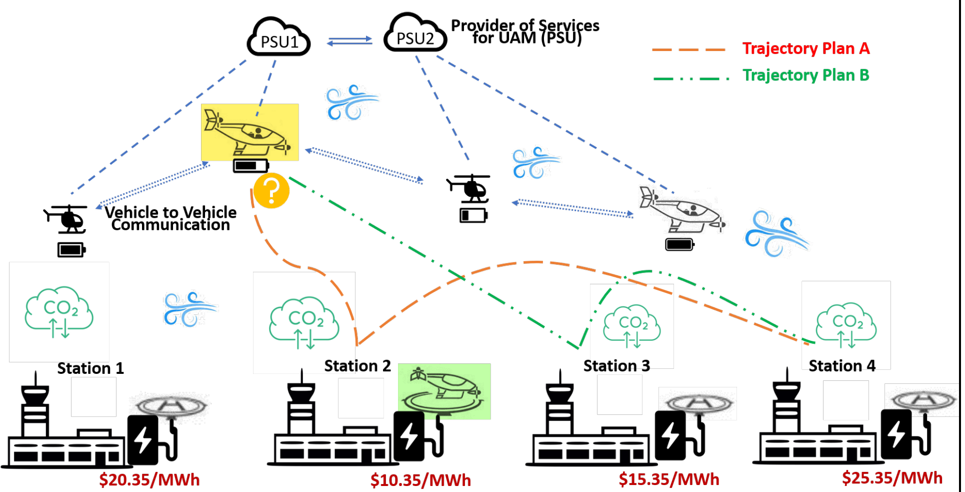

## Liang Sun

Mechanical and Aerospace Engineering Department
New Mexico State University
Jett Hall, Room 104, 1040 S. Horseshoe Street, Las Cruces, NM 88003-8001
lsun@nmsu.edu
(575) 646-4368


Liang Sun has served as an Assistant Professor in the MAE department at NMSU since 2015. He received his PhD degree from Brigham Young University in 2012. From 2013 to 2015, he worked as a Postdoc Research Fellow for a joint appointment of US Air Force Academy and the University of Texas at San Antonio. His current research focuses on integrating energy, emission, and equity in the development of autonomy policies for unmanned aerial systems (UAS). His group has endeavored in developing data-driven and AI-based decision-making, control, and estimation techniques for operating connected unmanned aerial systems (UAS) in GPS-degraded/free environments. In particular, his research group has developed fast and scalable distributed task-allocation algorithms for connected UAS, data-driven wind-estimation techniques for UAS, and reinforcement-learning-based control policies for UAS coordination in GPS-free environments. His lab is equipped with a Vicon motion-capture system and state-of-the-art nano drones for experiments and validation.

# Energy and Emission Aware Autonomy for Safe and Efficient Operation of Unmanned Aerial Systems for Advance Air Mobility

- **A motivating scenario**: future safe, efficient, and sustainable operation of UAS would have to consider vehicle energy consumption, electricity market prices, and emissions profile.




## Proposed Research

- Develop automated energy-consumption modeling methods for heterogeneous UAS platforms.
- Collect data for emission and energy market price by collaborating with experts in national labs and industry.
- Develop innovative algorithms for UAS routing and trajectory-planning using distributed stochastic optimization and multi-agent reinforcement learning
- Verify and validate the proposed techniques in scalable high-fidelity simulations and lab- and filed-experiments with heterogeneous UAS.

## Key Challenges

- Data acquisition for energy market price and emission knowledge and info.
- Multi-objective, multi-stage optimization formulation that balances between solution optimality and efficiency.
- Uncertainty and disturbances in vehicle states, parameters, communication links, and environments.
- UAS heterogeneity in weight, size, power, capabilities, types (e.g., fixed-wing, multi-copter, or hybrid).
- Scalability to handle UAS and /or task addition/removal without suffering a significant loss of performance or increase in complexity.

## PI's Expertise and Resources

- Energy-aware task allocation and planning for drone package delivery.
- Fast and scalable distributed task allocation.
- UAS energy consumption modeling.
- Distributed Model Predictive Control for dynamic systems.
- Reinforcement-learning-based formation flight control for UAS in GPS-denied environments.
- Data-driven wind estimation for UAS using machine learning approaches.
- Start-of-the-art UAS labs and UAS test site at NMSU.

# Intelligent Flight Systems and Trusted Autonomy: Smart cities, automation, robotics

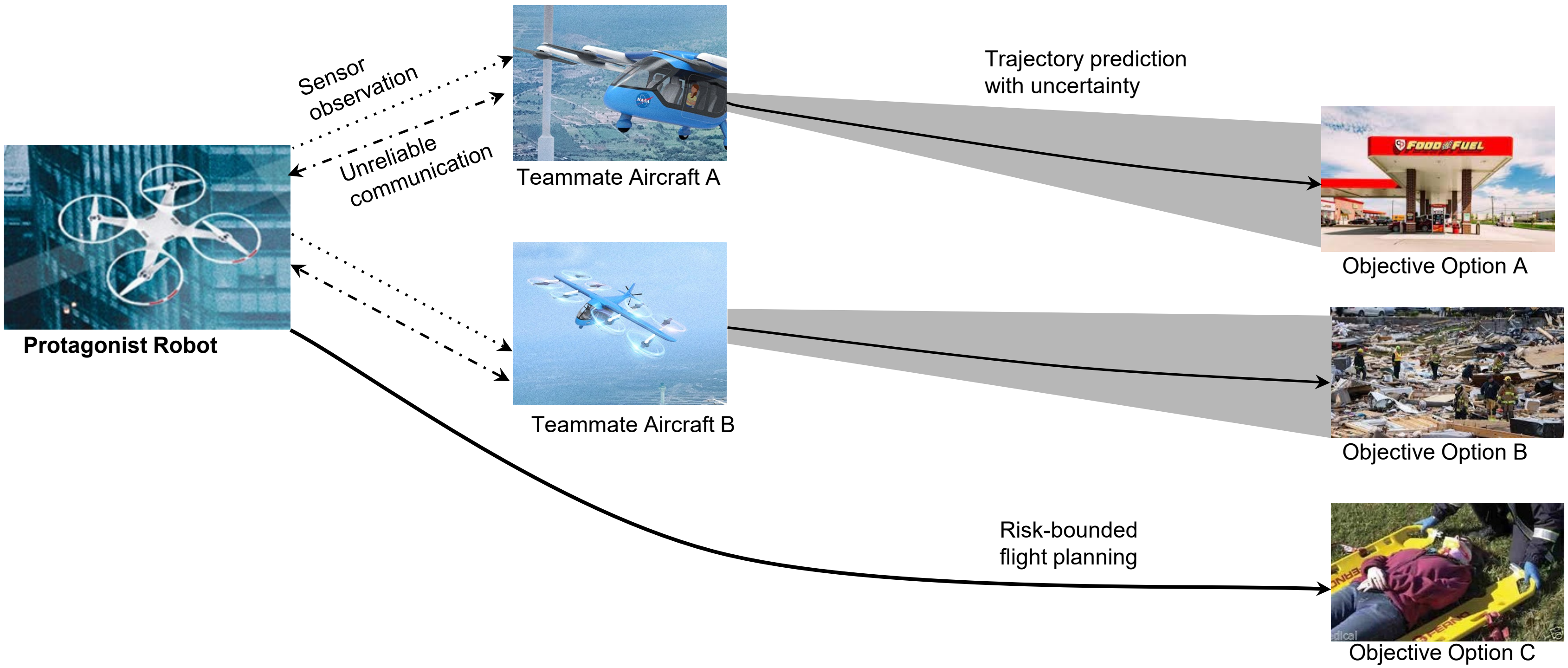
## Control Barriers in Bayesian Learning of System Dynamics


# Vikas Dhiman

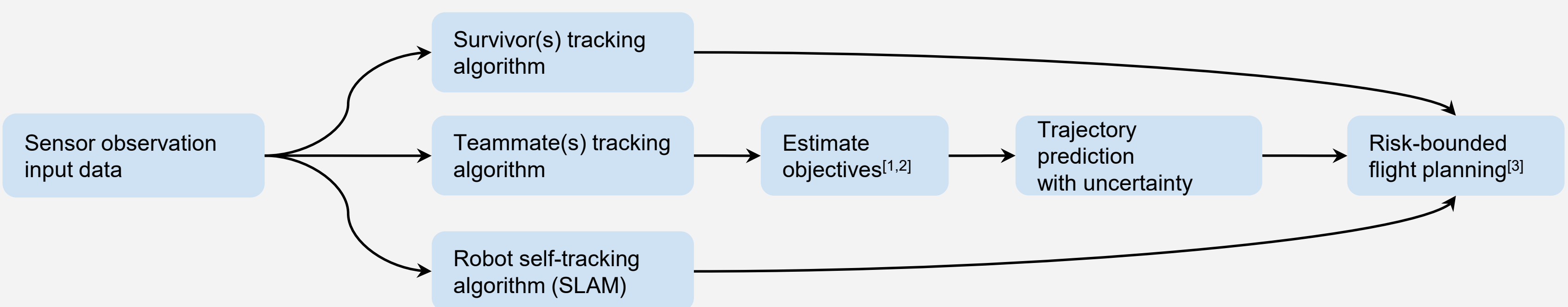
Assistant Professor in Electrical Engineering
Department of Electrical and Computer Engineering
University of Maine
vikas.dhiman@maine.edu


Vikas Dhiman is an assistant professor in Electrical and Computer Engineering at the University of Maine. He completed his PhD from the University of Michigan, Ann Arbor in 2019. His research has focused on robotics-perception and safe control. He has developed algorithms robotic mapping and localization algorithms that are more accurate and take fewer resources. More lately, he has developed novel machine learning algorithms and architectures to apply techniques like reinforcement learning and inverse reinforcement learning for more efficient robotic navigation. His recent work developed risk-bounded safe-control algorithms when robot dynamics are being learned online using Bayesian learning methods.

# Risk-bounded safety for decentralized autonomous flight in search and rescue missions using control barriers




## Data Flowchart For Protagonist Robot




[1] T. Wang, **V. Dhiman**, and N. Atanasov. Learning navigation costs from demonstration in partially observable environments. In *IEEE International Conference on Robotics and Automation (ICRA)*, pages 4434--4440, 2020.
[2] J. Bi, **V. Dhiman**, T. Xiao, and C. Xu. Learning from interventions using hierarchical policies for safe learning. In *AAAI Conference on Artificial Intelligence*, volume 34, pages 10352--10360, 2020.
[3] **V. Dhiman***, M. J. Khojasteh*, M. Franceschetti, and N. Atanasov. Control barriers in Bayesian learning of system dynamics. IEEE Transactions on Automatic Control 2021.

NASA EPSCoR Research for LaRC
January 27, 2021

# Intelligent Flight Systems and Trusted Autonomy: Smart cities, automation, robotics

Foldable robotic arms with minimum actuation, novel grasping mechanisms (robotic hand) for sampling, and a 360° vision system that can be mounted on an Unmanned Aerial Vehicles (UAV).


## Taher Deemyad

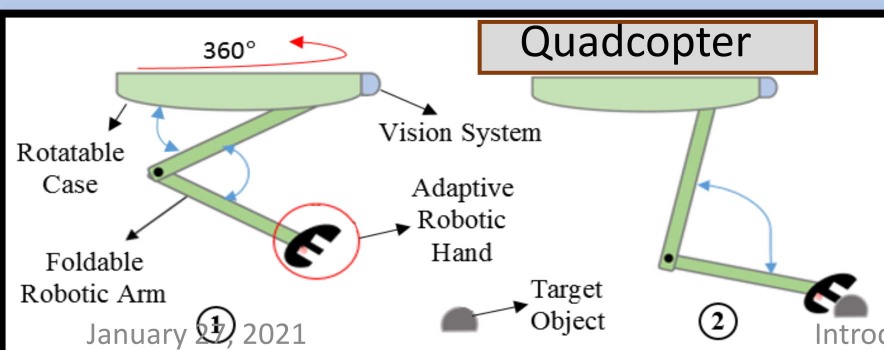
Idaho State University Colonial Hall
Bldg. 35 Room 3
South 8th Ave.
Stop 8060, Pocatello, ID 83209
Tel: (208) 282-5655 Email:deemtahe@isu.edu


Taher Deemyad is the Visiting Assistant Professor & Robotic Lab Director at Idaho State University. Dr. Deemyad got his PhD in Mechanical Engineering with a focus on Robotics and autonomous systems. His research interests include Design Novel Robotic Grippers, Kinematics and Dynamics of Serial and Parallel Manipulators, Autonomous Systems, Navigation, Obstacle Avoidance Systems, Image Processing, Designing Novel Mechanisms for Industrial and Agricultural Purposes, Automation, Optimization, Mechanisms Singularity Analysis.

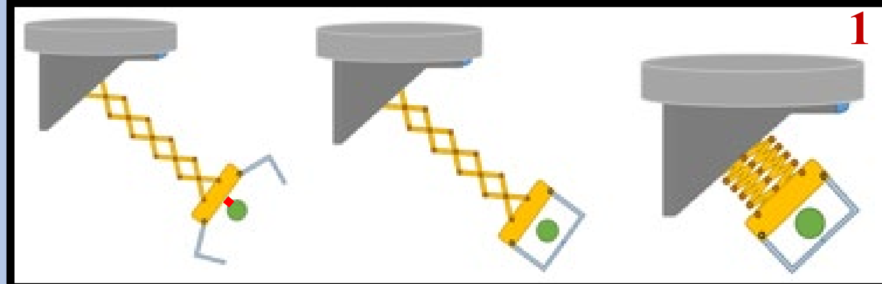
# Smart Sampling Mechanism for UAVs

## Sampling Data, AGVs or UAVs?

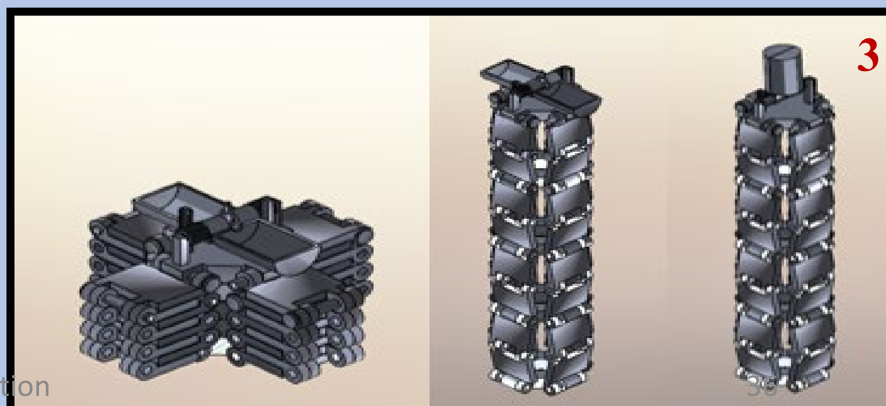
## Schematic of the Detection & Sampling System for UAVs




## Three Mechanisms with a Single Actuator for Sampling

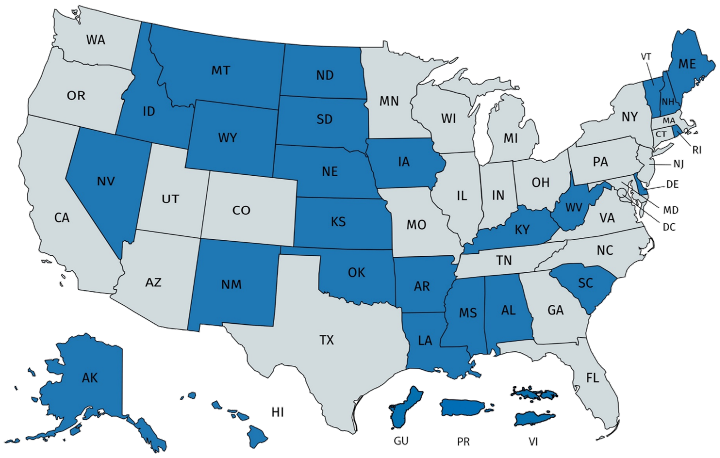


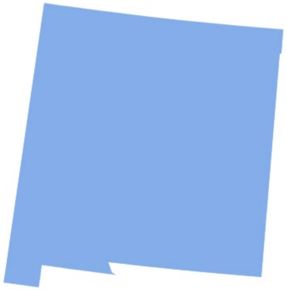




# Topic Area 2:

# Systems Analysis and Concepts: Air transportation system architectures and vehicle concepts





# Systems Analysis and Concepts: Air transportation system architectures and vehicle concepts

## Conceptual Design of Aerobot for Long-Endurance Mission on Venus


# Andreas Gross

New Mexico State University
Mechanical and Aerospace Engineering Department
Las Cruces, NM 88003
agross@nmsu.edu
(575) 646-6179


Andreas Gross graduated with a M.S. degree in Aerospace Engineering from the University of Stuttgart in 1997. His Ph.D. research was concerned with the frozen, equilibrium, and non-equilibrium flow through rocket motor nozzles and earned him a doctorate degree from the University of Aachen in 2002. From 2003 to 2013 he worked as a postdoc and then Assistant Research Professor at the University of Arizona on research topics involving large-eddy simulations, Reynolds-averaged Navier-Stokes calculations, data modal analysis, reduced order modeling, scaled model flight research, autonomous soaring, and renewable energy. In 2014 he joined the aerospace faculty at New Mexico State University. In 2019 he was promoted to Associate Professor. Gross is an AIAA Associate Fellow and serves as faculty advisor for the AIAA student chapter and Design/Build/Fly team. Gross holds a private pilot certificate (single engine land and glider).

# Conceptual Design and Analysis of Aerobot for Long-Endurance Mission on Venus

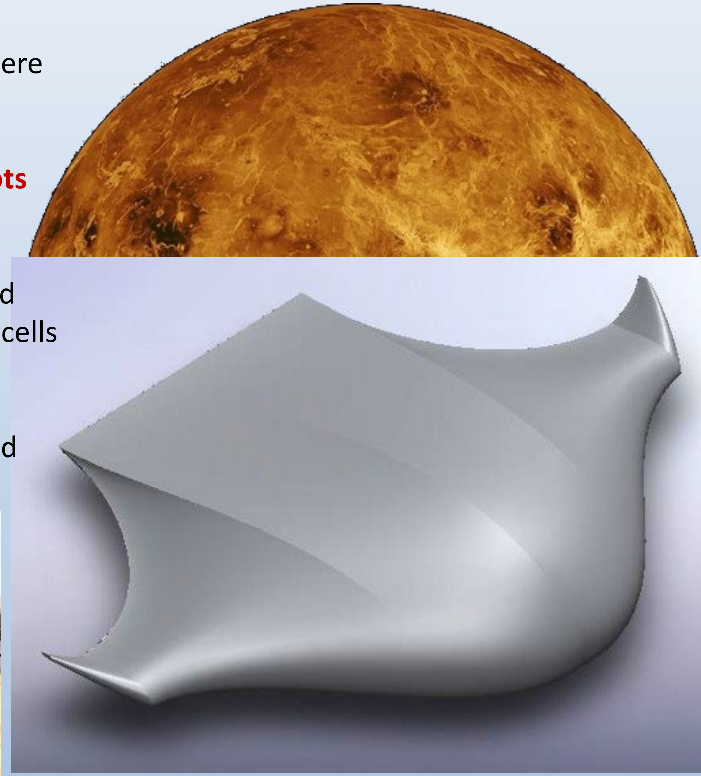
A. Gross (agross@nmsu.edu) and N. Chanover (chanover@nmsu.edu)
New Mexico State University

Grant number: 80NSSC21M0172 - Period of performance 07/01/2021-06/30/2022

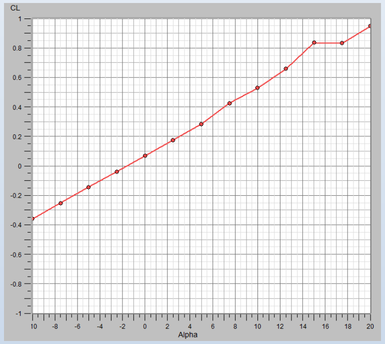
## Description and Objectives:

- **Scientific Merit:** In-situ exploration of Venus atmosphere will contribute to understanding of its formation and evolution, as well as the planet's climate history.
- **Technical Description:** Compared to balloons, **aerobots** offer **increased vertical mobility** which makes them attractive for exploring the Venus atmosphere. The aerobot will exploit **buoyancy** for remaining afloat and **aerodynamic lift** for improved maneuverability. Solar cells will power the vehicle.
- **Objectives:** The objective is to finish the vehicle **conceptual design and analysis** and begin the detailed design of major components.

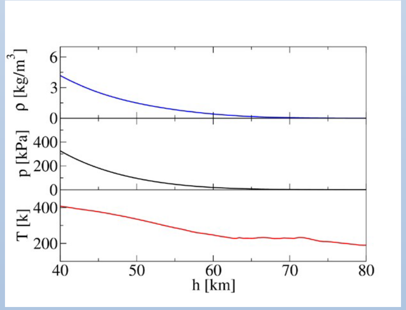
- 1 grad student and 2 undergrad students are presently working on the project; 2 out of the 3 students are minority students
- Abstract submitted for 2022 AIAA Aviation conference



*Perspective view of aerobot*



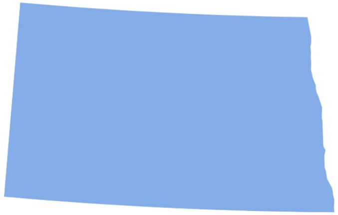

*Lift-curve for a Reynolds number of 12 million (NASA OpenVSP panel method)*




*Venus atmosphere density, pressure, and temperature*

## Approach:

- **Computer aided design (CAD) drawings** of vehicle and internal components
- **Aerodynamic analysis** (lift, drag, moment coefficient, static stability)
- **Buoyancy analysis**
- **Thermodynamic analysis** (radiative and convective heat flux)
- **Analysis of solar power, battery storage and propulsion requirements**
- **Mission analysis** (day-night cycle)
- **Venus atmospheric properties** derived from Magellan radio occultation data



# Systems Analysis and Concepts: Air transportation system architectures and vehicle concepts

## Multiphase High Voltage Electrified Propulsion for Spacecrafts/Aircrafts


# Omid Beik

Assistant Professor
Department of Electrical and Computer Engineering
1411 Centennial Blvd., EE 101R
North Dakota State University
Fargo, ND 58102
Phone: 701-231-1898
Email: omid.beik@ndsu.edu
URL: https://sites.google.com/view/omidbeik


Omid Beik received the Ph.D. degree in electrical and computer engineering from McMaster University, Hamilton, Ontario, Canada, in 2016. He was a Postgraduate Researcher with the Power Conversion Group, University of Manchester, U.K. (2011–2012) and a Postdoctoral Research Fellow at McMaster University, Hamilton, Ontario, Canada (2016–2017). Dr. Beik was a Senior Engineer with Magna Powertrain Inc., Concord, Ontario, Canada (2017-2018), a Lead R&D Engineer with Mirus International Inc., Brampton, Ontario, Canada (2018-2019), and a Senior Manager with Forte Mobility Co. Ltd., Aurora, Ontario, Canada (2020-2021). He is currently an Assistant Professor (tenure-track) at the Department of Electrical and Computer Engineering at North Dakota State University, Fargo, North Dakota, USA.

Current areas of research:

(i) Design and control of high voltage and power electric machines and multilevel power electronics converters for electric aircraft propulsion (EPA) and spacecraft power systems.

(ii) Multiphase design approaches for electric machines and drives for improved power density, efficiency, reliability, and fault tolerance

(iii) Reliability and security of high voltage power electronics converters

(iv) Electromagnetic transients modelling of medium-to-high voltage dc (MVDC/HVDC) systems for the spacecraft and aircraft power systems.

# Multiphase High Voltage Electrified Propulsion for Spacecrafts/Aircrafts

Omid Beik, Ph.D. @ Department of Electrical and Computer Engineering, North Dakota State University

## ❑ 9-phase Propulsion System (MW-scale)

- ➢ A proposed electric spacecraft/aircraft propulsion system with a medium-to-high voltage dc grid (MVdc/HVdc) is shown in Fig. 1. It uses a 9-phase dual rotor generator (DRG) and a 9-phase voltage source converter (VSC).
- ➢ The DRG comprises of two rotors, Fig. 2, a wound field (WF) rotor and a permanent magnet (PM) rotor. PM rotor has a fixed induced stator voltage while the WF rotor induces a variable voltage by adjusting the WF flux via injecting a controlled dc current into the WF rotor winding.
- ➢ **Contributions of the proposed 9-phase system** (Fig. 3): Improved power density, efficiency, increased reliability, fault tolerance, and security. The dual rotor topology facilitates an active control over the generator's output voltage and power providing further degree of redundancy to the vector control implemented by the VSC.

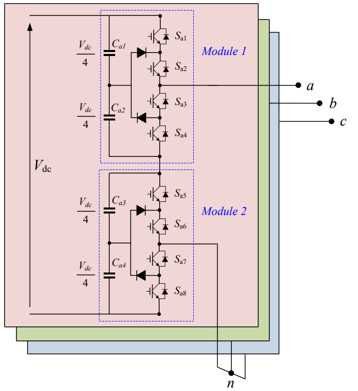



**Fig. 4. A 3-phase leg of proposed 9-phase 5-level VSC**

## ❑ 9-phase 5-level VSC and a Virtual Vector Control (VVC) Scheme

- ➢ A proposed 9-phase 5-level VSC for the DRG is shown in Fig. 4. The proposed 5-level topology is based on two 3-level neutral point clamped converters, and is amenable to higher voltages (up to 13.8 kV) using off-the-shelf power semiconductor switches (6.5 kV).
- ➢ The proposed topology facilitates a scalable configuration with different phase numbers (3-phase, 6-phase, 9-phase, and 15-phase) using commercial power electronics modules.
- ➢ A virtual vector control (VVC) scheme, Fig. 5, is developed that searches for optimal vectors in a space vector modulation technique, and uses a cost function that minimizes energy deviation among the VSC capacitors.

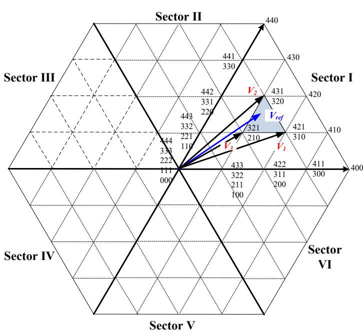



**Fig. 5. Proposed virtual vector control (VVC)**

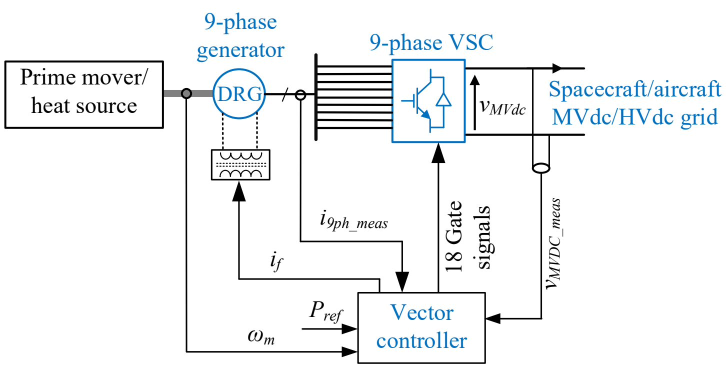



**Fig. 1. Proposed 9-phase electric spacecraft/aircraft prolusion**

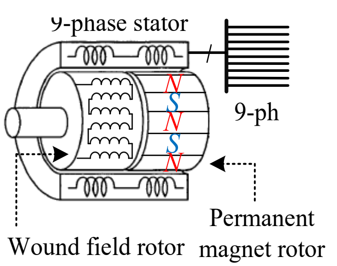



**Fig. 2. Dual rotor generator (DRG)**

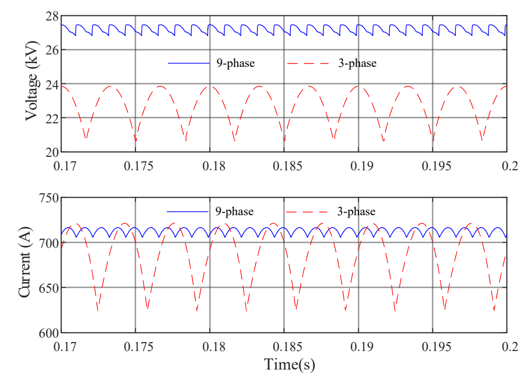
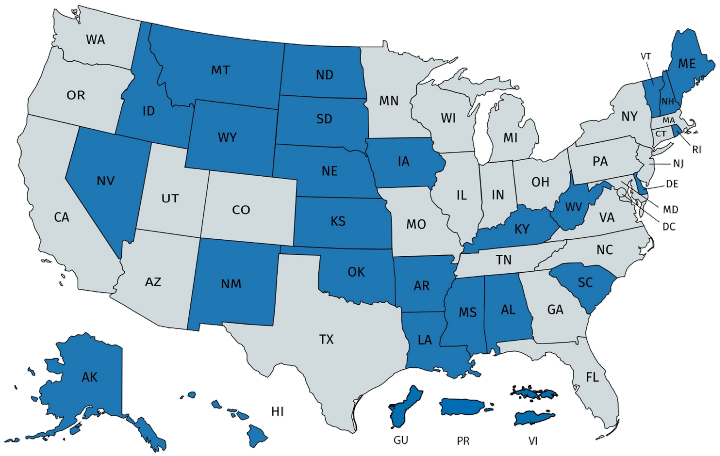


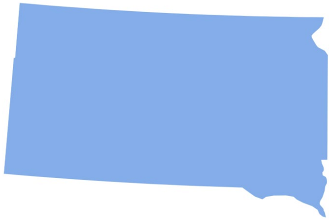

**Fig. 3. 3-phase and 9-phase rectified voltage & current**

Topic Area 3:

# Advanced Materials and Structural Systems: Advanced manufacturing



NASA EPSCoR Research for LaRC
January 27, 2021



# Advanced Materials & Structural Systems: Advanced manufacturing

Enhanced planetary protection via additive manufacturing of internal structures with integrated mechanical and energetic properties for end-of-mission sterilization


## Travis Walker

South Dakota School of Mines & Technology
travis.walker@sdsmt.edu


Dr. Travis Walker is a transport phenomena engineer who works to develop both theoretical and experimental methods that can be applied to the study of complex fluids, soft solids, miscible fluid interactions, and biological systems. He is interested in multiphase systems and the mechanics of materials. His ultimate goal is to provide new detailed insights into the macroscopic characteristics of materials and processes through an in-depth understanding of the fundamental physics that are active at the molecular level.

# Enhanced Planetary Protection via Additive Manufacturing of Internal Structures with Integrated Mechanical and Energetic Properties for End-of-Mission Sterilization

**Travis W. Walker, Katrina J. Donovan, Lori J. Groven, Hoaran Sun**

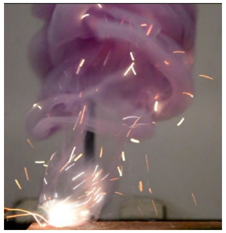
Europa De-Orbit Stage Planetary Protection (PP) Requirement: Level 1

- Proposed solution: terminal sterilization system (TSS) for end-of-mission destruction of the entire vehicle
- Engineering problem: added cost to carry energetic materials
- *Critical need*: multifunctional composite materials with structural strength through the mission and biocidal effects via detonation

Via extensive discussions with Marshall Space Flight Center, principal requirements for planetary protection (Europa Lander) is contamination probability $< 1 \times 10^{-4}$.

***Design Criteria***

(1) Utilize 10-12 kg of material
(2) Heat surroundings to 500°C in 10 s with a hold of 0.5 s
(3) Refrain from exploding
(4) Survive launch and travel time
(5) Ignite reliably by conventional means.



*Long-term goal*: establish integrated, collaborative program of *education* and *research* for the creation of novel, advanced composites for multiple practical uses.

Using our developed platforms, additive manufacturing (AM) can effectively construct physical components containing energetic materials.

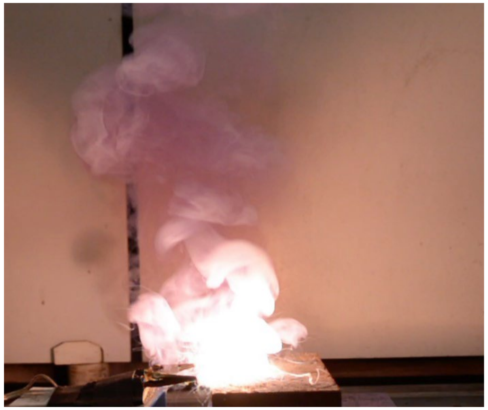
*Research objective*: establish novel strategies to create multifunctional fluoropolymer-energetic composites for structural & biocidal applications.

*Central hypothesis*: metamaterials can be effectively designed by controlling chemistry of fluoropolymer matrix; size, shape, distribution, and surface characteristics of energetic material; and processing of composite.

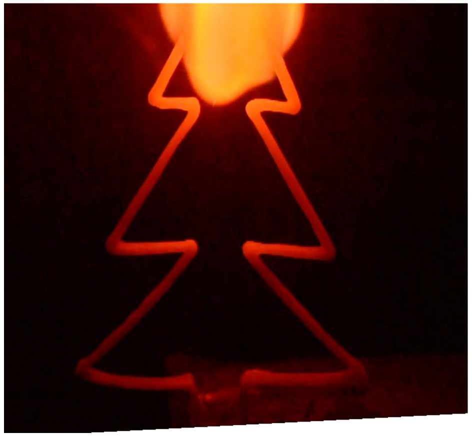
***Specific Aims***

(1) Synthesize fluoropolymers for better binding with energetic materials.
(2) Complete rheology of energetic formulations to guide processing.
(3) Develop printing protocols to optimize strength and biocidal capabilities.

## Preliminary Biocidal Formulations



## Preliminary AM Formulations



# Advanced Materials & Structural Systems: Advanced manufacturing

## Robotics for Automated Additive Manufacturing


## Pierre Larochelle

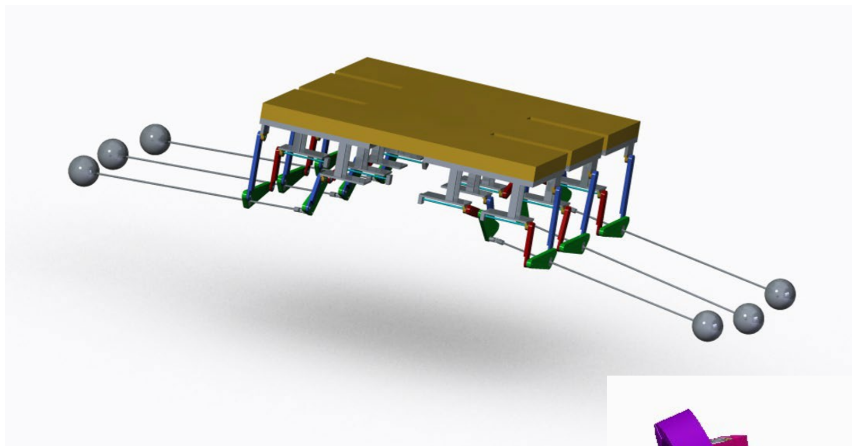
Department of Mechanical Engineering
South Dakota School of Mines & Technology
Rapid City, SD 57701
pierre.larochelle@sdsmt.edu

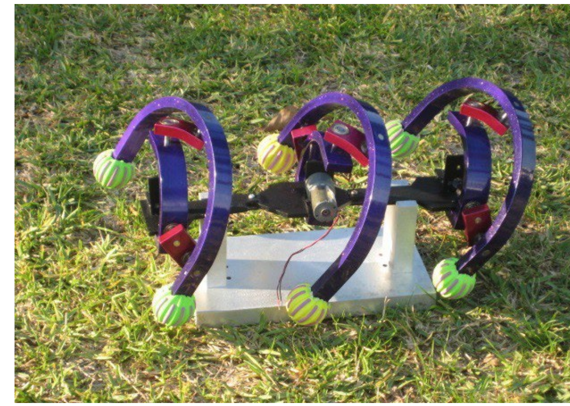

Pierre Larochelle serves as Department Head and Professor of Mechanical Engineering at the South Dakota School of Mines & Technology. Previously he served as an Associate Dean and Professor of Mechanical Engineering at the Florida Institute of Technology. His research focuses on the design of complex robotic mechanical systems and enabling creativity and innovation in design. He is the founding director of the RObotics and Computational Kinematics INnovation (ROCKIN) Laboratory, has over 100 publications, holds three US patents, and serves as a consultant on robotics, automation, machine design, creativity & innovation, and computer-aided design. In 2012 at NASA's request he created a 3-day short course on Creativity & Innovation. This course has been very well received and he has taught it exclusively more than 30 times at NASA's various centers and laboratories across the nation to more than 600 of NASA scientists and engineers. He currently serves as the Chair of the U.S. Committee on the Theory of Mechanisms & Machine Science and represents the U.S. in the International Federation for the Promotion of Mechanism & Machine Science (IFToMM) (2016-22). He serves as a founding Associate Editor for the ASME Journal of Autonomous Vehicles and Systems (2020-23). Moreover, he serves on ABET's Engineering Accreditation Commission (EAC) and as an ABET Accreditation Visit Team Chair. He has served as Chair of the ASME Design Engineering Division (2018-2019), the ASME Mechanisms & Robotics Committee (2010-2014), and as an Associate Editor for the ASME Journal of Mechanisms & Robotics (2013-19), the ASME Journal of Mechanical Design (2005-11), and for Mechanics Based Design of Structures & Machines (2006-13). He is a Fellow of the American Society of Mechanical Engineers (ASME), a Senior Member of IEEE, and a member of Tau Beta Pi, Pi Tau Sigma, ASEE, and the Order of the Engineer.

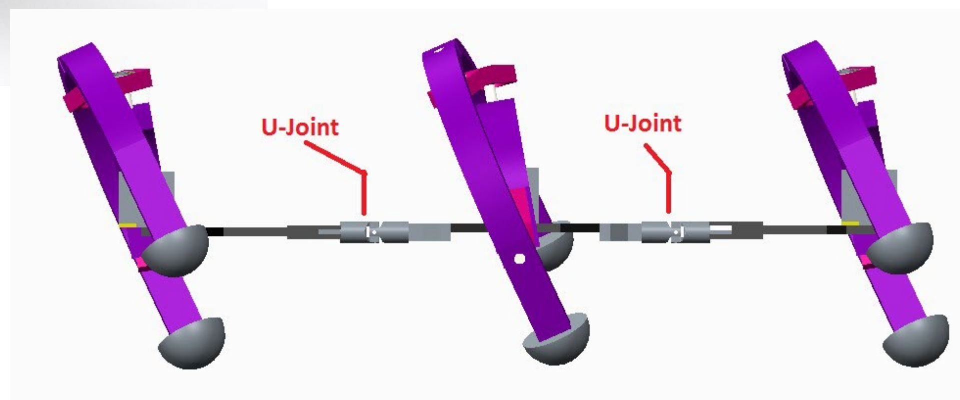
SOUTH DAKOTA MINES

# ROBOTIC WALKING MACHINES FOR AUTOMATED ADDITIVE MANUFACTURING, SURFACE EXPLORATION & ISRU

## SphereWalker and SCUD Walker








- Autonomous or Semi-Autonomous Modalities
- Bio-inspired hexapods that are energy efficient and can carry large payloads

ROCKIN Lab, **P. Larochelle**

CURIOUS SMART TENACIOUS

# Advanced Materials & Structural Systems: Advanced manufacturing

## Manufacturing of Polymer Nanoparticle Composite Coating for Dropwise Condensation

Lei Zhang

University of Alaska Fairbanks
lzhang14@alaska.edu
907-474-6135

Dr. Lei Zhang is an Associate Professor in the Department of Mechanical Engineering at the University of Alaska Fairbanks (UAF). Her research is focused on the development and characterization of novel anti-corrosion coatings on metallic alloys for aerospace applications. She is also an expert in the synthesis of nanoporous materials and the manipulation of their properties and applications in energy storage, gas storage and separation, and water treatment.

# Manufacturing of Polymer Nanoparticle Composite Coating for Dropwise Condensation

**Lei Zhang**, Associate Professor, lzhang14@alaska.edu, Mechanical Engineering, University of Alaska Fairbanks

**Problem**: The existing coating technologies have failed to provide stable dropwise condensation. Coating deterioration and fluctuating process conditions due to vulnerable coatings lead to surface flooding within hours or weeks of use.

**Research Solution**: Manufacturing of polymer nanoparticle composite coating with uniform distribution of nanoparticles at extremely high filler concentrations (>50% vol, denoted as PNCC) that exhibit a high water contact angle, low conductive thermal resistance, and long-term durability for use in dropwise condensation (DWC) applications.

## PNCC Manufacturing

PNCCs are produced by a polymer capillary infiltration method, without any mechanical mixing, enabling high filler concentrations

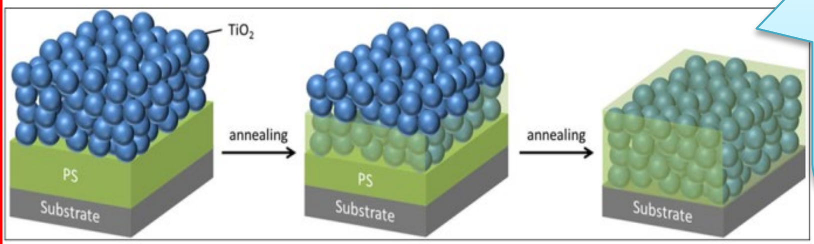



Fig. 1. Schematic illustration showing the process of PNCC formation by capillary infiltration of polystyrene (PS) into the nanopores of $TiO_2$ nanoparticle layer.

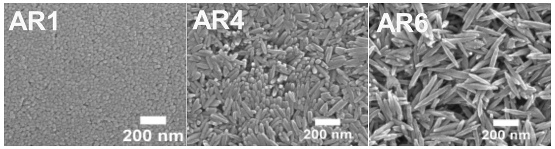



Fig. 2 SEM images showing the morphologies of $TiO_2$ nanoellipsoids. Dimensions for AR1 particles: the minor axis is 2a = 23 ± 3 nm; the major axis is 2b = 29 ± 4 nm; for AR4 particles: 2a = 32 ± 6 nm, 2b = 122 ± 6 nm; for AR6 particles: 2a = 32 ± 5 nm, 2b = 181 ± 33 nm.

Nanofillers of different shapes: $TiO_2$ nanoellipsoids with aspect ratio (AR) from 1 to 6

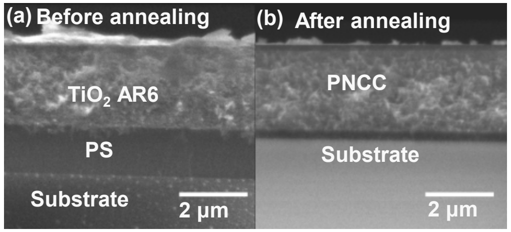



Fig. 3. SEM images showing capillary infiltration of PS into the nanopores of $TiO_2$ AR6 nanoellipsoids layer.

PNCC with uniform distribution of nanoparticles at extremely high filler concentrations

## PNCC Properties and Performance

Low PNCC wettability

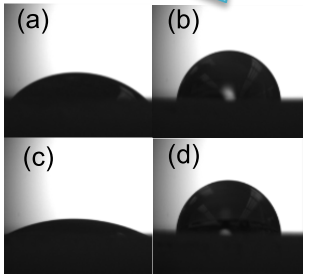



Fig. 4. Water contact angles of (a) $TiO_2$ AR6 coating, (b) PS coating, (c) PS + $TiO_2$ AR6 bilayer before annealing, (d) PS + $TiO_2$ AR6 PNCC after annealing.

High PNCC corrosion resistance

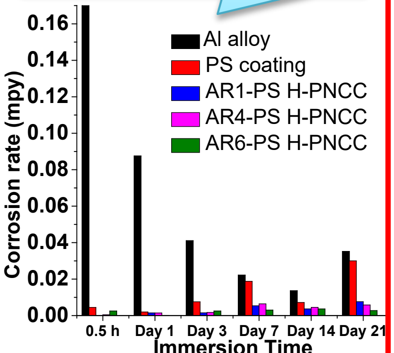



Fig. 5. Corrosion rates of Al alloy and PNCC coatings.

High PNCC durability for DWC

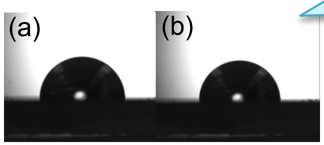



Fig. 6. Water contact angles of PS + $TiO_2$ AR4 PNCC (a) before and (b) after immersion in boiling water for 60 consecutive days.

**Significance**: PNCCs present the properties to promote long-term DWC.

# Advanced Materials & Structural Systems: Advanced manufacturing

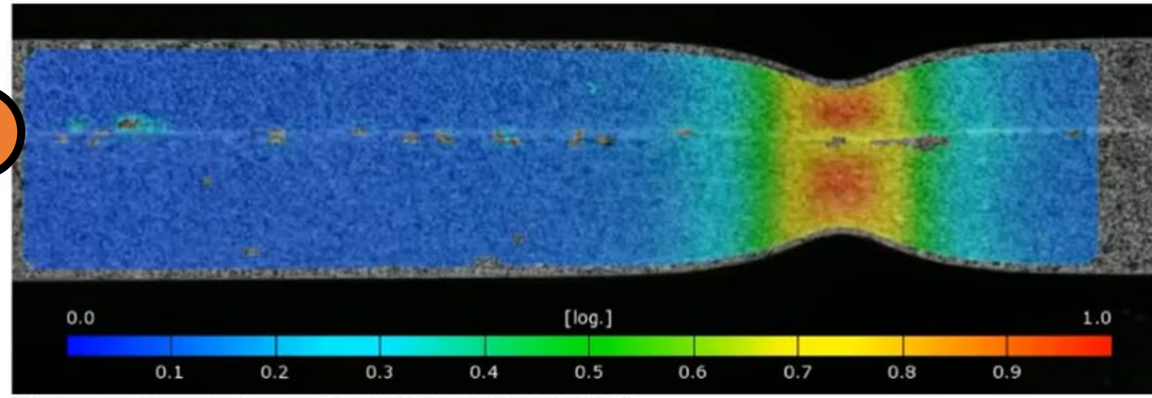
Low density architected materials for space structures

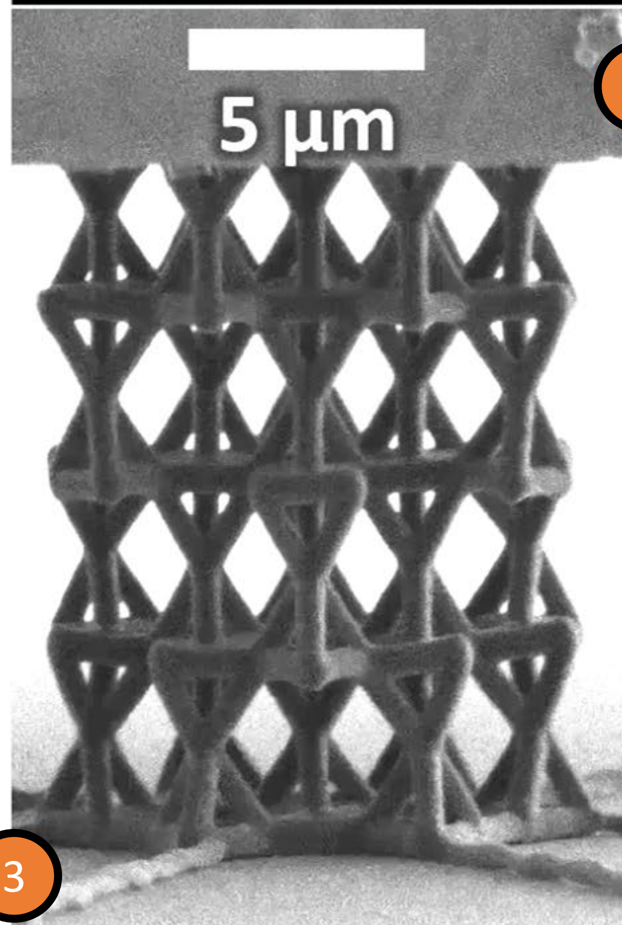

## Andrew Gross

Department of Mechanical Engineering
University of South Carolina
803-777-0183
andrewgross@sc.edu

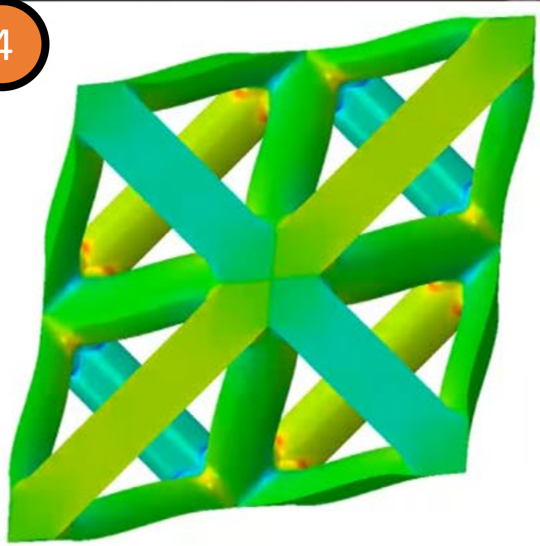

Andrew Gross is an Assistant Professor in the Department of Mechanical Engineering at the University of South Carolina. He leads the Gross Materials Lab, which focuses on the design, fabrication, and characterization of architected materials. He uses computational homogenization and analytical solid mechanics models to reveal the behavior of novel architected materials and cellular materials with imperfections. He has fabricated and characterized the mechanical properties of architected materials with characteristic sizes spanning from 10 nanometers to 100 millimeters. He is currently the Science PI on a NASA EPSCoR R3 project to develop new cellular materials that enable a new aerial platform for Venus exploration.

# Gross Materials Lab at UofSC South Carolina






Research capabilities

1. Mechanical testing (3D-DIC, high temperature)
2. In-situ nanoindentation
3. 3D printing (DIW, SLA)
4. Advanced simulation (unit cell, stochasticity, homogenization, optimization, buckling)

# Advanced Materials & Structural Systems: Advanced manufacturing

## Silanes, Silanization, and Nanocomposites for Coating


# Cheng-fu Chen

University of Alaska Fairbanks,
Department of Mechanical Engineering, UAF
PO BOX 755905 Fairbanks,
AK 99775-5905
cchen4@alaska.edu
(907) 474-7265 (office)

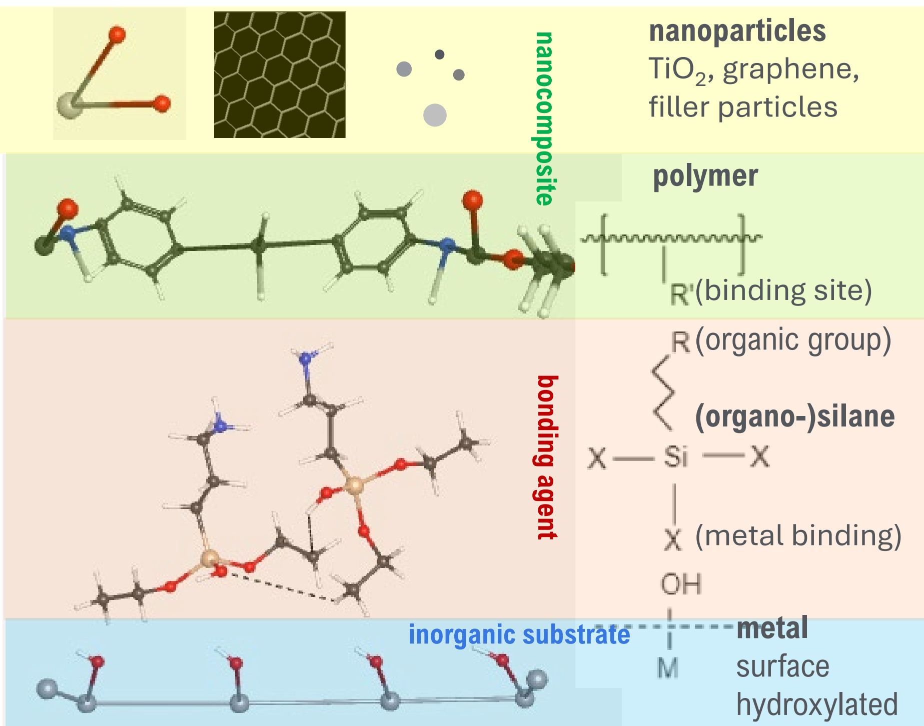

Cheng-fu Chen is Professor of Mechanical Engineering at the University of Alaska Fairbanks. His research interests span in the areas of organic coating on metallic alloys, detection of DNA strands, stress corrosion cracking, thermomechanical and vibrational analyses of electronic packaging and mechanical systems. His ongoing research is primarily on the development of silanized polymeric coatings for corrosion resistance, stress corrosion cracking, and electrostatic discharge management. Dr. Chen has completed a few NASA EPSCoR funded projects.

# Silanes, Silanization, and Applications

**S**ilanes are Si-based compounds, in which each Si atom bonds with four substituent groups like R-Si-$X_3$.

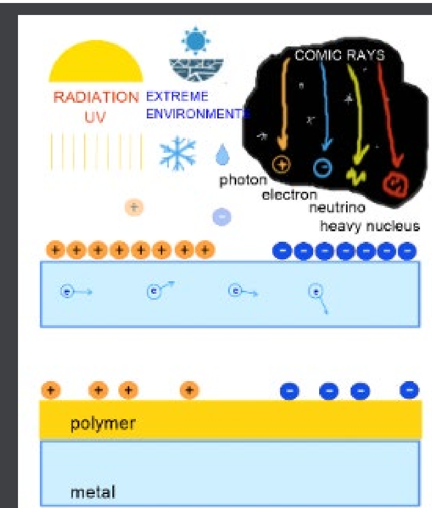
**M**etals and inorganic nanoparticles can be grafted with silanes for organic coating.

**T**o collaborate on the use of coatings in extreme environments.




## Applications of Coating

- Corrosion protection
- Stress corrosion cracking
- Electrostatic discharge
- In extreme conditions (cosmic rays, solar events, low temp)
- Biopolymers (tissue engineering)




funding

1

proposals

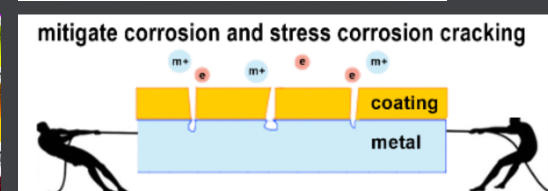
2

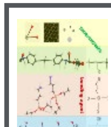
paper

1

manuscript

2



**E**xperienced in conduction and characterization of APTES-primed polystyrene coating.

**L**ooking for collaborations on characterization and testing of nanocomposite coatings in defined extreme environments.

**C**heng-fu Chen, Professor, Mech Engr
University of Alaska Fairbanks
cchen4@alaska.edu

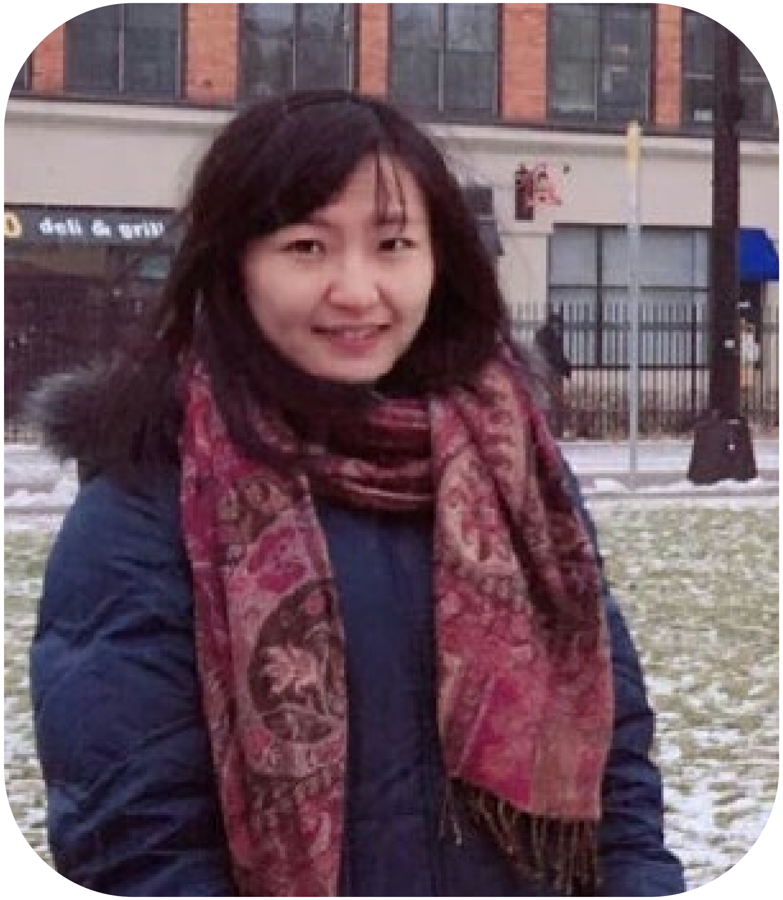
NASA EPSCoR Research for LaRC
January 27, 2021

# Advanced Materials & Structural Systems: Advanced manufacturing

## Multiscale Study of Multifunctional Soft-Matter Based Metamaterials with Applications to Space Exploration

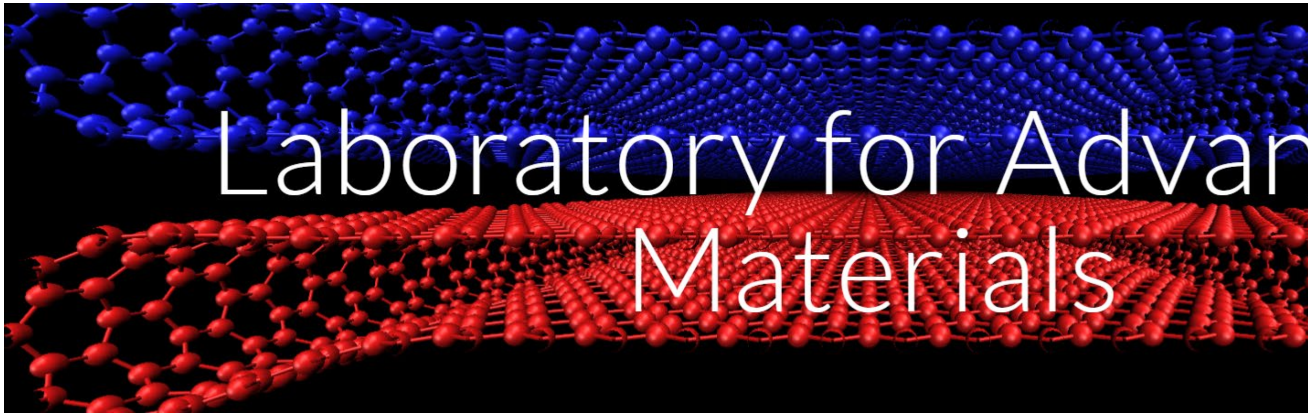

# Jihong Ma

University of Vermont
Department of Mechanical Engineering
Jihong.Ma@uvm.edu

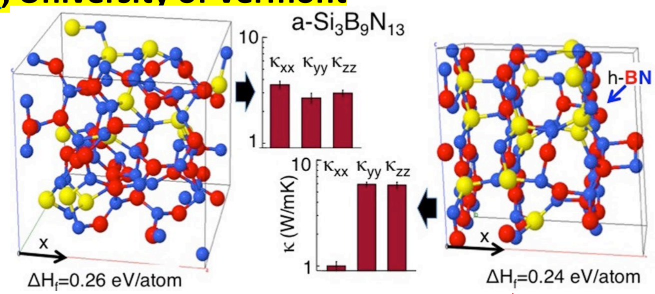
Dr. Ma is an Assistant Professor of Mechanical Engineering. She obtained her PhD in Mechanical Engineering from the University of Minnesota-Twin Cities, and her B.Eng. in Engineering Mechanics from Xi'an Jiaotong University (China). Prior to joining the faculty at Vermont, Dr. Ma was a Postdoctoral Research Associate at the Center for Nanophase Materials Sciences at Oak Ridge National Laboratory, where she worked on soft matter simulations. Dr. Ma is working on the structure-property relationship of materials at multiple scales (from nano- to macro-) via a combination of theoretical analysis, numerical simulations, and experimental characterizations. Her research goal is to uncover or enhance material performance characteristics for industrial, medical, and aerospace applications.

Jurisdictional research capabilities associated with this research include polymers; acoustics; metamaterials; materials science; atomistic simulation; additive manufacturing; chemical engineering; physics; microgravity; machine learning.



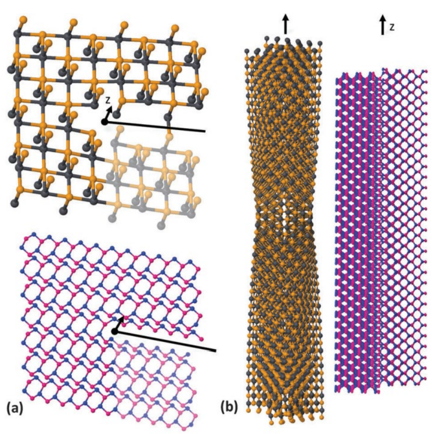

**PI: Dr. Jihong Ma, Jihong.Ma@uvm.edu, University of Vermont**

*Title figure: Ma & Dumitrica, Phys. Rev. Mater. 2017*




*Ma, et al, J. Phys. Chem. C 2016*

Ceramic composites

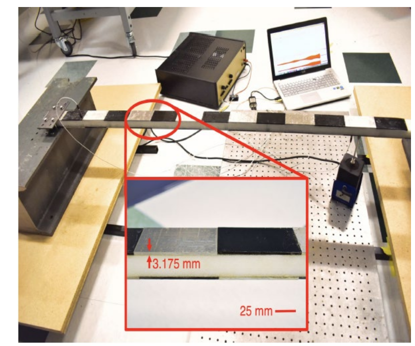


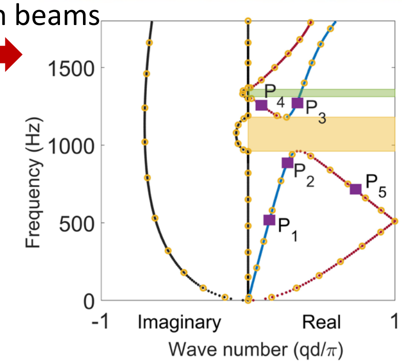

Semiconductor

*Ma, et al, Phys. Chem. Chem. Phys. 2016*

## Laboratory Capabilities:
## Structure-Property Relationship with Aerospace Applications

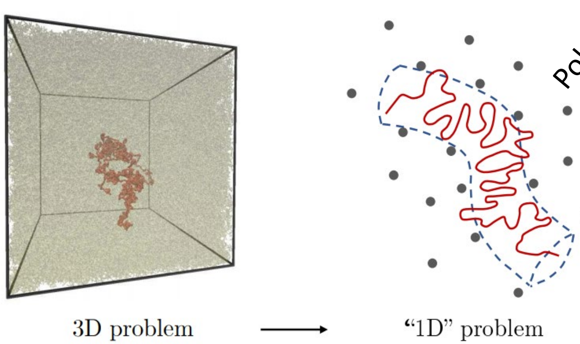
Sandwich beams



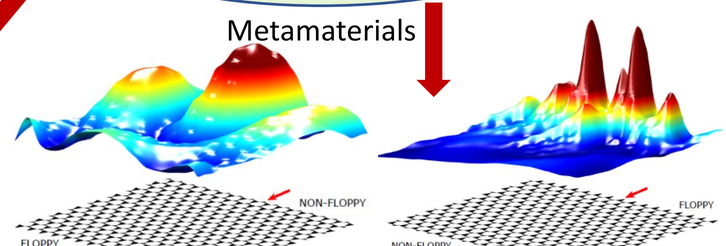

*Joubaneh & Ma, J Mech. Phys. Solids, under review*

Polymers




*Ma, et al, Phys. Rev. E 2021*

Metamaterials




*Ma, et al, Phys. Rev. Lett. 2018*

NASA EPSCoR Research for LaRC
January 27, 2021

# Advanced Materials & Structural Systems: Advanced manufacturing

Electro-Catalytic Flow-Cell System to Enable Space Travel by In Situ Resources - an Atoms to Space Approach

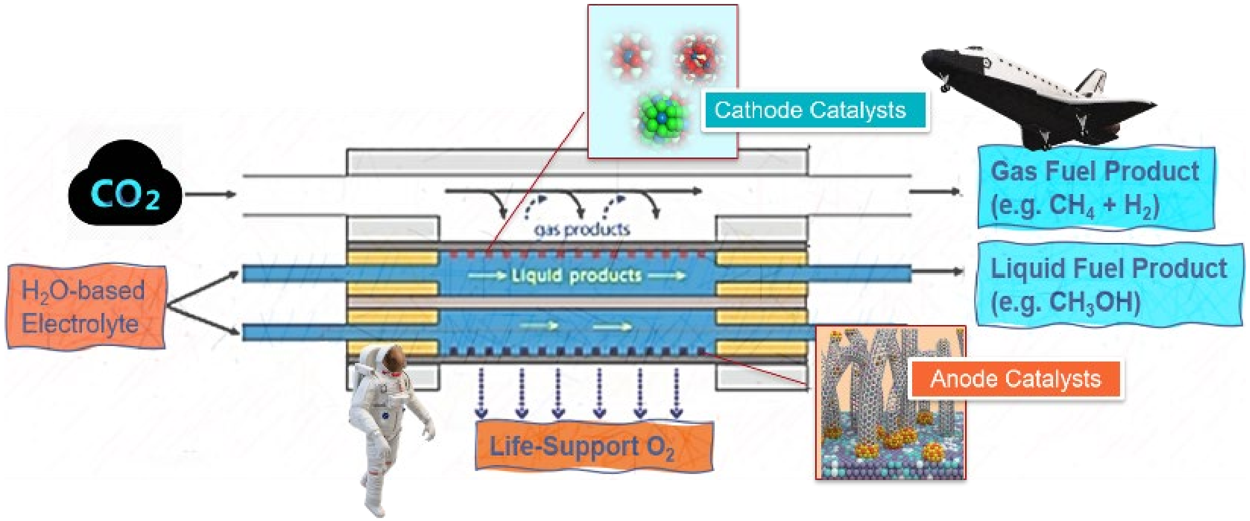
## Ming Yang

Department of Chemical and Biomolecular Engineering
Clemson University
Email: myang3@clemson.edu

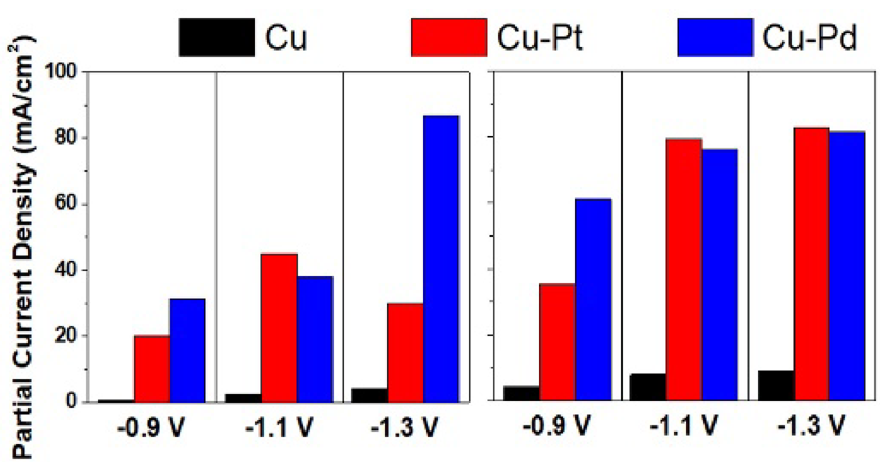
Ming Yang is an Assistant Professor in the Department of Chemical and Biomolecular Engineering at Clemson University. Yang is one of the researchers who launched the concept of single-atom catalysis that emphasizes the minimal use of expensive metal components to boost overall reaction performances. Yang's research funded by the NASA SC Space Grant Consortium has been centered around the design of cost-effective catalysts coupled with electrochemical flow cell reactors to directly convert in-space carbon dioxide and water into fuel molecule such as methane and life-supply oxygen at ambient temperature and pressure as separated products. Prior to joining Clemson, Yang had five years of industry experience at General Motors R&D in Michigan, and he remains serving as a Director of Michigan Catalysis Chapter under the North American Catalysis Society.

# Converting In-Space $CO_2$ into Propulsion Fuel through Cost-Effective and High-Performance Electrocatalysis Process

Ming Yang, Clemson University, myang3@Clemson.edu




Concept of One-Stage Fuel and Oxygen Generation from CO2 and H2O in Mild Conditions




Encouraging Flow-Cell Tests Data Showing over 10x Improvement Over Benchmarks

# Advanced Materials & Structural Systems: Advanced manufacturing

## Controlling Microstructure and Defects for Solidification-based Metal Additive Manufacturing


## Lang Yuan

Department of Mechanical Engineering
University of South Carolina
Tel: (803) 576-8226
Email: langyuan@cec.sc.edu

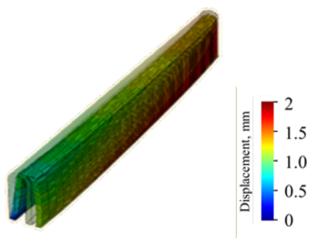

Lang Yuan is an Associate Professor at the University of South Carolina (UofSC). He led the development of physics-based computational models for advanced solidification processes, including casting and additive manufacturing (AM) processes at GE Research before joining UofSC in 2018. Currently, his research focuses on 1) advanced machine architecture for grain refinement in laser powder bed fusion (LPBF) AM; and 2) Integrated Computational Materials Engineering for materials and process development. He directs the Metal AM laboratory at UofSC, where hosts an open architecture LPBF printed with unique processing features and a suite of high-performance computational models from part-level residual stress to microscale grain structure and  composition prediction.

# Metal Additive Manufacturing Lab at UofSC

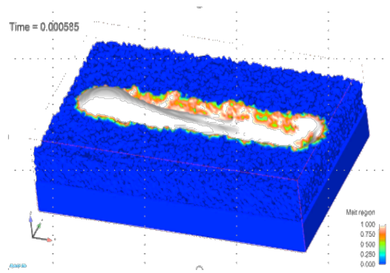
Current research focuses on both numerically and experimentally controlling microstructures and defect formation during alloy solidification to achieve desired mechanical and/or functional properties via additive manufacturing (AM)

- Multiscale computational models for AM
  - Part-level thermal-stress model
  - Melt pool dynamics model
  - Solidification microstructure model

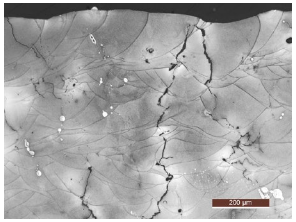
- AM process monitoring and innovation
  - Solidification cracking in Al-based and Ni-based alloys
  - In situ monitoring via thermal camera
  - Ultrasound-assisted AM



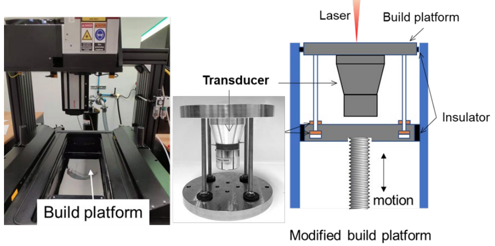
Distortion prediction



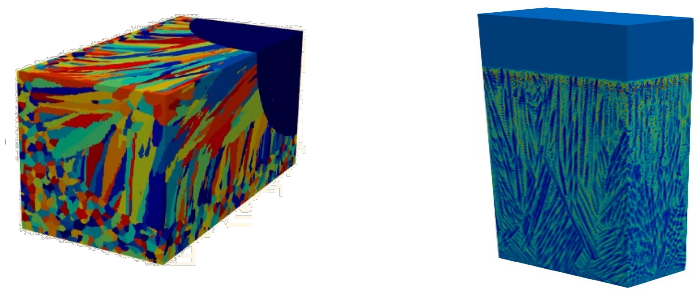
Melt pool dynamics

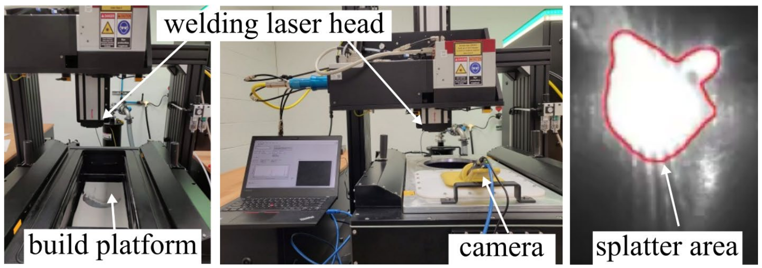


Cracking in Al6061



Process modification


Predictions on grain and subgrain structures with segregation



In situ process monitoring and control

- **Current materials:** Al6061, Tungsten, IN625, Rene108, Rene65, SS316L

POC: Lang Yuan, langyuan@cec.sc.edu

UofSC Engineering and Computing

NASA EPSCoR Research for LaRC
January 27, 2021

# Advanced Materials & Structural Systems: Advanced manufacturing

Design, Manufacture, and Analysis of Mechanical Metamaterials for Aerospace Applications


## Uttam Kumar Chakravarty

University of New Orleans
Department of Mechanical Engineering
Engineering Building, Room 922
2000 Lakeshore Drive, New Orleans, LA 70148
Email: uchakrav@uno.edu, Tel.: (504) 280-6191, Fax: (504) 280-7413


Dr. Chakravarty is from jurisdiction Louisiana and is an expert in design, additive manufacturing, computational and experimental mechanics of materials and structures. He is an Associate Professor, Huntington Ingalls Inc. Professorship of Engineering VI, in the Department of Mechanical Engineering at the University of New Orleans (UNO). Before joining UNO, he worked as a National Research Council Post-Doctoral Research Associate at the U.S. Air Force Research Laboratory, Eglin Air Force Base, Florida.

# Design, Manufacture, and Analysis of Soft Matter-Based Metamaterials for Aerospace Applications

THE UNIVERSITY of NEW ORLEANS

Uttam K. Chakrabarty, Ph.D.

Associate Professor, Department of Mechanical Engineering, University of New Orleans, Louisiana 70148, USA

## Project Objectives and Goals

- Design a novel, multifunctional. soft matter-based metamaterial for aerospace applications
- Manufacture the soft metamaterial using an advanced manufacturing process
- Analyze the soft metamaterial using the computational, experimental, and analytical methods

| Variable parameters | | Mechanical, Electromagnetic, Acoustic, and Modal Characteristics |
|---|---|---|
| Dimension of stiff structure, Applied load, Gravity, Sound, Applied electric and magnetic field excitations | Effects on → | Viscosity, refractive index, acoustic properties, fracture toughness, crack propagation, frequency, electrical conductivity, capacitance, EMI shielding, magnetic flux density, and magnetic permeability |

**Major Contribution** →

- Design and manufacture a new soft matter-based metamaterial
- Numerical solution by the commercially available tool
- Experimental characterization by using MTS, load cell, DIC, Shaker, etc.

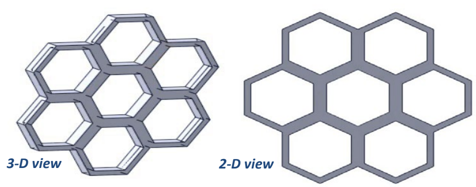
## Background

- Multifunctional metamaterials are engineered to have properties that are not found in naturally occurring materials


**Examples of Metamaterials**

- Soft matter-based metamaterials have improved performances in terms of absorbance [1], mechanical and dynamic behavior [2], integrated sensory, decision-making functionalities, actuation [3], electrical signal dependent modal behavior [4], and magnetic properties
- There is a significant scope of exploring new characteristics, especially focusing on space applications
- For space applications: microgravity, extreme thermal environment, electromagnetic response, and acoustic performances are among the many features to look at.

## Design a soft, composite, matter-based metamaterial



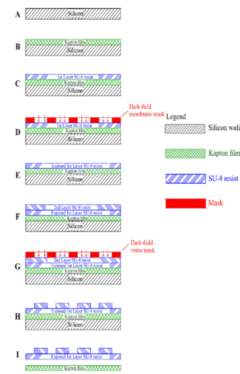

*Proposed Design*

**Stiff Skeleton** → Filled with → **Soft Hydrogel**

| Stiff Skeleton | Soft Hydrogel |
|---|---|
| • Stiff skeleton is a fractal structure of hexagonal shape<br>• Made of SU-8 using the photolithography process<br>• Internal gap ranges from 1-5 mm | • Soft polyacrylamide (PLA) hydrogel is inserted as the filler material<br>• Soft PLA is mixed with multiwalled carbon nanotubes (MWCNTs), cellulose nanofiber (CNF), and NdFeB microparticles |

## Manufacturing: Photolithography Process [5]

Photomask preparation using CAD software
↓
Conditioning the substrate surface: Silicon wafer
↓
Deposition and soft bake of the first layer of photoresist SU-8
↓
UV exposure of the pattern using 500 W Oriel Flood Exposure Source model 97532
↓
Repeating the deposition, soft bake, and UV exposure for subsequent layers
↓
Mixing the soft PLA hydrogel with MWCNTs, CNF, and NdFeB microparticles
↓
Infusing the soft PLA hydrogel into the cavities of the stiff skeleton



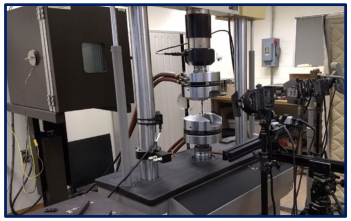

## Computational Analysis

- A finite element model will be developed for the soft composite metamaterial
- The commercially available Ansys Workbench will be used for Multiphysics analysis
- The transient structural module will be utilized for investigating fracture performance (fracture toughness and crack propagation)
- The modal (vibration) analysis will evaluate the natural frequencies and mode shapes of any proposed structure of the soft metamaterial
- Ansys HFSS will be considered for examining the electromagnetic performances (electrical conductivity, capacitance, and EMI shielding) and magnetic performances (magnetic flux density and magnetic permeability) of the soft metamaterial
- Other properties in terms of absorption coefficient, viscosity, refractive index, and acoustics will be explored and investigated for space applications
- A zero or microgravity environment will be taken into consideration during the computational analysis

## Analytical Analysis

- The equation of motion for the manufactured structure will be explored
- The multifunctionality of the soft metamaterial will be considered
- A correlation between the electric field sensitivity to the mechanical stress-strain properties will be analyzed
- The dielectric and magnetic performances of the soft, composite, matter-based metamaterial will be evaluated analytically
- Effect of the geometric dimensional dependency of stiff structure and soft hydrogel will be characterized for the different performance parameters

## Experimental Analysis



*Material testing setup*


*Load cell*

*Risepro decibel meter*

*Vibration experimental setup with the DIC system*

## Expected Outcomes

The soft, composite, matter-based metamaterial would have the following properties.

- Better performance in zero gravity and microgravity environments
- Negative refractive index and excellent other optical properties
- Improved mechanical behavior in terms of fracture toughness, tensile and compressive strength, crack propagation, resonance frequency, etc.
- Better dielectric, magnetic, and acoustic properties

## References

1Kowerdziej, R. and Jaroszewicz, L., 2019. Tunable dual-band liquid crystal based near-infrared perfect metamaterial absorber with high-loss metal. *Liquid Crystals*, **46**(10), pp. 1568–1573.

2Pishvar, M. and Harne, R.L., 2020. Soft Topological Metamaterials with Pronounced Polar Elasticity in Mechanical and Dynamic Behaviors. *Physical Review Applied*, **14**(4), pp. 044034: 1–7.

3El Helou, C., Buskohl, P.R., Tabor, C.E. and Harne, R.L., 2021. Digital logic gates in soft, conductive mechanical metamaterials. *Nature Communications*, **12**(1), pp. 1–8.

4Kowerdziej, R., Wróbel, J. and Kula, P., 2019. Ultrafast electrical switching of nanostructured metadevice with dual-frequency liquid crystal. *Scientific Reports*, **9**(1), pp. 1–8.

5Rubio, J.E. and Chakravarty, U.K., 2019. Experimental structural dynamic measurements of an artificial insect-sized wing biomimicking a crane fly forewing. *Acta Mechanica*, **230**(12), pp. 4273–4286.

# Advanced Materials & Structural Systems: Advanced manufacturing

Simulation of Processing-Induced Effects in Advanced Manufacturing

## Borys Drach

Mechanical & Aerospace Engineering
New Mexico State University
Jett Hall 234
1040 S. Horseshoe Street
Las Cruces NM 88003
575-646-8041, borys@nmsu.edu

Borys Drach is an Associate Professor in the Mechanical & Aerospace Engineering Department at the New Mexico State University. His research focuses on analysis and simulation of multi-physics response of advanced materials including composite and additively manufactured materials. Dr. Drach has recently developed an experimentally validated numerical approach to simulation of processing-induced residual stresses in 3D woven composites manufactured via resin transfer molding. The approach will enable the composites community to study contribution of residual stresses to static and fatigue response of woven composites, as well as aid the discovery of ways to mitigate the residual stresses or tailor them for improved performance under a given loading regime. One of the current research directions focuses on development of in-situ monitoring of additive manufacturing processing for detection of defects with the goal of on-the-fly adjustment of control parameters during printing.

# NASA EPSCoR: Next Generation Additive Manufacturing for Space Applications

***Contact***: *Borys Drach, Associate Professor, [borys@nmsu.edu](mailto:borys@nmsu.edu)*
*Mechanical & Aerospace Engineering, New Mexico State University*

**Goal**: integrated approach combining in-situ monitoring of additive manufacturing (AM) processes, ex-situ microstructural characterization, and modeling for optimization and real-time control of AM parameters for improved quality of AM components

**Team**: New Mexico State University, University of New Mexico, New Mexico Tech, collaborator: Navajo Tech

**Materials and technologies:**

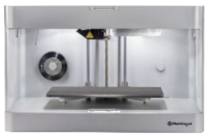
**metals** (DED)


optomec.com

**polymers** (FFF)


ultimaker.com

**composites**



markforged.com

**In-situ sensing:** ultrasound, acoustic emission, thermal imaging

**Ex-situ characterization:** ultrasound, optical microscopy, X-Ray computed microtomography, mechanical testing

**Modeling**: finite element analysis, micromechanics, artificial convolutional neural network

**Research objectives:**

- Develop in-situ sensing for real-time monitoring of component quality
- Correlate processing parameters with probability of defects (e.g. pores and microcracks)
- Develop models linking processing parameters to overall properties of AM specimens
- Develop a real-time control system for modification and optimization of process parameters to improve quality of AM components

NM STATE New Mexico State University

THE UNIVERSITY OF NEW MEXICO

NEW MEXICO TECH SCIENCE • ENGINEERING • RESEARCH UNIVERSITY

NAVAJO TECHNICAL UNIVERSITY

Dr. Dehghan Niri (Co-I), Ms. Ghasemi (Ph.D. student), and Dr. Drach (Co-I) discussing in-situ thermal imaging for composite AM (NMSU)

First set of AlSi10Mg specimens manufactured using a reference set of AM DED parameters and characterized using X-Ray CT at Navajo Tech

# Advanced Materials & Structural Systems: Advanced manufacturing

## Stochastic modeling for advanced manufacturing: Machine Learning and Statistical Modeling

Pejman Tahmasebi

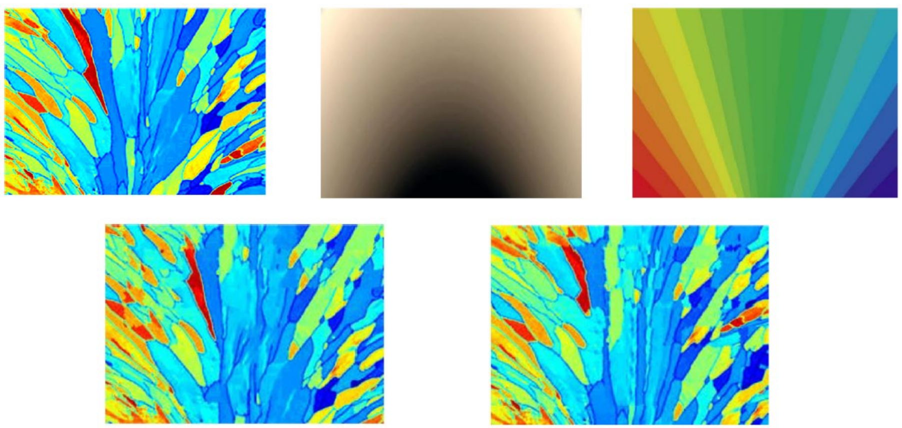
Department of Petroleum Engineering
Department of Civil Engineering
University of Wyoming
ptahmase@uwyo.edu
307-766-6555

Pejman Tahmasebi is working on materials characterization, machine learning, mechanical modeling and also multiscale geo-systems. Dr. Tahmasebi is working with several agencies, such as NSF, DoE, NIH, and NASA on a variety of projects.

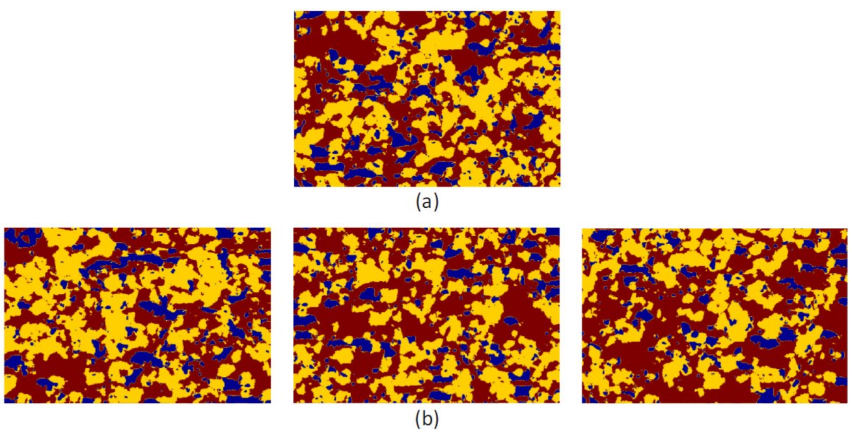
# Pejman Tahmasebi, Associate Professor, University of Wyoming

## Stochastic modeling for advanced manufacturing: Machine Learning and Statistical Modeling

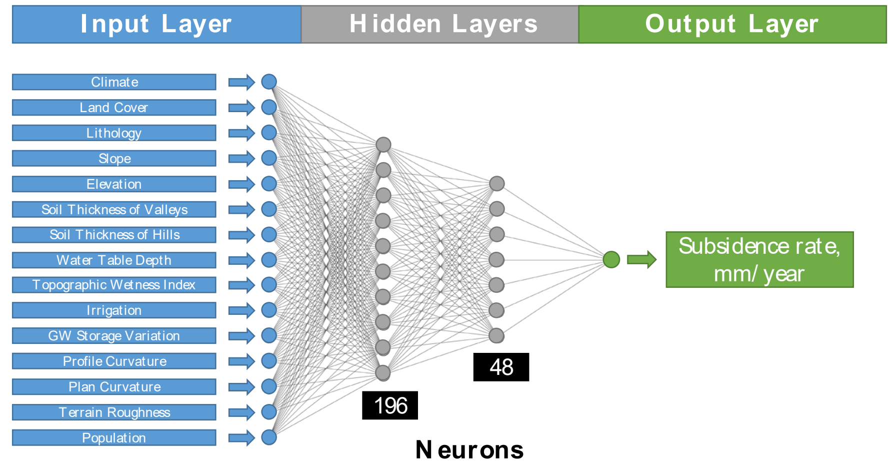
Nonstationary oxygen-free copper

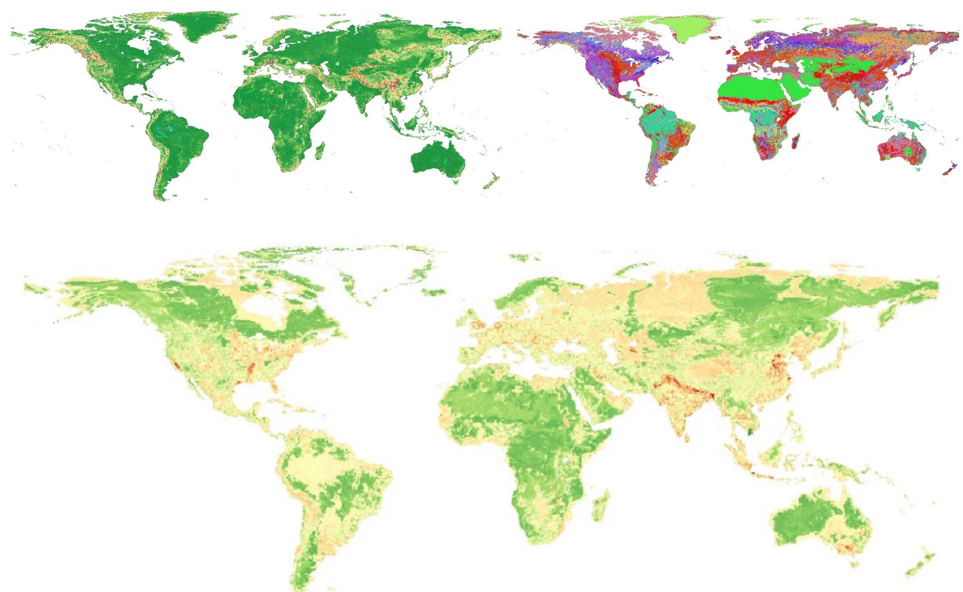


Fuel cells: Ni-YSZ (Nickel Yittria-Stabilized Zirconia) composite




## Mapping the subsidence using machine learning: A direct result of climate change



# Advanced Materials & Structural Systems: Advanced manufacturing

## In-Situ Materials Creation from Regolith

Jessica Vold

Mechanical Engineering Department
North Dakota State University
Jessica.l.vold@ndsu.edu
701.231.5324

Dr. Jessica Vold is an Assistant Professor in the Mechanical Engineering Department at NDSU with an Engineering Entrepreneurship and Innovation emphasis. Her research focuses on advanced materials for a variety of applications including biobased materials, advanced composite materials, and materials for additive manufacturing. Her lab includes an 18 mm twin screw extruder, a 100-ton injection molding press, compression molding equipment, filament fed 3D printers, and a roughly one cubic meter pellet fed 3D printer. Her lab is also equipped with a full suite a materials testing devices.

# In-Situ Materials Creation from Regolith

- Current research:
  - Effect of Lunar and Martian regolith simulant source location on the mechanical properties of polypropylene based composites
  - These composites are being studied for the use in additive manufacturing
  - Designed a regolith compaction and excavation rover prototype (UG Capstone)
  - Designing a power generation and storage rover prototype (UG Capstone)
- Where do we go next:
  - In-situ creation of polymer from regolith
  - Creation of composite materials for use in autonomous AM processes
  - Creation of polymeric materials from bio-waste for when a human presence is established
    - Alternative bio-waste generated fillers for targeted mechanical properties
- NASA Collaboration:
  - Build on what NASA has already explored in terms of additive manufacturing and to take it one step further by laying out the process of in-situ material creation from regolith itself
  - Help ensure the research is focused on producing material properties valuable towards the goal of a human presence on the Moon and Mars
  - Develop autonomous rovers to create polymers from regolith and incorporate fillers for targeted material properties

NDSU NORTH DAKOTA STATE UNIVERSITY

Dr. Jessica Vold
Engineering Entrepreneurship & Innovation
Assistant Professor | Mechanical Engineering

NASA EPSCoR Research for LaRC
January 27, 2021

# Advanced Materials & Structural Systems: Advanced manufacturing

Material discovery and design using multiscale material modeling approaches


## Sara Adibi

Center for Advanced Vehicular Systems (CAVS)
Mississippi State University (MSU)
Tel: +1 713 367-2612
sara.adibi@gmail.com, sara.adibi@msstate.edu


Sara Adibi is an Assistant Research Professor at the Center for Advanced Vehicular Systems (CAVS) at Mississippi State University. She conducts research in the area of multistage materials modeling where she is PI and Co-PI of several projects funded by the National Center for Manufacturing Science (NCMS) and the US Department of Army Research Lab. Prior to joining CAVS, she worked as a postdoctoral research fellow at Texas A&M University, College Station, TX and at the Department of Civil and Environmental Engineering at the University of Houston. Sarah received her PhD in Mechanical Engineering from the National University of Singapore (NUS) in collaboration with the Institute of High-Performance Computing (IHPC) in 2015. She received her master's and bachelor's degrees in Mechanical Engineering from Isfahan University of Technology, Iran, in 2010 and 2005, respectively.

# Material discovery and design
# using multiscale material modeling approaches

## The general process of machine learning in materials science:

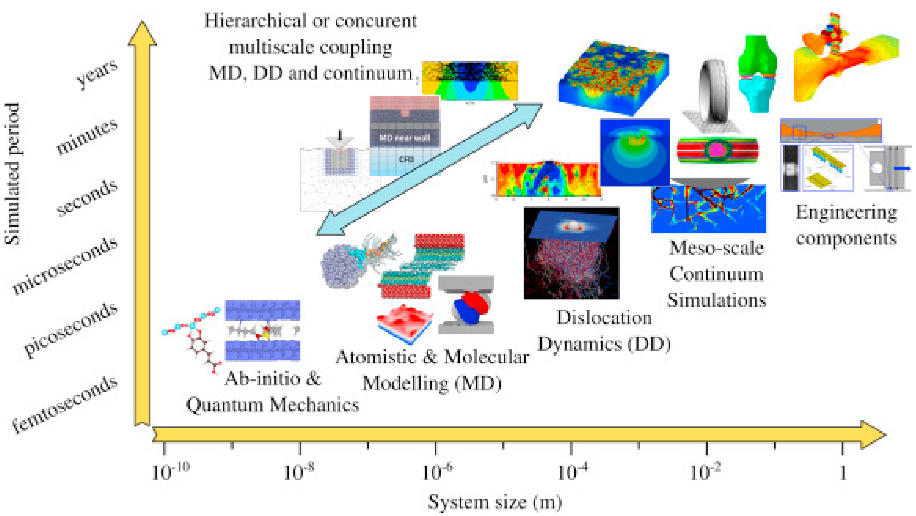
**Characterization**
- Faster & automated processing
- Hidden information discovery

**Property Prediction**
- Direct model substation with AI
- Actively guided simulation
- Simulation accuracy improvement
- Property prediction in material systems with limited understanding

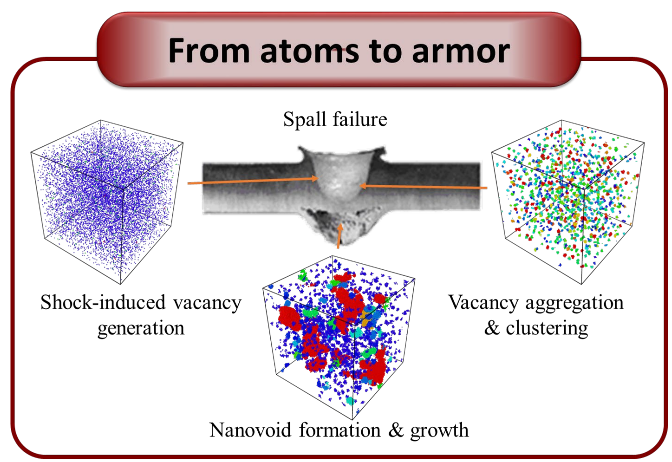
**Synthesis**
- Synthesis protocol prediction & inverse design
- Automated ML synthesis system

**Theory Discovery**
- Extraction of generalizable scientific principles with interpretable AI methods
- Extraction of generalizable scientific principles with a combination of AL & simulations methods

## Computational modeling approaches:

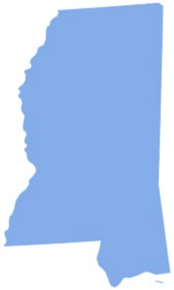



## Examples:




**Armor ballistic performance**

NASA EPSCoR Research for LaRC
January 27, 2021



# Advanced Materials & Structural Systems: Advanced manufacturing

## Leveraging Ultrasonics for Printing Nanocomposites Containing Controlled Nanofiller Patterns and Inspecting Additively Manufactured Structures


## Zhenhua Tian

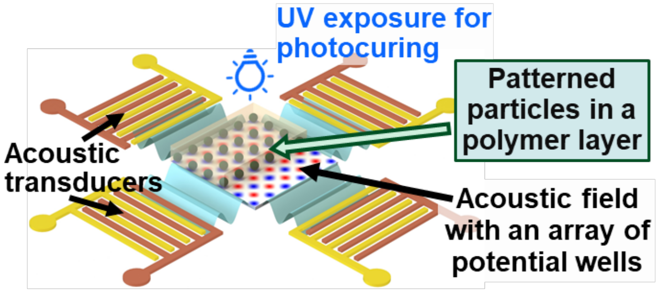
Assistant Professor,
Department of Aerospace Engineering
Mississippi State University
Email: tian@ae.msstate.edu
Phone: 662-325-7085 (office)
Address: 316C Walker Hall, 501 Hardy Road, Mississippi State, MS 39762

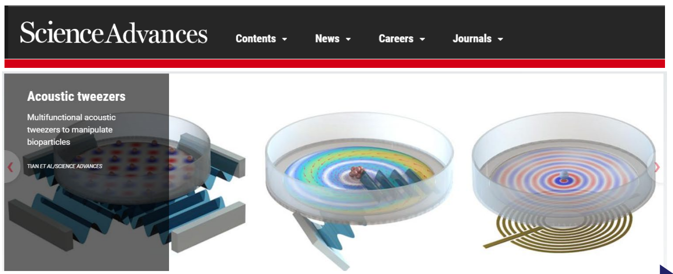

Dr. Tian is an Assistant Professor in the Department of Aerospace Engineering at Mississippi State University. He received his Ph.D. in Mechanical Engineering from the University of South Carolina in 2015 and complete his Postdoctoral training at Duke University in 2019. Dr. Tian's research focuses on Acoustic Tweezers-Assisted Additive Manufacturing, Nanocomposites, and Ultrasonic NDE. Dr. Tian has co-authored more than 50 peer-reviewed journal articles with multiple articles in high-impact journals, such as Science Advances and Advanced Functional Materials. His lab at MSU has state-of-the-art manufacturing and acoustic equipment, such as stereolithography 3D printers, ultrasonic phased imaging systems, and a laser Doppler vibrometry system. Currently, his group is developing acoustic tweezers-assisted 3D printing platforms for manufacturing multifunctional nanocomposites and wearable sensors, which contain controlled patterns of micro/nanofillers such as carbon nanotubes and SiC whiskers. His research currently is supported by the NSF Advanced Manufacturing Program.

# Ultrasonics for Printing Nanocomposites & Inspecting Additively Manufactured Structures

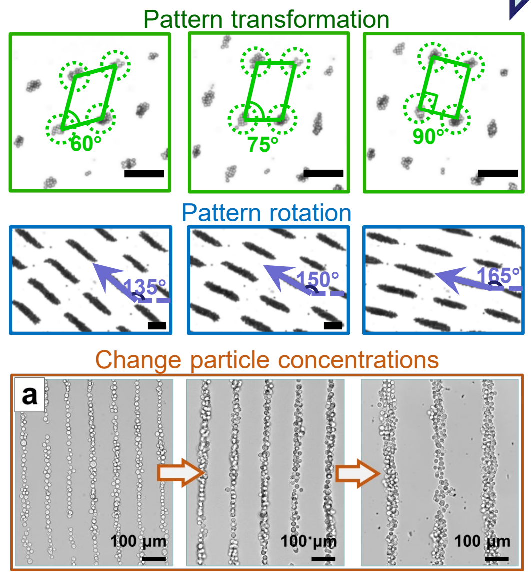
*Zhenhua Tian, Department of Aerospace Engineering, Mississippi State University*

## Mechanism of Acoustic Tweezers Assisted Printing of Nanocomposites

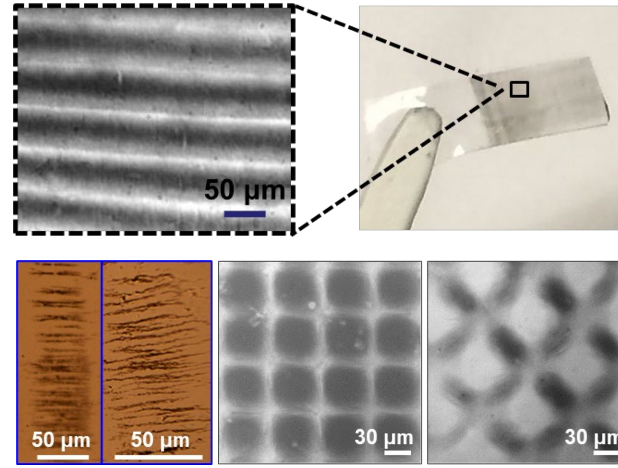



## Control the Patterns of Internal Micro/nanoparticles



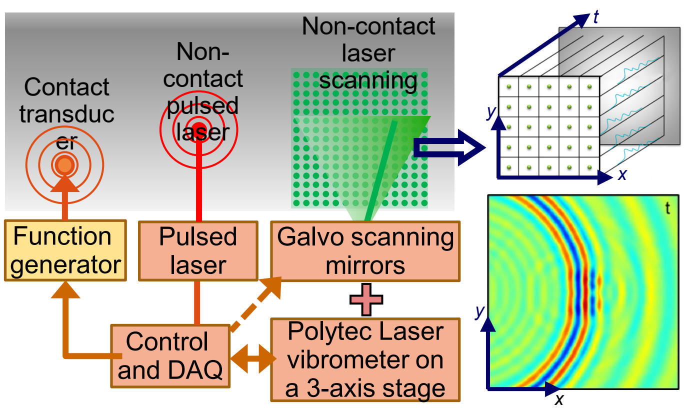

## Printed Nanocomposites with Patterned Carbon Nanotubes (CNTs)




*Z. Tian*, et al., ***Science Advances***, 2019

*Z. Tian*, et al., ***Science Advances***, 2020, 6: eabb0494

## Laser-based Acquisition of 3D Time-space Ultrasonic Wavefields

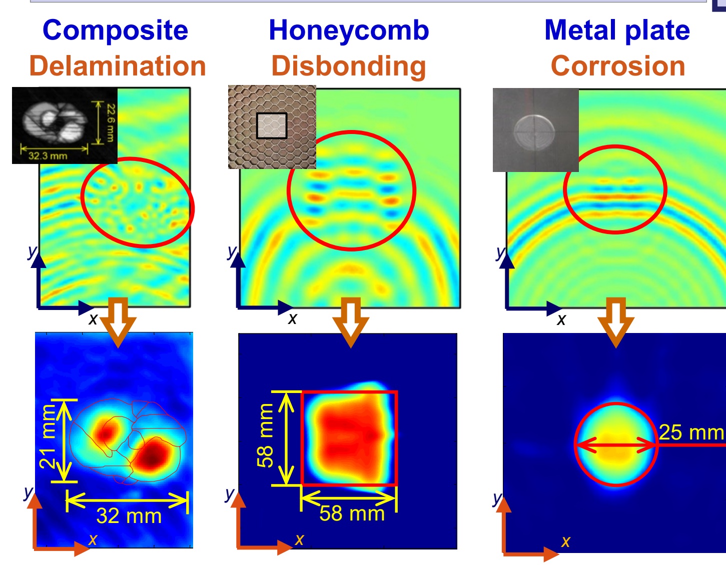



*Z. Tian*, et al., ***Mechanical Systems and Signal Processing***, 2019

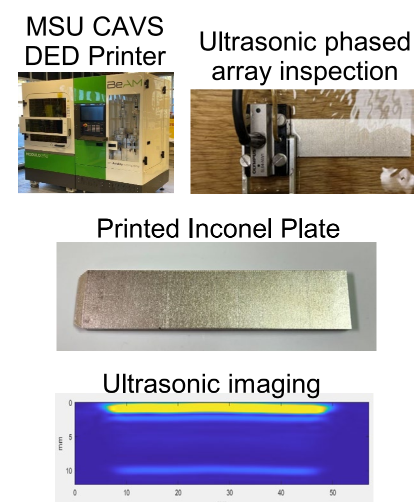
*Z. Tian*, et al., ***Mechanical Systems and Signal Processing***, 2020

*Z Tian*, et al. ***Smart Materials and Structures***, 2015

## Wavefield Analysis for Detecting Defects




## Additively Manufactured Metals



NASA EPSCoR Research for LaRC
January 27, 2021

# Advanced Materials & Structural Systems: Advanced manufacturing

## Energy Efficient and Rapid Composite Manufacturing via Frontal Polymerization


# Xiang Zhang

Assistant Professor
Department of Mechanical Engineering
University of Wyoming
1000 E. University Ave
Laramie, WY 82071
Tel: 307-766-4238
E-mail: xiang.zhang@uwyo.edu
Website: http://uwyo.edu/camml

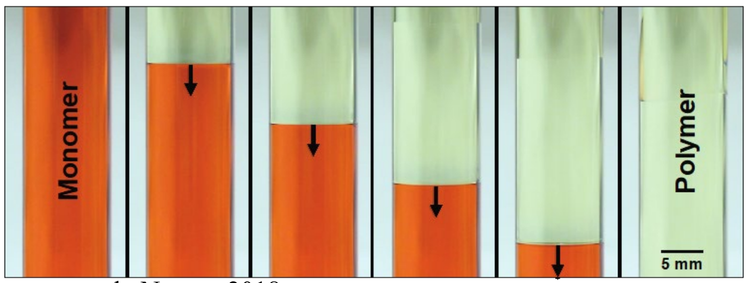

Dr. Xiang Zhang is an assistant professor in the Mechanical Engineering Department at the University of Wyoming, where he leads the Computations for Advanced Materials and Manufacturing Laboratory. Before joining UW in 2019, he conducted his postdoctoral research in the Aerospace Engineering Department at University of Illinois at Urbana-Champaign, and earned his Ph.D. from the Civil Engineering Department at Vanderbilt University.

Dr. Zhang's group focus on developing computational tools to understand how materials response and evolve during their lifespan, from manufacturing to service and eventually failure. In the area of advanced manufacturing, his group has been developing multiphysics modeling approach to simulate the thermo-chemo-mechanical process associated with composite manufacturing, including additive manufacturing process, to provide insights and guidance for optimizing processing parameters. Recently, his group is building a customized 3D printer for composite 3D printing, and aim to develop an augmented reality environment to use realtime analysis and optimization to optimize the printing process on the fly. His group also has access to various 3D printers at the UW Innovation Wyrkshop, including a state-of-the-art metal 3D printer, where one of his student is currently printing and testing 3D printed Titanium parts

# Manufacturing Thermoset Polymer and Polymer Composites via Frontal Polymerization

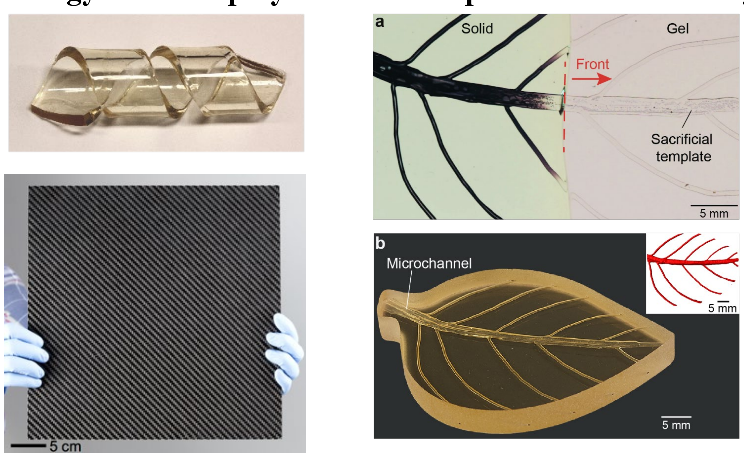
- Energy efficient: self-propagating reaction front driven by exothermic heat
- Accurate and supportless printing: simultaneously ink extrusion and curing
- Toward multifunctionality: reinforcement phases and additives to the ink

**Self-propagating polymerization front for fast curing**



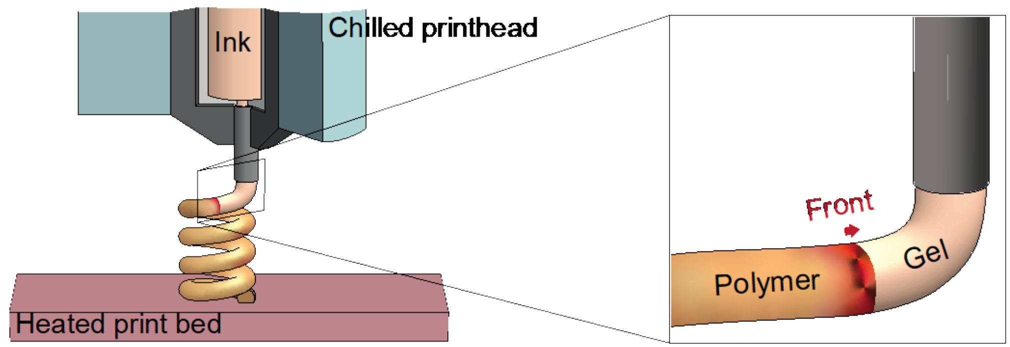

Robertson et al., Nature, 2018

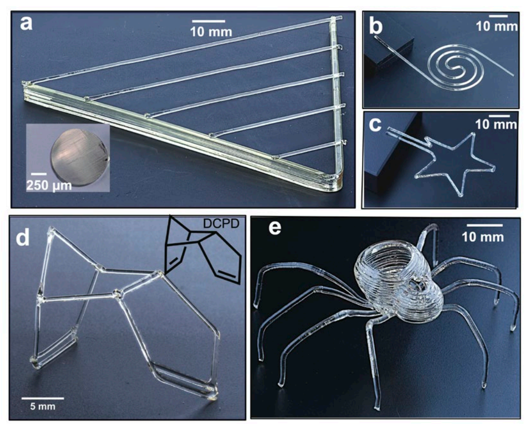
**Energy-efficient polymer and composite manufacturing**

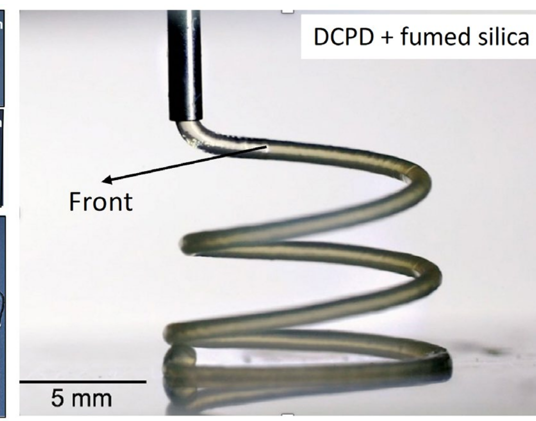



Garg et al., Nature Communications, 2021

**3D printing application**

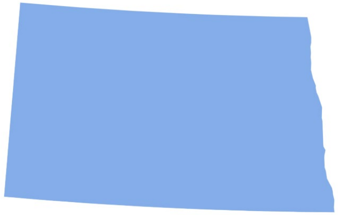



Aw et al., Advanced Materials, under review

NASA EPSCoR Research for LaRC
January 27, 2021



# Advanced Materials & Structural Systems: Advanced manufacturing

## High Temperature Coatings by Thermal Spray Technology


# Fardad Azarmi

Department of Mechanical Engineering
North Dakota State University
Contact Address: Dolve Hall 111D, Dept 2490, P. O. Box 6050, Fargo, ND 58108-6050
fardad.azarmi@ndsu.edu


Dr. Fardad Azarmi is a Professor of Mechanical Engineering at North Dakota State University (NDSU), USA. He has received his Ph.D. from University of Toronto in 2007 with an emphasis in advanced manufacturing techniques to develop complex structures. Fardad Azarmi is a licensed Professional Engineer in Canada (ON) and United states (ID). Dr. Azarmi is the Chair of Training Committee of International Thermal Spraying Society and Served as Associate Editor of Journal of Thermal Spray Technology published by Elsevier for several years. His research is primarily in advanced manufacturing, thermal spraying, computational solid mechanics, and materials science. He has published two textbooks in 3D modeling for advanced applications and fundamentals of engineering graphics. He has more than 120 peer-reviewed journal and conference proceedings. He has been the Principal or Co-principal investigator for several projects funded by NSF, US DOD, US DOT, US Department of Commerce, NASA, ND EPSCoR, FORD, and CATERPILLAR. For more information, please visit http://www.ndsu.edu/faculty/azarmi

NDSU MECHANICAL ENGINEERING

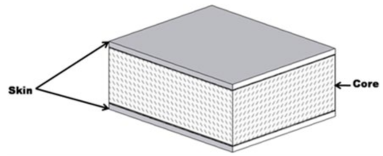
ND NASA EPSCoR Award

# Development of High Temperature Sandwich Structures for Turbine Engine Combustor Shrouds Using Thermal Spraying

PI: Fardad Azarmi

## Objectives

This research study proposes an alternative strategy of using metallic foam core sandwich structures with high temperature constituents for hot sections of turbine engines. The light weight cellular structure of the combustor walls will allow cooling air to be circulated inside it and more gas permeability. The potential application of such a sandwich structure is in the combustion area of heat engines due to its potential for higher performance associated with the preservation of fossil fuel reserves




## Thermal Spraying

Thermal spraying is a general term for a group of coating techniques which rapidly deposit various materials available in powder or wire forms as molten or semi-molten particles onto the surface of a substrate. Processes such as *Wire Arc Spray*, *Cold Spraying*, *High Velocity Oxy-Fuel (HVOF)*, *Vacuum Plasma Spray (VPS)* and *Atmospheric Plasma Spray (APS)* processes can be used for deposition of a coating layer on the surface of the materials which improves base material's resistance to corrosion, erosion, cavitation, friction, and abrasion.

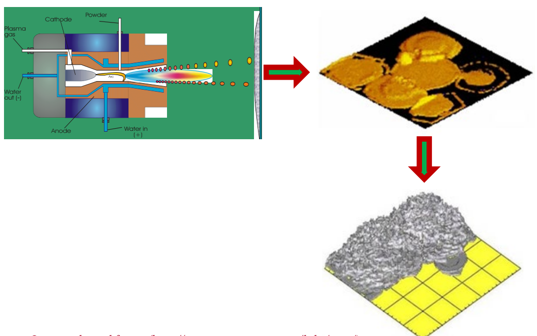



*Image adapted from: (http://www.mie.utoronto.ca/labs/cact/)*

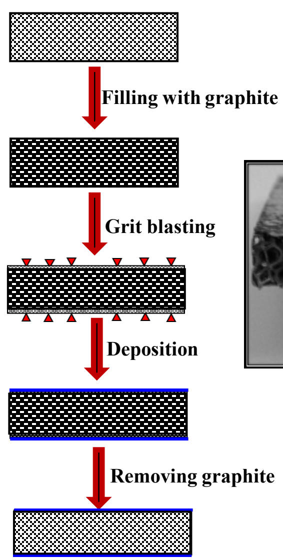
## Research Plan

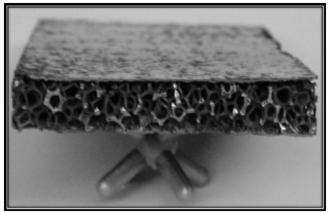
i. Selection of suitable materials for foam core and skin materials.
ii. Develop a suitable process to deposit skins on foam core.
iii. Characterize the microstructural properties of sandwich structures.
iv. Investigation on the mechanical performance of the sandwich structure.

## Fabrication of Sandwich Structure

Building on the methodology previously developed by PI, sandwich structures with high temperature constituents are fabricated using thermal spraying deposition technique. This eliminates most of the machining and forming steps, and significantly reduces manufacturing costs. The open cell foam core allows cooling gas to be circulated through it, eliminating the need for extra machining as required at the present time.

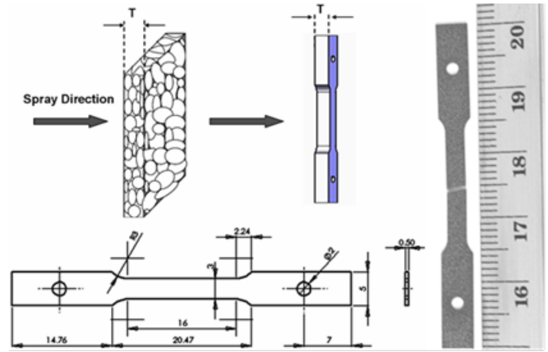
### Near Net Shape Forming Concept



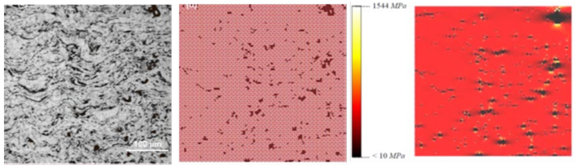



## Results

Mechanical properties of thermally sprayed coating as skin constituent examined in this study. **No prior investigation** was found for mechanical testing on free standing coating samples due to the difficulty of separation of such a thin coating (100-500 μm) from substrate and preparation of sub size tensile test samples.




Next, Image- based Finite Element Analysis (FEA) used to evaluate thermo-mechanical properties of thermal sprayed coatings. A micrograph of the as sprayed arc sprayed coating is subjected to stress distribution analysis.



## Future Works

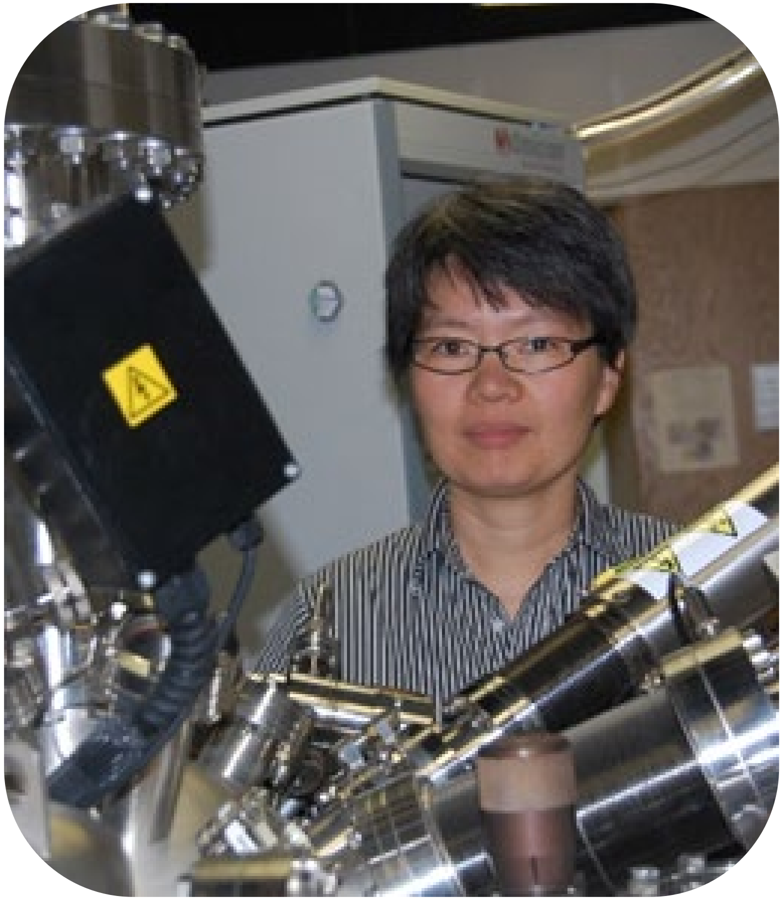
- Examine mechanical strength of foam core.
- Investigation on mechanical performance of Sandwich structure as one component .

## Acknowledgements

ND NASA EPSCoR Supplemental Project Funding Award for financial support.
NDSU Mechanical Engineering Department.

# Advanced Materials & Structural Systems: Advanced manufacturing

Studies of Ceria-supported Metal Catalysts from UHV to Reactor Conditions




## Jing Zhou

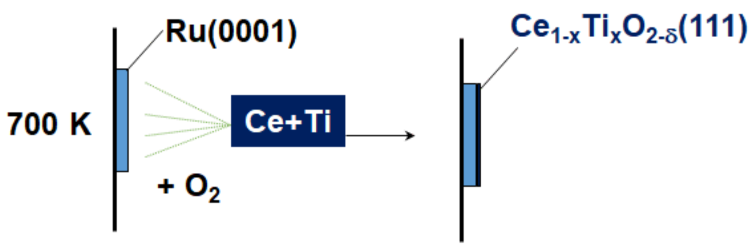
Chemistry Department
University of Wyoming
jzhou2@uwyo.edu
307-766-2812


Jing Zhou, Professor of Chemistry, joined Department of Chemistry at the University of Wyoming in 2007. She obtained her B.S. degree (1997) at Xiamen University (China) and her Ph.D. (2004) at the University of South Carolina. She was a postdoctoral researcher at the Oak Ridge National Laboratory (2004–2007). Her group research focuses on the fundamental understanding of structure-reactivity relationships of nanocatalysts for heterogeneous catalysis. The research involves controlled catalyst growth by design, in-situ characterization of catalyst structures, and chemical mechanism studies through surface science investigations of well-defined model surfaces under ultrahigh vacuum conditions as well as catalytic studies of powders and nanostructures under reactor conditions. The design and synthesis of catalytic materials with controlled structures and characteristics at the atomic/molecular scale as well as a thorough characterization coupled with the understanding of the local structure can provide important knowledge for the engineering of materials with desirable properties for specific applications.

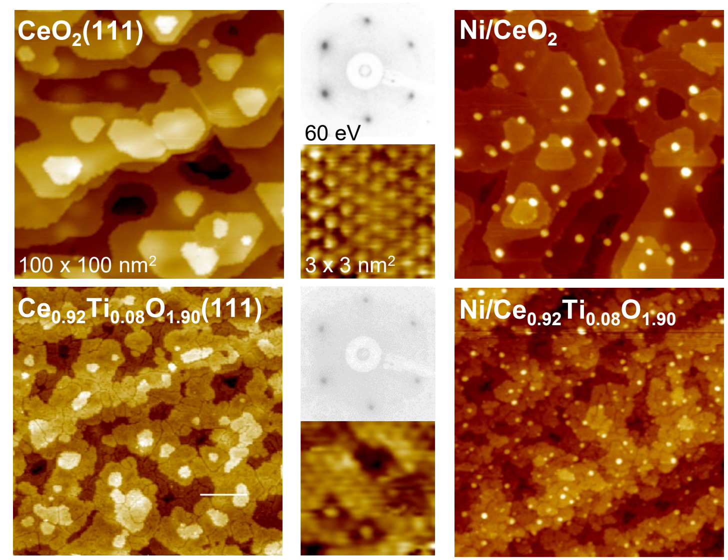
# *Studies of Ceria-supported Metal Catalysts from UHV to Reactor Conditions*

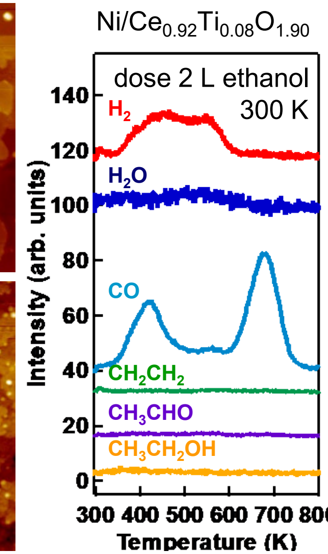
*Jing Zhou, Professor of Chemistry, University of Wyoming*

❑**Growth of well-ordered $Ce_{1-x}Ti_xO_{2-\delta}(111)$ oxide thin films and demonstration that Ti-doping in $CeO_2$ can better anchor Ni as smaller nanocatalysts and show an enhanced activity toward ethanol**

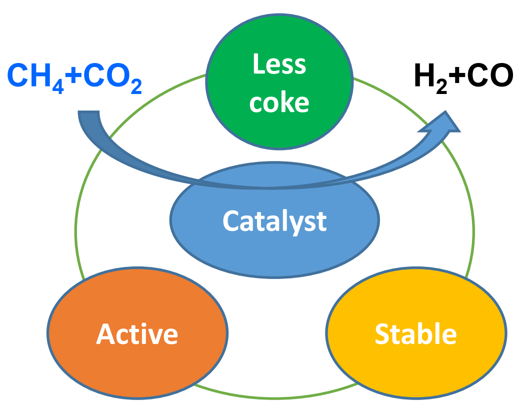



**$p<1\times10^{-11}$ Torr; low energy electron diffraction, x-ray photoelectron spectroscopy, scanning tunneling microscopy, and temperature programmed desorption**

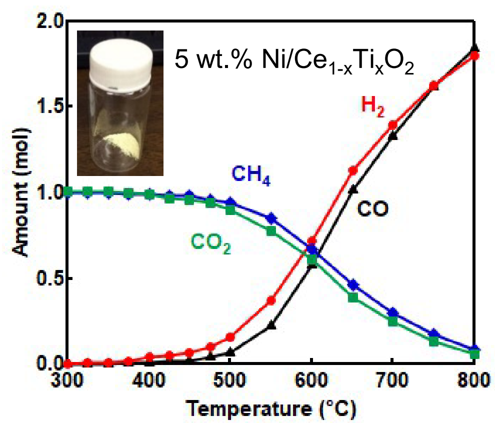



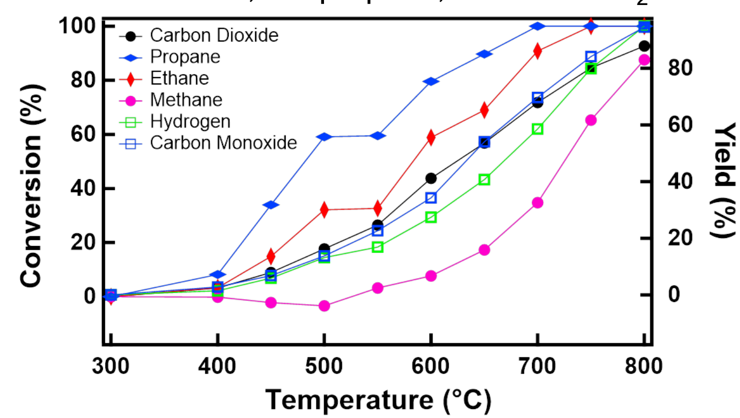

❑**Synthesis of Ni nanoparticles supported over Ti-promoted $Ce_{1-x}Ti_xO_2$ and demonstration of good catalytic activity toward dry reforming of methane and mixed hydrocarbons for syngas production**




$CO_2 + CH_4 \rightarrow 2CO + 2H_2$




reaction mixture of 25% methane, 8% ethane, 5% propane, and 62% $CO_2$




Funding support: National Science Foundation (CHE1151846), Wyoming NASA Space Grant Consortium (NASA Grant #NNX15AI08H), and Wyoming Carbon Engineering Initiative

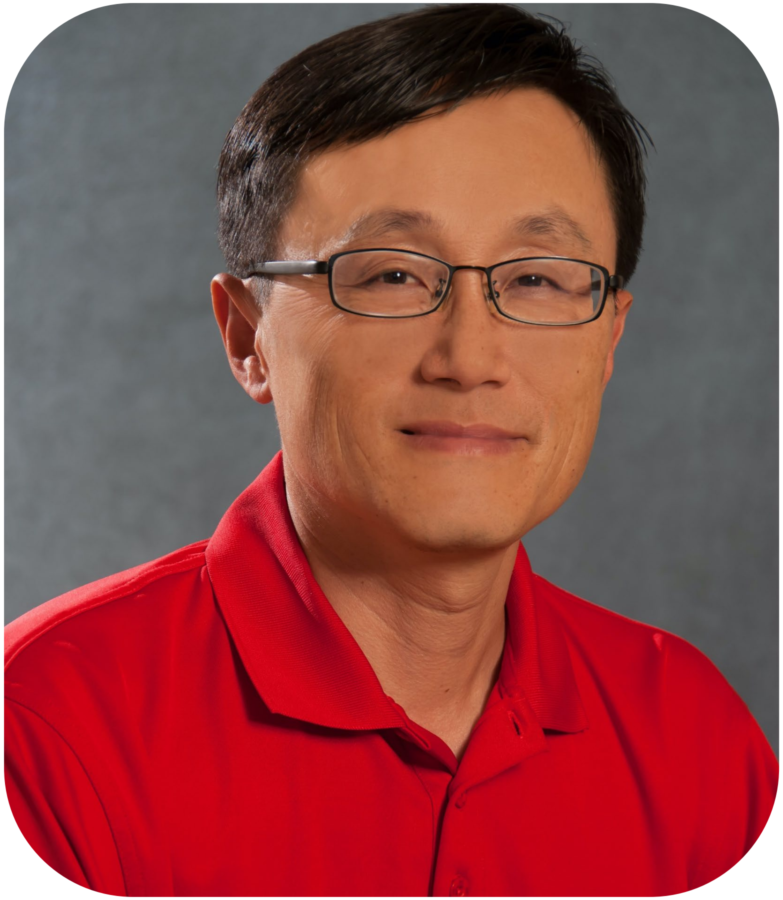
# Advanced Materials & Structural Systems: Advanced manufacturing

## Soft robotics and advanced manufacturing


## Kwang J. Kim

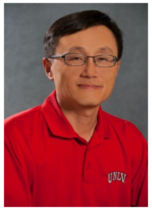
Mechanical Engineering Department
University of Nevada, Las Vegas (UNLV)
kwang.kim@unlv.edu, 702-774-1419,
www.kwangjinkim.org


Kwang J. (Jin) Kim is Distinguished Professor of the Mechanical Engineering Department at the University of Nevada, Las Vegas (UNLV). He graduated from Yonsei University, Korea, in 1987 and received his MS and Ph.D. from Arizona State University (ASU) in 1989 and 1992, respectively. Later, he completed a postdoctoral study at the University of Maryland-College Park UMCP (1993-1995). His research interests are in a broad spectrum of Active Materials/Sensors and Energy Systems. He has authored/ co-authored 420+ technical publications including 210 referred journal papers and 3 monographs and was awarded 3 U.S. patents. He is a Fellow of ASME and National Academy of Inventors (NAI). His laboratory, namely Active Materials and Smart Living (AMSL) Laboratory, has the capability of fabricating and testing active materials and devices.



# Soft Robotics and Advanced Manufacturing

PI: Kwang Kim*, University of Nevada, Las Vegas (UNLV); Email: kwang.kim@unlv.edu; Web: www.kwangjinkim.org
Collaborators: Yantao Shen, University of Nevada, Reno (UNR) and Leon Leon Liao, Iowa State University (ISU)
Potential LaRC collaborator, Ji Su LARC-D307

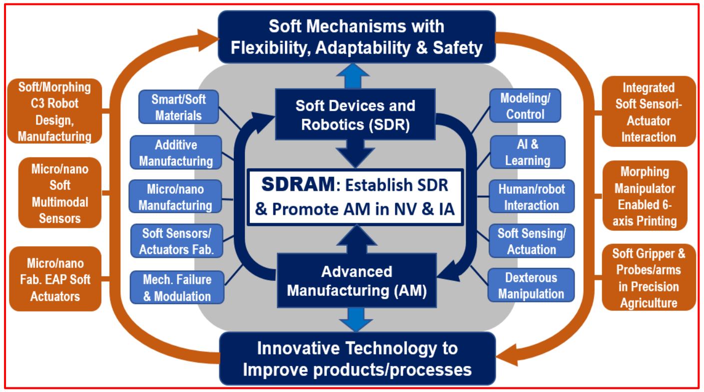



- **Soft robotic components and systems offer new features and advantages over conventional robotic devices.** The research and application of soft robotic systems is an interdisciplinary field, requiring expertise in robotics, electronics, controls, modeling, materials engineering, etc. Biological systems are generally comprised of soft, elastic, and flexible materials in order to survive in complex unstructured environments. Given such salient differences in constituent materials of artificial and natural autonomous systems, there has been an increasing interest in the studies of "softness" in the context of embodied intelligence research, for which the field of soft robotics is emerging.
- **There is the need for a systematic framework and manufacturing methods** that can extract the basic principles of the embodied intelligence and morphological adaptation, transferring them into an artificial soft robot system while taking into account the technological limits/challenges of the field. Many innovative solutions have been developed in recent years to design soft components and systems. ***They all demonstrate how soft robotics development is closely dependent on advanced manufacturing processes*** [1]. For example, the development of soft actuators and sensors requires the use of fluids (gas or liquid), shape-memory polymers, electroactive polymers or stimuli-responsive materials, soft smart structures, or soft-rigid hybrid systems. The manufacturing methods used include but are not exclusive to molding, additive manufacturing, micro-/nanomanufacturing, thin-film manufacturing, shape deposition manufacturing, and bonding [1]. ***The above soft robot manufacturing cycle, in turn, promotes advanced manufacturing and its innovations*** [2]. In contrast to robots built from rigid materials, soft robots allow for increased flexibility and adaptability for accomplishing tasks, as well as improved safety when working around humans [3]. These characteristics allow for its potential use in the fields of advanced manufacturing, space engineering, and medicine [3][4]. ***The explored NASA-related examples*** could include, i) the human-robot cooperation (or astronauts) in manufacturing work-cell where soft robots could work alongside humans/astronauts safely, as in a collision the compliant nature of the robot would prevent or minimize any potential injury; ii) space sample-pick or package at the Moon using soft dexterous robotic hands; and/or iii) applications within the medical profession, specifically for invasive surgery [4].
- A synergistic team of researchers and collaborators from **Nevada** and **Iowa** is assembled with expertise in soft robotics and manufacturing to advance the state of the art, as well as to train and prepare the future NASA-related work force to tackle emerging challenges in soft robotic systems and advanced manufacturing.

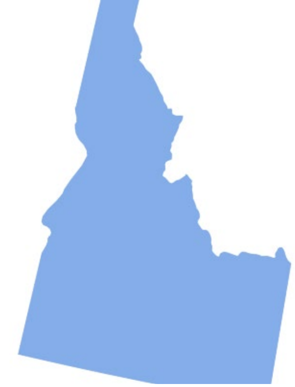
[1] F. Schmitt, O. Piccin, L. Barbé L and B. Bayle. (2018). *Front. Robot. AI* 5:84.
[2] G. Stano, G. Percoco. (2021). *Extreme Mechanics Letters*, Vol, 42, 101079.
[3] N. Elango, A.A.M. Faudzi, (2015). *Int J Adv Manuf Technol* 80, 1027–1037.
[4] M. Cianchetti, T. Ranzani, G. Gerboni, T. Nanayakkara, K. Althoefer, P. Dasgupta, A. Menciassi, (2014). *Soft Robotics*. 1 (2): 122–131.

UNLV | Howard R. Hughes College of Engineering

ACTIVE MATERIALS AMSL & SMART LIVING




Soft Devices and Robotics for promoting Advanced Manufacturing (SDRAM)



# Advanced Materials & Structural Systems: Advanced manufacturing

## Additively Manufactured Flexible Hybrid Electronic Devices and Sensors for Normal-to-Extreme Environments


# Harish Subbaraman

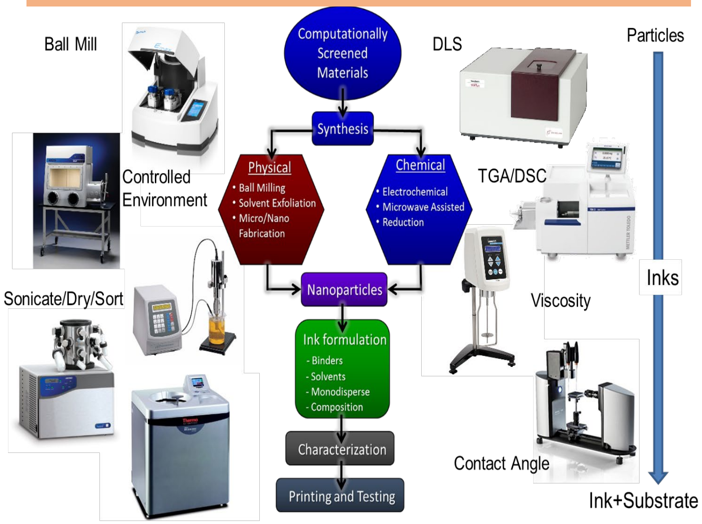
Associate Professor – Department of Electrical and Computer Engineering
Boise State University
1910 University Dr,
MS2075
Boise, ID 83725
Ph: 208-426-4803

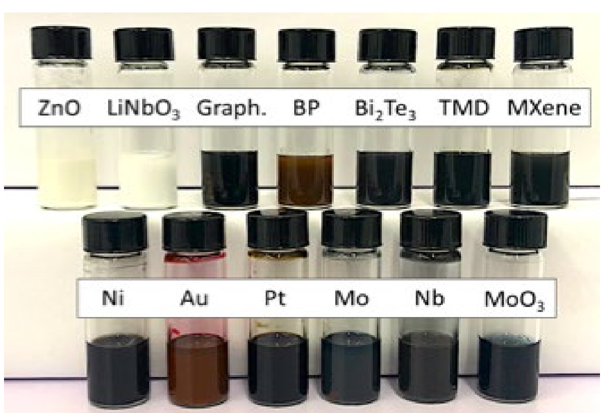

Prof. Harish Subbaraman is from the Idaho Jurisdiction. He earned his M.S. and his Ph.D. degrees in Electrical Engineering from The University of Texas at Austin. He joined the Electrical and Computer Engineering Department at Boise State University in the Fall of 2016, and is currently an Associate Professor. Prior to that, he was a senior research scientist at Omega Optics in Austin, TX, where he worked on printed and flexible photonics and electronics; and silicon and polymer based optical interconnects. He is currently also the director and co-founder of the Advanced Nanomaterials and Manufacturing Laboratory (https://www.boisestate.edu/coen-anml/); the Associate Site Director of the NSF ATOMIC Center - an I/UCRC center focused on 2D materials and applications (https://www.mri.psu.edu/mri/facilities-and-centers/welcome-atomic); and the Advanced Manufacturing Focus Area Lead at Boise State for the Center of Advanced Energy Studies (https://caesenergy.org/). His areas of research focus are in– (1) additive manufacturing: printed electronics/optoelectronics, flexible hybrid electronics, conformal phased array antennas, materials and process development, and AI-enabled print process optimization, 2) photonics: silicon photonics, RF photonics, optical interconnects, and fiber optics. His research has led to a total of 65 peer-reviewed journal articles, and he has 6 issued and 4 pending patents.

# Additively Manufactured Flexible Hybrid Electronic Devices and Sensors for Normal-to-Extreme Environments

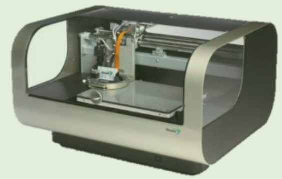
Goal: Use additive manufacturing techniques for developing low-cost sensors for a wide range of applications

## In-house ink synthesis & characterization



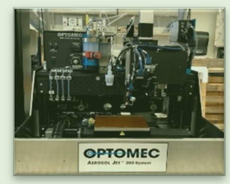



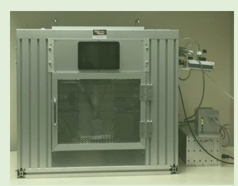

## Multimodal Printing Technologies



Dimatix Ink-Jet
Viscosity: 8-12cP
Resolution: 30μm

Optomec Aerosol-Jet
Viscosity: 1-1000cP
Resolution: 10μm



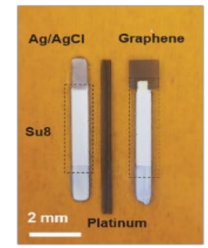



SpaceFoundry Plasma Jet
Viscosity: 1-1000cP
Resolution: 50μm

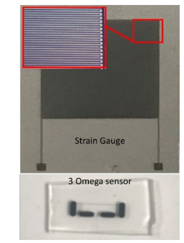
nScrypt Microdispense
Viscosity: 1-100000cP
Resolution: 20μm

## Printed Sensor Applications

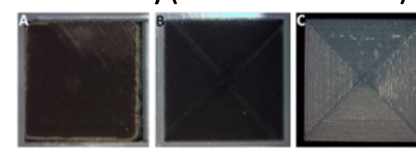
**Electrochemistry**



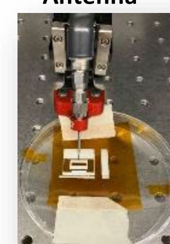

**Strain**




**Dosimetry (Radiation Detection)**

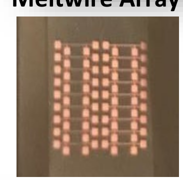



**Antenna**

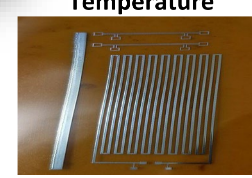


**Thermoelectricity**

**Meltwire Array**



**Temperature**



Harish Subbaraman, Ph.D. – Associate Professor (ECE)

ANML
BOISE STATE UNIVERSITY

# Advanced Materials & Structural Systems: Advanced manufacturing

Design, Analysis, and Manufacturing of Functionally-Graded Composite Materials

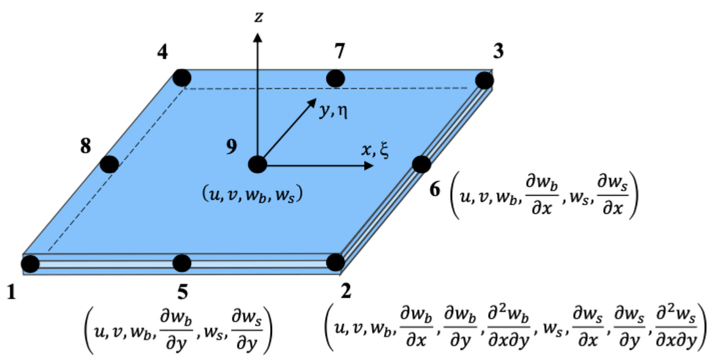
## Nithi Sivaneri

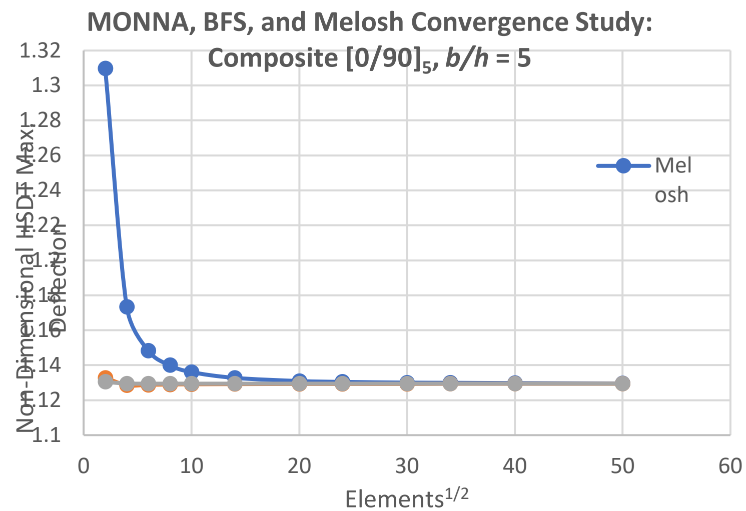
Professor, Dept. of Mechanical & Aerospace Engineering
Nithi.sivaneri@mail.wvu.edu

Dr. Sivaneri received his PhD in Aeronautics Astronautics from the Stanford University. His research areas are finite elements, structural dynamics, and composite materials. During his research, he has invented HSDT composite beam elements, a composite curved-beam element, and a composite plate element. As part of his AFRL Summer Fellowships in 2019 and 2020, he developed and tested a new nine-node, 68-d.o.f., composite plate element based on the higher order shear deformation theory. Applying this element to static and dynamic analysis of composite plates has shown that convergence as the number of elements is increased is faster than many of the existing plate elements.

# New HSDT Composite Plate Element, MONNA

Nithi Sivaneri, MAE, WVU

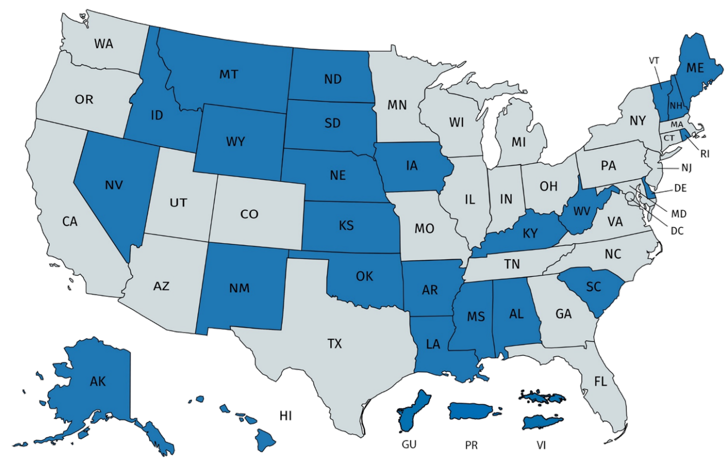



- New Composite HSDT plate element developed as part of AFRL Summer Fellowship
- Apply to the analysis of the impact analysis of functionally graded materials (FGM)
- Explore manufacturing processes

# Topic Area 4:

# Entry, Decent and Landing: Robotic mission entry vehicles



# Entry, Decent & Landing: Robotic mission entry vehicles

Modeling, Learning, and Control for Autonomy and Human-Robot Collaboration Systems

Yue Wang

Clemson University
yue6@clemson.edu

Dr. Yue Wang is the Warren H. Owen – Duke Energy Associate Professor of Engineering and the Director of the Interdisciplinary and Intelligent Research (I2R) laboratory at Clemson University. Her research interests include human-robot interaction, multi-robot systems, and cyber-physical systems. Dr. Wang received both AFOSR YIP award and NSF CAREER award. Her research has been supported by NSF, AFOSR, ARC, ARO, NASA EPSCoR, ONR, AFRL, and Clemson University. Her work has resulted in over 50 journal publications, peer-reviewed conference papers and books, which are cited 1676 times (Google scholar) with an h-index of 21. Dr. Wang is a senior member of IEEE, and member of ASME and AIAA and serve as Associate Editor on several journals and conference proceedings. Her work has been featured in NSF Science360, ASEE First Bell, State News, SC EPSCoR/IDeA Research Focus, and Clemson University.

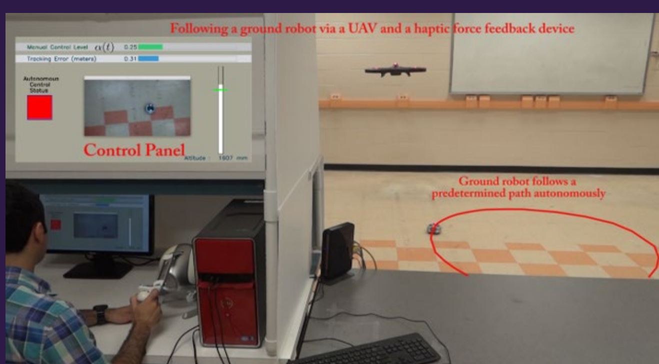
# Modeling, Learning, and Control for Autonomy and Human-Robot Collaboration Systems

Yue "Sophie" Wang, Clemson University

CLEMSON MECHANICAL ENGINEERIGN

## Research Overview:

- Computational modeling for human-robot trust
- Shared control of mobile robots
- Human-robot collaborative manufacturing
- Symbolic motion planning for multi-robot systems
- Human-aware autonomous driving
- Deep reinforcement learning for mobile robots





CLEMSON MECHANICAL ENGINEERING

NASA EPSCoR Research for LaRC
January 27, 2021

# Entry, Decent & Landing: Robotic mission entry vehicles

## Bio-inspired Autonomous Navigation and Mapping of Energy-Optimal Heterogeneous Collaborative Multi-Agent System


# Chaomin Luo

Department of Electrical and Computer Engineering
Mississippi State University
312 Simrall Bldg., 406 Hardy Rd., Box 9571
Mississippi State, MS 39762
Email: Chaomin.Luo@ece.msstate.edu


Dr. Chaomin Luo received his Ph.D. degree in electrical and computer engineering in the Department of Electrical and Computer Engineering at the University of Waterloo, Waterloo, Ontario, Canada in 2008; his M.Sc. degree in engineering systems and computing at the University of Guelph, Guelph, Ontario, Canada, and his B.Eng. degree in electrical engineering from the Southeast University, Nanjing, China. He is currently an Associate Professor, Department of Electrical and Computer Engineering, at the Mississippi State University, Mississippi State, MS 39762, USA. He received the Best Paper Award in the IEEE International Conference on Information and Automation (IEEE ICIA2017). He is Associate Editor in 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2019). He is Tutorials Co-Chair in the 2020 IEEE Symposium Series on Computational Intelligence.

His research interests include Robotics, Autonomous Systems, Control Systems, Applied Artificial Intelligence and Machine Learning for Autonomous Systems and Robotics, Intelligent Systems, and Mechatronics and Automation, and Embedded Systems. His industry experience includes working as an electronics engineer, hardware designer and a director of the embedded systems and intelligent instrument Lab. He was an early researcher to apply semi-definite programming and second order cone programming into VLSI optimization design. He was the first researcher to successfully develop biologically inspired neural dynamics model for complete coverage robot motion planning.

Dr. Luo is an IEEE senior member, INFORMS, and ASEE member. He has shown his leadership nationally and internationally on his research field. He was the Panelist in the Department of Defense, USA, 2015-2016, 2016-2017 NDSEG Fellowship program and Panelist in 2017 NSF GRFP Panelist program. He was the General Co-Chair of the 1st IEEE International Workshop on Computational Intelligence in Smart Technologies (IEEE-CIST 2015), and Journal Special Issues Chair, IEEE 2016 International Conference on Smart Technologies (IEEE-SmarTech), Cleveland, OH, USA. He was Chair and Vice Chair of IEEE SEM - Computational Intelligence Chapter and was a Chair of IEEE SEM - Computational Intelligence Chapter and Chair of Education Committee of IEEE SEM. Dr. Luo serves as Associate Editor of IEEE Transactions on Cognitive and Developmental Systems, International journal of Robotics and Automation, and Associate Editor of International Journal of Swarm Intelligence Research (IJSIR).

# Bio-inspired Autonomous Systems of Energy-Optimal Heterogeneous Collaborative Multi-Agent System

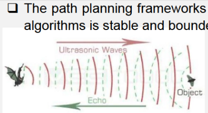
Chaomin Luo, Ph.D., Associate Professor, Robotics and Intelligent Systems Research Group, Department of Electrical and Computer Engineering, Mississippi State University

## Introduction

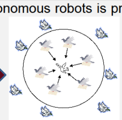
- From biologically inspired neural networks algorithms to evolutionary computation algorithms, nature inspired intelligence techniques and dynamic evolutionary optimization with developed AI-based methods are employed to autonomous system navigation, mapping, localization and vision including a swarm of unmanned aerial vehicles (UAVs) and unmanned ground vehicles (UGVs) with potential applications on entry, decent and landing of robots, and intelligent UAVs.
- Our results of research projects will continue to generate benefits in areas such as earth observations, remote sensing for space, space science, sensors and measurements for environments, wildfire disaster relief and education programs that inspire future scientists, engineers, roboticists and space explorers.
- Research has developed practically feasible, computationally efficient, and theoretically solid algorithms and implementation for energy-optimal multi-agent navigation in unknown environments with multi-UAV and multi-UGV.

## Proposed Methods

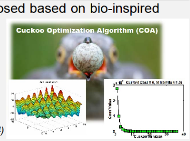
- The path planning frameworks of autonomous robots is proposed based on bio-inspired algorithms is stable and bounded.



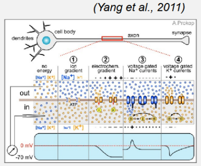
Bat behavior: Echolocation (Yang et al., 2011)



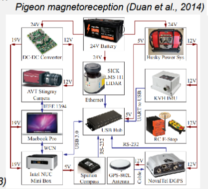
Pigeon magnetoreception (Duan et al., 2014)



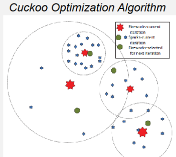
Cuckoo Optimization Algorithm



Anatomy of the neuron. (Akkaya et al., 2013)



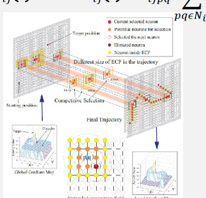
(Sensor integration Luo et al 2015)



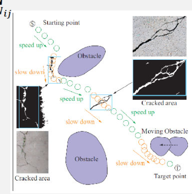
FWA search process

- BNN-based method has no learning process, which is different from machine learning.
- FWA, BPA, and COA are population-based meta-heuristic optimization algorithm.
- Robot navigation in a grid-based environment with cracks and other potential risk areas.

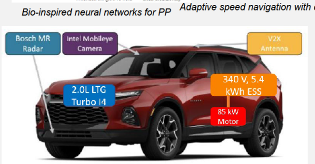
$$\frac{d}{dt}G_{ij}(t) = -A \cdot G_{ij}(t) + S_{ijpq}\sum_{pq\in N_{ij}}^{k} \omega_{ijpq}[G_{pq}(t)]^{+} + I_{ij}$$



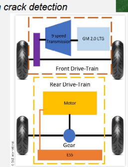
Bio-inspired neural networks for PP

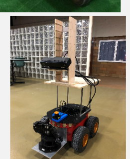


Adaptive speed navigation with crack detection



(Taoudi and Luo 2021)

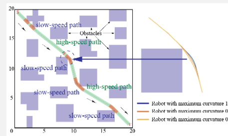




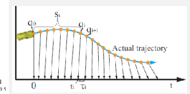
(Gao and Luo 2019)

## Proposed Methods and Results

- Multi-speed profile planning with smooth modulation can adjust the speed according to environmental conditions.



Segmented cubic B-spline path smoother



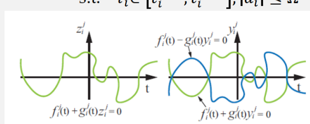
Evenly sampled waypoints on the smoothed path

(Luo et al 2017)

- Time optimal model with longitudinal, lateral acceleration/jerk, and reference speed.

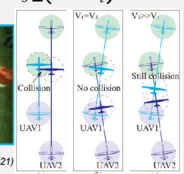
$$\min_{t_1,\cdots,t_n} w_1\sum\left|a_i^t\right|^2 + w_2\sum\left|a_i^n\right|^2 + w_3\sum\left|j_i^t\right|^2 + w_4\sum\left|j_i^n\right|^2 + w_5\sum\left(v^r - v_i^t\right)^2$$

$$\text{s.t.} \quad \tau_i \in \left[t_i^{min}, t_i^{max}\right], |a_i| \le \Omega$$



Nonlinear equality constraint and relaxed nonlinear inequality constraint

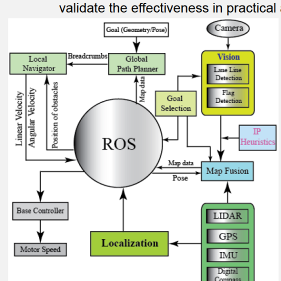
Wildfire disaster relief (Lei and Luo 2021)



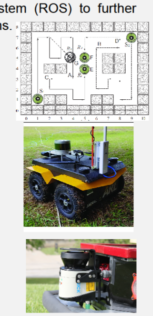
Multi-task allocation – UAVs (Lei and Luo 2021)

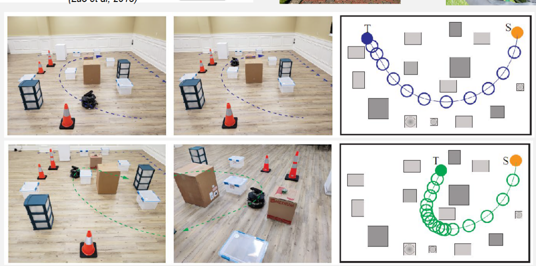
## Experimental Results

- Experiments are conducted based on the robot operating system (ROS) to further validate the effectiveness in practical applications of our algorithms.




(Luo et al, 2015)

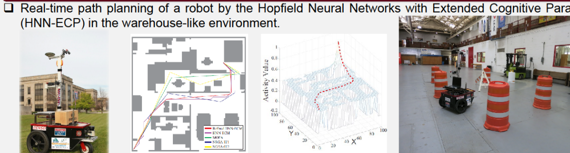




(Lei and Luo 2021)

## Simulation and Comparison Results

- Real-time path planning of a robot by the Hopfield Neural Networks with Extended Cognitive Paradigm (HNN-ECP) in the warehouse-like environment.

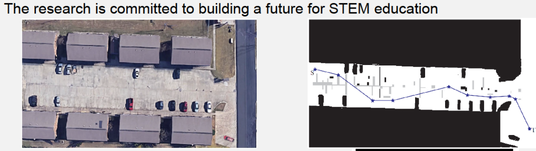


(Luo et al 2019) (Luo et al 2016)

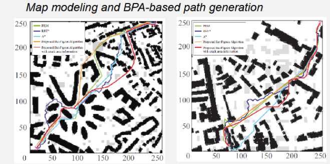
- Adaptive speed navigation and mapping based on the FWA model of segmented cubic B-spline path smoothing applied to a coverage robot.

Lunar surface and (L1:Lunar craters with object mergence. L2: Impact craters of Mars with object mergence. R2: Optimization of exploration. R1: Order to visit terrains) (Lei and Luo 2021)

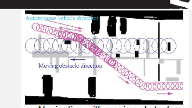
- The autonomous vehicles decelerate in the crack areas and the proposed BPA model generates minimal time-consuming collision-free trajectories.
- The research is committed to building a future for STEM education



Map modeling and BPA-based path generation

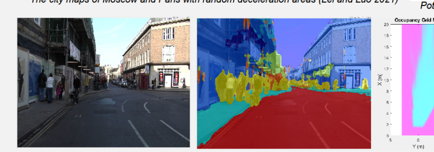


The city maps of Moscow and Paris with random deceleration areas (Lei and Luo 2021)

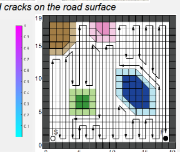


Navigation with moving obstacles

Potholes and cracks on the road surface



IP, Monocular Camera and Semantic Segmentation (Lei and Luo 2021)

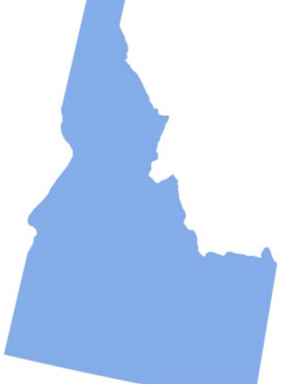


BNN (Luo et al, 2014 ICRA)

## References


- T. Lei, **C. Luo**, T. Sellers, and S. Rahimi, A Bat-Pigeon Algorithm to Crack Detection-Enabled Autonomous Vehicle Navigation and Mapping. *Intelligent Systems with Applications*, 12, p.200053, Elsevier, 2021.
- **C. Luo,** S. X. Yang, X. Li, and M. Q.-H. Meng, Neural Dynamics Driven Complete Area Coverage Navigation Through Cooperation of Multiple Mobile Robots, *IEEE Transactions on Industrial Electronics,* vol. 64, no. 1, pp. 750-760, Jan. 2017.
- S. X. Yang and **C. Luo**, A neural network approach to complete coverage path planning. *IEEE Transactions on Systems, Man, and Cybernetics*, Part B, 34(1). pp.718-725.
- T. Lei, **C. Luo**, and J. Ball, Hybrid Fireworks Algorithms to Intelligent Robot Navigation and Map Building," Chapter 10, "Handbook of Research on Fireworks Algorithms and Swarm Intelligence." IGI Global, pp 213-232, 2020.
- **C. Luo,** S. X. Yang, A bioinspired neural network for real-time concurrent map building and complete coverage robot navigation in unknown environments. *IEEE Transactions on Neural Networks*, 19(7), 2008. pp. 1279-1298.
- T. Lei, **C. Luo**, G. E. Jan, K. Fung. Variable Speed Robot Navigation by an ACO Approach, vol. 1, pp. 232-242, 10th International Conference on Swarm Intelligence. vol. 1, pp. 232-242, 2019.
- T. Lei, **C. Luo**, and Y. Jin, Extended Cognitive Paradigm to Time Optimal based Speed-adaptive Navigation. Submitted to *IEEE Transactions on Cybernetics, 2021.*

NASA EPSCoR Research for LaRC
January 27, 2021



# Entry, Decent & Landing: Robotic mission entry vehicles

## Experimental Study of Flag Fluid-Structure-Interactions (FSI) with Application for Parachutes Aerodynamics


## Vibhav Durgesh

Assistant Professor
Mechanical Engineering
University of Idaho
vdurgesh@uidaho.edu


Dr. Vibhav Durgesh holds a Bachelor’s degree in Mechanical Engineering from the Indian Institute of Technology (IIT) Kharagpur, and Master's and Ph.D. degrees in Mechanical Engineering from the University of Wyoming. Following his doctoral work, Dr. Durgesh worked as a Research Associate at the Pacific Northwest National Laboratory, WA. He is currently an Assistant Professor in the Department of Mechanical Engineering at the University of Idaho, Moscow. His research interests include both fundamental and applied topics in the field of experimental aerodynamics and fluid dynamics. He is currently working on studying the FSI behavior of flag fluttering and the impact of the observed oscillation modes of the surrounding fluid flow and aerodynamic performance of the flag.

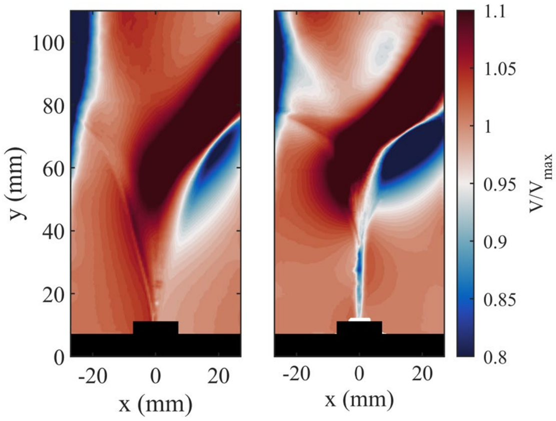
# Experimental Aerodynamics Laboratory
Dr. Vibhav Durgesh (vdurgesh@uidaho.edu)
University of Idaho

- Facility
  - Subsonic wind tunnel ( max velocity 50m/s)
  - Flow visualization water tunnel (max velocity 1 m/s)
  - State of art multi-material 3D printer system (12 micro-meter resolution)

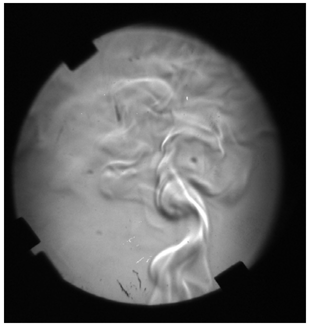
- Instrumentation
  - Velocity measurement systems
    - Particle Image Velocimetry (2D and 3D space) – non-intrusive
    - Hot-wire and hot-film (single point with high response rate)
  - Pressure instrumentation systems
  - Oil-Film-Interferometry system (Wall shear stress measurements)
  - Schlieren imaging system (Shock wave visualization)
  - Digital Image Correlation system (Strain measurements)

- Projects
  - Fluid-Structure-Interactions (Parachute aerodynamics)
  - Biomimetic filter design and analysis (non-clogging filter design)
  - Porous media flow (Flow of contaminants in soil)

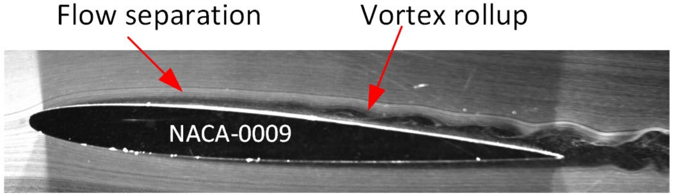
- Analysis techniques
  - Modal decompositions (POD and DMD)
  - Spectral analysis




Low-order model of fluttering flag



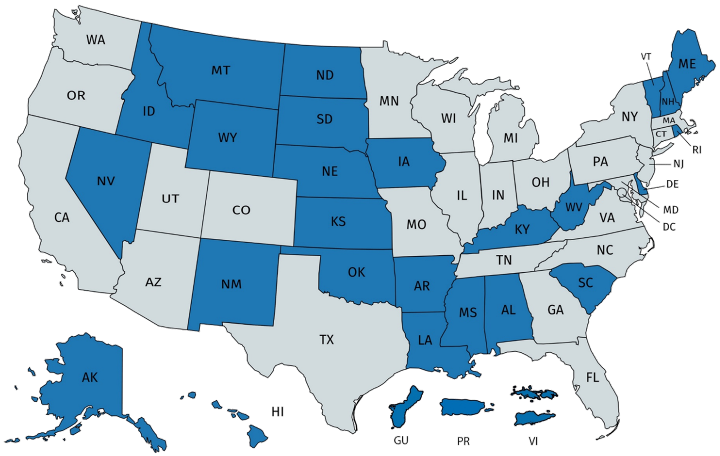
Visualization of thermal plume




Flow visualization of flow over an airfoil

# Topic Area 5:

# Terrestrial and Planetary Atmospheric Sciences: Air quality, properties of clouds, winds, aerosols, water vapor, trace gases, climate change



# Terrestrial and Planetary Atmospheric Sciences: Air quality, properties of clouds, winds, aerosols, water vapor, trace gases, climate change

## Measuring Aerosol Chlorides/Sulfates for Atmospheric Corrosion Studies in Cold Alaskan Climate

# Raghu Srinivasan

Assistant Professor,
Department of Mechanical Engineering,
College of Engineering,
University of Alaska Anchorage
3211 Providence Drive, ECB 301F
Anchorage, AK 99508-4614
Phone: 907 786 4815
Fax: 907 786 1079
Email: rsrinivasan2@alaska.edu

Dr. Raghu Srinivasan is an assistant professor in the Mechanical Engineering Department at UAA's College of Engineering. He established, and currently serves as the director of the Environmental Degradation lab at UAA. He grew up in India and moved to Hawaii to do Ph.D. in atmospheric corrosion before landing here in Alaska. His research interests include atmospheric corrosion of light alloys, materials compatibility, and materials selection.

# Measuring Aerosol Chlorides for Atmospheric Corrosion Studies in Arctic Climate

**LaRC Research Topic: Terrestrial and Planetary Atmospheric Sciences (Aerosols)**

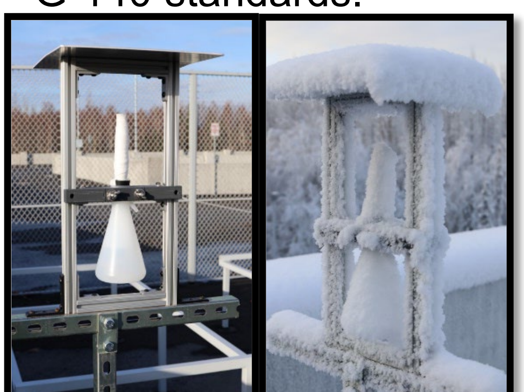
**PI: Raghu Srinivasan (rsrinivasan2@alaska.edu), University of Alaska Anchorage**

## Need

- Corrosion continues to be a major problem for NASA since its inception in 1962 and it is included in NASA's Space Technology Roadmap to reduce the cost and improve the sustainability and efficiency of its ground operations.
- One of the major parameters that affects atmospheric corrosion of metals is aerosol chlorides.
- Measuring aerosol chlorides in cold freezing climate is challenging using the existing measuring standards.

## Approach

- Wet chloride candle method are used to measure the aerosol chloride following ASTM G-140 standards.



Frozen candle during winter months make it difficult to measure aerosol chlorides and other particles in the atmosphere.

## Benefit

- The proposed collaboration with LaRC atmospheric science team will enhance the aerosol measurement techniques in cold arctic climate.
- This will lead to a better understanding of atmospheric corrosion and to develop a corrosivity map for the state of Alaska based on aerosol and weather data.

## Competition

- Test sites along the Trans-Alaska Pipeline and marine transportation sectors are already established using NASA EPSCoR CAN project.
- The combination of urbanization and proximity to marine environments make arctic and sub-arctic regions in North America, particularly Alaska, an important natural laboratory to study atmospheric corrosion.

NASA EPSCoR Research for LaRC
January 27, 2021

Terrestrial and Planetary Atmospheric Sciences: Air quality, properties of clouds, winds, aerosols, water vapor, trace gases, climate change

# The Clemson Air Quality Lab


## Andrew Metcalf

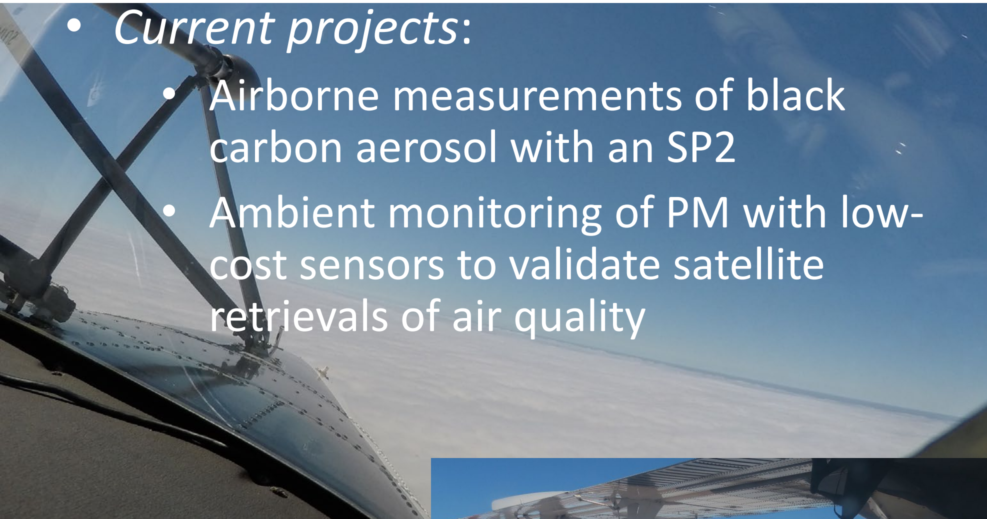
Clemson University
864-656-0464
ametcal@clemson.edu


Andrew Metcalf is an Assistant Professor in Environmental Engineering and Earth Sciences at Clemson University. He directs the Clemson Air Quality Lab and teaches courses on air pollution engineering, combustion and air pollution control technologies, Earth's atmosphere and climate, and atmospheric aerosols. Dr. Metcalf has expertise in aerosol instrumentation and field measurements and is currently focused on techniques using electrical mobility and laser light scattering and absorption. Ongoing research projects include ambient sampling of prescribed fire activities in the Upstate of South Carolina, analysis of airborne field project datasets for aerosol-cloud interactions, developing low-cost air quality sensor packs for a dense network of ambient monitoring for satellite retrieval validation, and understanding the relationship between outdoor and indoor air quality. Dr. Metcalf has been previously funded by the SC NASA EPSCoR $25k Research Grant Program (RGP) and is currently mentoring a student who was awarded a NASA SC Space Grant Consortium Graduate Research Fellowship (GRF).

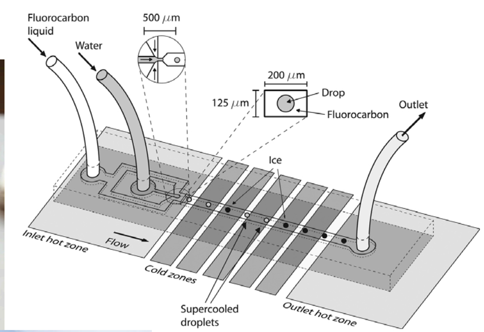
# Clemson Air Quality Lab


PI: Andrew R. Metcalf
ametcal@clemson.edu


- Aerosol particle measurements
  - *Current projects*:
    - Airborne measurements of black carbon aerosol with an SP2
    - Ambient monitoring of PM with low-cost sensors to validate satellite retrievals of air quality



- Microfluidic device fabrication and experiments
- *Current project*:
  - Developing an ice nucleation particle counter




CLEMSON
ENVIRONMENTAL ENGINEERING AND EARTH SCIENCES

College of ENGINEERING, COMPUTING AND APPLIED SCIENCES

# Terrestrial and Planetary Atmospheric Sciences: Air quality, properties of clouds, winds, aerosols, water vapor, trace gases, climate change

Ground validation for ecosystem carbon and GHG fluxes and other atmospheric variables from flux towers in SC

## TOM O’HALLORAN

ASSISTANT PROFESSOR
Affiliation
Forestry & Environmental Conservation Dept.
Baruch Institute of Coastal Ecology & Forest Science
Clemson University
tohallo@clemson.edu

Dr. Tom O’Halloran is an Assistant Professor at the Baruch Institute of Coastal Ecology and Forest Science in the Department of Forestry and Environmental Conservation at Clemson University in South Carolina. His research examines the effects of ecosystem disturbances and land management on land-atmosphere interactions in the coupled biosphere-climate system. He has built and operates 7 eddy covariance tower systems in Virginia and South Carolina for measuring land-atmosphere fluxes of heat, water, carbon dioxide and methane. He is also an active user of MODIS, Landsat, and CERES remote sensing observations. His doctoral work examined atmospheric aerosol formation above forests and their subsequent interactions with cumulus clouds. He was a summer graduate research fellow at the NASA Goddard Space Flight Center working with Dr. Wei-Kuo Tao and the Goddard Cumulus Ensemble Model.

# Tom O'Halloran, *Micrometeorologist*



tohallo@clemson.edu

University of Virginia

B.A., M.S., Ph.D.
*Environmental Sciences*

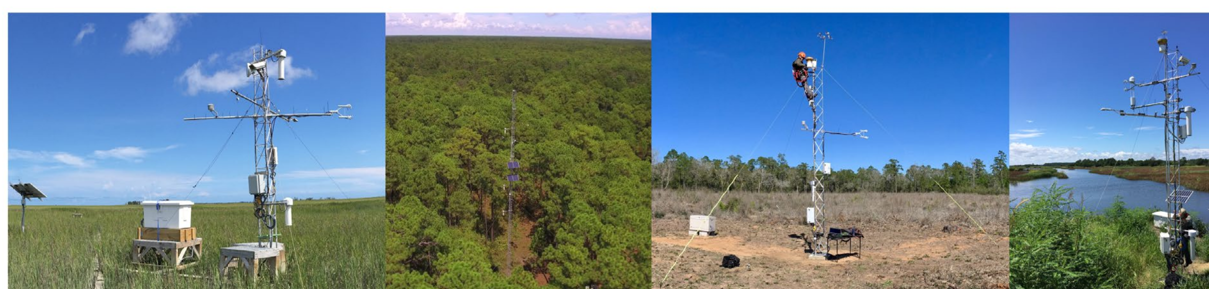
Assistant Professor

*Department of Forestry and Environmental Conservation,* Clemson University

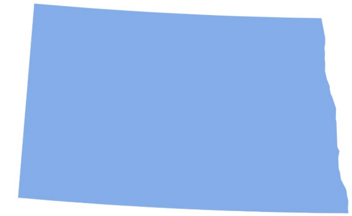
*Baruch Institute of Coastal Ecology and Forest Science*


- Primary interests
  - Land-atmosphere interactions, GHG fluxes
- Data provider
  - Operate 7 eddy flux towers ($CO_2$ & $CH_4$ fluxes)
    - 3 in central Virginia (pine forest & switchgrass bioenergy)
      - Aerosol SMPS, Gas analyzers: $O_3$, NOx, $SO_2$
    - 4 in coastal South Carolina (forests and wetlands – blue carbon)
  - Soil GHG mobile flux lab: $CH_4$, $N_2O$, $CO_2$
- Satellite data user, model developer
  - MODIS, Landsat, **CERES**

- Bright, R. M. and **O'Halloran, T. L.,** 2019. Developing a monthly radiative kernel for surface albedo change from satellite climatologies of Earth's shortwave radiation budget: CACK v1.0, Geosci. Model Dev., 12, 3975–3990, https://doi.org/10.5194/gmd-12-3975-2019.



NASA EPSCoR Research for LaRC
January 27, 2021



## Terrestrial and Planetary Atmospheric Sciences: Air quality, properties of clouds, winds, aerosols, water vapor, trace gases, climate change

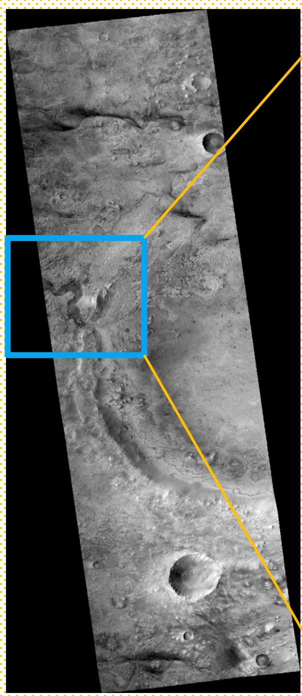
# Hydrodynamics of Jezero Inlet


## Trung Bao Le

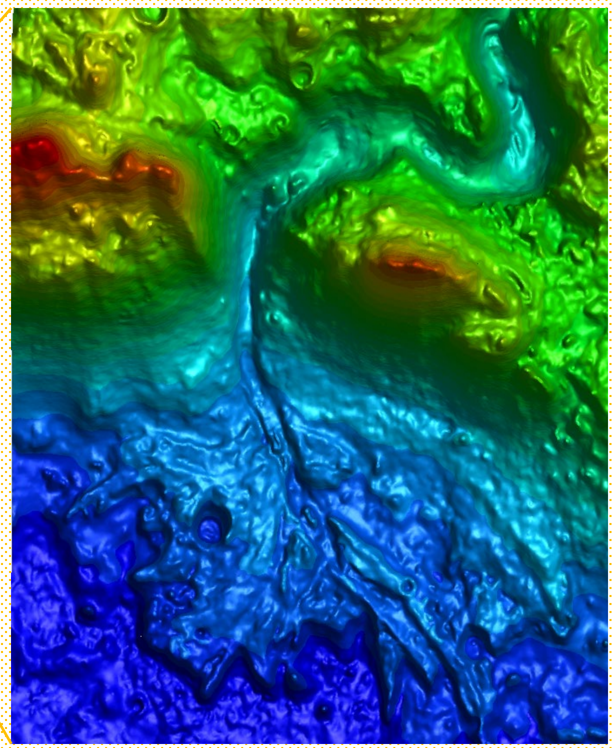
Department of Civil, Construction, and Environmental Engineering
North Dakota State University
trung.le@ndsu.edu


Dr. Trung Bao Le is an Assistant Professor at the Department of Civil, Construction, and Environmental Engineering at North Dakota State University, United States. He is the recipient of national and international awards including the Gallery of Fluid Motion (American Physical Society - Division of Fluid Dynamics) and a pre-doctoral fellowship from United States National Academies. He obtained his bachelor's degree at Thuy Loi University in Vietnam, master's degree at Asian Institute of Technology in Thailand and PhD degree at the University of Minnesota. His research focuses on fundamental phenomena in fluid mechanics and hydraulics problems. His expertise involves the development for scalable numerical algorithms that can run from desktop computer to supercomputers.

## ANCIENT CLIMATE AT THE JEZERO CRATER



CTX

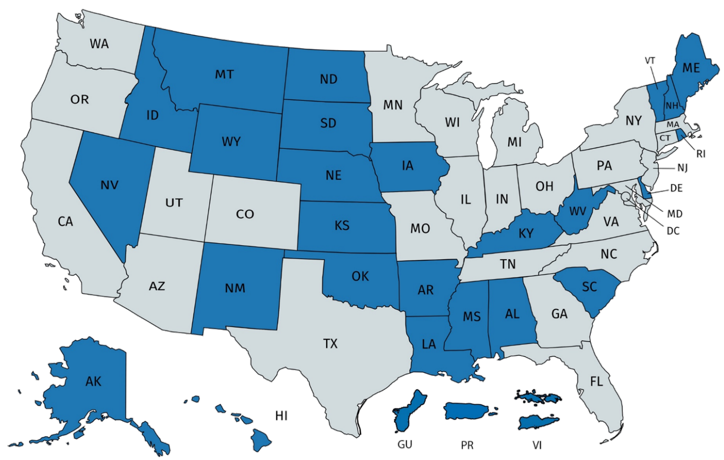


3D Topography of the delta fan

- We study the impact of past climate on the hydrodynamics of an ancient river on Mars.
- Investigate the forming mechanism of the delta fan at the Jezero inlet from the three-dimensional hydrodynamic conditions at the Jezero inlet
- CTX terrain data is used to generate the three-dimensional topography of the Jezero inlet
- Our in-house Large Eddy Simulation code is used to perform hydrodynamic simulation.
- Provide accurate estimation of shear stresses distribution near the bed, which can be used to infer past sediment transport processes.
- Our results might be used for planning future path of the Perseverance rover.

# Topic Area 6:

# Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement



NASA EPSCoR Research for LaRC
January 27, 2021

Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

Deep Learning-Based Super Resolution of Satellite Gravity Data for Geophysical Exploration



# Dr. Jyotsna Sharma

Dept. of Petroleum Engineering
Louisiana State University
JSharma@lsu.edu
225-573-4498


Dr. Sharma joined LSU as an Assistant Professor in Petroleum Engineering in 2019, after working in the energy industry for over eight years at Chevron, Schlumberger, and Shell. Her primary research interests include fiber optic sensing and machine learning applications in the energy industry. Dr. Sharma conducts experiments both at bench-scale and well-scale (several thousand feet) in her optical sensing lab and at the LSU well-facility. She has worked extensively on Chevron's fiber optic monitoring program in the U.S., Indonesia, and Venezuela. She also consults for E&P companies for fiber optics data interpretation. She has a multidisciplinary background with Ph.D. in petroleum engineering and B.Tech. in electrical engineering. Dr. Sharma has given invited talks on optical sensing at Stanford University, University of Wyoming, Exxon, and Shell and authored numerous publications on fiber optic sensing and machine learning.

# Deep Learning-Based Super Resolution of Satellite Gravity Data for Geophysical Exploration

- **Objective:** To develop a workflow for utilizing **GRACE**-derived gravity data for mapping of **hydrocarbon** resources by improving spatial resolution using **super-resolution** algorithm.

## Hydrocarbon Reservoir Classification using Gravity Anomaly

**Data Collection:**
Gravity anomaly data and oil/gas reserves

↓

**Geospatial Interpolation:**
Estimate gravity anomaly at well location

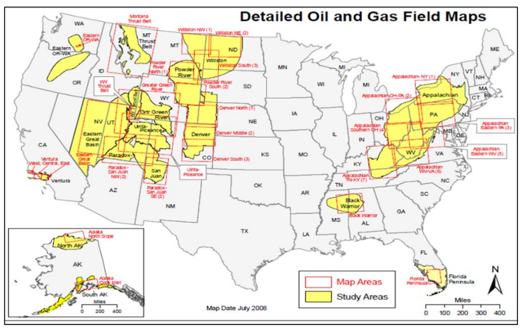
↓

**Random Forest Regression** → **Random Forest Classification**

**Petrel Convergent Interpolation** → **Random Forest Classification**

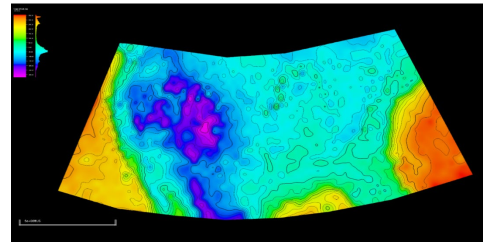
***Classifications Investigated***

**Test 1: {Oil, Gas, Oil and Gas, Low Oil and Gas}**
**Test 2: {Hydrocarbon, No hydrocarbon}**
**Test 3: {Oil, No Oil}**
**Test 4: {Gas, No Gas}**

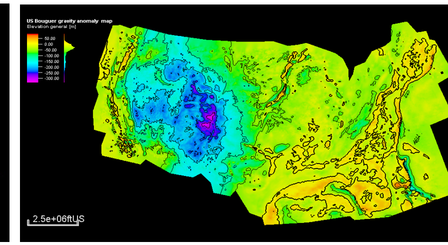



### Reservoir Classification Results

| | Precision | Recall | F1-score | Support |
|---|---|---|---|---|
| Gas | 0.86 | 0.87 | 0.86 | 27515 |
| Gas and Oil | 0.85 | 0.86 | 0.85 | 27669 |
| Low Hydrocarbons | 0.98 | 0.96 | 0.97 | 28544 |
| Oil | 0.91 | 0.90 | 0.90 | 28272 |
| Accuracy | | | **0.8970** | 112000 |

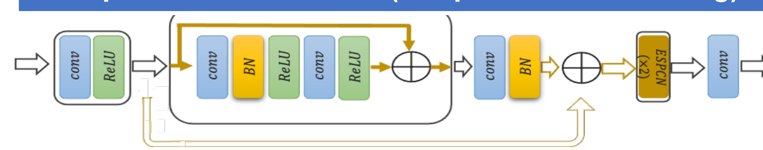


**Satellite-based Gravity** (Bouguer)

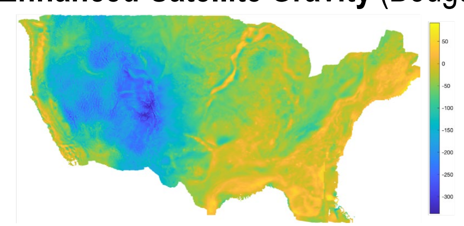


**Land-based Gravity** (Bouguer)

## Super Resolution CNN (Deep Machine Learning)




**Enhanced-Satellite Gravity** (Bouguer)



NASA EPSCoR Research for LaRC
January 27, 2021

Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

## Active remote sensing with a spaceborne imaging radiometer


# Ashanthi Maxworth

Assistant Professor in Electrical Engineering
Department of Engineering
University of Southern Maine
ashanthi.maxworth@maine.edu


Ashanthi Maxworth is originally from Sri Lanka where she obtained her bachelor's degree in Electronics and Telecommunications Engineering from the University of Moratuwa. She obtained her Master's and Ph.D. from the University of Colorado Denver in 2014 and 2017 in Electrical Engineering with an emphasis on space physics. Her Ph.D. dissertation was on Magnetospheric Whistler Mode Ray-tracing with Finite Electron and Ion Temperature. For her doctoral dissertation, she used the NASA Global Core Plasmasphere Model (GCPM) and the Van Alleb Probe – EMFISIS data to verify her simulation results. After graduation, she completed two and half years of a postdoctoral fellowship at the University of Saskatchewan Canada with the Institution of Atmospheric and Space Physics, analyzing the natural and man-made data collected by the Radio Receiver Instrument (RRI) on the Canadian e-POP satellite.

Since August 2020, she is a faculty member at the University of Southern Maine, Department of Engineering. In November 2021, she was awarded the STEM Educational Grant through the Maine Space Grants Consortium to develop her course EGN 321- Plasma Engineering with emphasis on Space Plasmas. As a part of this course, students will be building instruments such as Langmuir probes and ionosonde to be used in future NASA collaborative missions. Ashanthi has been an active member of the Maine Cubesatellite initiative assisting both the University of Maine and the University of Southern Maine on their Attitude Determination and Control systems. She has ten years of experience in space physics. Her newly built lab is equipped with state-of-the-art instruments and an industrial-level Helmholtz cage, which is the only Helmholtz cage available within the state of Maine. Starting in January 2022, she will be in charge of the cube satellite ground station at the University of Southern Maine.

# Active Remote Sensing with a Space-borne Imaging Radiometer

- Motivation: Visible Infrared Imaging Radiometer Suite (VIIRS) On the Suomi NPP satellite mission – NASA and NOAA
- Collects imagery within the visible and infrared range.
- Provide high resolution images of the landmass, atmosphere, oceans, polar-ice covered regions.
- Can monitor, wild-fires, polar ice melting, atmospheric aerosols, forestry etc.
- Reference: https://www.jpss.noaa.gov/viirs.html

- Pros: light weight, low power consumption, low construction time, low cost
- Cons: low resolution compared to VIIRS

- Goal: to develop an imaging radiometer that can be hosted on a Low Earth Orbit, 6U cube satellite.
- The existing instrument provides a resolution of 400m. Power required: 319 Watts, and mass is 280kg.
- Limitations: weight 12kg, power ~60W.
- Proposed idea:
  - Use a 2D array of 16 infrared (IR) sensors.
  - Transmit the signal and measure the reflected signal.
  - Using reflected spectroscopy create the image.
  - Ideally image creation will be done in-space, but may be done on ground due to power limitations.

Ashanthi Maxworth PhD, Assistant Professor in Electrical Engineering, USM

Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

# Ultra-Compact Plasma Spectrometer

## Earl Scime

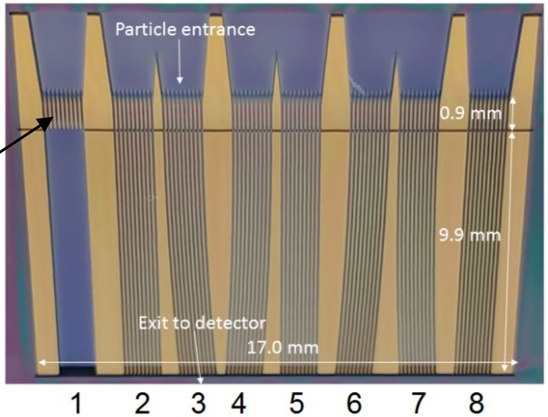
Oleg Jefimenko Professor of Physics and Astronomy
Director of the School of Mathematical and Data Sciences
Director, Center for KINETIC Plasma PhysicsDepartment of Mechanical and Aerospace Engineering
West Virginia University
escime@wvu.edu

Earl Scime is the Oleg D. Jefimenko Professor of Physics and Astronomy at West Virginia University (WVU). He currently serves as the Director of the School of Mathematical and Data Sciences at WVU and is a past Chair of the American Physical Society's Division of Plasma Physics. He moved to WVU in 1994 from Los Alamos National Laboratory, where he was a DoE Distinguished Postdoctoral Fellow. His research interests span fusion plasmas, space plasmas and industrial plasmas – with a cross-cutting focus on particle heating and velocity distribution function measurements. He was part of the Ulysses mission electron instrument team and his neutral atom imaging instrument concept was used for the IMAGE and TWINS missions.  He has continued to measure particle velocity distributions in laboratory and space plasmas through a variety of diagnostic techniques. His current space instrument development work has focused on microscale fabrication for particle instruments.  He has contributed to over 190 peer-reviewed publications and was named a Fellow of the American Physical Society in 2011.

# Ultra-Compact Plasma Spectrometer – *E. Scime*

**MEMS Wafer Scale Processed**
- Lithographically Designed
- 3D Device Hybridization
- Double Sided Lithography

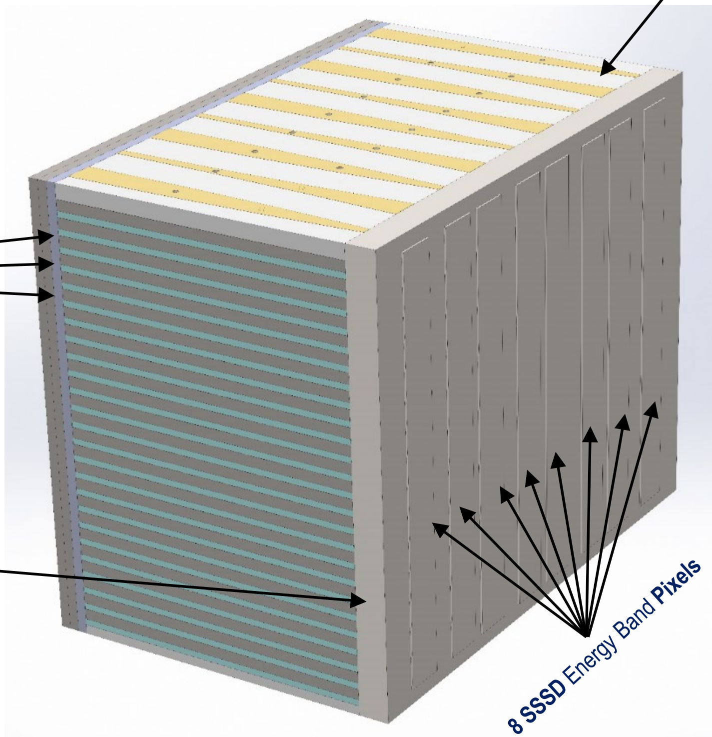
**Integrated Particle Collimator**
- 2º x 2º angular acceptance




**Nominal Form Factor - 1 cm x 1 cm x 1 cm**
- 8 simultaneous energy bands per chip level
- Target of 50% collection area for each "layer."

**Energy Analyzer Vertical 3D Stack**
- 25 Energy Analyzer Layers in a 3D Stack
- Nominal 5- 20 keV energy range

**Energy Resolving Silicon Detector**
- Nominal ~100 V operating voltage
- Energy thresholds of 1.1 keV for electrons and 5 keV for ions



NASA EPSCoR Research for LaRC
January 27, 2021

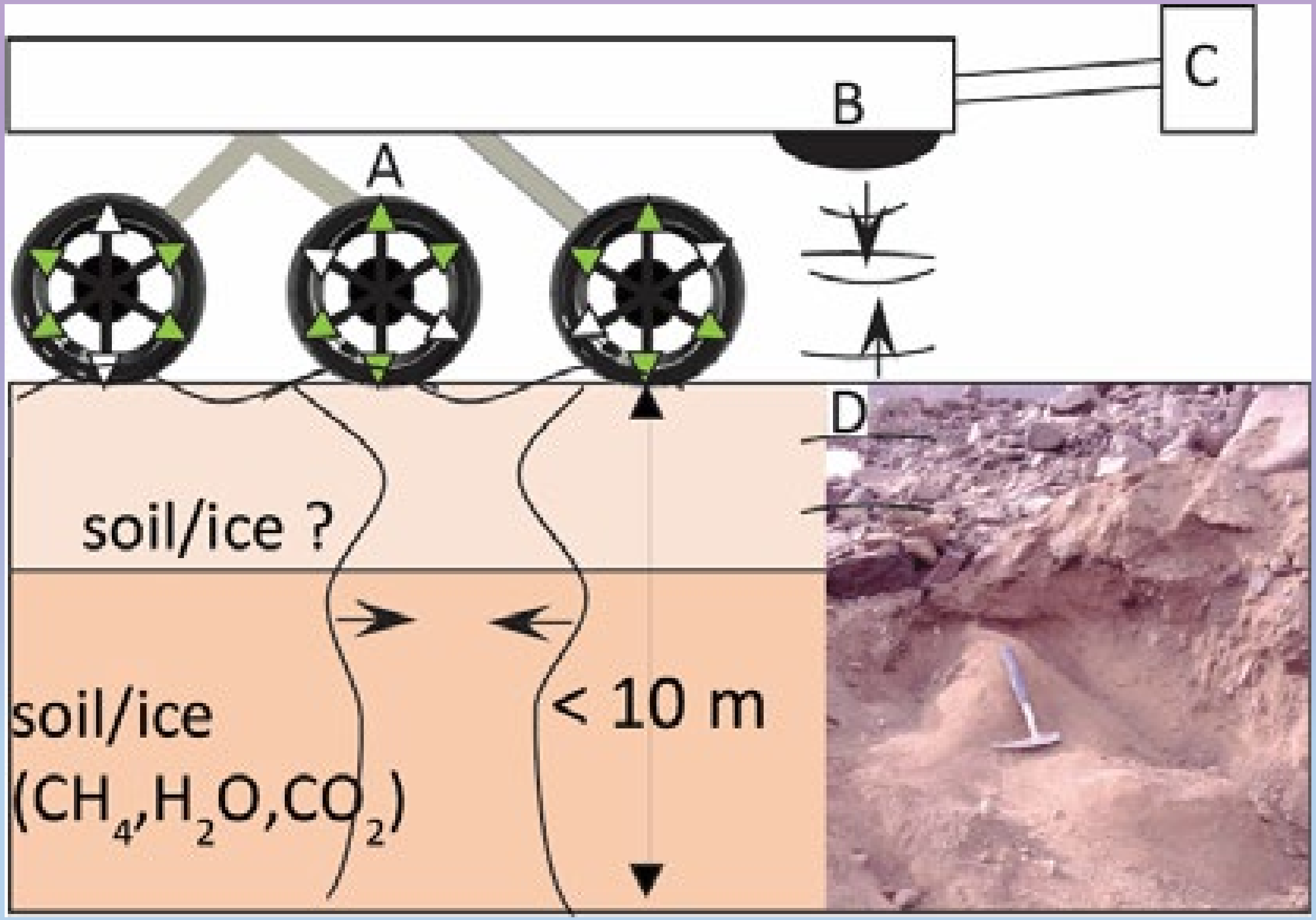
Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

Seismic Wheel for Shallow Characterization (0- 1 m) of Soils on Mars and the Moon

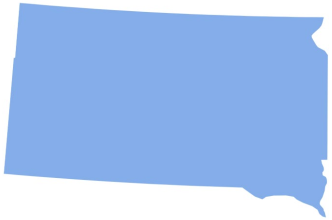

# Juan M. Lorenzo

Louisiana State University
Dept. Geology and Geophysics
Email: gllore@lsu.edu


Juan is a Professor in the Department of Geology and Geophysics. He experiments at both field and laboratory scales with seismic sources and sensors to better understand the physical properties and geologic history of near-surface soils (< 30 m). He has been a Marshall Space Flight Center Summer Faculty Fellow and is currently supported by an EPSCoR Rapid Response Research Award to develop an ISRU-mapping, wheel-mounted, mini-seismic system.




Integrated Geophysics: seismic (A), GPR (B) and chemical (C), for Shallow Characterization (0 - 1 m) of Soils on Mars



Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

## Stretchable Sensors for Motion and Structural Monitoring

# Dr. Zhengtao Zhu

Associate Professor
Department of Chemistry, Biology, and Health Sciences
South Dakota School of Mines and Technology
Phone: 605 394 2447
Email: Zhengtao.Zhu@sdsmt.edu

Dr. Zhengtao Zhu is an Associate Professor of Chemistry and Head of the Department of Chemistry, Biology, and Health Sciences at South Dakota Mines. Dr. Zhu's research focuses on nanomaterials and conducting polymers, flexible electronics and sensors, energy storage materials, and advanced manufacture/nanofabrication. Dr. Zhu has more than 80 publications in a variety of research areas and his research has been funded by NSF, NASA, ACS, EPA, and private companies.

SOUTH DAKOTA MINES
An engineering, science and technology university

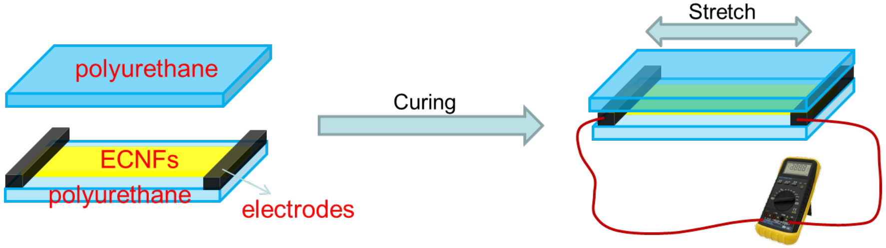
Dr. Zhengtao Zhu, Associate Professor and Head
Department of Chemistry, Biology and Health Sciences
Phone: 605 394 2447; Email: zhengtao.zhu@sdsmt.edu

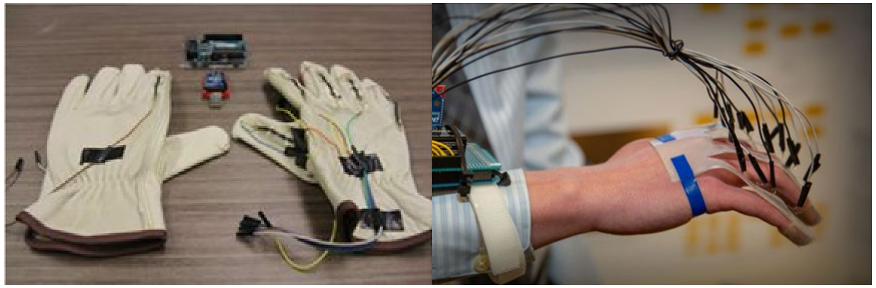
# Flexible and Stretchable Sensors for Motion and Structural Monitoring

## Background and Expertise

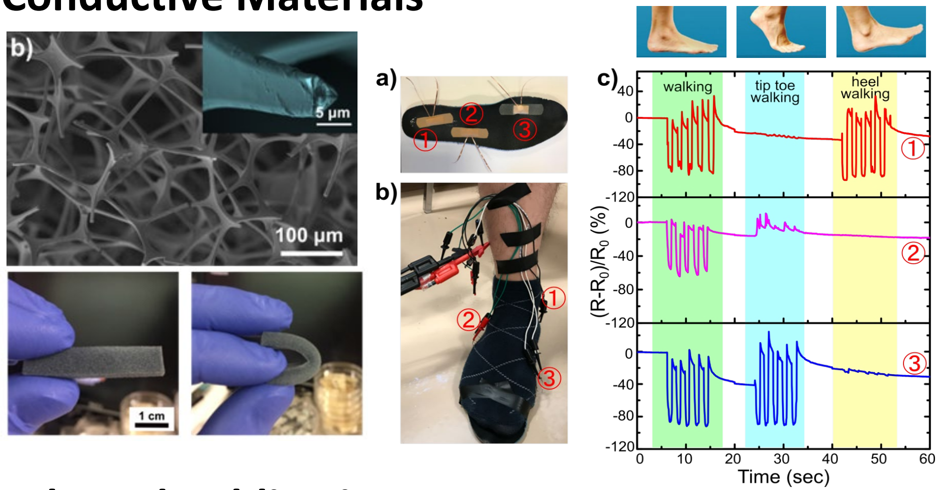
- Nanomaterials and conducting polymers
- Flexible electronics and sensors
- Energy storage materials
- Advanced manufacture/nanofabrication

## Stretchable Strain Sensors based on Electrospun Nanofibers



## Flexible Tactile Sensors based on Spongy Conductive Materials




## Selected Publications

1. *RSC Adv., 2016, 6, 79114*
2. *J. Mater. Chem. C, **2017**, 5, 10288*
3. *ACS Appl. Mater. Interfaces,* 2018, *10*, 1607
4. *ACS Appl. Mater. Interfaces,* 2019, *11, 6685*

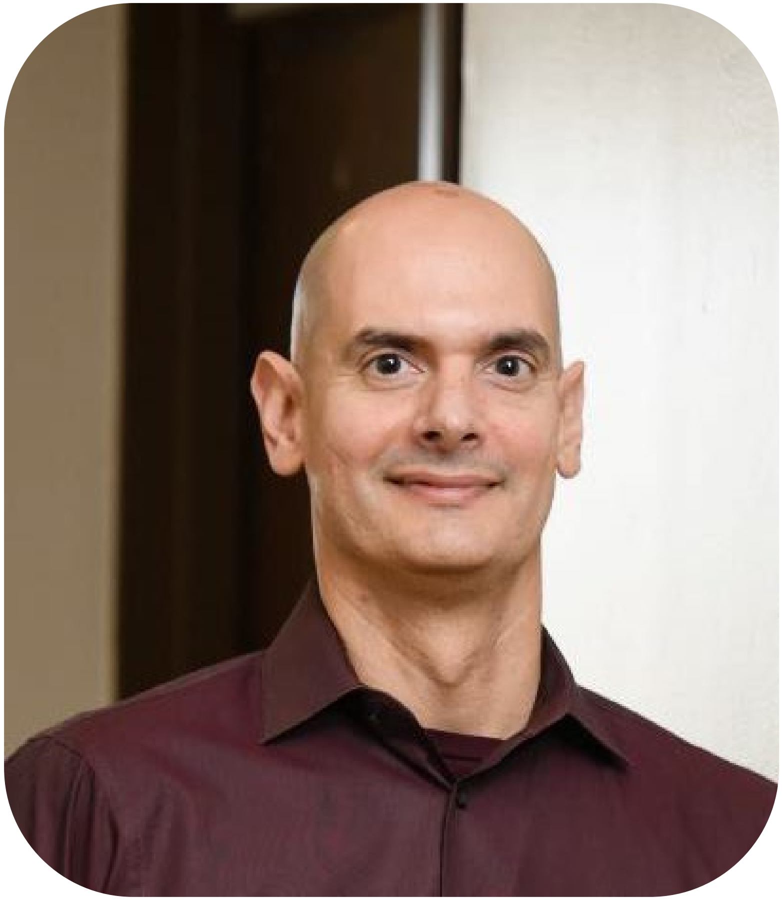
## Funding Support

NASA EPSCoR 80NSSC18M0022
NASA EPSCoR NNX13AD31A

Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

## Optical Spectroscopy and Optical Materials Research at Clemson University

# Luiz G. Jacobsohn



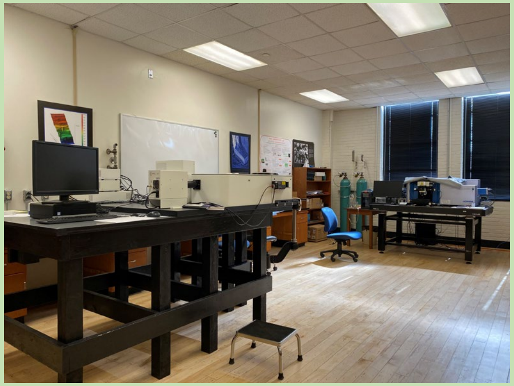
Prof. Luiz G. Jacobsohn
Department of Materials Science and Engineering Clemson University
515 Calhoun Dr., Sirrine Hall #161
Clemson, SC 29634
E-mail: luiz@clemson.edu
Website: https://cecas.clemson.edu/~luiz/

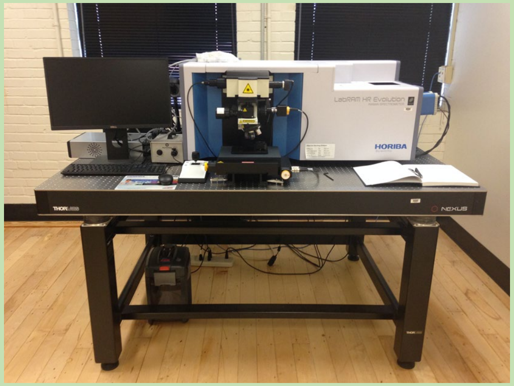
Dr. Jacobsohn, a former technical staff member with the Materials Science and Technology Division of Los Alamos National Laboratory, is associate professor with the Department of Materials Science and Engineering of Clemson University. He holds a B.Sc. in Physics, a M.Sc. in Materials Science, and a D.Sc. in Physics. He has about 130 peer-reviewed publications, one issued patent, and a book chapter that collectively received more than 2000 citations. His research interests are related to optical materials and optical spectroscopy in general with a focus on luminescence dosimeters, scintillators as well as radiation damage. His experimental facilities cover from the synthesis of inorganic materials and atmosphere-controlled thermal processing to structural characterization via Raman confocal microscopy and a broad variety of luminescence and optical spectroscopy techniques.

**Prof. Luiz G. Jacobsohn (luiz@clemson.edu)**
**Dept. Materials Science and Engineering, Clemson University**

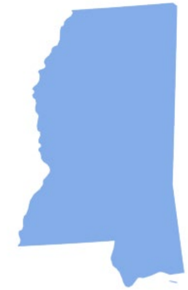
**Research Interests:** optical materials and optical spectroscopy in general with a focus on luminescence, dosimeters, scintillators as well as radiation damage

**Experimental Facilities:** synthesis of inorganic ceramic materials, atmosphere-controlled thermal processing, microstructural characterization (Raman confocal microscopy, FTIR, X-ray diffraction, electron microscopy, XPS) and a broad variety of luminescence/fluorescence (under UV and X-ray excitation) and optical spectroscopy techniques







NASA EPSCoR Research for LaRC
January 27, 2021

Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

Recycling the Radio Spectrum for Science: Advancing land remote sensing with ground, air, and space borne platform

# Mehmet Kurum

Mississippi State University
Department of Electrical and Computer Engineering
InforMation PRocEssing and SenSing (IMPRESS) Laboratory
Mississippi State, MS 37962
kurum@ece.msstate.edu

Mehmet Kurum received M.S. and Ph.D. degrees in Electrical and Computer Engineering from the George Washington University, Washington, DC in 2005 and 2009 respectively. He held NASA Postdoctoral fellow and research associate positions at NASA Goddard Space Flight Center, Greenbelt, MD. He is currently Assistant Professor of Department of Electrical and Computer Engineering at Mississippi State University (MSU) and co-director of InforMation PRocEssing and SenSing (IMPRESS) Lab.

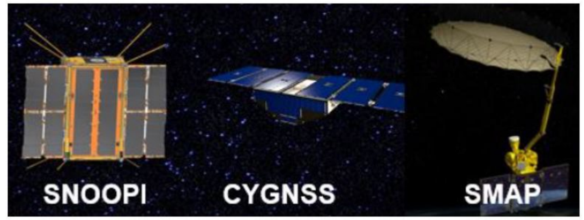
His principal technical area is applied electromagnetics and remote sensing. He does research on opportunistic and conventional microwave remote sensing from satellite scales to small aerial platforms in environmental sustainability and monitoring. His current research focuses on recycling the radio spectrum to address the challenges of decreasing radio spectrum space for science while exploring entirely new microwave regions for land remote sensing.

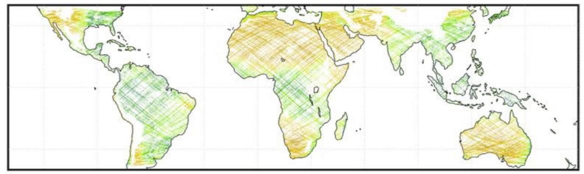
# Recycling the Radio Spectrum for Science: Advancing Land Remote Sensing with Ground, Air, and Space Borne Platforms

MISSISSIPPI STATE UNIVERSITY

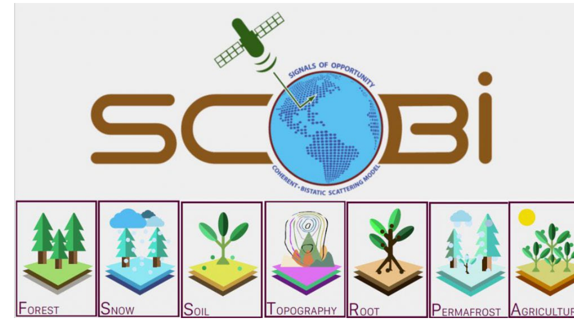

Mehmet Kurum
Assistant Professor ECE
kurum@ece.msstate.edu


More info:
**http://impress.ece.msstate.edu/**

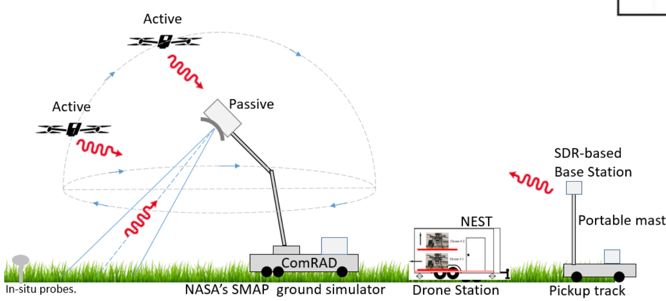


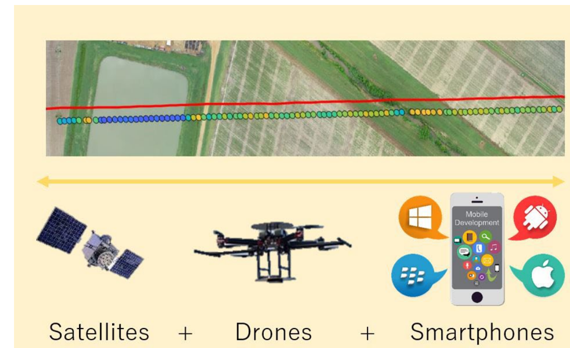
**Information Retrievals**



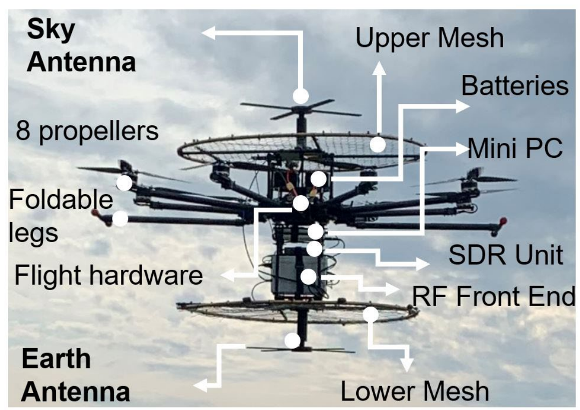

**EM Modeling & Simulation**



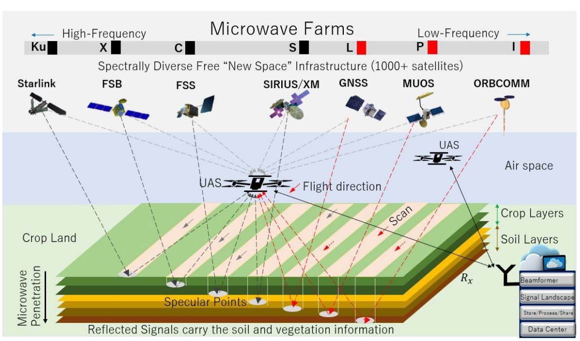

**Spectrum Coexistence**




**Ubiquitous RF Sensing**




**SoOp Software Defined Radio**




**RF Testbed for Digital Agriculture**

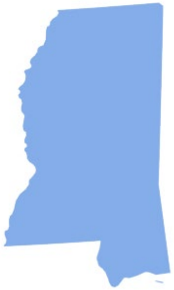
**Off-Road Robotics and Autonomy**


IMPRESS INFORMATION PROCESSING AND SENSING

**Sponsors**

USDA Agricultural Research Service
ERDC
NSF
NASA
Goddard SPACE FLIGHT CENTER
JPL Jet Propulsion Laboratory

NASA EPSCoR Research for LaRC
January 27, 2021



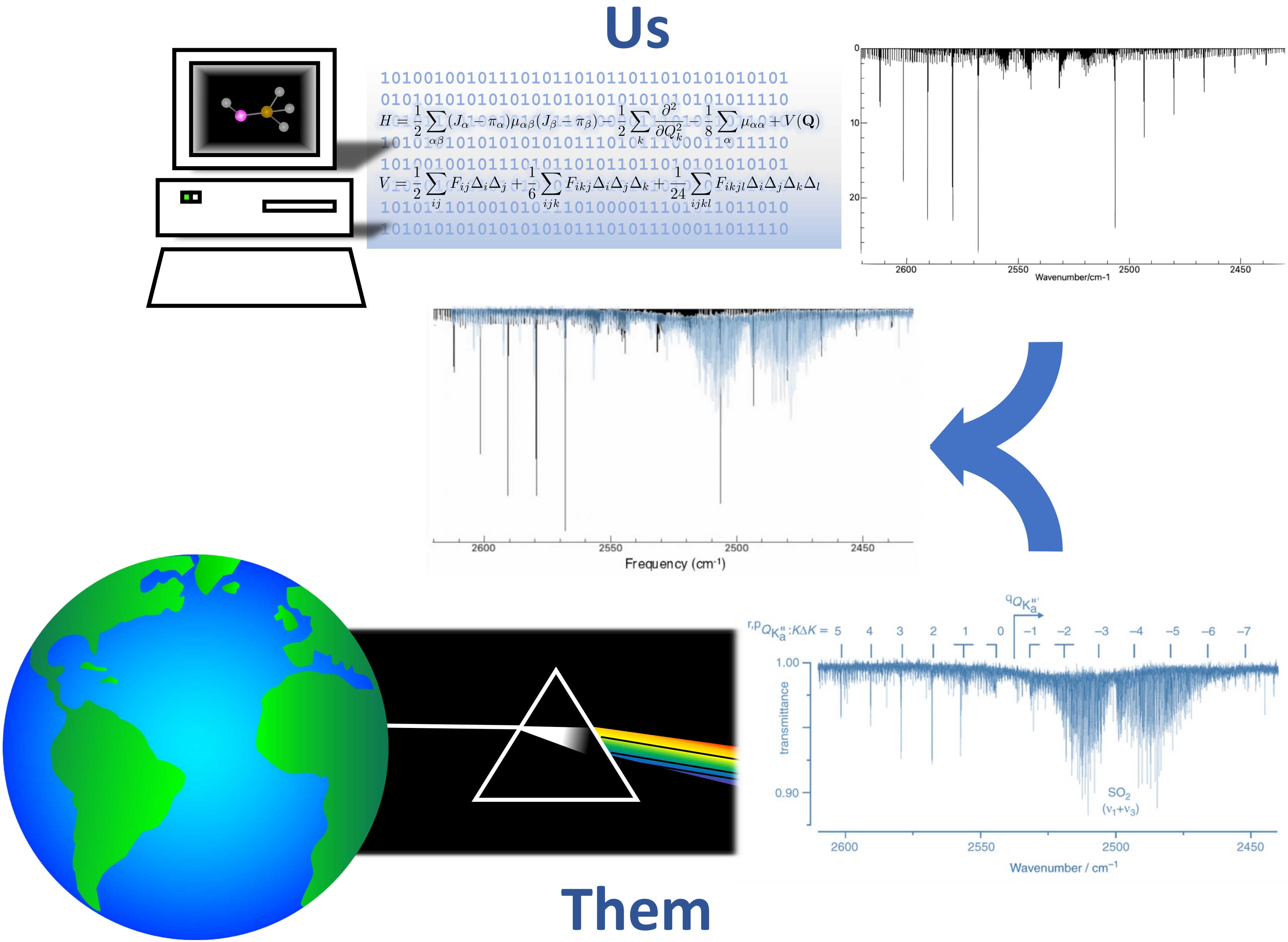
Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

## Knowing What's Out There: Spectral Data Production across the Wavelengths

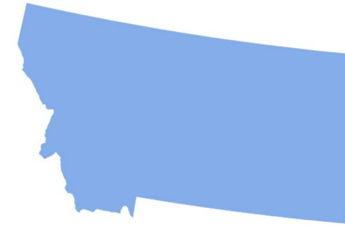

# Ryan Fortenberry

University of Mississippi
r410@olemiss.edu
662-915-1687


Ryan C. Fortenberry is Associate Professor of Chemistry at the University of Mississippi (UM) and also is the Graduate Program Coordinator for the Department of Chemistry & Biochemistry. Fortenberry's research exists at the intersection of chemistry, astronomy, mathematics, and computer science. His work in quantum chemistry and simulated spectroscopy is geared towards assisting in the detection of novel molecules in space as well as in providing new insights for materials related to radiation shielding, solar energy harvesting, and the production of refractory and ceramic materials. Fortenberry was previously at Georgia Southern University for five years and granted tenure & promotion there before joining UM. Fortenberry earned a BS in Mathematics and a MS in Communication from Mississippi College; received a Ph.D. at Virginia Tech in Theoretical Chemistry; and was a NASA Postdoctoral Program Fellow at the NASA Ames Research Center in Mountain View, California. Fortenberry was recently the Chair & Past-Chair of the ACS Astrochemistry Subdivision and is currently the Ole Miss Campus Coordinator for the Mississippi Space Grant Consortium. Fortenberry has over 150 peer-reviewed scientific publications, received several research grants, was selected as the Virginia Tech College of Science 2019-2020 Outstanding Recent Alumni Awardee, has been published in Scientific American, and is the author of Complete Science Communication, a text on how to write and talk about science both to expert and non-expert audiences alike.


Us
$H = \frac{1}{2}\sum_{\alpha\beta}(J_\alpha - \pi_\alpha)\mu_{\alpha\beta}(J_\beta - \pi_\beta) - \frac{1}{2}\sum_k \frac{\partial^2}{\partial Q_k^2} - \frac{1}{8}\sum_\alpha \mu_{\alpha\alpha} + V(\mathbf{Q})$
$V = \frac{1}{2}\sum_{ij} F_{ij}\Delta_i\Delta_j + \frac{1}{6}\sum_{ijk} F_{ikj}\Delta_i\Delta_j\Delta_k + \frac{1}{24}\sum_{ijkl} F_{ikjl}\Delta_i\Delta_j\Delta_k\Delta_l$
Wavenumber/cm-1
Frequency (cm-1)
transmittance
$^{r,p}Q_{K_a''}:K\Delta K =$ 5 4 3 2 1 0 −1 −2 −3 −4 −5 −6 −7
$^{q}Q_{K_a''}$
$SO_2$
$(\nu_1+\nu_3)$
Wavenumber / cm$^{-1}$
Them

NASA EPSCoR Research for LaRC
January 27, 2021



Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

## Topographic Correction of Broadband Snow Albedo Measured from an Uninhabited Aerial Vehicle (UAV)


# Eric Sproles

## Montana State University
eric.sproles@montana.edu


Eric Sproles is an Assistant Professor of Earth Sciences at Montana State University (MSU). His work integrates geospatial science and remote sensing with field-based measurements and models to better understand the geospatial and climatic controls on the world's water resources. At MSU, Eric leads the Geospatial Snow, Water, and Ice Resources Lab (GeoSWIRL), who as a team collectively applies geospatial approaches to bridge the scaling gaps between field- and space-based measurements of the hydrosphere and cryosphere.

# Q. How do you effectively measure the albedo of snow across mountainous landscapes?
# A. Deploy UAVs to account for topography and Processing Field of View (PFOV)

The real world is complex!



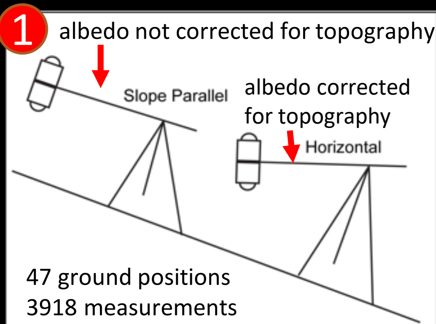
Eric A. Sproles
Andrew Mullen
MONTANA STATE UNIVERSITY
GEOSWIRL
Geospatial Snow, Water & Ice Resources Lab
Montana View
NASA
ESIP
USGS science for a changing world


UAV sensor

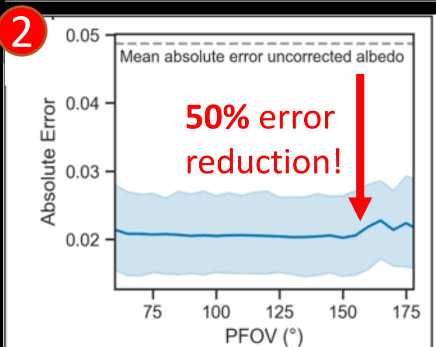
3


Topographic correction

1

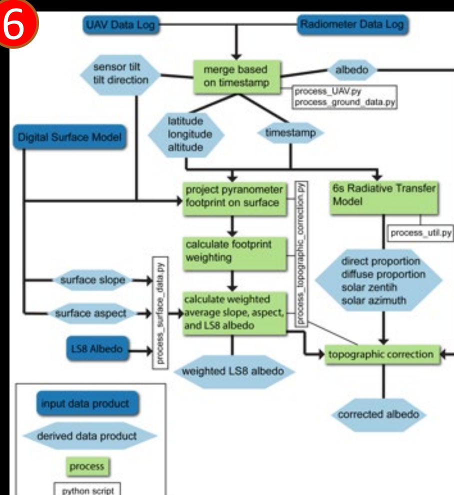



2




Full workflow

6

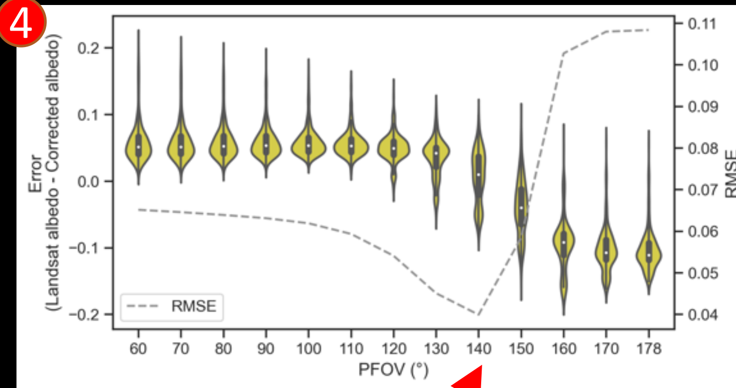



Mullen, Sproles, et al. (2022). An Operational Methodology for Validating Satellite-Based Snow Albedo Measurements Using a UAV. *Front. Remote Sens.* 2:767593. doi: 10.3389/frsen.2021.767593


eric.sproles@montana.edu

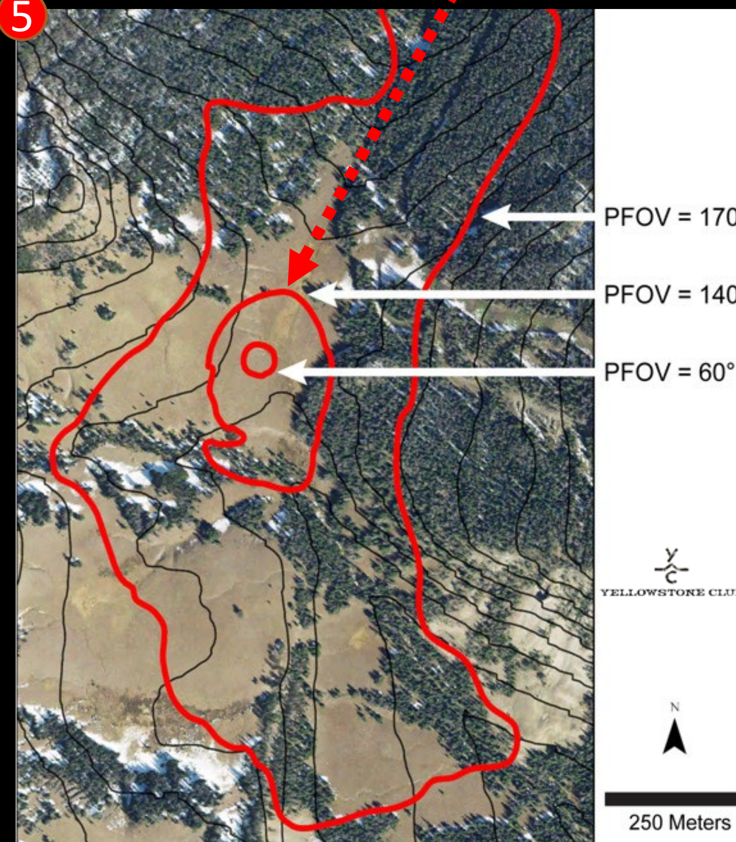

PFOV optimization

4




Optimized albedo measurements

5



Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

## High Resolution Imaging under Data Sparse Conditions

Ryan Norris

New Mexico Tech
ryan.norris@nmt.edu

Ryan Norris is an assistant professor of Physics at New Mexico Tech. He completed his PhD in Astronomy at Georgia State University in 2019, using the CHARA Array to image and study convective surface features on red supergiant stars. Following his doctorate, Norris worked on advanced optical and radar sensing techniques at the Georgia Tech Research Institute. At NMT, Norris is assisting with the development of the Magdalena Ridge Optical Interferometer. He works with undergraduate and graduate students on projects which apply high resolution imaging to study stellar evolution and on projects aimed at improving space domain awareness. The unifying theme of his work is pushing the boundaries of high-resolution imaging under data sparse conditions.

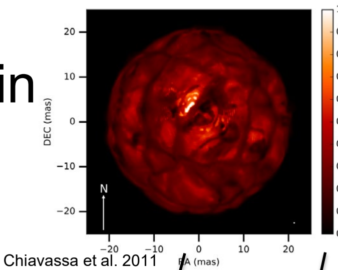
# High Resolution Imaging under Sparsity

How to make a reliable image with limited information.

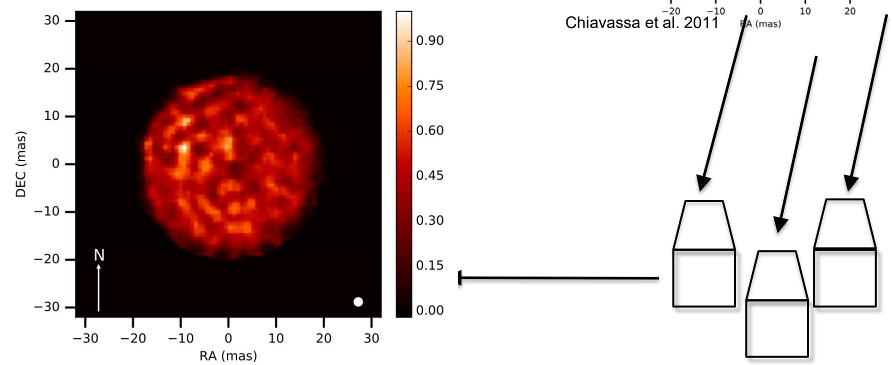
## Current Research

- Regularization for temporally variable sources
- Patch priors and other ML techniques
- Regularization with quantum annealing

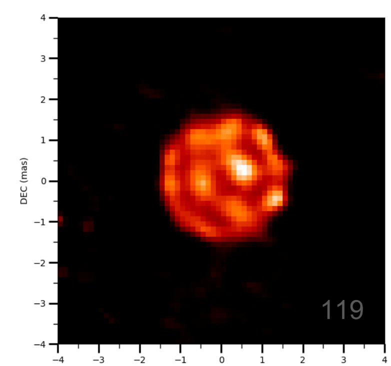
Example:
Optical interferometry in astronomy



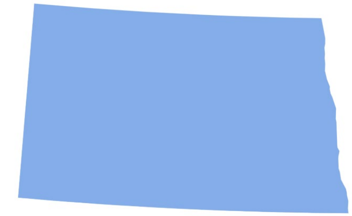

Chiavassa et al. 2011




Red supergiant
SU Per
Reconstructed using simulated annealing technique (SQUEEZE code)



NASA EPSCoR Research for LaRC
January 27, 2021



Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

## Towards a Better-Connected World: Combining Sensing Technologies with Radio Frequency Identification.


# Shuvashis Dey

Department of Electrical and Computer Engineering
North Dakota State University
Office: 101 U, EE Building
1411 Centennial Blvd, Fargo, ND-58102
Email: Shuvashis.dey@ndsu.edu
Phone: 701-231-1874


Shuvashis Dey is an Assistant Professor in the Department of Electrical and Computer Engineering at North Dakota State University (NDSU), USA. Prior to joining NDSU, he was a Post-doctoral Research Fellow in the Department of Electrical and Computer Systems Engineering at Monash University, Australia. In 2016, he worked as a visiting researcher in the Auto-ID Labs at Massachusetts Institute of Technology (MIT), Cambridge, USA. Dr. Dey received the Bachelor of Technology (B. Tech) degree in Electronics and Communication Engineering from National Institute of Technology-Durgapur, West Bengal, India in 2007, the M.Sc. degree in Wireless Networks from Queen Mary, University of London, England, United Kingdom in 2009 and the Ph.D. degree in Electrical and Computer Systems Engineering from Monash University, Australia in 2018. Dr. Dey's awards and honors include the Young Scientist's Travel Grant at IEEE International Symposium on Antennas and Propagation (ISAP) 2012, the IEEE MTT-S PhD Student Sponsorship Initiative Award in 2016 and the Best Presentation Award at International Conference on Sensing Technology (ICST) 2017. He is a member of IEEE.

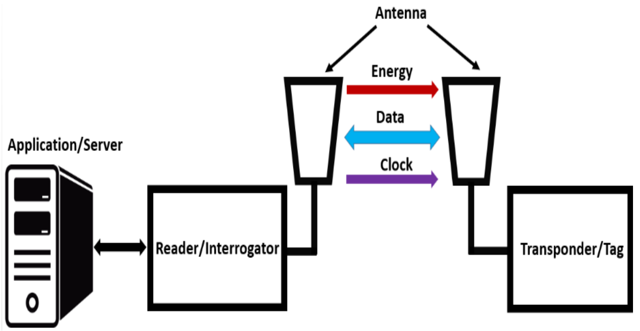
Dr. Dey's research capabilities and interests include Microwave devices and antennas, planar phased array antennas, microwave sensors for biomedical and smart farming applications, metamaterial and Terahertz devices, Internet of Things (IoT) and machine learning, smart sensing materials as well as chipless and chip-based UHF RFID tag and sensors.

Internet of Things (IoT) makes extensive use of sensor technologies to empower any application under its realm. However, current sensors are expensive, restricting the mass adoption of IoT application areas such as precision agriculture, maintenance management, smart buildings, and supply chain. This creates the necessity of compact and real-time sensors for these application areas. Recent advancements in wireless sensor networks have paved the way for combining sensing technologies with Radio Frequency Identification (RFID) systems. To that end, Dr. Dey's current research has focused on the development of low-cost and compact RFID tag-sensors. While IoT and RFID remain the main theme, the inter-disciplinary and collaborative approach has resulted in a diversified direction of his research. The core elements that help develop the RFID based sensing system are the antennas, microwave resonators, characterization of smart materials, and finally, integration of these materials in the passive design to enable physical sensing of tagged objects.

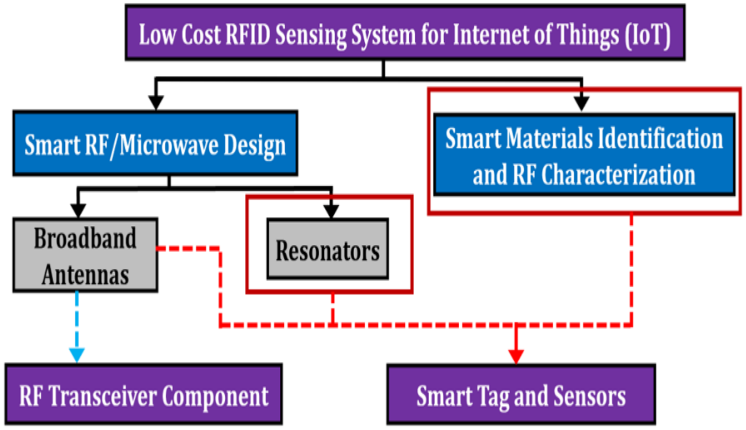
NDSU NORTH DAKOTA STATE UNIVERSITY

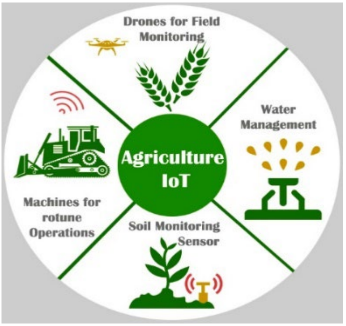
# Towards a Better-Connected World: Combining Sensing Technologies With Radio Frequency Identification

- Chipless RFID Sensors and Tag for Internet of Things
- Chip based UHF RFID sensing system and Machine Learning
- Broadband Antenna for RF transceiver and 5G Applications

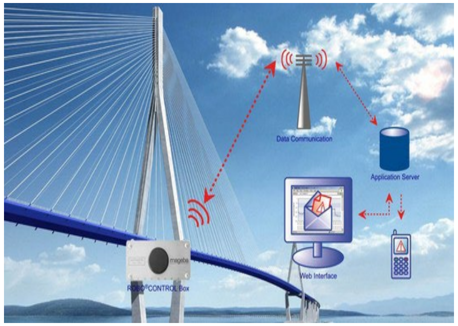



RFID system

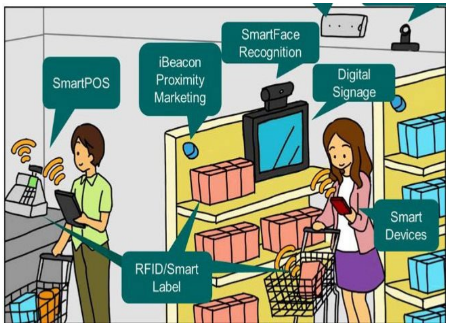




Precision Agriculture (PA)

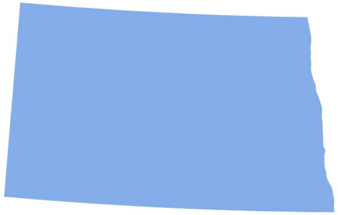


Structural Health Monitoring




Retail and Supply Chain

Maintenance Management-Mining Conveyor Belt

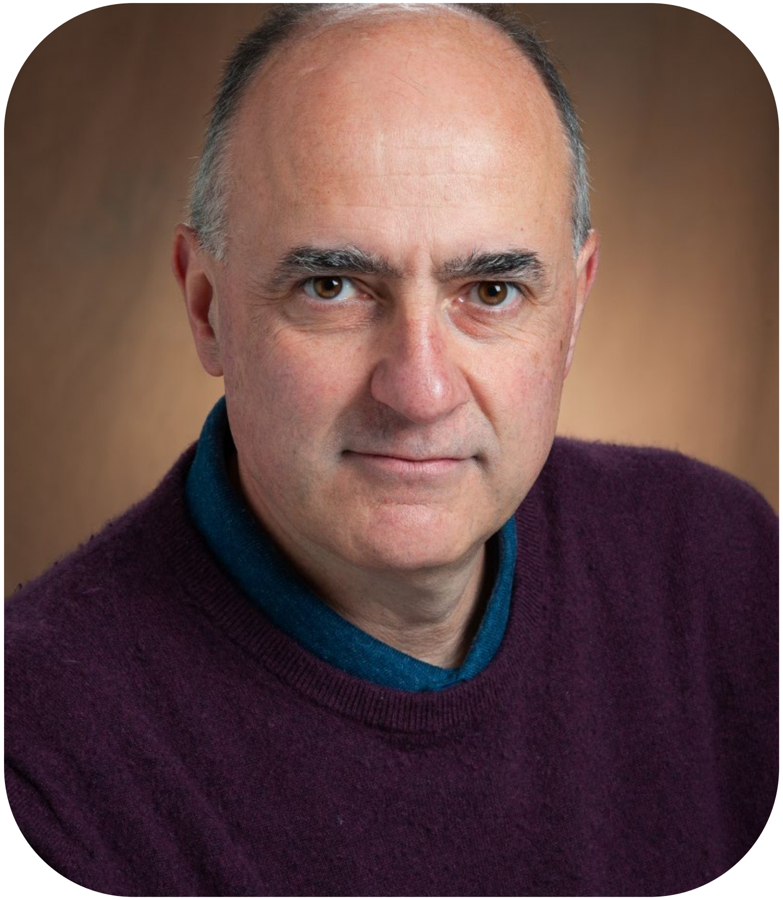


Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

Hypersonics: High-Speed and High-Temperature Diagnostics

# Jordi Estevadeordal

North Dakota State University
Mechanical Engineering Department
Email: jordi.estevadeordal@ndsu.edu
Phone: 701-231-9223



Dr. Jordi Estevadeordal is an Associate Professor in the Mechanical Engineering Department of North Dakota State University since 2015. He has previously worked in industry (GE Global Research in NY and Innovative Scientific Solutions Inc. in OH) working on optical and laser diagnostics for harsh environments (jet engine, combustion chambers, etc.) Currently he is actively performing advanced flow measurements using state of the art techniques such as tomographic Particle Image Velocimetry, Pressure Sensitive Paints and Background oriented Schlieren in high-speed aerodynamics and advanced materials characterization using laser breakdown plasma.

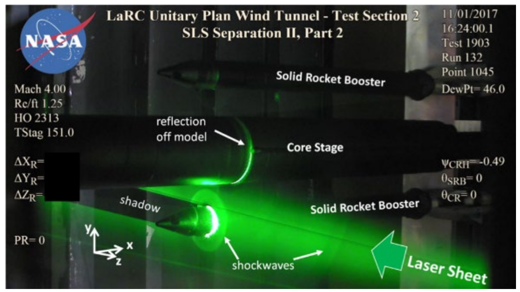
# NASA EPSCoR Research
# Dr. Jordi Estevadeordal, Mechanical Engineering, North Dakota State U.

## Hypersonics: High-Speed and High-Temperature Diagnostics

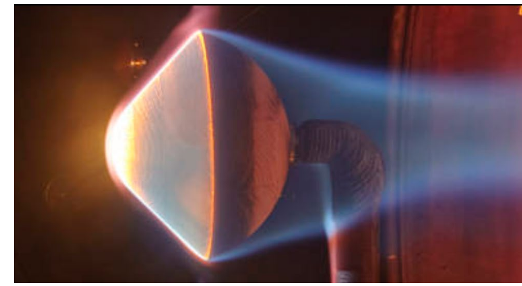
### NASA Research :

**Space Exploration**:
- High Speed,
- High Temperature,
- Laser Diagnostics,

etc.




**NASA Langley**
**Space Launch System Solid Rocket Boosters**
**SLS/SRB models (UPWT --Laser Diagnostics)**
*AIAA-2019-3507*

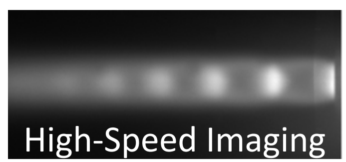


**NASA Ames**
**Conical nozzle model arc-heated test in the Interaction Heating Facility (IHF)**
*AIAA-2005-3326*

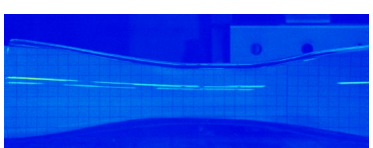
### NDSU Research :

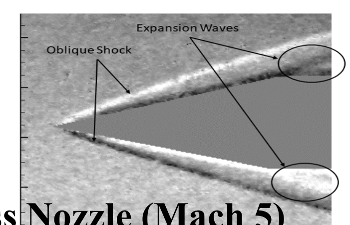
**High Speed, High T:**
- Optical/Laser Meas. (tomo-PIV, plasma)
- Schlieren (BOS)
- Pressure Sensitive Paints,

etc.

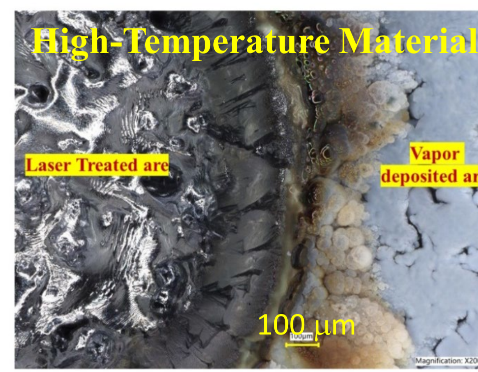




**NDSU Hybrid Rocket (Mach 2-5)**
*AIAA2021-1020*






**NDSU Hypersonic Glass Nozzle (Mach 5)**
*AIAA2021-4119*




**NDSU Laser Breakdown/Plasma sample:**
vapor deposited area and melted (and solidified) region of TBC sample (SiC) after 300 seconds

NASA EPSCoR Research for LaRC
January 27, 2021

Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

Crystal and glass measurements of molten and solidified lava using visible near-infrared spectroscopy


# Erika Rader

University of Idaho
erader@uidaho.edu
208-885-1142

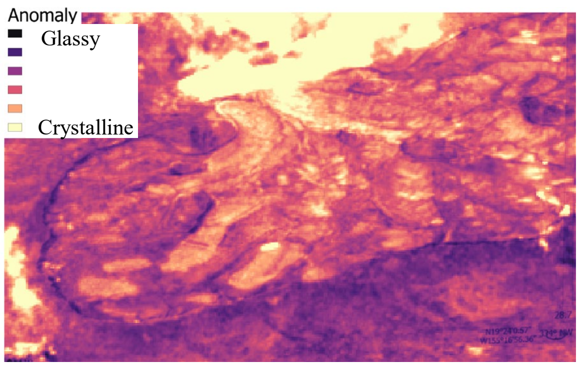

Dr. Rader is an assistant professor at the University of Idaho Her research focus is on lava flows both on Earth and on extra-terrestrial surfaces. She completed a postdoc at NASA Ames where she learned about incorporating in-situ and satellite spectroscopy measurements into her field work in Iceland, Idaho, Oregon, and Alaska. She is especially keen on lava flow morphology which signals lava-water interactions during emplacement and is working on a new method using VNIR reflectance to deduce glass content in solidified and molten lavas. These methods have the potential to influence exploration of lava world exoplanets, currently and previously volcanically active bodies in our solar system, and active lava flows on Earth.

# New application of visible-near infrared (VNIR) spectroscopy on lava flows

This spectral method allows for the visualization of glass/crystal content of molten and solidified basalt.

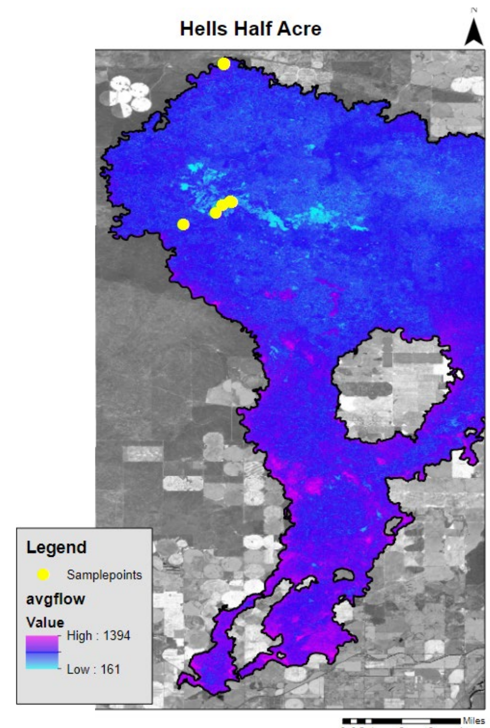
Including this type of measurement in missions has the potential for:

- Improved lava flow **hazard modeling** by providing rheological constraints.
- Targeted sampling for regions of high glass (**geochemistry**) or crystals (**geochronolog**
- Sample-less constraints on **magma chamber characteristics** on planetary surfaces.



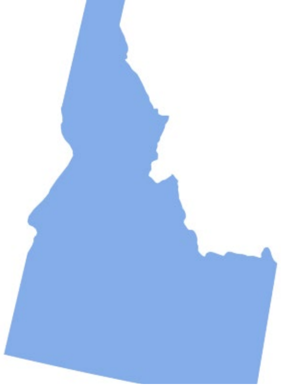

Molten lava lake – Kilauea, HI

In-situ spectral and geochemical analysis to target glassy sampling sites




2000 year old lava flow - Idaho

Dr. Erika Rader – University of Idaho



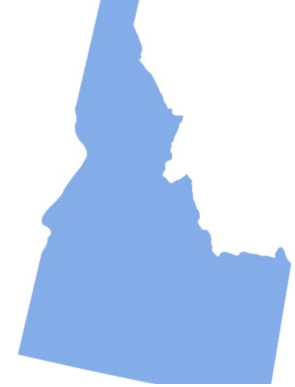
Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

Application of LiDAR for mapping and monitoring forest landscapes from the tree to the ecosystem level: Establishing a strong measurement foundation as extreme events and environmental factors change future tree growth patterns

# Dr. Paul Gessler

University of Idaho
paulg@uidaho.edu
208-885-2595

Paul Gessler is a Professor of Remote Sensing and Geospatial Ecology and has been engaged in LiDAR research for over 20 years with >10,000 citations. He recently served as Director of the Northwest Knowledge Network, a research cyberinfrastructure and data science support unit. His research has largely focused on mapping, monitoring, and modeling landscapes using remote sensing and digital topographic analysis in combination with machine learning and other advanced statistical methods. He has also been involved in sensor development, calibration, and acquisition from various platforms. Professor Gessler works with collaborators across the globe, holds dual US/Australian citizenship, and recently has been engaged in DARPA funded research modeling infectious disease spread. He currently consults with the forest industry on application of remote sensing for mapping forest landscapes.



Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

Application of LiDAR for mapping and monitoring forest landscapes from the tree to the ecosystem level: Establishing a strong measurement foundation as extreme events and environmental factors change future tree growth patterns

# Mark Kimsey

University of Idaho
mkimsey@uidaho.edu
208-885-7520

Mark Kimsey is Director of the Intermountain Forestry Cooperative and Co-Director of the National Science Foundation IUCRC Center for Advanced Forestry Systems at the University of Idaho. His scientific career is centered on integrating forest science and ecology into operational forest management through the use of geospatial tools and models. Dr. Kimsey collaborates nationally with academics, Federal and State agencies, and forest industry. Currently his work focuses on modeling and mapping tree and stand growth dynamics across multiple scales and regions of the United States utilizing photogrammetry and LiDAR acquisitions from UAV, aerial and satellite platforms.

# UNIVERSITY OF IDAHO – NASA EPSCoR PROPOSAL

DR. PAUL GESSLER & DR. MARK KIMSEY

**Topic:** Application of LiDAR for mapping and monitoring forest landscapes from the tree to the ecosystem level: Establishing a strong measurement foundation as extreme events and environmental factors change future tree growth patterns

**Objective:** Intensively test lidar platform performance, bias and precision in estimating forest metrics required to model and predict current and future forest health and productivity

**Expertise:** Depth in remote sensing and forest biometrics, ecological modeling

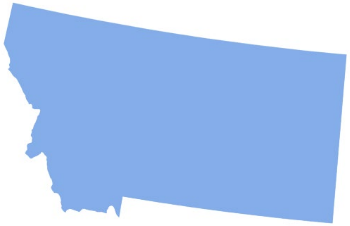
**University Resources:**

- **UofI Experimental Forest:** 4,000+ hectare working forest with first Land-grant University lidar derived single tree digital inventory
- **Intermountain Forestry Cooperative:** Forest research collaborative of public/private forest industry dedicated to developing models and tools for sustainable forest management at the local, regional and national scale
- **Research Computing and Data Services:** State-of-the-art high-performance computing and data management cyberinfrastructure

**Synergies:**

- Working relationships with Dr. Mike Falkowski (Program Scientist @ NASA HQ) and Prof. Ralph Dubayah (PI for NASA's GEDI-LiDAR mission)

NASA EPSCoR Research for LaRC
January 27, 2021



Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

Active and Passive Optical Polarimetric Remote Sensing of Aquatic Ecosystems

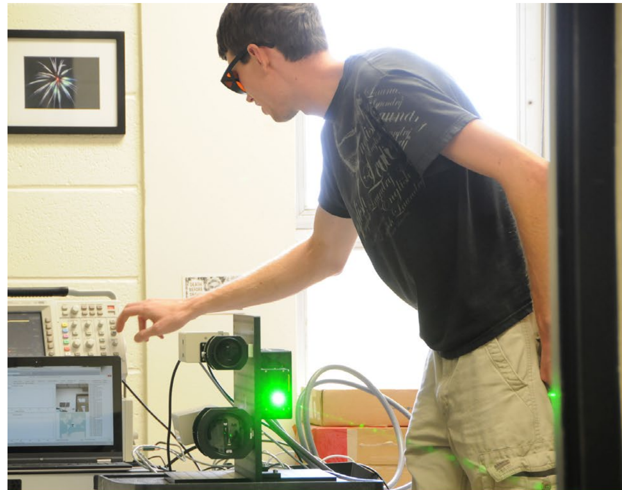

# Michael Roddewig

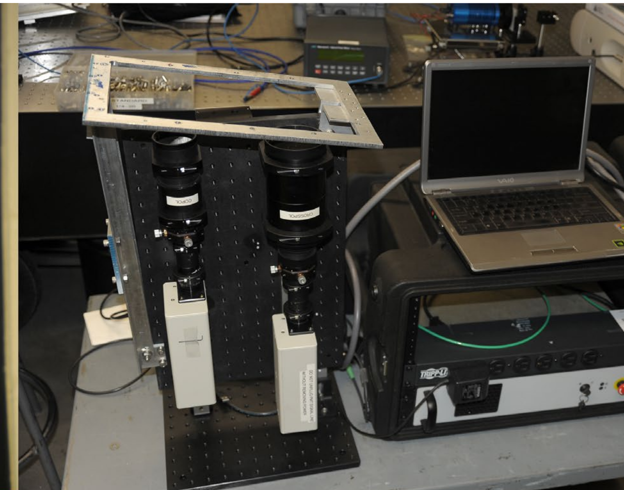
## Montana State University
michael.roddewig@montana.edu


Michael R. Roddewig is a Senior Research Engineer with the Optical Technology Center at Montana State University. His research interests are on the development and deployment of novel lidar remote sensing systems and passive imagers. With the Optical Technology Center he has worked on the development of coherent lidar, airborne incoherent lidar, and polarimetric imagers and their applications in the field for ecological remote sensing and defense. He received his PhD in Optical Engineering from Montana State University in 2017 and was with AdvR, Inc. before joining the Optical Technology Center in 2020.

# Michael R. Roddewig
# Montana State University

- Extensive experience with design and field deployment of active and passive optical remote sensing systems
- Droneborne and airborne lidar design and deployment
- Airborne lidar remote profiling of lakes
- Novel optical remote sensing techniques for improving water optical property retrieval and biological measurements
- Application of FMCW and other novel lidar techniques to remote sensing problems





NASA EPSCoR Research for LaRC
January 27, 2021

Innovative Concepts for Earth and Space Science Measurements: LIDAR, spectroscopy, radiometry active remote sensing, advanced sensors and optical measurement

## Anomaly Detection in Hyperspectral Imagery


# Nasser M. Nasrabadi

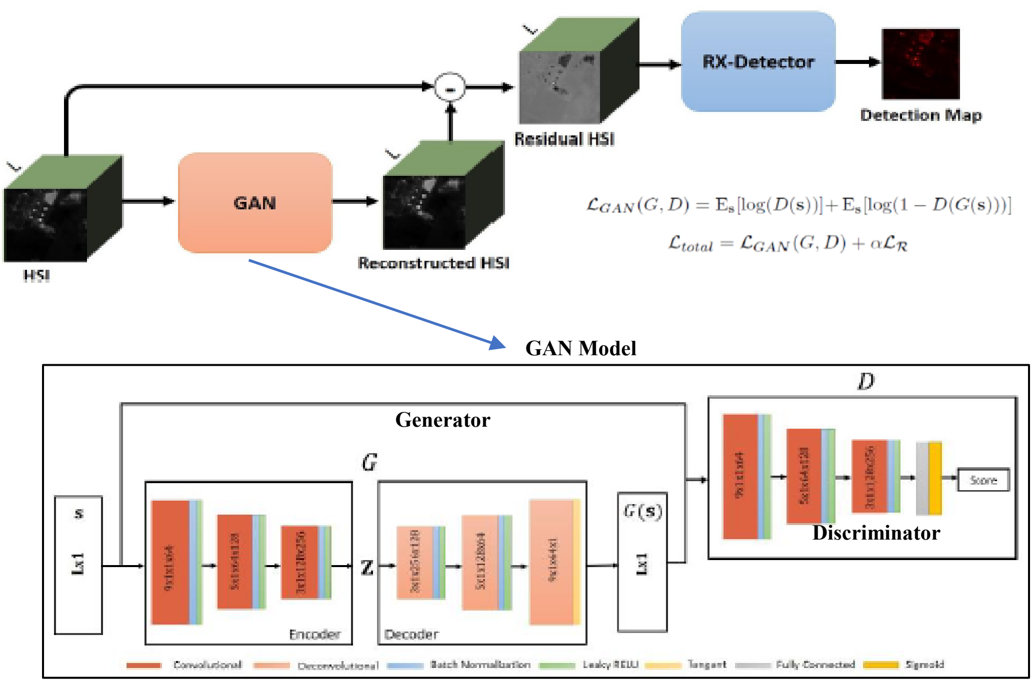
Professor in the Department of Lane Computer Science and Electrical Engineering
Nasser.nasrabadi@mail.wvu.edu,
(304) 293-4815


Expert in machine learning and its applications to hyperspectral remote sensing, computer vision and biometrics. He is a fellow of IEEE and has been working on AI/ML research topics for more than thirty years. He has experience in anomaly detection and image segmentation for hyperspectral imagery. Recently he has developed an anomaly detector based on the Generative Adversarial Network (GAN) architecture for locating small objects in hyperspectral imagery.

# Anomaly Detection in Hyperspectral Imagery Using Generative Adversarial Networks

Nasser M. Nasrabadi, LCSEE, WVU

- Anomaly detection is used to detect rare pixels (outliers) in a Hyperspectral Image (HSI) which have different spectral signatures compared to the main background/neighborhood pixels.
- Anomaly detectors are useful for many space applications i.e., Gas & chemical plume detection, soil analysis, analyzing data on-board a spacecraft to prioritize observations to make the best use of limited bandwidth and reacting to dynamic events as they happen.
- Our anomaly detector is based on a Generative Adversarial Network (GAN) architecture which is trained to model (learn) only the distribution of the background pixels of hyperspectral images.
- During testing the predicted background HSI is subtracted from the original image and the residual HSI highlights the anomaly pixels which can be detected with the classical hyperspectral RX detector.




$$\mathcal{L}_{GAN}(G,D) = \mathrm{E}_{\mathbf{s}}[\log(D(\mathbf{s}))] + \mathrm{E}_{\mathbf{s}}[\log(1 - D(G(\mathbf{s})))]$$

$$\mathcal{L}_{total} = \mathcal{L}_{GAN}(G,D) + \alpha\mathcal{L}_{\mathcal{R}}$$

Fig. 1: GAN-based anomaly detector

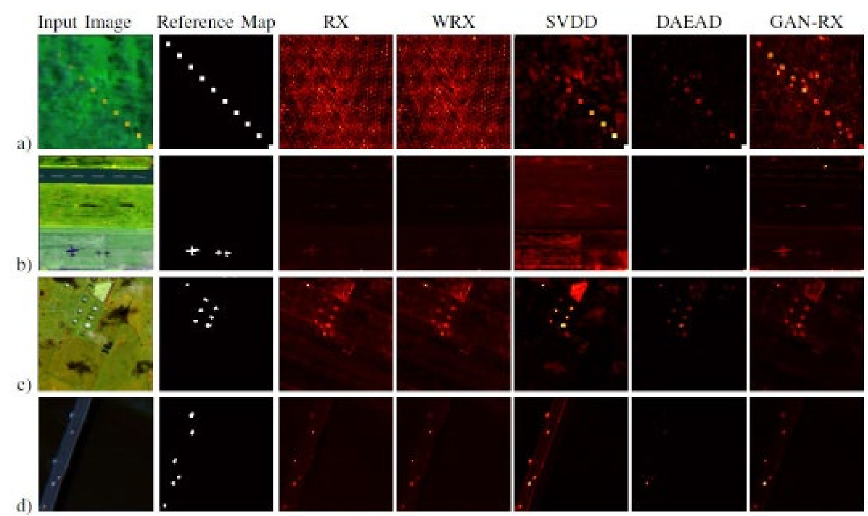



Fig. 2: Comparing different anomaly detectors on a) Cooky City Synthetic, b) AVIRIS-Airport, c) AVIRIS-Urban, and d) AVIRIS-Beach