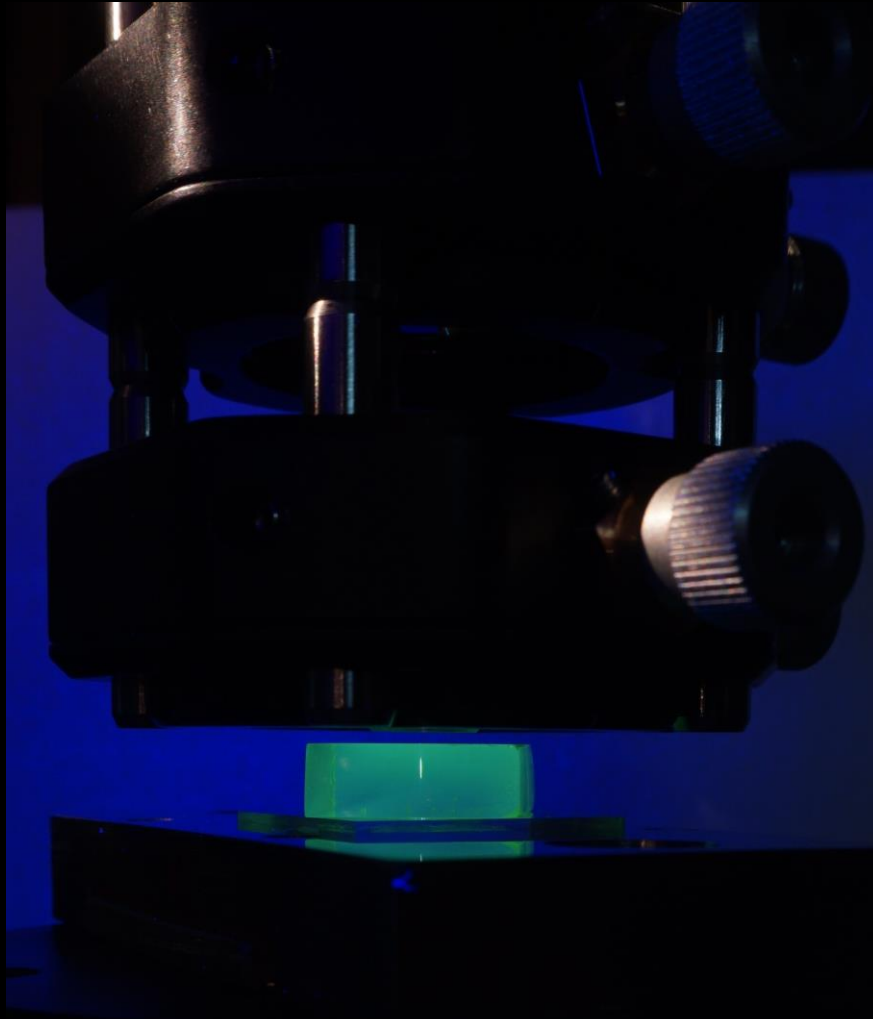




THE UNIVERSITY OF
TENNESSEE
KNOXVILLE

SPACE INSTITUTE AT TULLAHOMA



Center For Laser Applications Annual Report 2021 – 2022

ABOUT THE COVER





On the cover:

A Bessel beam generated with an infrared laser interacts with a glass scintillator sample. Laser processing will result in the formation of light-guiding crystalline arrays within the glass. These materials can be used to increase efficiency in high-energy radiographic imaging applications, including medical, industrial, and security. The laboratory set-up was photographed under ultraviolet light to demonstrate the luminescent nature of the sample. The laser beam's interaction volume appears as the thin, white, vertical line segment near center within the sample.

Additional information may be found on Dr. Lee Leonard's faculty page in this report.

Photo credit: B. K. Canfield, L. Costa, and R. L. Leonard

Special Thanks To

Editing:  **Dr. Brian Canfield**
 **Dr. Jaqueline Johnson**
 **Dr. Lee Leonard**
 **Rob Northcutt**

Photography:  **Dr. Brian Canfield**
 **Dr. Lino Costa**
 **Laura Horton**
 **Dr. Lee Leonard**
 **Meghan Morris**

Graphic Design:  **Rob Northcutt**

Contributors:  **Michelle Carmack**
 **CLA Staff and Faculty**
 **Meghan Morris**
 **Dr. James Simonton**
 **Carole Thomas**

WELCOMING REMARKS

The Center for Laser Applications (CLA) at the University of Tennessee Knoxville Space Institute at Tullahoma is pleased to present our annual report of research projects funded by the Center.

This has been another transformative year for CLA. The CLA has established capabilities, both in faculty and equipment, that are unique for both the state and the nation. The strengths and interest in the applications of lasers for diagnostics and materials processing represent a unique university-based combination that is critical for many industrial, defense, and basic science application areas. Our capabilities now include combustion systems and jet engine/space propulsion systems development, laser materials processing, ground-based (simulated) aerospace testing, electro-optics, nonlinear optics, quantum optics, molecular spectroscopy, and laser-induced or laser-assisted chemical reactions. All of these areas fit with CLA's original and current Mission. They have obvious relevance to the future competitiveness of technological industries and institutions of the state, region, and nation.

We continue to move our strategic plan forward by bringing faculty and researchers from different disciplines to work together, each bringing a different expertise to the table. These include Bio/Nano-photonics, Material Science, Laser-Material Interaction, Laser Spectroscopy, Laser Based Measurement/Diagnostics, Advanced Clean-Combustion Strategies, Reacting Flows, Alternative Fuels, as well as Thermal Management and Thermal Runaway for Li-ion Batteries and Non-Equilibrium Fluid Physics. Our multidisciplinary collaborations with the MABE faculty have the potential to open many new opportunities. The process has already expanded our capabilities by allowing budgetary carry-over that is being used to purchase new and up-to-date equipment, with more to come.



James L. Simonton Ph.D.













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CENTER FOR LASER APPLICATIONS












Annual Report 2021 – 2022

Table of Contents








Program Report

 Introduction	Page 1
 Mission Statement	Page 1
 Focus Areas	Page 2
 Personnel	Page 3
 Collaborations	Page 5
 Graduated Students	Page 5
 Executive Summary	Page 6
 Community Outreach	Page 7
 Research Accomplishments	Page 10
 Five Year Benchmark	Page 10
 Future Direction	Page 10
 Center for Laser Applications Budget	Page 11

Faculty Reports

 Lino Costa	Page 12
 Mark Gragston	Page 13
 Charles Johnson	Page 14
 Jacqueline Anne Johnson	Page 15
 Saeed Kamali	Page 16
 Phillip Kreth	Page 17
 Lee Leonard	Page 18
 Trevor Moeller	Page 19
 Christian Parigger	Page 20
 Feng-Yuan Zhang	Page 21
 Peng Zhao	Page 22

Achievements

 Publications	Page 23
 Conference Proceedings	Page 28
 Conference Organizing	Page 32
 Book Chapters	Page 32
 Appointments	Page 33
 Inventions and Patents	Page 33
 Research Funded Externally	Page 34

INTRODUCTION








The Center for Laser Applications (CLA) continues to establish capabilities that are unique for both the state and the nation. The strengths and interest in the applications of lasers for diagnostics and materials processing represent a unique university-based combination that is critical for many industrial, defense, and basic science application areas. Examples of the strengths and interests include combustion systems and jet engine/space propulsion systems development, laser materials processing, ground-based (simulated) aerospace testing, electro-optics, nonlinear optics, quantum optics, molecular spectroscopy, and battery thermal run away, and laser-induced or laser-assisted chemical reactions. All these areas fit with CLA's original and current Mission. They have obvious relevance to the future competitiveness of technological industries and institutions of the state, region, and nation.

One of the strengths CLA possesses is the ability of faculty from different disciplines to work together, each bringing a different expertise to the table. These include Bio/Nano-photonics, Material Science, Laser-Material Interaction, Laser Spectroscopy, Laser Based Measurement/Diagnostics, Advanced Clean-Combustion Strategies, Reacting Flows, Alternative Fuels, as well as Thermal Management and Thermal Runaway for Li-ion Batteries and Non-Equilibrium Fluid Physics. These multidisciplinary collaborations have the potential to open many new opportunities for CLA.







MISSION STATEMENT

The original purpose and mission of CLA remains relevant as described in the original 1984 proposal. It has evolved to stay abreast and ahead of science and technological needs. This evolutionary process was the exact intent of the original proposers and better serves the needs of Tennessee by adding goals and objectives to an existing solid foundation.

Education

-  Attract nationally recognized faculty and student scholars
-  Produce well-trained graduates for employment in Tennessee
-  Disseminate state-of-the-art information on laser application technology to the industrial and scientific communities
-  Provide quality educational experiences for multidisciplinary students
-  Generate opportunities for undergraduate student research
-  Assist businesses in development and implementation of technology
-  Increase interest in STEM areas, i.e., support science education for students and teachers





Research

-  Develop state-of-the-art experimental facilities for research on a variety of laser application problems
-  Develop a world class reputation for research and innovation to meet the needs of science and industry
-  Utilize center funds for the exploration and development of new research areas
-  Enhance the amount of research support from industrial and governmental organizations
-  Transfer new laser application technology to state and regional industry and scientific organizations
-  Enhance the research capability of other UTSI research groups through development of advanced laser-based measurement techniques








FOCUS AREAS

The focus of the mission-related research programs of the Center is the application of lasers and associated technology. These focus areas of specialization were selected to correspond to known scientific and engineering challenges and to areas of development and regional and national needs.






Bio/Nanophotonics

-  Lino Costa - devices for cellular chemotaxis
-  Jacqueline Johnson - storage phosphor materials for dental imaging
-  Christian Parigger- photo-acoustic imaging, diagnostics, and applications
-  Feng-Yuan Zhang - MEMS/NEMS, micro/nanofluids



Materials Science

-  Lino Costa - phase transformations, laser cladding and modeling of direct metal deposition
-  Christian Parigger - laser-induced materials physics
-  Jacqueline Johnson - nanoparticles for medical theranostics
-  Charles Johnson - Mössbauer spectroscopy
-  Saeed Kamali - Mössbauer spectroscopy
-  Lee Leonard - glasses and glass ceramics for radiographic imaging and dosimetry
-  Feng-Yuan Zhang - micro/nanomanufacturing multifunctional materials



Laser-Materials Interaction

-  Lino Costa - laser cladding and femtosecond laser machining
-  Trevor Moeller - laser ablation dynamics and modeling of laser ablation for space propulsion
-  Christian Parigger - laser-induced ablation physics
-  Feng-Yuan Zhang - micro/nanomanufacturing multifunctional materials
-  Phillip Kreth - laser-based heating of material samples for high-enthalpy flows






Laser Spectroscopy

-  Christian Parigger - ultrasensitive spectroscopy and combustion diagnostics
-  Feng-Yuan Zhang - tomography, diode-laser absorption spectroscopy, thermography

Laser Measurement and Diagnostics

-  Phillip Kreth - laser-induced fluorescence, radar REMPI, Raman scattering, molecular tagging velocimetry
-  Mark Gragston - I-MHz Burst Mode Laser, particle image velocimetry, krypton tagging velocimetry and laser-induced fluorescence

Non-Equilibrium Fluid Physics

-  Trevor Moeller - plasma dynamics and combustion
-  Christian Parigger - laser-plasma physics, combustion, and fluid physics and computational physics
-  Feng-Yuan Zhang - hypersonic flow and reaction, electrochemical reaction
-  Phillip Kreth - diagnostics development for hypersonic flow
-  Peng Zhao - clean combustion, reacting flows, alternative fuels, thermal management, and thermal runaway for Li-ion batteries.

PERSONNEL



Dr. Brian Cranfield
Researcher IV

Dr. Brian Canfield (Ph.D. in Physics, Washington State University) contributes to a wide range of CLA's research projects in applied and nonlinear optics, in particular, ultrafast laser materials processing. Technologies relying on these processes include machining of microfluidic/nanofluidic systems, large-scale roll-to-roll replication template fabrication, custom foil mesh drilling for energy production and storage, surface modification for improved physical environmental interaction, and thrust and charge dissipation schemes for orbiting satellites. He has also been instrumental in the development of experimental systems for ultrasensitive fluorescence detection and single-nanoparticle trapping and tracking for biotechnology applications. Dr. Canfield has implemented various focusing methods with Gaussian and Bessel beams for precision laser-machining of very high aspect ratio holes in the surfaces and channels through various transparent substrates including polymers, glasses, and crystalline materials like diamond and sapphire. His current research projects include producing next-generation monolithic electro spray microthruster chips, surface modification of hardened steel tool bits to increase their duration and lifetime, etching QR codes for additive manufacturing, and cutting trenches in diamonds for alpha-spectrometry diagnostics in power-generating molten salt reactors.

PERSONNEL



Dr. Lu Liu
**Research Scientist I &
Chemical Hygiene Officer**

Dr. Lu Liu (Ph.D. in Chemistry, University of Maryland) has more than 10 years' experience in experimental design, material synthesis, testing and screening, including magnetic materials, battery electrode materials, metal/metal oxide nanoparticles w/o coating, and functional polymeric materials and composites. Since she joined UTSI in February of 2021, she has been working on (Fe NP) synthesis, nanofluids and novel battery material development. She has developed experimental apparatus for both thermal-decomposition and reduction methods to synthesize Fe NPs with different size distributions and crystalline structures. She has also participated in nanomaterial characterizations using TEM, SEM, XRD, Dynamic Light Scattering (DLS) and Mössbauer Spectroscopy. She is also Chemical Hygiene Officer of UTSI, and works with the safety office to provide technical guidance in the development and implementation of the provisions of the Chemical Hygiene Plan.

PERSONNEL



Alexander Terekhov
**Research Consultant and
Manager of CLA Research,
Engineering, and Operations**

Mr. Alexander Terekhov (M.S. in Solid State Physics and Quantum Radiophysics, Moscow Engineering Physics Institute (National Research Nuclear University), Moscow, Russia; M.S. in Materials Science, University of Illinois at Urbana-Champaign) supports graduate students and faculty in their research projects and contracts. He is responsible for Laser Safety and maintaining the laser systems and other technical hardware at CLA. Mr. Terekhov has 3 patents and is a co-author on many scientific papers in a variety of fields.

PERSONNEL



Doug Warnberg
Technical Specialist I

Doug retired from the United States Air Force and has an Associate's degree in Applied Science from the Community College of the Air Force and Motlow State Community College. He also has a diploma from the Tennessee College of Applied Technology-Shelbyville in Industrial Maintenance. Doug maintains the vacuum systems, Class 1000 clean room, and Rigaku SmartLab X-Ray Diffraction System.



Fig. 1 - Three Split-Hopkinson Pressure Bar Systems for the Measurement of the Dynamic Stress-Strain Response of Materials in Tension, Compression, or Shear Mode. Note: The three systems are currently being refurbished and updated with new instrumentation.

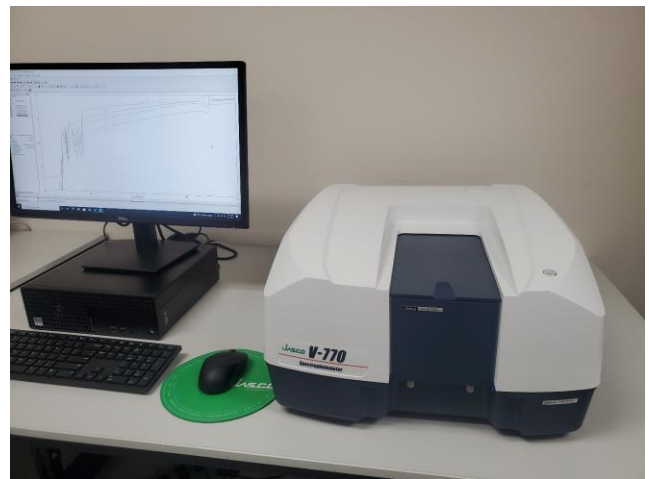


Fig. 2 - JASCO V-770 Wide Wavelength Range UV-visible/NIR Spectrophotometer.

COLLABORATIONS

A significant fraction of the research and development program of the Center is supported by state, regional, and national industries. CLA actively collaborates with the Center for Industrial Services to provide studies for Tennessee industries. CLA has also formed long-term research partnerships with the traditional federal agencies, the National Institutes of Health, the National Science Foundation, and National Laboratories at Oak Ridge and Los Alamos, as well as numerous collaborations with national and international Universities, and the nearby Arnold Engineering Development Center. These diverse research activities, along with our outstanding facilities and low student-to-faculty ratio, combine to offer a very productive academic experience for diligent graduate students.



GRADUATES

Please congratulate our recent degree recipients.

CONGRATULATIONS

- | | |
|--|--|
|  Ahmad Hadi Bakir, Ph.D. ME |  Ethan Long, M.S. AE |
|  Anna Bull, M.S. BME |  Theron Price, Ph.D. AE |
|  Derek Burkhart, M.S. ME |  Brandon Roberts, M.S. AE |
|  Eric Endlsey, M.S. ME |  Gurwinder Sidhu, M.S. AE |
|  Daniel Epperson, M.S. AE |  Samuel Smith, M.S. AE |
|  Justin Garrard, Ph.D. ME |  Brady Wattenbarger, M.S. AE |
|  Haley Goldston, M.S. ME |  Sam Wright, M.S. ME |
|  Justin Harris, M.S. ME |  Shule Yu, Ph.D. ME |
|  Christopher M. Helstern, Ph.D. PHYS |  Liwen Zhang, Ph.D. ME |
|  Joshua H. Howell, M.S. ME | |

AE – Aerospace engineering
BME – Biomedical engineering
ME – Mechanical engineering
PHYS – Physics

EXECUTIVE SUMMARY

Foreword

The Center for Laser Applications (CLA) moved to become a world-class operation that is increasing its notoriety nationally and internationally. CLA has established capabilities that are unique for both the state and the nation. The strengths and interest in the applications of lasers for diagnostics and materials processing represent a unique university-based combination that is critical for many industrial, defense, and basic science application areas. Examples of the strengths and interests include combustion systems and jet engine/space propulsion systems development, laser materials processing, ground-based (simulated) aerospace testing, electro-optics, nonlinear optics, quantum optics, molecular spectroscopy, and laser-induced or laser-assisted chemical reactions. All of these areas fit with CLA's original and current Mission. They have obvious relevance to the future competitiveness of technological industries and institutions of the state, region, and nation.

CLA Leadership

Dr. James Simonton - Interim Director

Dr. Jacqueline Johnson - Senior Manager of Laboratories

New Faculty Alliances

An important part of the original mission of CLA was the formation of alliances that would foster multidisciplinary work. Drs. Trevor Moeller, Phillip Kreth, Feng Zhang, Jackie Johnson, Lino Costa, Lee Leonard, Peng Zhao, and Mark Gragston of the Mechanical Aerospace, and Biomedical Engineering Department (MABE) are now using lab space in CLA. Dr. Christian Parigger is a member of the Physics Department faculty and also a CLA researcher. They are utilizing lasers to develop research related to measurements and diagnostics of hypersonic flow combustion characteristics, as well as clean hydrogen-augmented turbine engine propulsion. We are also pleased to add battery research to our cross-disciplinary work this year. These areas are of high interest to the Department of Defense (DOD), NASA, private industry, and the citizens of Tennessee.

New Equipment Purchased

Our growth in grants and contracts this year has allowed CLA to carry over funding from last fiscal year, which in turn has provided us the opportunity to replace/add equipment and capabilities. In 2022 we invested \$1,052,222 in new equipment while encumbering an additional \$189,000 for new equipment that will not hit the ledgers until 2023. Our newest additions to the CLA lab are the diamond deposition machine and the Raman Microscope. Both will be great additions to our capabilities. The Diamond Deposition Machine is already part of a \$462k funded project to be completed over the next two years. The Raman microscope has multiple applications that will make it a key component of future funding proposals.

Activities

In FY 2022 CLA associated staff and faculty had 50 peer reviewed articles published and/or accepted into press, 1 book chapter, and 39 national/international presentations.

Percent Allocation of CLA Total Expenditures \$1,628,945

- ✓ Salaries and benefits 24%
- ✓ Equipment related expenditures (repair, supplies, and new) 65%
- ✓ Student Fees 2%
- ✓ Assistantships 3%
- ✓ Supplies 6%

Ended the year with a carryover of \$192,480. This carryover will be utilized toward major equipment purchases as described in the New Equipment Purchased section.



COMMUNITY OUTREACH



HSV Space & Rocket Center

The UTSI 2021 summer interns toured the Huntsville Space & Rocket Center on Friday, July 23, 2021.

AE531 Field Trip to UTSI

Undergraduates came from UT Knoxville to see the UTSI labs and learn about research being conducted on April 21, 2022. The students a subset of Dr. John Schmisser's AE 351 Compressible Flow course. The group met with faculty, toured the facilities, enjoyed lunch in The View (dining hall), and ended the day at a reception with UTSI Graduate Research Assistants.



Star Party – May 7th

The 50+ visitors watched Star Wars, enjoyed shows in our planetarium, and played with STEM activity sets, as well as enjoyed refreshments. Due to cloudy weather, we were not able to use our observatory and telescopes, but visitors still had a great time watching hobby rockets blast off on the front lawn! The Hands-On Science Center in Tullahoma, TN provided STEM activities for our attendees.



COMMUNITY OUTREACH



The UT Institute for Public Service Leadership Academy visited the UTSI research facilities on May 16, 2022. The ISP Leadership Academy provides training, mentoring, and coaching, promotes IPS goals, and strives to better understand the culture and structure of the UT System.



Summer Intern Program

UTSI welcomed the 2022 Undergraduate Summer Research Interns on June 6, 2022. It was a nine-week program where the interns spent their time working with faculty and graduate students on advanced research projects while experiencing what graduate school is like on a daily basis. At the end of the program, they gave a presentation on the work they completed over the summer. UTSI selected 26 interns from an application pool of almost 200. The interns came from the University of Tennessee, University of Alabama in Huntsville, University of Utah, University of Kentucky, University of Kansas, Mississippi State University, Tennessee Technological University, Embry Riddle Aeronautical University-PreScott, the US Army, and more.

Other activities included a tour of the Space and Rocket Center in Huntsville, AL, Summer Information Sessions from local industry, and a tour at the Arnold Engineering Development Complex.



COMMUNITY OUTREACH



Recruiting events

- ✓ Over 60 career/recruiting events in FY 2021–2022
- ✓ At least 20 undergraduate tours with over 50 students from UT Knoxville, UT Chattanooga, Middle Tennessee State University, Lipscomb University, University of North Carolina - Charlotte, and others
- ✓ Engineering Management Visit from Managers from Nissan, Decherd – July 2021
- ✓ Franklin County HS Career Fair – May 13, 2022
- ✓ Tullahoma High School Career Fairs – November 18, 2021 and April 13, 2022
- ✓ Tennessee State University – McNair Scholar’s Information Session with Dr. Gragston and EM Students L. Glass and K. Coney – February 4, 2022
- ✓ Franklin County Chamber of Commerce Industry Appreciation – October 21, 2022
- ✓ Student Veterans of America NatCom 2022 representing SERVE in Orlando with UTK students – January 2022

UTSI Summer Info Sessions

Over the course of the summer, local Engineering Industry and Government agencies and business gave one-hour overview presentation of their capabilities, needs, and plans moving forward with UTSI’s summer interns, graduate research assistants, faculty, and staff. The purpose of the sessions was to not only make collaborative connections with UTSI but to help build our workforce in the local area.

RESEARCH ACCOMPLISHMENTS AND FIVE-YEAR BENCHMARK

Our research mission is growing. The funding provided by the Tennessee Higher Education Commission, coupled with support from the university, provided valuable leverage for sponsored research. The research awards continue to increase. This growth is possible because of the dedication of our faculty and the support of THEC and UTSI.

CLA remains active in Outreach and Business Development. The faculty are active in scientific conferences and local business meetings. Productivity among Center faculty has been outstanding during the last five-year period. During fiscal years 2018 through 2022, Center faculty published 194 peer reviewed articles, 8 book chapters, and presented (or had abstracts accepted) at 102 regional, national, and international meetings.

Benchmark Data	FY 2018 – 2022 Cumulative	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Publications						
Peer-Reviewed Articles	194	29	18	44	57	46
Books or Book Chapters	8	1	3	2	1	1
Presentations						
International	26	3	11	3	3	6
National	76	7	1	12	24	32

FUTURE DIRECTIONS

Hypersonics research has grown tremendously over the past three years and from all projections, it will continue this growth. CLA is strategically placed to benefit from the associated funding. CLA’s current involvement, through laser measurement and diagnostics, will be a key element in our future growth. This alliance will spur growth related to our material science area in the form of thermal protection materials, both synthesis and characterization. The alliances we have formed, with the Hypersonics Group and Propulsion Caucus at UTSI, have the potential for introducing CLA capabilities to a much wider audience in the Aerospace and Defense sectors. To help bolster our presence in one of the largest aerospace and defense markets, Huntsville, Alabama, we have opened an office in the 2nd largest research park in the country. We have staffed the office to enable us to make the connections necessary to expand our funding with the Department of Defense (DOD) and private entities located in the area.

BUDGET

CENTERS OF EXCELLENCE ACTUAL, PROPOSED, AND REQUESTED BUDGET

Institution: University of Tennessee Space Institute Center: Center for Laser Applications

	FY 2021-22 Actual			FY 2022-23 Proposed			FY 2023-24 Requested		
	Matching	Apppr.	Total	Matching	Apppr.	Total	Matching	Apppr.	Total
Expenditures									
Salaries									
Faculty	\$102,000	\$123,751	\$225,751	\$75,000	\$100,000	\$175,000	\$65,000	\$100,000	\$165,000
Other Professional	\$100,000	\$177,336	\$277,336	\$72,000	\$140,000	\$212,000	\$68,000	\$140,000	\$208,000
Assistantships	\$145,000	\$53,090	\$198,090	\$75,000	\$38,000	\$113,000	\$72,000	\$42,000	\$114,000
Total Salaries	\$347,000	\$354,177	\$701,177	\$222,000	\$278,000	\$500,000	\$205,000	\$282,000	\$487,000
Longevity (Excluded from Salaries)	\$1,913	\$1,073	\$2,985	\$533	\$667	\$1,200	\$553	\$676	\$1,229
Fringe Benefits	\$83,280	\$84,423	\$167,703	\$66,100	\$66,498	\$132,598	\$49,200	\$67,680	\$116,880
Total Personnel	\$432,193	\$439,674	\$871,866	\$288,633	\$345,165	\$633,798	\$254,753	\$350,356	\$605,109
Non-Personnel									
Travel	\$6,000	\$5,846	\$11,846	\$4,000	\$9,000	\$13,000	\$7,500	\$9,000	\$16,500
Software	\$750	\$10,457	\$11,207	\$500	\$2,000	\$2,500	\$1,200	\$2,000	\$3,200
Other Supplies	\$55,000	\$72,375	\$127,375	\$49,820	\$60,203	\$110,023	\$55,000	\$60,000	\$115,000
Equipment	\$223,057	\$1,052,222	\$1,275,279	\$173,000	\$646,000	\$819,000	\$85,000	\$474,000	\$559,000
Maintenance	\$13,943	\$51	\$13,994		\$16,000	\$16,000	\$15,000	\$25,000	\$40,000
Other (Specify):									
Prof Services and Memberships	\$500	\$1,149	\$1,649	\$200	\$500	\$700	\$250	\$850	\$1,100
Printing and Duplicating	\$180	\$2,035	\$2,215	\$400	\$800	\$1,200	\$450	\$1,200	\$1,650
Postage and Freight	\$250	\$629	\$879			\$0			\$0
Rentals	\$600	\$11,043	\$11,643	\$500	\$8,000	\$8,500	\$550	\$12,000	\$12,550
Grants & Subsidies (Student Fees)	\$75,000	\$26,182	\$101,182	\$35,000	\$18,000	\$53,000	\$36,000	\$22,000	\$58,000
Contractual & Special Services	\$7,000	\$7,282	\$14,282	\$2,000	\$4,000	\$6,000	\$25,000	\$5,000	\$30,000
Total Non-Personnel	\$382,280	\$1,189,272	\$1,571,552	\$265,420	\$764,503	\$1,029,923	\$225,950	\$611,050	\$837,000
GRAND TOTAL	\$814,473	\$1,628,945	\$2,443,418	\$554,053	\$1,109,668	\$1,663,721	\$480,703	\$961,406	\$1,442,109
Revenue									
New State Appropriation		\$885,863	\$885,863		\$917,188	\$917,188		\$961,406	\$961,406
Carryover State Appropriation		\$935,562	\$935,562		\$192,480	\$192,480			\$0
New Matching Funds	\$814,473		\$814,473	\$554,834		\$554,834	\$480,703		\$480,703
Carryover from Previous Matching Funds			\$0			\$0			\$0
Total Revenue	\$814,473	\$1,821,425	\$2,635,898	\$554,834	\$1,109,668	\$1,664,502	\$480,703	\$961,406	\$1,442,109

Materials Science Research



Dr. Lino Costa

**Research Associate Professor
Mechanical, Aerospace, and
Biomedical Engineering Department
Ph.D., University of Lisbon, Portugal**

Dr. Costa continues to explore the unique micromachining capabilities of ultrafast lasers to develop new approaches to difficult fabrication problems. Ultrashort laser pulses, nominally as short as a few picoseconds, can directly etch micrometer-scale structures with precise and sharp geometries on virtually any surface without a photomask and in just a single step. Materials directly exposed to the ultrashort laser radiation ablate away so rapidly that virtually no transfer or accumulation of heat occurs in the surrounding material. In addition, ultrafast lasers promote non-selective ablation of materials, a characteristic that is useful when working with composites. These characteristics make ultrafast lasers ideal tools for cutting, trimming, drilling, and patterning many opaque materials including metals, ceramics, and composites, and enables all sorts of novel and interesting applications, especially when it comes to extremely hard and brittle materials, and thin foils, that are traditionally difficult to work. Also, ultrafast lasers can clean, texture, and increase the surface energy of materials at very precise locations to enhance wetting of and adhesion to other materials. For certain transparent dielectric materials, both surface and sub-surface (embedded) structures are possible. Under certain conditions, one can form structures that cannot be attained using conventional lithography. For example, the highly nonlinear nature of the photon absorption process on the instantaneous irradiance of a tightly focused ultra-short laser pulse, allows sub-diffraction limited features to be precisely etched. In addition, filament propagation, that is, propagation of the laser beam through the material without diffraction due to self-focusing, can produce waveguides and microcapillaries with ultrahigh aspect ratios. These unique capabilities are explored extensively on lab-on-a-chip microfluidic devices for biomedical research applications.

At UTSI, ultrafast lasers are used to fabricate next-generation electric micro-propulsion thrusters for Cubesats. The (UTRF) patent-pending technology being developed by Dr. Costa and [Dr. Moeller](#) is called Micro Scalable Thrusters for Adaptive Mission Profiles in Space (μ STAMPS) and uses ionic liquid (IL) propellants to generate thrust via well-known electrospray mechanisms. Dr. Costa also works on the selection and characterization of IL propellants with properties well-suited for this application, and teaches the topic of electric micro-propulsion to UTK Mechanical, Aerospace, and Biomedical Engineering (MABE) seniors taking the courses of “Introduction to Aerospace Design” and “Aerospace System Design”. In the past year, Dr. Costa and Dr. Moeller received a 2022 UTRF Technology Maturation Grant to develop a stand-alone μ STAMPS thruster prototype with power and propellant sub-systems housed inside a 1U unit. In addition, this past spring, Dr. Moeller and Dr. Costa secured a Space Force Small Business Technology Transfer (STTR) phase I award with NearSpace Launch, Inc., during the first-ever round of Space Force funding, to explore integration of μ STAMPS with NSL’s Black Box EyeStar.

Dr. Costa continues to support the research activities of several small businesses. In the past year, Dr. Costa helped International FemtoScience, Inc. develop and characterize diamond nanofluids. Additionally, International FemtoScience, Inc., awarded Dr. Costa additional funds to characterize the performance of diamond-based diodes. Ultra Small Fibers, LLC, awarded Dr. Costa with several grants to continue the development of a proprietary nanoimprinting process. Dr. Costa also leads two contracts that are part of the UT-lead \$50 million Advanced Manufacturing Project for the Army. These two contracts focus on use of ultrafast lasers for advanced manufacturing applications. Dr. Costa has also been awarded a Missile Defense Agency STTR phase II grant with International FemtoScience, Inc., to continue development of diamond-based electronics. Dr. Costa is also leading the procurement of a microwave plasma chemical vapor deposition system for diamond, to further support this work.

Dr. Costa is grateful for the support and the many contributions of the UTSI research support staff, including Alexander Terekhov, Doug Warnberg, Jonathan Kolwyck, Joel Davenport, Dr. Brian Canfield, and Dr. Lu Liu.

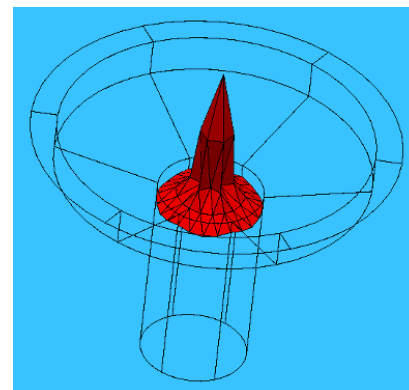


Fig. 1 - Surface Evolver simulation of a Taylor Cone forming inside a μ STAMPS emitter.

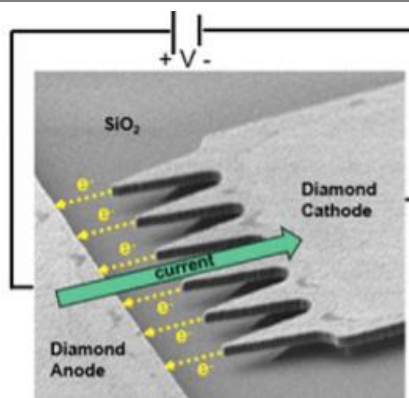
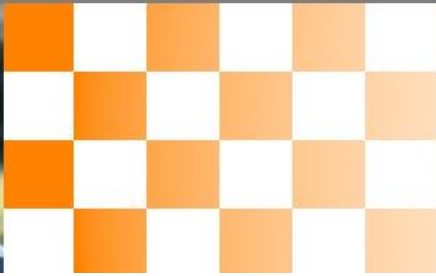


Fig. 2 - Diamond diode fabricated by International FemtoScience, Inc. Credit: International FemtoScience, Inc.



Dr. Mark Gragston

Assistant Professor
Mechanical, Aerospace, and Biomedical
Engineering Department
Ph.D., University of Tennessee

Dr. Gragston’s research focuses on developing and applying aerodynamic measurement technology (AMT), particularly optical techniques and devices, to measure and characterize phenomena such as boundary layer transition, shock-boundary layer interactions, aerodynamic heating, and more in high-speed flows. He is the head of the ARCADE research center and is a member of the HORIZON hypersonics research group at UTSI, working alongside Dr. Phillip Kreth and Dr. John D. Schmisser.

During the 2021–2022 academic year, Dr. Gragston worked on the development of a velocimetry technique for use in the UTSI Mach 4 wind tunnel. The technique uses a partial pressure of acetone, which can be tagged with the UV output from a Nd:YAG laser. He also helped incorporate a similar technique known as femtosecond laser electronic excitation tagging (FLEET) that utilizes molecular nitrogen into the diagnostic capabilities in the Tennessee Aerothermodynamics Laboratory.

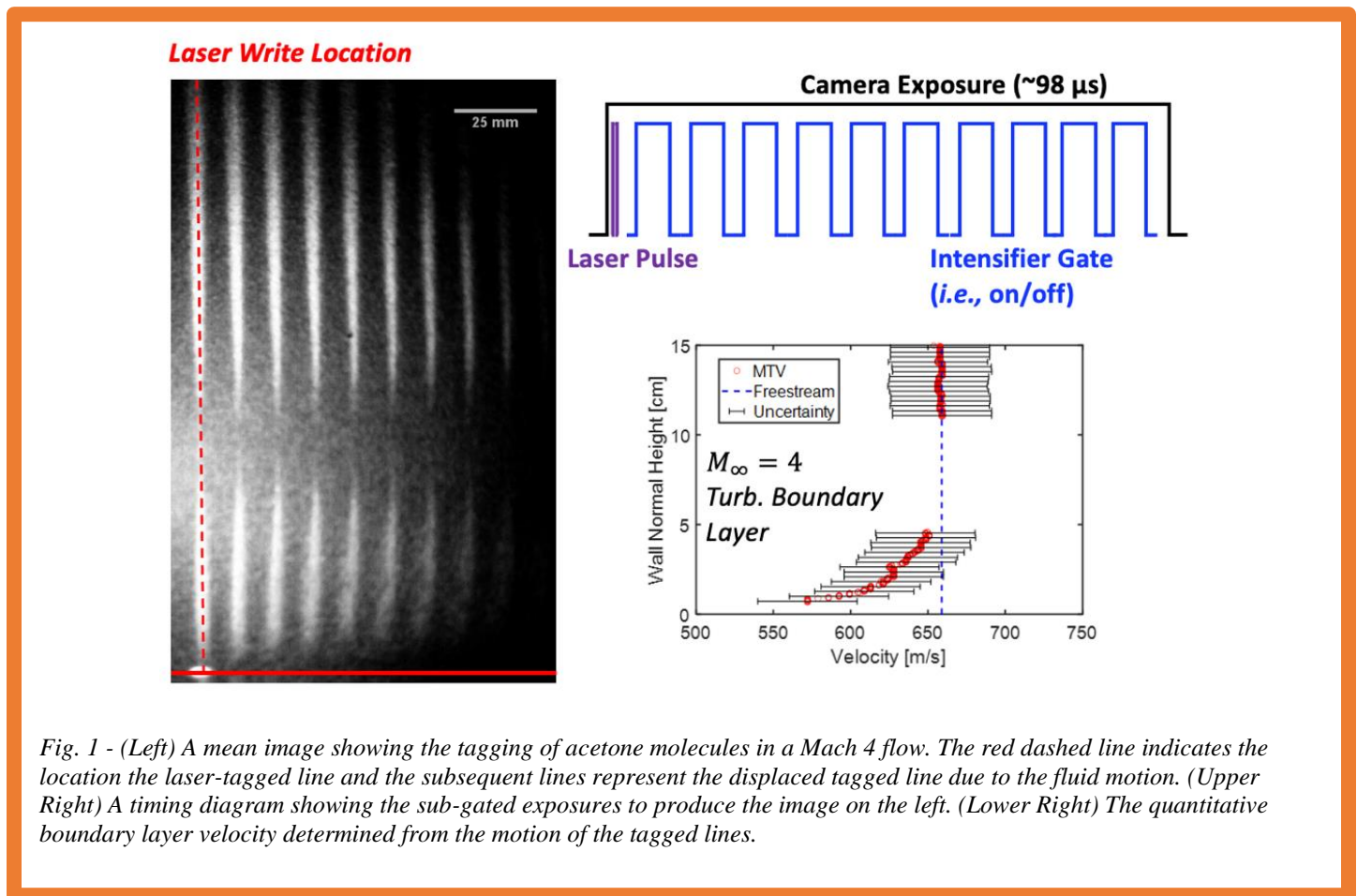


Fig. 1 - (Left) A mean image showing the tagging of acetone molecules in a Mach 4 flow. The red dashed line indicates the location the laser-tagged line and the subsequent lines represent the displaced tagged line due to the fluid motion. (Upper Right) A timing diagram showing the sub-gated exposures to produce the image on the left. (Lower Right) The quantitative boundary layer velocity determined from the motion of the tagged lines.

Mössbauer Spectroscopy

Dr. Charles Johnson

Adjunct Professor of Physics
 Mechanical, Aerospace, and Biomedical
 Engineering Department
 M.A., Oxford University, England
 D. Phil., Oxford University, England

Charles Johnson has studied the magnetic properties of Feridex using Mössbauer spectroscopy. Feridex is an enhancement agent for MRI (Magnetic Resonance Imaging). It is a colloid of superparamagnetic iron oxide nanoparticles, SPIOs. When injected to selectively target certain organs, such as the liver, it produces enhanced contrast of the image. It was, at one time, FDA approved but has subsequently been withdrawn from the market pending more studies. The Mössbauer spectrum at room temperature is a broadened doublet which splits further at low temperatures (Fig. 1) and when a magnetic field is applied (Fig. 2).

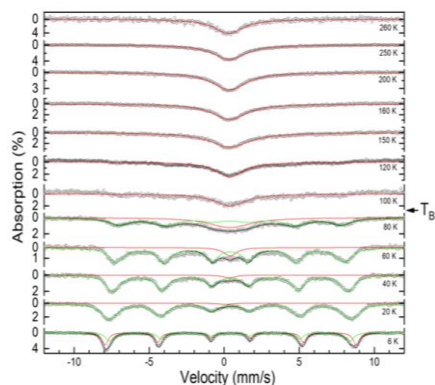


Fig. 1 - Mössbauer spectra at different temperatures.

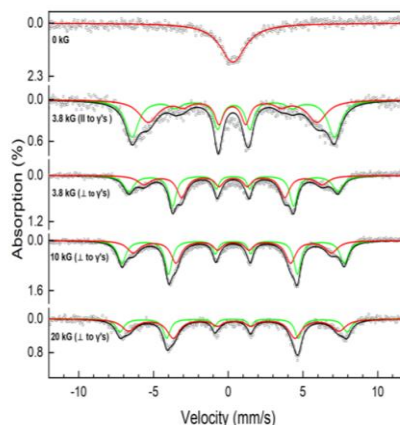


Fig. 2 - Mössbauer spectra in applied magnetic fields.

With no magnetic field, the doublet is symmetrical, but well below the blocking temperature (the temperature below which a material shows slow relaxation of magnetization) of 90 K it is asymmetrical, showing two sites: 32% have a hyperfine field of 503 kG and isomer shift 0.38 mm/s (A-sites), the other 68% having 530 kG and 0.43 mm/s (B-sites).

Magnetic fields of up to 20 kG were produced by a NdFeB permanent magnet in a Halbach array. The split into two 6-line spectra in magnetic fields shows that the particles are ferrimagnetic (Fig. 3), with the (negative) field at the nuclei increasing with applied field for the majority (spin-up with octahedral isomer shift) sites, while for the other (spin-down with tetrahedral isomer shift) sites the field at the nuclei decrease with applied field. The average magnetic moment of the particles was estimated to be 11,250 Bohr magnetons, from which the size of the magnetic core was estimated to be about 8 nm. This is smaller than the hydrodynamic size (Fig. 4) of 30 nm, which includes a protective coating of dextran. These results confirm that the Feridex core is $\gamma\text{-Fe}_2\text{O}_3$, by comparison with the literature.

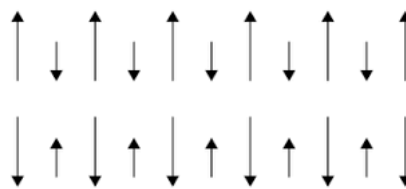


Fig. 3 - Ferrimagnetic, showing the relative magnitude of up and down spins.

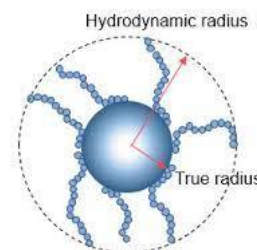


Fig. 4 - Comparison of true and hydrodynamic radii.

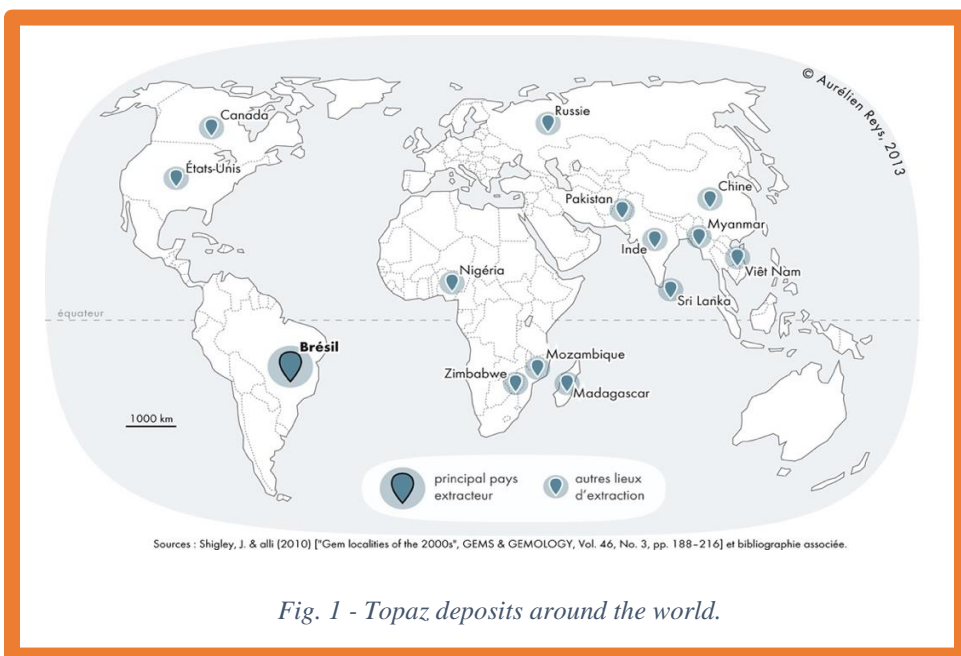
Identification Of Topaz Origins Via Trace Elements And Luminescence



Dr. Jacqueline Anne Johnson

Professor
Mechanical, Aerospace, and Biomedical Engineering Department
B.Sc., University of Liverpool, England
Ph.D., University of Liverpool, England
Fellow of the American Ceramic Society
Fellow of The Institute of Physics

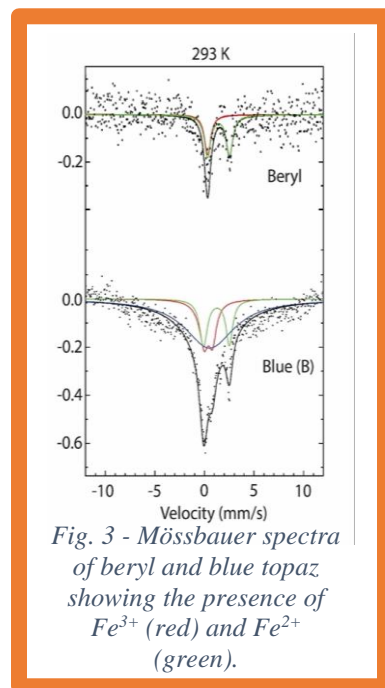
In the nineteenth century, topaz was predominantly mined from the Ural mountains in Russia. Today there are many locations where it is available (Fig. 1). Topaz is a nesosilicate mineral with chemical formula $\text{Al}_2\text{SiO}_4(\text{F},\text{OH})_2$. In its natural state, it is colorless, maybe with a grey cast or golden brown to yellow (Fig. 2). There are several impurities which lead to variations in the color of topaz; there are also treatments such as heat or radiation that can deepen a color.



The Johnson group is working with the Gemological Institute of America based in Carlsbad, CA, to characterize the trace elements in different colors of topaz. Mössbauer is particularly good at identifying the presence of Fe^{3+} and Fe^{2+} . Prior to experiments performed in UTSI's Mössbauer laboratory, it was thought that all iron in topaz should be in the 3+ state. The Mössbauer spectra in Fig. 3 clearly show the presence of 2+ (green line) in both beryl (top) and blue topaz (bottom). This infers previously unknown conditions during formations. The implications of this information are unknown at this point but will be explored soon.

Dr. Johnson is the Program Manager for the Center for Laser Applications and the Diversity, Equity, and Inclusion Director for the Mechanical, Aerospace, and Biomedical Engineering (MABE) department. She also recently became the College of Engineering leader for the Development of Women Faculty.

Dr. Johnson is grateful for the hard work of group members, Lee Leonard, Charles Johnson, Saeed Kamali, Austin Thomas, Aleia Williams, Emily Moore, and Eric Ramsey, as well as 2022 summer interns Richmond Boone, Ashley Isbell, and Tyler Roy.





Dr. Saeed Kamali

Research Associate Professor
 Mechanical, Aerospace, and Biomedical
 Engineering Department
 M.A. Uppsala University, Sweden
 Ph.D., Uppsala University, Sweden

Synchrotron-based High Energy X-Ray Diffraction (HE-XRD), combined with a Pair Distribution Function (PDF) analysis and Density Functional Theory (DFT) have been utilized to extract valuable structural information on an amorphous FeCrMoCBY sample. Furthermore, Mössbauer spectroscopy has been used to investigate the magnetic and structural properties of layered low-dimensional structures and Carbon nanotubes (CNTs).

The Reversed Monte Carlo (RMC) structural model based on the PDF analysis from the HE-XRD data for amorphous $\text{Fe}_{48}\text{Cr}_{15}\text{Mo}_{14}\text{C}_{15}\text{B}_6\text{Y}_2$, consistent with our DFT-based simulations, reveals the presence of spatial heterogeneity in the glass with nanoscale fluctuations, hosting an icosahedral order in the densely packed regions and a tetragonal order in the less dense regions. Fig. 1 shows selected partial PDFs, where the first peak at around 2 Å is mainly due to the contributions between Fe/Cr/Mo and C/B, while the main peak at around 2.5 Å is due to the contributions between the transition metals.

Transition metal-based pnictides and arsenides are an interesting class of compounds with exciting magnetic and superconducting properties. In recent work, we have demonstrated a novel way to induce chirality and polarity in hybrid compounds by using covalent pentagonal $[\text{As}_3\text{Se}_2]$ -Se linkers connecting 1D quinto-tetrahedral Fe-Se chains in a 2D layered network. Mössbauer spectroscopy, Fig. 2, shows that the Fe atoms in the AFM, chiral, and polar $[\text{Fe}_5\text{Se}_9]$ chains, acquire a mixed-valent state and competing intrachain and interchain ferrimagnetic interactions, which resulted in hidden local magnetic ordering.

CNTs are another interesting class of nanostructured materials due to their potential for applications in material science, medicine, and electronics. These 1D nanostructures exhibit exceptionally high mechanical strength but are extremely light-weight. Alumina (Al_2O_3), with high thermal conductivity but very low electrical conductivity, is an attractive substrate in nanoparticle form due to its stability under high temperature and other rigorous processing conditions. The nanocomposite material created by combining CNTs with alumina is a promising material for its interesting magnetic properties, as it encompasses traits of both its constituents. Iron nanoparticles dispersed in alumina powder facilitated the precipitation of carbon atoms and resulted in the formation of tubular structures. The Mössbauer spectrum for this compound is shown in Fig. 3. Based on the extracted hyperfine parameters, we determined the presence of Fe in austenite (FCC), martensite (BCT), and cementite (orthorhombic Fe_3C), as well as $\gamma\text{-Fe}_2\text{O}_3$.

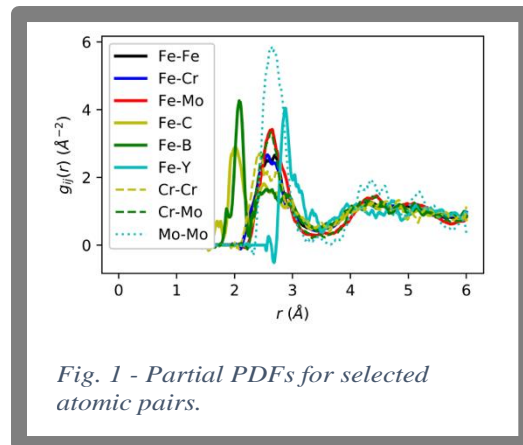


Fig. 1 - Partial PDFs for selected atomic pairs.

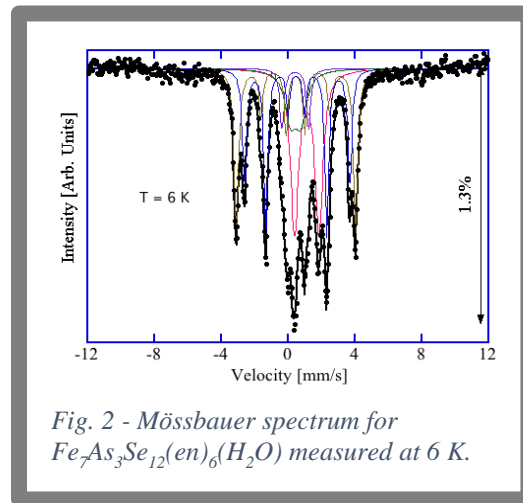


Fig. 2 - Mössbauer spectrum for $\text{Fe}_7\text{As}_3\text{Se}_{12}(\text{en})_6(\text{H}_2\text{O})$ measured at 6 K.

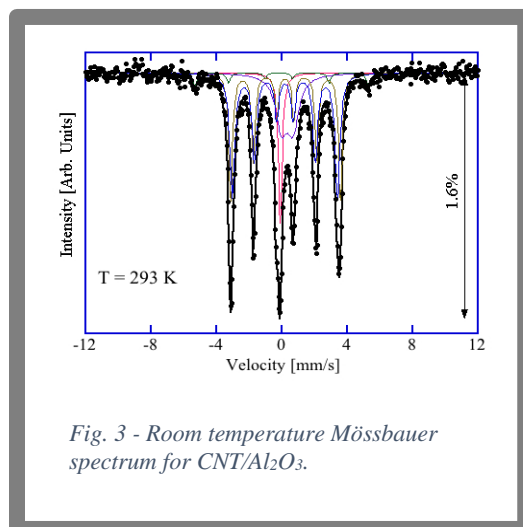


Fig. 3 - Room temperature Mössbauer spectrum for CNT/ Al_2O_3 .

Advanced Optical Diagnostics And Flow Control Strategies For High-Speed Flows



Dr. Phil Kreth

Assistant Professor
Mechanical, Aerospace, and
Biomedical Engineering Department
Ph.D., Florida State University

Dr. Phil Kreth's research interests are focused on advanced optical diagnostic techniques, image-based data reduction methodologies, and novel flow control strategies for application in high-speed and hypersonic flows. Dr. Kreth is an assistant professor within the HORIZON research group (<http://horizon.utsi.edu/>) which studies hypersonic aerothermodynamics and other research areas spanning both aerospace and defense. Recently relocating their Imaging and Flow Diagnostics Laboratory to the Tennessee Aerothermodynamics Laboratory (TALon) building, Dr. Kreth's group has been able to implement diagnostics into the hypersonic wind tunnels located in the TALon lab more easily. In TALon, the student researchers in HORIZON work with optical diagnostic techniques such as high-speed shadowgraphy and schlieren, pressure- and temperature-sensitive paints (PSP & TSP), laser-induced fluorescence (LIF), planar and stereoscopic particle image velocimetry (PIV), and focused laser differential interferometry (FLDI). Optical benchtops are typically used for exploratory efforts and training new graduate student researchers, where smaller-scale configurations can be studied prior to the deployment of these techniques in the TALon Ludwig Tubes or the supersonic blowdown wind tunnels located in the Propulsion Laboratory.

Over the last year, the HORIZON team has continued developing diagnostic capabilities such as temperature-sensitive paint (TSP), and they have been working towards new techniques such as molecular tagging velocimetry (MTV) and femtosecond laser electronic excitation tagging (FLEET) velocimetry. The latter has been enabled by Dr. Mark Gragston's recent acquisition of a Spectra-Physics Solstice ACE femtosecond laser and an associated optical parametric amplifier (OPA). The new laser is capable of producing 6.2 mJ/pulse at repetition rates up to 1 kHz, and the OPA wavelength can be varied from 190 nm to 3 μm . Dr. Kreth's work in optical diagnostics recently enabled two noteworthy collaborations with Arnold Engineering Development Center (AEDC). In one effort, Air Force researchers in AEDC's von Karman Gas Dynamics Facility (VKF) asked UTSI to construct a new LED-based light source to upgrade one of the schlieren systems in VKF. Dr. Kreth and Mr. Kirk Davenport (an engineer with the HORIZON group) advanced the technology of the group's existing LED light sources and provided two LEDs to AEDC at the end of the effort (see Fig. 1). In the second effort, Dr. Kreth teamed with a Tullahoma-based small business called Non-Contact Technologies to provide a new optical diagnostic measurement platform for sub-scale engine/nozzle testing at AEDC. Dr. Kreth and students from HORIZON deployed a retroreflective shadowgraph system to AEDC's engine test bays twice during the effort and collected substantial amounts of data that provided AEDC with very detailed high-speed videos and entirely new insights into the flows they were studying (see Fig. 2).

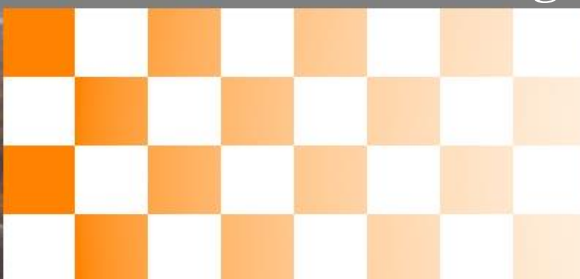


Fig. 1 - Researchers at AEDC receiving two LED light sources from UTSI. From left: Caleb Bell (AEDC), Dr. Taylor Swanson (AEDC), Kenneth Scott (AEDC), Dr. Phil Kreth, John Strike, Dr. Carl Hall (AEDC). Photo by Laura Horton.



Fig. 2 - Dr. Phil Kreth and Haley Goldston install UTSI's retroreflective shadowgraph system in AEDC's SL-2, a sea level turbine engine test cell at Arnold Air Force Base. U.S. Air Force photo by Jill Pickett.

Advanced Materials For Radiographic Imaging



Dr. Lee Leonard

**Research Associate Professor
Mechanical, Aerospace, and
Biomedical Engineering Department
Ph.D., University of Tennessee**

Dr. Lee Leonard's research interests include glasses and glass ceramics, thin films, composite materials, and imaging techniques. He is a member of the American Ceramic Society and has served as a reviewer for the National Science Foundation on multiple occasions. Prior to joining UTSI in early 2009, Dr. Leonard worked for twelve years as a project and tooling engineer in the high-pressure aluminum die casting industry.

Dr. Leonard is developing luminescent glass and glass-ceramic materials for radiographic imaging applications (see Fig. 1). The luminescent properties of these materials can be tuned by varying composition and processing conditions. Dr. Leonard's present focus is on highly efficient x-ray conversion screens for indirect flat panel detectors (I-FPDs). The conversion screens, through a process known as scintillation, convert incident x-ray radiation into visible light, which is detected by the I-FPDs and used to create an x-ray image.

Dr. Leonard, along with fellow CLA researchers Dr. Jacqueline Johnson and Dr. Lino Costa, is currently investigating the use of lasers to improve the characteristics of glass-based, x-ray conversion screens. This work is in collaboration with researchers at Stony Brook University. University of Tennessee Space Institute graduate research assistant Ms. Emily Moore, and undergraduate summer research intern Ms. Ashley Isbell, are also participating in this project (see Fig. 2). Applications that will benefit include digital radiography, portal imaging, and megavoltage cone-beam computed tomography.

Dr. Leonard is also participating in projects concerning high-temperature carbon-carbon composites, anti-fogging diamond-like carbon coatings, seals for hypersonic applications, paint removal using ion beams, antimicrobial surfaces, and solid-state batteries. These projects are in collaboration with Dr. Jacqueline Johnson.

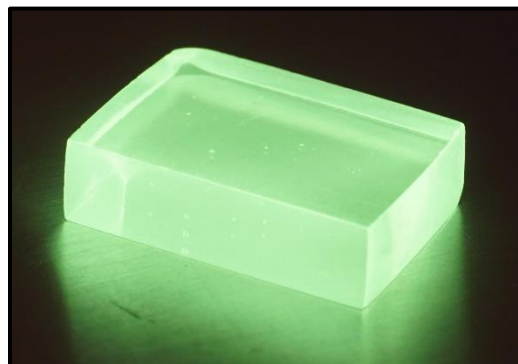


Fig. 1 - Photograph of a glass scintillator sample in 365 nm UV light.

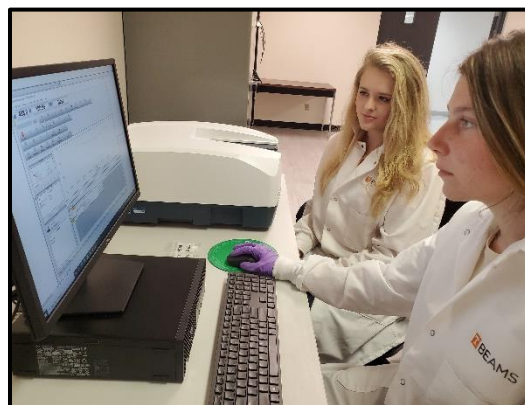


Fig. 2 - Ms. Emily Moore, a graduate research assistant, and Ms. Ashley Isbell, a summer intern, review spectrophotometry data from a glass scintillator sample.

Nonequilibrium Fluid Physics

Dr. Trevor Moeller

Jack D. Whitfield Professor
UTSI Program Coordinator and Graduate Programs
Director for the Department of Mechanical,
Aerospace, and Biomedical Engineering Department
Ph.D., University of Tennessee



Dr. Trevor Moeller’s research focuses primarily on high temperature gases and plasmas and high-speed flows, including both modeling and experimentation. NASA is highly interested in LCH₄/LOX rockets for exploration of Mars. Recently, Dr. Moeller continues to conduct research on liquid methane (LCH₄) liquid oxygen (LOX) rocket engines and propellants. The sensitive nature of this program precludes the presentation of further details. Dr. Moeller is currently conducting research on tunable laser absorption spectroscopy (TLAS) in the mid-infrared for diagnostics in high-temperature flows for the Air Force. He is also pursuing research in nuclear thermal propulsion and the development of micro-electric propulsion thrusters. Additionally, Dr. Moeller is conducting basic research in high-speed flows and the development of tools for the modeling of coupled electromagnetic/fluid systems in nonequilibrium. Additional details are provided below.

Microthruster Development: Dr. Moeller has experience in electric propulsion systems and has continued development of a micro-electrostatic thruster in a collaborative effort with [Dr. Lino Costa](#). Providing propulsion for CubeSats and other micro- and nano-satellites will enable constellations of numerous, inexpensive CubeSats that act together to economically replace larger, expensive individual satellites. This effort utilizes ultrafast laser micromachining to reduce the scale of features by 10-fold over state-of-art thrusters. The microthruster is expected to produce thrust levels on the order of tens of μN , roughly the weight of a housefly. The thruster’s low thrust and small size make it ideal for use on CubeSats. Prototypes of the thruster are undergoing testing. As a part of this testing, Drs. Moeller and Costa are designing a novel thrust stand (Fig. 1) built around a vacuum-rated microbalance capable of direct measurement of low thrust.

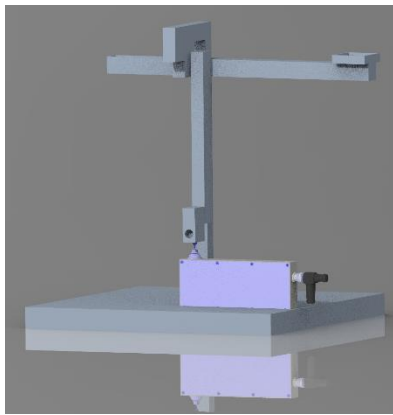


Fig. 1 - Schematic of μN thrust stand for microthruster performance evaluation.

Mid-IR Absorption Spectroscopy Basic Research: UTSI currently uses a single-zone absorption cell to conduct spectral studies for common combustion products in the Mid-IR; however, typical absorption cells suffer from non-uniform temperature distributions that lead to instrument calibration with large uncertainties. As a part of Dr. Moeller’s TLAS research, a three-zone absorption cell was designed to achieve a uniform temperature distribution that exceeds 1000° C for the calibration of mid-infrared spectral lines. The three-zone calibration device has been developed through US

government funding and is currently undergoing checkout testing. This cell will allow for greatly improved accuracy in TLAS measurements, enabling improved characterization of high-temperature flows.

Nonequilibrium Plasma Simulations: Dr. Moeller’s group continued to work with our SUPG finite element method solver for the two fluid plasma model. In our recent work, we have been seeking to improve upon the weight function modification used to stabilize the scheme, which was developed for advection/convection dominated models, and seems to be less effective when large solution gradients appear in areas where the source terms are much stronger than the convective terms. We have had some success with a simplified one-equation model, an advection-diffusion-reaction equation, as illustrated in Fig. 2, and are hoping to be able to extend what we have learned to the full two fluid plasma model in the near future.

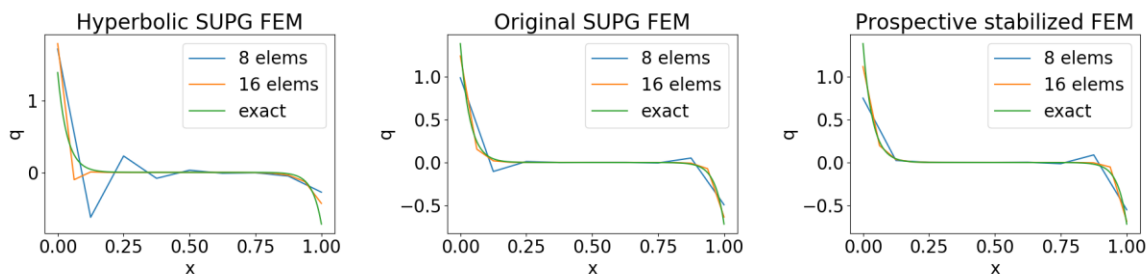


Fig. 2 - Numerical solutions of an advection-diffusion-reaction equation with strong reaction term, slow advection, and sharp layers near the boundaries. The “hyperbolic limit” SUPG scheme currently employed does not prevent oscillations in the numerical solutions as well as the “original” SUPG scheme, and that the prospective stabilized scheme is able to suppress the oscillations more, still, at the left boundary.

Atomic And Molecular Laser Spectroscopy



Dr. Christian Parigger

Associate Professor of Physics and Astronomy
Mechanical, Aerospace, and Biomedical Engineering
Department

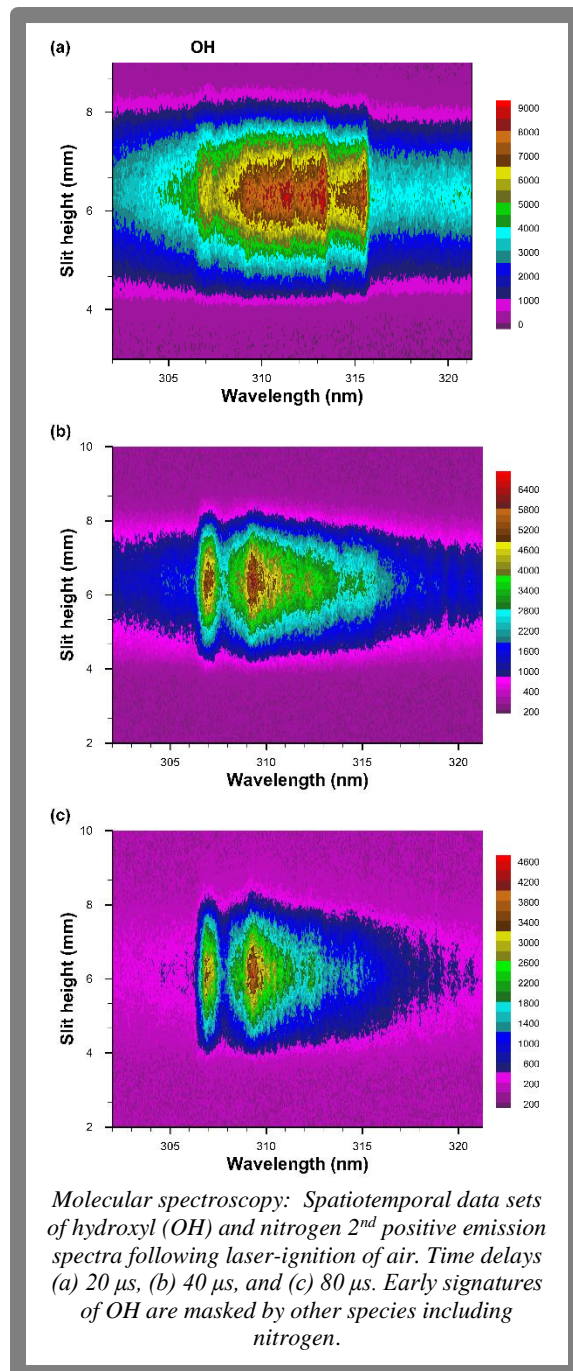
Ph.D., University of Otago, Dunedin, New Zealand

Dr. rer.nat. in Physics, University of Innsbruck, Austria

Professor Parigger's research during the current reporting period included experimental, theoretical, and computational physics, with focus in atomic and molecular and optical (AMO) physics. Of interest are fundamental and applied spectroscopy, nonlinear optics, quantum optics, ultrafast phenomena, ultrasensitive diagnostics, laser spectroscopy, combustion science and plasma physics, nonequilibrium fluid physics, optical diagnostics, applied optics, biomedical applications. Continued experimental research is associated with plasma diagnosis in combustion, non-equilibrium fluid physics, and study of expansion phenomena that occur at well-above hypersonic and supersonic speeds. Recent molecular spectroscopy interrogates spatially and temporally resolved molecular "fingerprints" and association with recorded shadowgraphs. The figure "Molecular spectroscopy" illustrates results for laser-ignition of air in the time-delay range of 20 μ s to 80 μ s. Several communications of ongoing research were published in well-respected archived journals.

Professor Parigger is strongly committed to postgraduate education and taught core PhD courses for UTK campus physics with excellent-outstanding student comments during the current reporting period. He continued offering of postgraduate-research related courses and PhD program core courses, introduced students of physics and engineering to research projects of interest to CLA, and as senator of the UTK faculty senate, president of the UTSI faculty assembly, and showed engagements in athletic and other committees, including member of the university systems committee in the upcoming year.

Christian Parigger's recent research interrogates applications to diverse fields that include plasma diagnostics, combustion diagnostics, molecular plasma spectroscopy, selected astrophysics spectra analyses, and space physics with emphasis on space debris removal. During last year, several proposals on space physics and zero emission aviation were submitted with an individual company and as joint proposals, respectively. These proposals bode well with the CLA vision in research and training. In the coming year, efforts will be expanded towards increasing educational offerings with potential overlap of postgraduate education for UTSI's engineering focus, including research opportunities for MSc and PhD students associated with CLA. Moreover, an invited lecture will be presented at the Federation of Chemical and Spectroscopy Societies (FACSS) this fall, and a 2nd edition of his book on diatomic spectroscopy with applications will be prepared.





Dr. Feng-Yuan Zhang

Professor
Mechanical, Aerospace, and Biomedical
Engineering Department
Ph.D., Nagoya University

The research interests of Dr. Zhang's NanoHELP group (<http://fzhang.utsi.edu/>) lie in thermal-fluid sciences, nanotechnology, and advanced spectroscopies and diagnostics. The goal of his NanoHELP group is to take advantage of nanotechnology and associated engineering for developing high-efficiency, low-cost and sustainable energy, power and propulsion devices, such as fuel cells, electrolyzers, batteries, direct combustion engines, and electric thrusters. The research ranges from fundamental understanding to system optimization with a strong interdisciplinary program for the study of micro/nano-scale reaction, heat/mass transport, fluid mechanics, novel materials, electrochemistry, catalytic reaction, corrosion, 3D printing/additive manufacturing, degradation, and MEMS/NEMS.

One of the recent research studies is on high-efficiency green hydrogen and oxygen productions and energy storage with PEM electrolyzer cells (PEMECs). Combining advanced manufacturing and novel material/component design fabrication, state-of-the-art characterization, system testing, and theoretical modeling/simulations, the NanoHELP has revealed a structure innovation to significantly reduce the PEMEC cost, weight, and volume.

Recently, we have developed a new high-efficiency electrode with significantly reduced catalyst loadings for low-temperature PEM water electrolysis, by coating catalysts on the thin liquid/gas diffusion layer (LGDL) to form a catalyst-coated LGDL (CCLGDL). In conventional electrode designs, the catalyst is ink-coated on the proton exchange membrane (PEM), which causes much catalyst waste and involves expensive and complex fabrication processes. By the novel CCLGDL design, the catalyst utilizations are significantly enhanced. The catalyst mass activity has been increased by over 10 times compared with the conventional CCM/PTL electrode design.

Accompanying this novel design, a standard conditioning protocol was developed to boost the performance of CCLGDLs to the best level with excellent stability. By this simple stepped galvanostatic conditioning, the cell efficiency can be increased by more than 9%. With the help of *in-situ* electrochemistry and visualization characterization, the increased catalyst activity and reaction sites were identified. This novel electrode design and the standard conditioning protocol opens new pathways to improve the catalyst utilization and reduce cost for next-generation electrochemical energy storage/conversion systems.

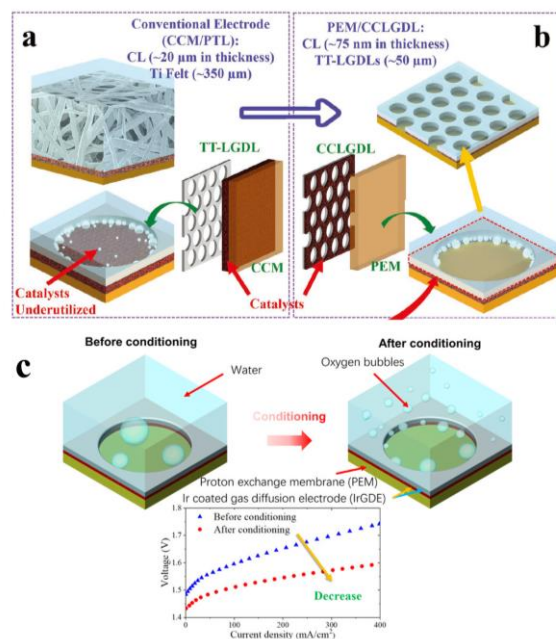


Fig. 1 - Schematic of conventional CCM/PTL electrode design (a) novel CCLGDL/PEM electrode design (b), and the impacts of essential conditioning process on boosting the performance of novel CCLGDL/PEM electrodes. (Yu, Shule, Kui Li, Weitian Wang, Zhiqiang Xie, Lei Ding, Zhenye Kang, Jacob Wrubel, Zhiwen Ma, Guido Bender, Haoran Yu, Jefferey Baxter, David A. Cullen, Alex Keane, Kathy Ayers, Christopher B. Capuano, and Feng-Yuan Zhang. "Tuning Catalyst Activation and Utilization Via Controlled Electrode Patterning for Low-Loading and High-Efficiency Water Electrolyzers." *Small* 18, no. 14 (2022): 2107745.; Wang, Weitian, Kui Li, Lei Ding, Shule Yu, Zhiqiang Xie, David A. Cullen, Haoran Yu, Guido Bender, Zhenye Kang, Jacob A. Wrubel, Zhiwen Ma, Christopher B. Capuano, Alex Keane, Kathy Ayers, and Feng-Yuan Zhang. "Exploring the Impacts of Conditioning on Proton Exchange Membrane Electrolyzers by In Situ Visualization and Electrochemistry Characterization." *ACS Applied Materials & Interfaces* 14, no. 7 (2022): 9002-9012.)

Research On Advanced Combustion And Battery Fire Safety



Dr. Peng Zhao

Associate Professor
Mechanical, Aerospace, and
Biomedical Engineering Department
Ph.D., Princeton University

Dr. Peng Zhao joined CLA in February of 2021. His research interests are focused on the development of clean-combustion strategies, zero-carbon alternative fuels, computational reacting flows, as well as thermal management and safety for Li-ion batteries.

The PI's lab has a state-of-the-art Accelerating Rate Calorimetry (ARC) (EV+, THT) as shown in Fig. 1a, which allows thermal runaway testing triggered by well-controlled step heating, ramp heating, over-charging, internal short circuit and nail penetration conditions. This chamber has been carefully calibrated using standard samples with very satisfactory thermal sensitivity and repeatability. Fig. 1b shows the temperature profiles of both the ARC and the cell in a typical step-heating thermal runaway test. A heat-wait-seek (HWS) strategy is adopted to make sure thermal equilibrium is achieved between the cell and the ARC during the test, and meanwhile to detect self-exothermic onset when temperature rise rate is beyond $0.02\text{ }^{\circ}\text{C}/\text{min}$. Fig. 1c shows the cell-to-cell variations in the thermal runaway testing results among 9 fresh LCO 18650 cells with nearly identical SOC, capacity, impedance. Surprisingly, the onset temperature, delay time and reduced mass during thermal runaway are largely distinct among individual cells, although good consistency has been shown in the activation energy obtained from the heat-release profile (Fig 1d). The results directly show that thermal runaway is very sensitive to manufacturing variations, even for relatively mature LIBs. These variations lead to substantial ambiguities in target selection for safety evaluation and modeling. Hence, battery safety evaluation must be obtained from statistical analysis of behaviors of multiple cells.

The Laboratory of Advanced Mobility and Power (LAMP), directed by Dr. Zhao, now is equipped with the state-of-the-art battery cyclor Maccor 4200 with environmental control, electrical impedance spectrum, and gas analyzer for venting gas analysis. Zhao's research is on the frontier of energy sustainability, advanced propulsion, and safety, and has been sponsored by the US Department of Energy, Los Alamos National Lab, Oak Ridge National Lab, Ford Motor Company and National Science Foundation. Prof. Zhao has published 1 book chapter and 50 journal articles in leading combustion and energy journals, including Combustion and Flame, Proceedings of the Combustion Institute, Applied Energy, etc. He is a Bernard Lewis Fellow of the International Combustion Institute, session Chair of the International Combustion Symposium, organizer of SAE world congress, and member of the Early Career and Diversity Development Committee of the US Combustion Institute.

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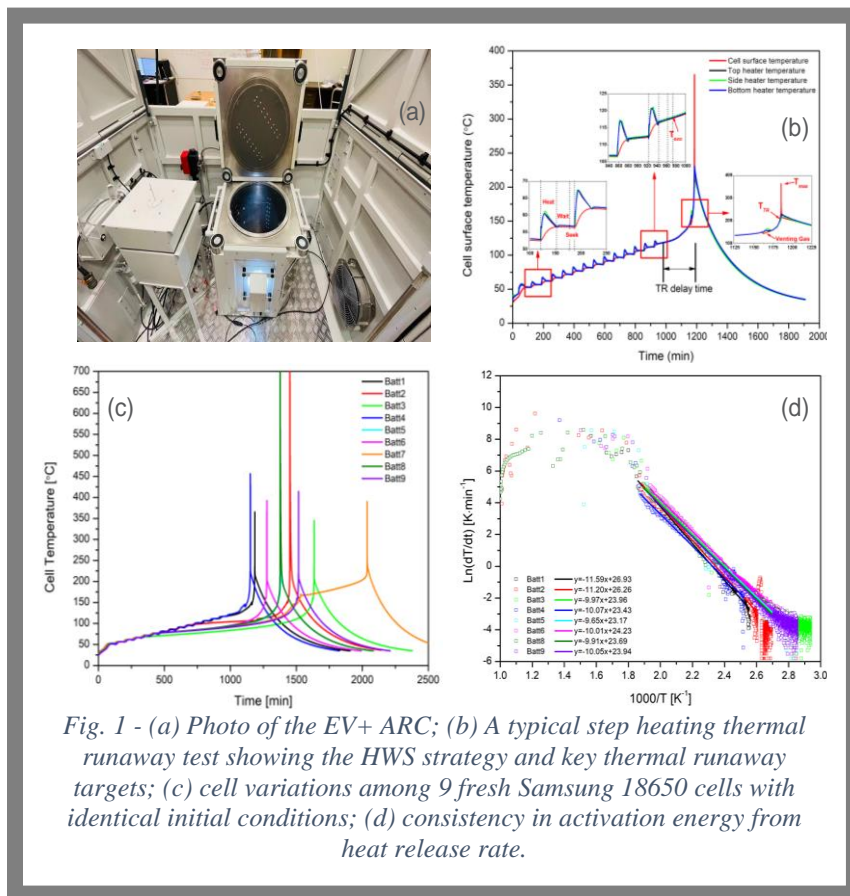













Fig. 1 - (a) Photo of the EV+ ARC; (b) A typical step heating thermal runaway test showing the HWS strategy and key thermal runaway targets; (c) cell variations among 9 fresh Samsung 18650 cells with identical initial conditions; (d) consistency in activation energy from heat release rate.



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CONFERENCE ORGANIZING


-  P. Zhao, Session organizer and chair of BEV congress on Storage and Battery Safety, (2022).
-  P. Zhao, Session organizer of SAE World Congress PFL120 session “Multi-Dimensional Engine Modeling,” (2022).
-  P. Zhao, Session organizer of SAE World Congress PFL180 session “Advanced Propulsion/Powertrain for Ground Transportation,” (2022).
-  C. G. Parigger, International steering committee member for the International Conferences on Spectral Line Shapes (ICSLS), 25th ICSLS Caserta, Italy, June 19-24, (2022).



BOOK CHAPTERS


-  C. G. Parigger and J. O. Hornkohl, “Quantum Mechanics of the Diatomic Molecule with Applications,” Institute of Physics Publishing, United Kingdom, 2nd edition preparation agreement, June, (2022).


APPOINTMENTS

 T. M. Moeller, Chair of the AIAA Plasma Dynamics and Laser Technical Committee, May 2021 – present.


INVENTIONS, DISCLOSURES, PROVISIONAL PATENT APPLICATIONS, AND PATENT APPLICATIONS


 F. Y. Zhang, Electrodes Comprising Liquid/Gas Diffusion Layers and Systems and Methods for Making and Using the Same. United States Patent Application Serial no. 17/717,899. (2022).


 F. Y. Zhang, Novel-Architecture Electrodes with Enhanced Mass Transport for High-Efficiency and Low-Cost Hydrogen Energy. United States Patent Application Serial no. 17/717,821. (2022).

 F. Y. Zhang, Development of Ruthenium-Copper Nano-Sponge Electrodes for Ambient Electrochemical Reduction of Nitrogen to Ammonia. United States Patent Application Serial no.17/085,720. (2021).

 R. L. Leonard, L. Costa, A. Lubinsky, A. Howansky, J. Johnson, A. Terekhov, and B. Canfield, Structured Glass-Ceramic Scintillators; JETH Ref. No. 1306/161 PROV

 J. Jones, A. Terekhov, B. K. Canfield, T. Moeller, and L. Costa, Micro Scalable Thrusters for Adaptive Mission Profiles in Space – μ STAMPS; Disclosure and Assignment to University of Tennessee Research Foundation, UTRF Number: 21047-07, Date of Final Approval: 10/05/2020; Patent application #: 17/548446, Filed: 12/10/2021.

 B. K. Canfield, A. Y. Terekhov, and J. L. V. Costa, Burst-pulse Ultrafast Laser Micromachining; UTRF Invention Disclosure # 22068-07, 03 November, (2021).

 W. H. Hofmeister, A. Y. Terekhov, J. L. V. Costa, K. S. Lansford, D. Rajput, and L. M. Davis, Nanostructures from laser-ablated nanohole templates; U. S. Patent # 11,115,007; 26 October, (2021).

RESEARCH FUNDED EXTERNALLY

Investigator	Contract Title	Funding Agency	Period of Performance	Awarded	2021 – 2022 Expended
Costa, Lino	Process FemtoSci Supplied Nanodiamond in Laboratory (R024428022)	International FemtoScience, Inc.	07/01/2016 – 03/01/ 2023	\$140,000.00	\$7,706.41
Costa, Lino	SEM Imaging of Electronic Device Samples (R024428033)	International FemtoScience, Inc.	03/01/2020 – 03/01/2023	\$58,000.00	\$3,721.48
Costa, Lino	Laser Marking of Rollers (R024428036)	Ultra Small Fibers	11/30/2020 – 12/31/2022	\$28,000.00	\$987.56
Costa, Lino	Design and Fabrication of Novel Radiation Immune Microelectronic Devices and Circuits (R024428037)	International FemtoScience, Inc.	04/27/2021 – 10/27/2021	\$43,500.00	\$16,730.64
Costa, Lino	Preparation and Replication of Silanized Templates (R024428041)	Ultra Small Fibers	01/06/2022 – 10/01/2022	\$20,000.00	\$10,876.27
Costa, Lino	Design and Fabrication of Novel Radiation Immune Vacuum Microelectronic Devices and Circuits (R024428042)	International FemtoScience, Inc.	06/15/2022 – 06/15/2024	\$453,966.00	\$0.00
Costa, Lino Moeller, Trevor	RP 3: Subtask 5: Ultrafast-laser surface texturing of carbide cutting tools (R024428038)	DOD–Army–ARL	07/01/2021 – 12/16/2022	\$91,316.00	\$10,983.98

RESEARCH FUNDED EXTERNALLY

Investigator	Contract Title	Funding Agency	Period of Performance	Awarded	2021 – 2022 Expended
Costa, Lino Moeller, Trevor	RP-4: Subtask 5: Ultrafast-Laser Surface Texturing for Metal AM (R024428039)	DOD–Army–ARL	07/01/2021 – 12/16/2022	\$94,453.00	\$10,834.96
Costa, Lino Moeller, Trevor Canfield, Brian Terekhov, Alexander	Electrospray Thrusters for Cubesats (R024428040)	UTRF Technology Maturation Funds 2022	01/10/2022 – 10/03/2022	\$9,355.00	\$434.48
Johnson, Charles	Running Mossbauer Spectra	RK Pharmaceuticals and Johnson Matthey	10/01/2021 – 04/30/2022	\$7,700.00	\$7,700.00
Johnson, Jacqueline	Gas Flow Hollow Electrode Depaint Technology (R024417034)	UL Tool, LLC	09/29/2020 – 12/30/2022	\$99,917.00	\$51,486.88
Johnson, Jacqueline Leonard, Lee	Diamond-like Carbon Thin Films for Anti-fog Lens Coating in Laparoscopy (R024417032)	HHS – NIH – National Institutes of Health	09/01/2019 – 08/31/2022	\$422,057.00	\$162,761.00
Johnson, Jacqueline Leonard, Lee	Phase II HT Seal - UITool LLC Sub001 (R024417036)	UL Tool, LLC	10/01/2021 – 12/31/2022	\$300,000.00	\$83,887.40
Johnson, Jacqueline Leonard, Lee	DLC Coating- ULTOOL LLC ULTOOL 2021-01 (R024417037)	UL Tool, LLC	11/01/2021 – 04/29/2022	\$40,000.00	\$9,181.44

RESEARCH FUNDED EXTERNALLY

Investigator	Contract Title	Funding Agency	Period of Performance	Awarded	2021 – 2022 Expended
Moeller, Trevor	ACE Booster 2 (R024348072)	Gloyer-Taylor Laboratories LLC	09/03/2019 – 12/05/2022	\$155,439.00	\$17,224.29
Moeller, Trevor	Development of Three Zone Absorption Cell for Spectral Measurement Verification (R024348073)	DOD – Air Force – AFRL – Air Force Research Laboratory	09/01/2019 – 08/15/2022	\$138,402.00	\$32,153.42
Moeller, Trevor	Modeling of Laser Induced Plasma Process (R024348074)	DOD – AEDC/FMF	12/13/2019 – 12/31/2021	\$50,000.00	\$15,280.99
Moeller, Trevor	Cryo-Tube Testing Support (R024348075)	Gloyer-Taylor Laboratories LLC	08/01/2020 – 01/31/2022	\$5,000.00	\$3,679.64
Moeller, Trevor	Standards for Impure Propellants (R024348076)	Gloyer-Taylor Laboratories LLC	12/04/2020 – 09/30/2021	\$25,000.00	\$23,432.03
Moeller, Trevor	NASA Space Grant Consortium (R024348080)	Gloyer-Taylor Laboratories LLC	10/15/2021 – 11/19/2021	\$5,000.00	\$4,850.01
Moeller, Trevor	NASA Space Grant Consortium (R024348081)	Vanderbilt University	06/04/2020 – 06/03/2023	\$87,801.00	\$46,232.45
Moeller, Trevor	Sample Evaluation, imaging, spectroscopy, and material testing (R024395089)	Gloyer-Taylor Laboratories LLC	06/03/2022 – 12/31/2022	\$2,500.00	\$0.00

RESEARCH FUNDED EXTERNALLY

Investigator	Contract Title	Funding Agency	Period of Performance	Awarded	2021 – 2022 Expended
Zhang, Feng-Yuan	Developing Novel Electrodes with Ultralow Catalyst Loading for High-Efficiency Hydrogen Production in Proton Exchange Membrane Electrolyzer Cells (R024421025)	DOE – EERE – The Office of Energy Efficiency and Renewable Energy	10/01/2018 – 09/30/2021	\$1,154,825.00	\$87,838.01
Zhang, Feng-Yuan	Developing Novel Electrodes with Ultralow Catalyst Loading for High-Efficiency Hydrogen Production in Proton Exchange Membrane Electrolyzer Cells (R024421026) C/S	DOE – EERE – The Office of Energy Efficiency and Renewable Energy	10/01/2018 – 09/30/2021	\$0.00	\$0.00
Zhang, Feng-Yuan	Electrolyzer Integrated Modular (R024421027)	Skyre, Inc./DOE – EERE – The Office of Energy Efficiency and Renewable Energy	10/01/2018 – 06/30/2022	\$300,000.00	\$105,374.36
Zhang, Feng-Yuan	Electrolyzer Integrated Modular (R024421028) C/S	Skyre, Inc./DOE – EERE – The Office of Energy Efficiency and Renewable Energy	10/01/2018 – 06/30/2022	\$0.00	\$0.00

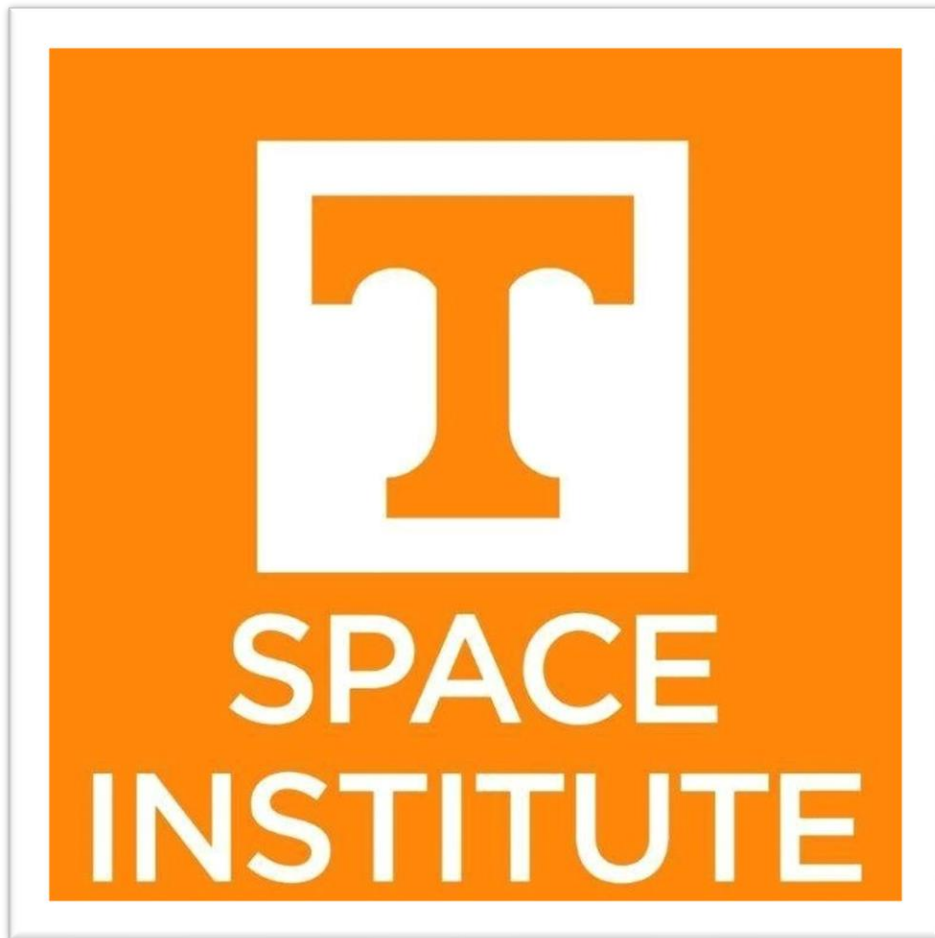
RESEARCH FUNDED EXTERNALLY

Investigator	Contract Title	Funding Agency	Period of Performance	Awarded	2021 – 2022 Expended
Zhang, Feng-Yuan	Integrate Membrane Anode Assembly & Scale Up (R024421029)	Plug Power	10/01/2018 – 07/31/2022	\$265,648.00	\$114,167.76
Zhang, Feng-Yuan	Integrate Membrane Anode Assembly & Scale Up (R024421030) C/S	Plug Power	10/01/2018 – 07/31/2022	\$0.00	\$0.00
Zhao, Peng	Miniature Ignition Screening Rapid Compression Machine for Kinetic Measurements of Novel Fuels (R024435020)	DE-EE0007985 UIC- The Board of Trustees of the University of Illinois	08/11/2021 – 06/30/2022	\$79,544.00	\$79,656.50
Zhao, Peng	URP Award: TCI and Combustion (R024435021)	Ford Motor Co.	11/01/2021 – 10/31/2022	\$50,000.00	\$28,448.39
Zhao, Peng	Kernel initiation, stretch dependence and EGR tolerance of LPG flames (R024435022)	ONRL DOE	05/06/2022 – 05/05/2023	\$35,000.00	\$3,126.48
				Total	\$938,756.83



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