DEPARTMENT OF

PHYSICS & APPLIED PHYSICS

MERGING SCIENCE WITH TECHNOLOGY

Olney Science Center

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UMASS LOWELL

Learning with Purpose

A MESSAGE FROM FROM THE CHAIR

Welcome to our research world, where faculty and students of the Department of Physics and Applied Physics are engaged in exploring the universe we inhabit, from the infinitesimal to the infinite, from the quantum to the cosmic, where we study light, matter and energy, where we combine scientific rigor with emerging technology, where we expand beyond our disciplines, where we celebrate diversity and transform education to train the next generation.

MERGING SCIENCE WITH TECHNOLOGY

With over $10 million annually in funded research, we were recently ranked among the top 50 programs in the United States for research and development expenditures by the National Science Foundation. Graduates from our programs hold positions in academia, national laboratories, government agencies, major medical facilities and industry. Our comfortable faculty size (not too large, not too small), coupled to our high commitment to research, both in fundamental and applied arenas, allows quality interactions and mentoring of students, both graduate and undergraduate. Our faculty are world leaders in their research areas, and our university is fully committed to growth.

We invite you to sample what we have to offer as a department and join us in our explorations. To learn more about our exciting B.S., M.S. and Ph.D. programs in physics, please visit our website, www.uml.edu/physics, or contact us directly. We look forward to hearing from you.

PChowdhury.

Partha Chowdhury, Ph.D.
Chair

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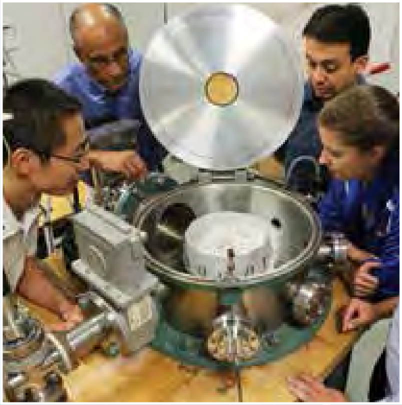

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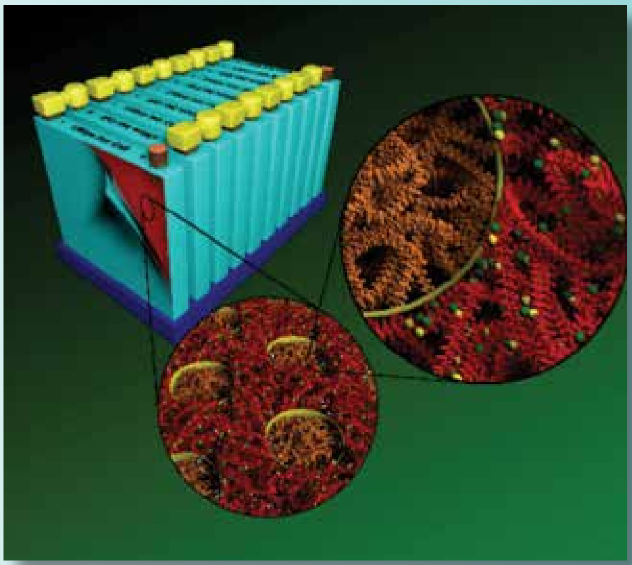
SOFT CONDENSED MATTER

Predicting the Structural, Mechanical and Electrical Properties of Materials

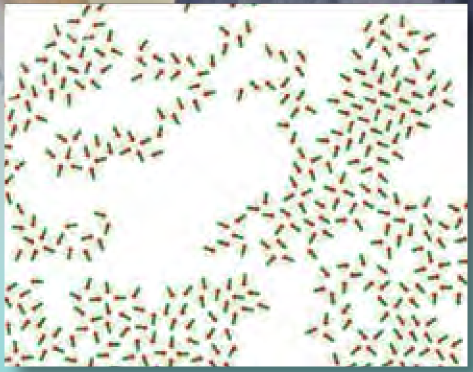
The Soft Condensed Matter Group of Asst. Prof. Johannes Zwanikken uses theoretical and computational methods to study the properties of a wide variety of complex systems, such as colloidal suspensions, nanoparticles, bio-polymers, interfaces, membranes, and active particles, among other topics. These systems are characterized by a complex phase behavior and a hierarchy of length and time scales. Projects in the group interface with research in the Chemistry and Biology departments at UMass Lowell, and have been inspired by many experimental collaborators in physics, chemistry, biology and materials science.

The SCM Group is specialized in calculating the properties of polyelectrolytes and charged components in electrolyte solutions, using classical density functional theory, liquid state theory and self-consistent field theory for polymers, among other techniques. The common goal of these methods is to predict the structural, mechanical and electrical properties of materials that consist of charged components, such as electrochemical capacitors, electrolyte membranes, electrified oil-water interfaces, polymer brushes, and suspensions of functionalized nanoparticles.

The SCM Group is also highly interested in dissipative systems and the dynamic properties of reaction networks, applied to “active matter.” There are many complex phases of matter with useful mechanical, electrical, optical, and functional properties, of which gels, liquid crystals, polymer melts and lipid bilayers are but a few examples.



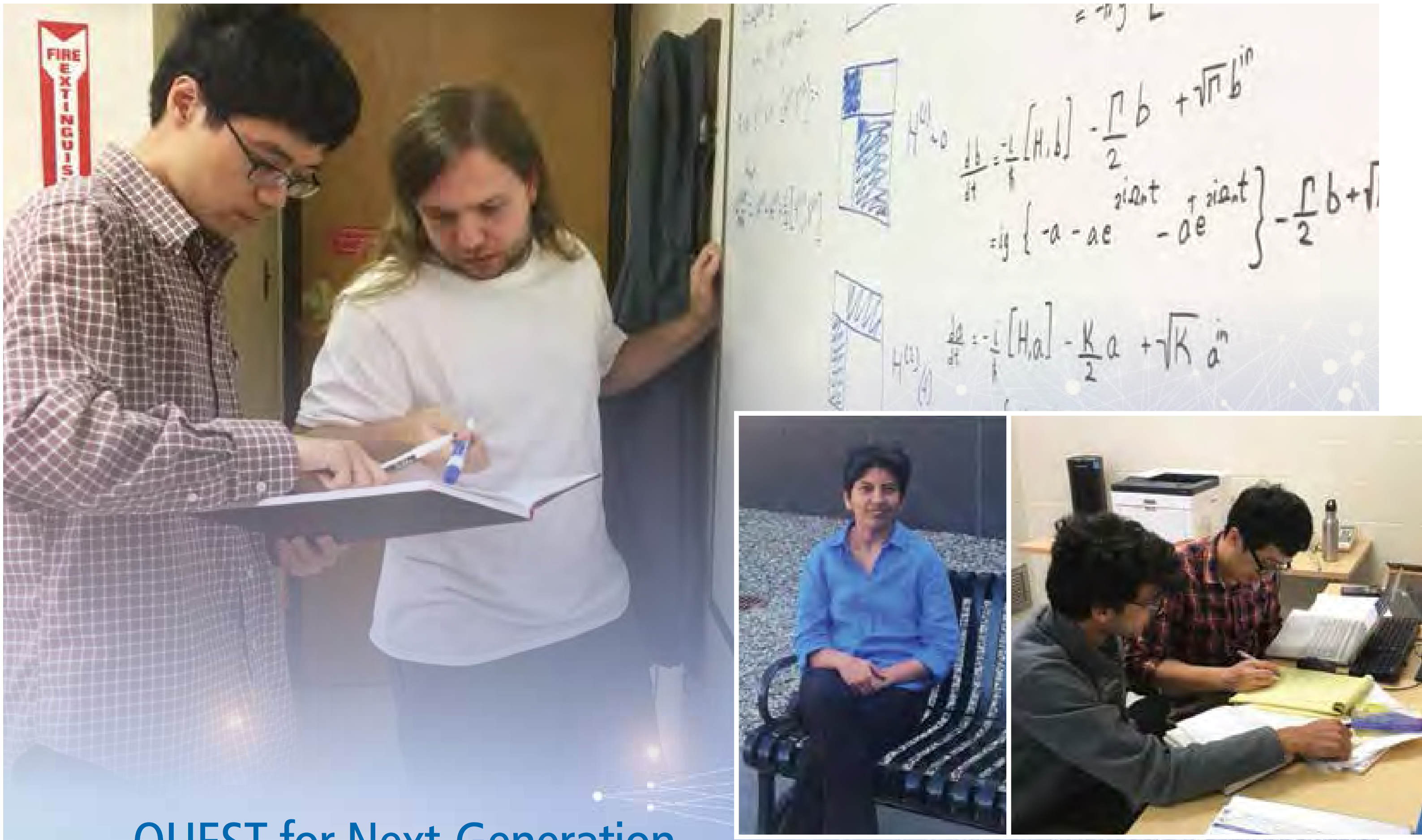
Structural properties of a polymer membrane at different length scales



Snapshot of a computer simulation of active particles

Discoveries of new advanced materials have been fueled by the control of nanometer-sized components that have the ability to self-assemble into unique phases. Since recently, it has become possible to imbue these components with an ability to propel themselves in a directed fashion, using molecular motors, or other principles that employ light or catalysis. Materials that consist of such components are also referred to as active matter, and have inspired a rapidly growing field in science, because of their exceptional properties and promise for a wide range of applications.

These principles have been heavily utilized by nature, e.g. for cell motility and the functional properties of muscle fiber and flocking. However, active matter also escapes the fundamental laws of equilibrium statistical thermodynamics because of its inherent dissipative character, which makes it very difficult to describe and control. The SCM Group uses several methods to study active matter, by means of computer simulations, stochastic equations, and network theory, to build towards a rational bridge between the microscopic properties of the components and the functional properties of the ensemble. Currently the group interrogates the mixing properties and cluster formation of anisotropic self-propelled particles and how the nucleation process depends on propulsion direction.



Above left: Asst. Prof. Archana Kamal.

QUEST for Next-Generation Quantum Technologies

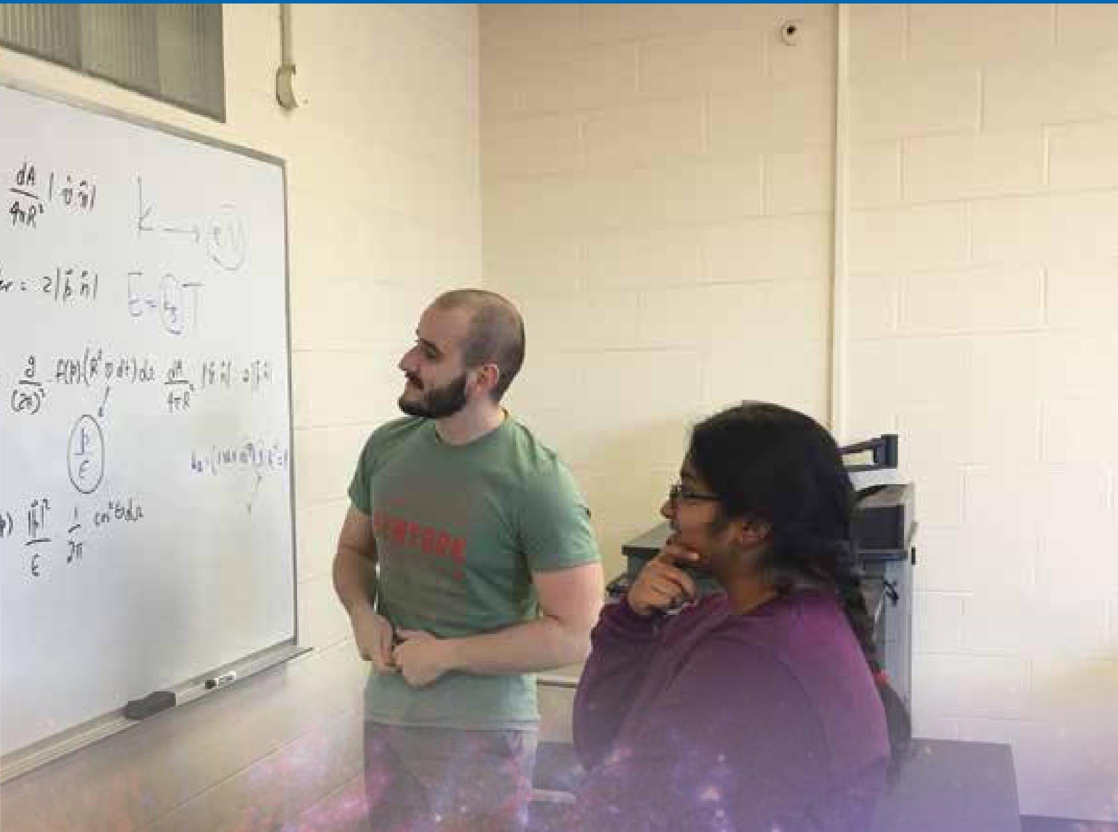
Asst. Prof. Archana Kamal leads the QUEST (Quantum Engineering Science and Technology) Group at UMass Lowell. The research in the group lies at the interface of quantum information and quantum optics and encompasses several aspects of high-fidelity quantum information processing in low-dimensional systems.

“Precise control of quantum dynamics enabled by such systems not only makes them the workhorse for almost all practical quantum technologies, but it also makes these systems attractive as testbeds for demonstrating the fundamentals of quantum physics itself,” says Kamal.

According to Kamal, one of the primary challenges for scalable quantum information processing is to realize quantum effects at macroscopic scales while preserving the delicate physics. “We have recently been tackling this challenge head on by using dissipation as a resource for quantum state engineering and control in strongly coupled quantum systems. Such dissipation-engineered systems can exhibit a natural robustness to decoherence, which is untenable in usual quantum systems one encounters in textbooks,” she says.

Another component of her research focuses on developing high-fidelity quantum measurement protocols. “The challenge is to get away with the minimum possible perturbation, or back action, as permitted by quantum mechanics. We develop new schemes for quantum-limited amplification and detection; many of these are now routinely employed in experiments in solid-state quantum computing,” says Kamal.

A related theme of her research is engineering reciprocal symmetry-breaking in photon transmission and amplification. Photons are the universal carriers of information across several quantum information platforms. Since the laws of electromagnetism are inherently time-reversal invariant, photon-propagation and information transfer is naturally reciprocal. “We have pioneered schemes that implement several forms of nonreciprocal photon scattering,” says Kamal. “Unlike commercial nonreciprocal devices, our proposals do not rely on magnetic fields or introduce any dissipation, which are both extremely crucial considerations for any practical on-chip quantum-mechanical processor. Such dissipationless nonreciprocity, especially at the level of a few quanta, opens doors to qualitatively new phenomenon in interacting quantum systems.”



Asst. Prof. Nishant Agarwal

Cosmic Acceleration: Quantum Origins and Deviations from General Relativity

Asst. Prof. Nishant Agarwal leads the Theoretical Cosmology Group at UMass Lowell. Interests of the group include understanding the evolution of the universe starting from its earliest stages to the current energy landscape dominated by dark energy and dark matter.

We believe that the universe underwent a phase of rapid exponential expansion, called inflation, for a fraction of a second just after the Big Bang.

"My work on the early universe focuses on the study of quantum fields and perturbations on an expanding background and their imprints in cosmological data. I have used cosmic microwave background and large-scale structure (LSS) data extensively to probe the physics of inflation," says Agarwal. "I am also interested in understanding whether the perturbations generated during inflation could carry information from the pre-inflationary Universe, which would in turn give us important insights into quantum gravity."

The current universe is undergoing accelerated expansion once again, the reason for which is undoubtedly one of the deepest mysteries of contemporary physics. "Unless we are observing the effects of a non-trivial form of energy, commonly called dark energy, the acceleration suggests that Einstein's general relativity might not be the correct description of gravity on large scales," notes Agarwal.

He says any such deviations from general relativity would have also left imprints in, for example, the growth of structure, redshift space distortions and, possibly, the equation of state of dark energy at different redshifts. "I am interested in understanding what modifications of gravity are theoretically allowed, how they affect the evolutionary history of the Universe, and how our perturbative modeling of LSS interferes with constraints on dark energy."

Another major constituent of the universe today is dark matter—the invisible matter that holds galaxies together. "Various dark matter candidates are expected to interact with radiation in the universe and influence galaxy formation," says Agarwal. "My research in this direction has involved developing models which, in conjunction with upcoming polarization experimental data, could be used to test the existence of certain pseudo-scalar particles that might form at least part of dark matter."

Prof. Noureddine Melikechi

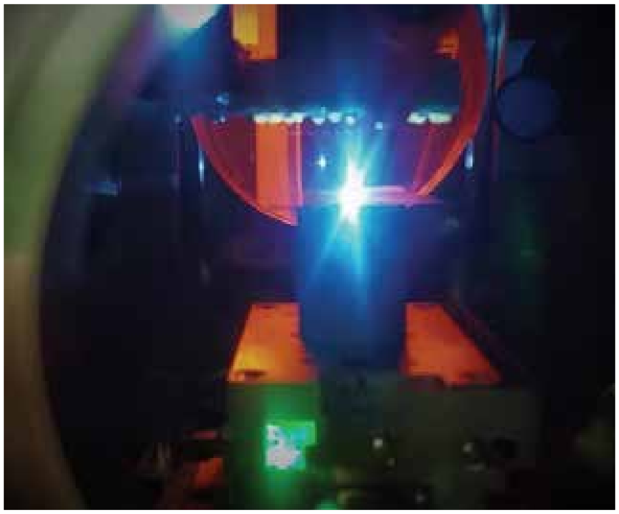
Laser Spectroscopy of Complex Samples in Crowded Environments: a Vehicle to Better Understand Matter in its Own Environment

Our research group focuses on the science of spectral signatures: Laser spectroscopy of complex systems in crowded environments.
One of the primary strengths of our research group is experimental and analytical methodologies of Laser-Induced Breakdown Spectroscopy (LIBS), fluorescence spectroscopy and Raman spectroscopy with an emphasis on two seemingly distinct areas:

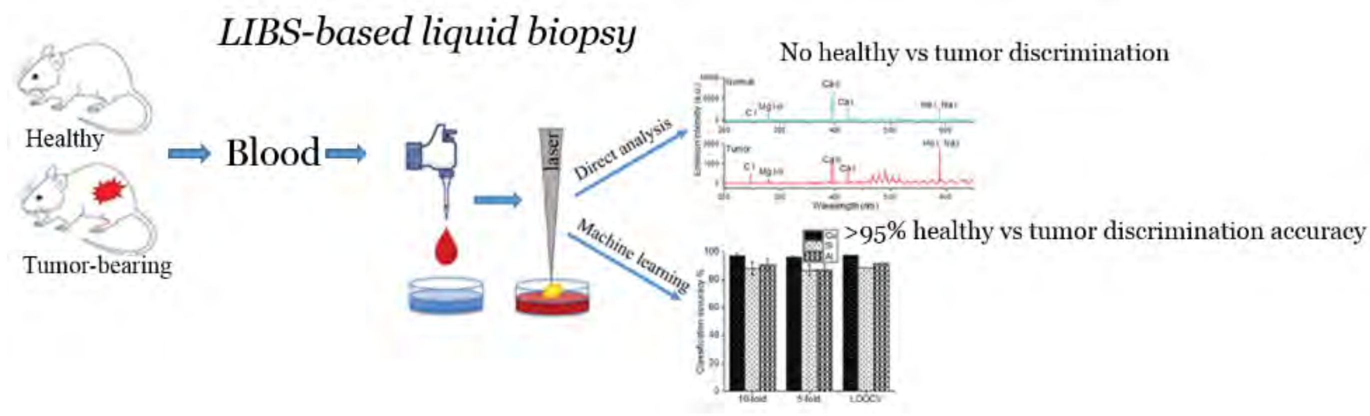
DEVELOPING SENSITIVE OPTICAL TECHNIQUES FOR THE EARLY DETECTION OF CANCERS

Early detection of many forms of cancer has proved vital in reducing mortality rates. From a physics point of view this is an interesting confluence of fundamental science and application. While we are helping to solve one of our great societal problems, we also investigate micro/nanoparticle interactions in laser-induced plasma during tagging procedures, laser-plasma-material interactions while investigating the substrate dependence of our results, and the role of machine learning tools in analysis and detection of spectroscopy for cancer detection.

We seek to develop spectroscopic methods to diagnose certain types of cancer in a minimally invasive fashion using bodily fluids such as blood. One such method is to tag specific biomarkers and look for changing in the LIBS signal using a technique call TAG-LIBS. We have previously shown this to be feasible for human blood by tagging the biomarker CA 125 for the detection of epithelial ovarian cancer.



LASER-INDUCED BREAKDOWN SPECTROSCOPY



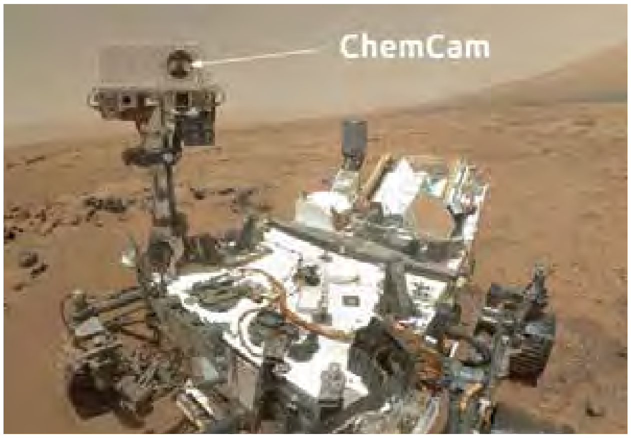
The figure above shows a process we have used to study the detection of melanoma in mice. We investigated blood deposited on several substrate surfaces and investigated discrimination between healthy and cancerous subjects using several machine learning algorithms. Careful selection of the substrate and machine learning algorithm yielded a 97% classification accuracy. Continued interests and further work on this subject involves considering extensions other diseases.

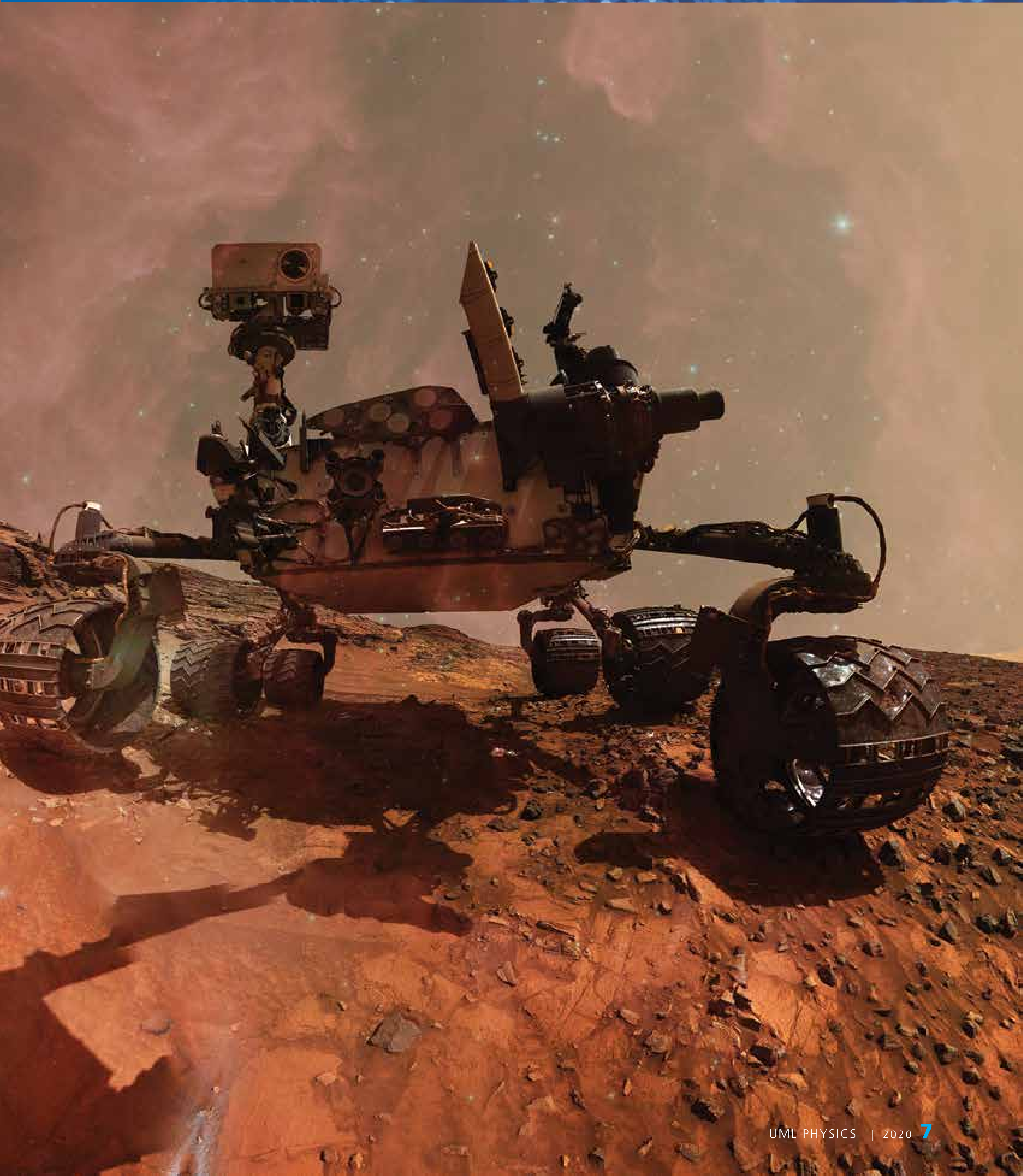
ANALYZING MARTIAN SOILS, DUST AND ROCKS USING LASER-INDUCED BREAKDOWN SPECTROSCOPY

The Mars Curiosity Rover is equipped with a scientific suite of instrumentation designed to study the surface geology of the Red Planet in the hopes of learning more about Martian geological history and more about the formation of our own solar system. One of the instruments onboard the rover is the ChemCam (pictured to the left from the ChemCam website https://mars.nasa.gov/msl/mission/instruments/chemcam/) in which one of its purposes is to study Martian rocks and regolith using LIBS. One of the research thrusts of our group is to support ground analysis of spectra collected on Mars. This has included various aspects including:

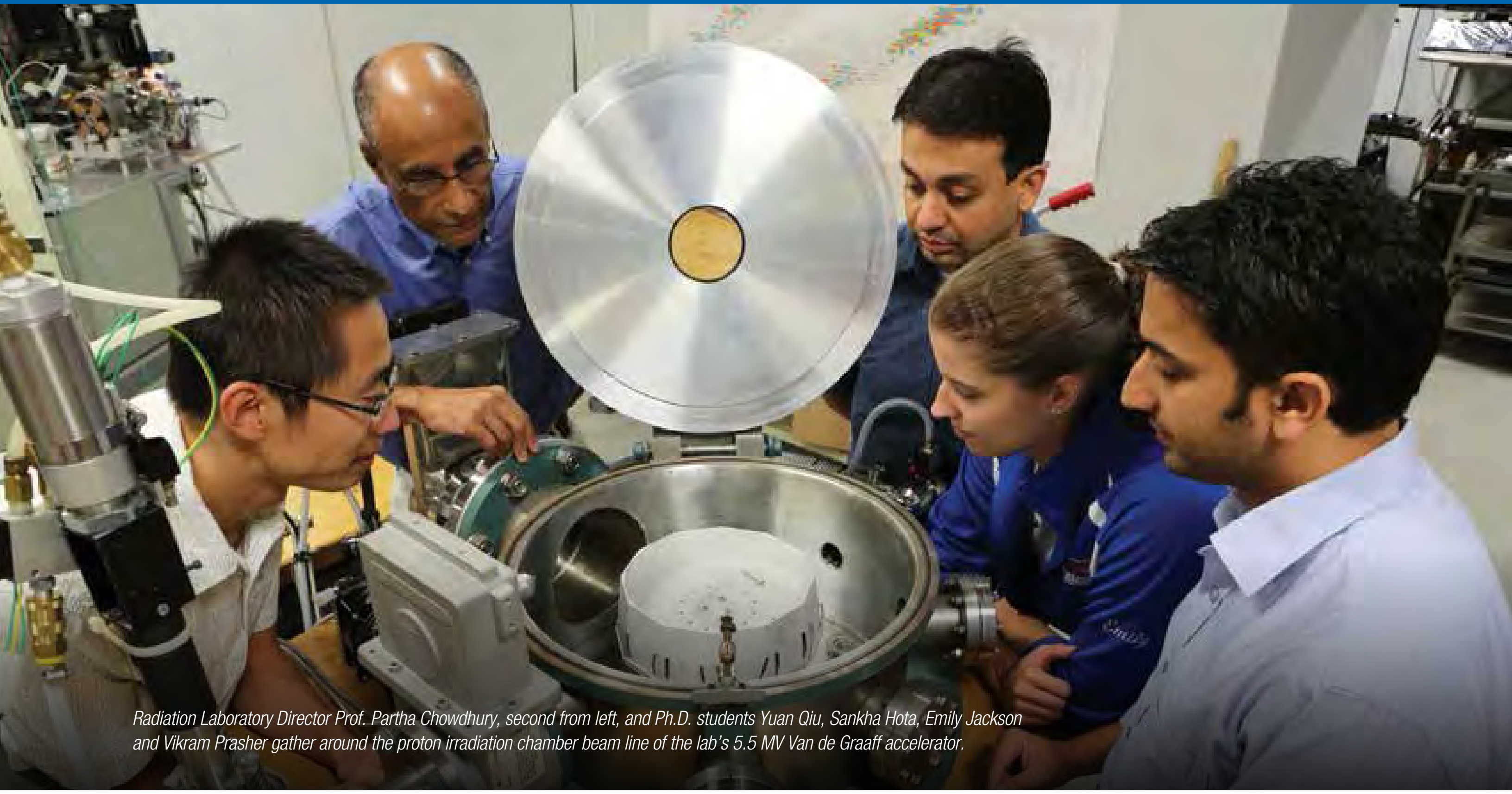
- First principle hydrodynamic plasma modeling and collisional radiative simulation of emission spectra under Martian conditions in which sample ambient conditions and concentrations are the only inputs
- Advanced chemometric/multivariate numerical modeling for increased predicative capabilities

In pursuit of the the two research goals, we search for novel numerical techniques (chemometirc, multi-variate, physics/plasma/spectral based) to improve quantification and predictive capabilities. We also work on developing novel ways of expanding the experimental methodologies of LIBS by combining the technique with other spectroscopic techniques such as Raman, fluorescence, and tagging features of interest such as biomarkers.





RADIATIONLABORATORY



Radiation Laboratory Director Prof. Partha Chowdhury, second from left, and Ph.D. students Yuan Qiu, Sankha Hota, Emily Jackson and Vikram Prasher gather around the proton irradiation chamber beam line of the lab's 5.5 MV Van de Graaff accelerator.

Interdisciplinary Program in Nuclear Science and Technology

At the center of all atoms in the universe are the nuclei. They are a million times smaller than the atom but provide 99.9 percent of its mass. Learning how these tiny systems behave teaches us about forces in nature that are found only inside atomic nuclei, forces that generate almost all the energy that powers the sun and stars. They are the core of all matter and the fuel of stars. They play a crucial role in our understanding of how all the elements that comprise us and the world we live on were forged in the stars. A century after the discovery of the nucleus, new experiments, particle accelerators and detector technologies are being developed to synthesize and study thousands of previously unknown isotopes and deepen our understanding of the way neutrons and protons hold together in the nucleus of an atom, and how they are created in stellar environments.

The Radiation Laboratory at UMass Lowell offers a well-rounded portfolio of academic and applied research. On the academic side, we have programs in nuclear structure and nuclear astrophysics, where we explore the balance of forces that dictate how nuclei arrange their constituent protons and neutrons, and nuclear processes that occur in extreme astrophysical environments. These experiments are carried out at national and international heavy-ion accelerator facilities. Our close-knit research group of students (graduate and undergraduate), post-docs and faculty study how nuclei form and when they fall apart. We measure and calculate properties of the lightest nuclei, how we might synthesize the heaviest elements, and how nuclei with exotic neutron-proton ratios exist and behave. In studying these quantum systems, many new experimental and theoretical techniques are developed, methods which permeate into diverse branches of science. Applied nuclear techniques are used in medical diagnostics and therapeutics, space science, power generation, stockpile stewardship, environmental monitoring, homeland security, geology and oceanography, as well as many other new and emerging sciences.

UMass Lowell has a long history of excellence in nuclear science. The Radiation Laboratory hosts a 1-megawatt (MW) research reactor and a 5.5-million-volt (MV) Van de Graaff accelerator, enabling both academic and applied research avenues. The facility is especially well-equipped for neutron science, with thermal neutrons available at the reactor and mono-energetic fast neutrons at the accelerator. Partnerships with industry and national laboratories are in place for developing new detector technologies. For example, new scintillating materials from a local Massachusetts company show great promise for fast-neutron spectroscopy, and federal grants support the R&D to develop multi-modal detectors which can differentiate between thermal neutrons, fast neutrons and gamma rays through differences in their pulse shapes.

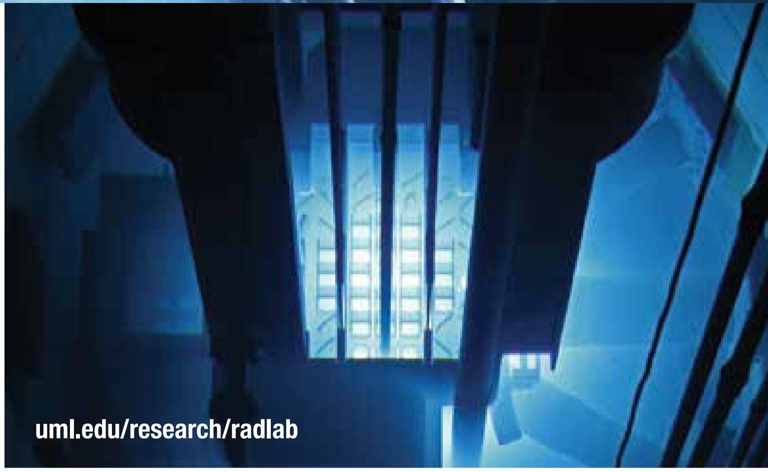
Another cutting-edge research avenue in collaboration with a company from Tennessee is in the development of position-sensitive germanium detectors, through neutron damage and recovery studies, for medical imaging, space science and homeland security, as well as for heavy-element spectroscopy. In the process, students learn the nuts and bolts of advanced high-resolution semiconductor detectors. Inter-disciplinary research examples include the commissioning of a proton microprobe, funded by a Science and Technology grant from the UMass President's Office, which can focus the accelerator's proton beams down to micron sizes. Potential applications range from surface modification and characterization in materials science to biomedical research, such as mapping specific metal content in the brain that has been tied to Alzheimer's Disease. UMass Lowell students and post-doctoral researchers, mentored by faculty, lead many of these projects, working with a robust in-house infra-structure that includes multi-parameter data acquisition and analysis, digital signal processing, as well as computation and Monte Carlo simulation of detector response.

Radiological health and medical physics are also vibrant areas of research at the Radiation Laboratory. The reactor has capabilities for thermal neutron radiography. Research topics include developing and investigating new isotopes for theranostic applications in nuclear medicine, detectors and methods for dosimetry and treatment planning, and radiation mitigating drugs.

NUCLEAR PHYSICS AND ASTROPHYSICS

Asst. Prof. Peter Bender is the newest faculty member in the experimental nuclear physics group. His research takes place both at the UML Radiation Laboratory as well as various national and international facilities. Bender's interests lie in the field of nuclear structure, in understanding how protons and neutrons are arranged and configured within the atomic nucleus, and how they behave when they are energetically excited. "I like to explore when neutrons and protons in an atomic nucleus decide to behave as individual particles, jumping up and down in their quantum orbits, and when the nucleus decides to rotate or vibrate as a collective entity, and how these single-particle and collective modes of nuclear excitation interact," explains Bender, who received his doctorate from Florida State University in 2011.

Short-lived, radioactive nuclei that are composed of many more neutrons than protons compared to those near stability can reveal surprising changes in structure as one traverses across a chain of isotopes or isotones (same number of neutrons and varying protons). "These changes are observed through studying the excitation pattern of the nuclei, which provide a map of the underlying nuclear shape as well as how individual nucleons occupy the quantum orbits in the nucleus," says Bender. "These properties can either be directly measured or inferred by studying the gamma radiation emitted when an excited nuclear state releases energy." Experimental measurements, combined with input from nuclear structure and reaction theory, can help explain the forces that drive the often dramatic modifications in nuclear structure, and enhance state-of-the-art nuclear models that aspire to predict properties of nuclei very far from stability.



Top: The bluish glow of Cerenkov radiation, emitted by charged particles from fission traveling faster than the speed of light in water, lights up the core of UMass Lowell's research reactor. Below: Asst. Prof. Peter Bender, second from left, visiting student Daniel Foulds-Holt, Ph.D. student Sanjanee Waniganeththi and undergraduate senior Andrew McGregor setting up the germanium detector array.

Bender's expertise lies in the detection, characterization and analysis of gamma rays that are emitted in nuclear reactions. He is intimately involved in the Gamma-Ray Energy Tracking Array project— which is currently the premier facility in the world to detect gamma rays emitted from in-beam experiments. This array can help study nuclei in the most extreme systems and will be a key instrument to fully utilizing the most exotic nuclei produced by the future Facility for Rare Isotope Beams that will be starting operations soon in the United States.

In addition to involving his students in cutting-edge research in national laboratories, Bender also conducts and supervises hands-on projects in-house at the UML Radiation Laboratory. Using fast, mono-energetic neutrons produced at the Van de Graaff accelerator, undergraduate and graduate students have helped characterize the position sensitivity and

RADIATION LABORATORY

Left: Radiation Laboratory Assoc. Director (Accelerator) Asst. Prof. Andrew Rogers, right, and graduate student Alvin Kow with the proton microprobe at the Van de Graaff accelerator. Center: The Nuclear Physics group after a celebratory lunch outside Fuse Bistro in downtown Lowell following a Ph.D. dissertation defense. Right: Ph.D. students Kartikeya Sharma (left) and Sanjanee Waniganeththi during an experiment at the National Superconducting Cyclotron Laboratory.

radiation hardness of high-purity planar and coaxial germanium detectors with segmented contacts, the same material used in the high-resolution gamma ray spectroscopy performed in the premier accelerator facilities around the world.

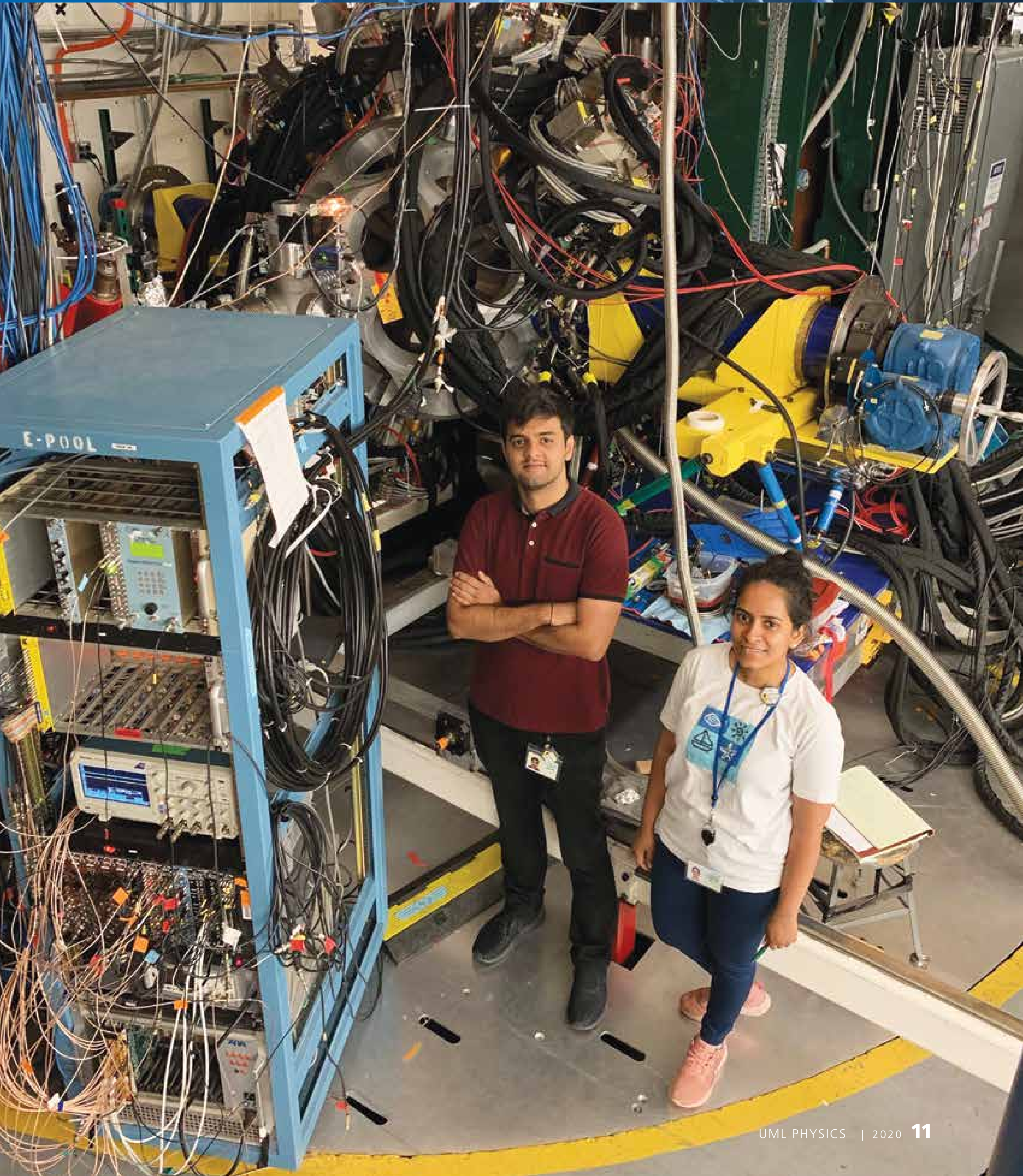
The field of expertise of Asst. Prof. Andrew Rogers is experimental nuclear structure and nuclear astrophysics. “My research focuses on the study of exotic nuclei, the role they play in unlocking the fundamental inner workings of the nucleus, and understanding nuclear processes occurring in extreme astrophysical environments,” says Rogers, who obtained his doctorate in physics from Michigan State University in 2009. “I’m particularly interested in neutron-deficient isotopes—nuclei containing far fewer neutrons than their stable counterparts—at the limits of nuclear stability. While exotic isotopes live only for a fraction of a second after they are produced, their properties are critical for our understanding of processes that create the heavy elements in stars, in supernova explosions and in Type I X-ray bursts on the surface of neutron stars. Much of my work is centered on learning about the rapid proton-capture process, thought to take place during X-ray bursts,” he explains.

To access these short-lived isotopes here on Earth, powerful particle accelerators must be used. Rogers’ experiments are conducted at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University as well as other accelerators in the United States and around the world. An upgrade to the NSCL facility—the Facility for Rare Isotope Beams, with a price tag of three quarters of a billion dollars—is scheduled to come online soon. “This upgrade will allow us to explore, study and discover nuclei that are currently difficult or impossible to access but are key to our understanding of the cosmos,” notes Rogers.

Rogers is a hands-on experimentalist, with strong expertise and interest in radiation detection, instrumentation, digital electronics and software. At the Radiation Laboratory, Rogers—with the help of undergraduate physics majors as part of their capstone projects—completed the commissioning of a proton microprobe at the Van de Graaff accelerator facility. The microprobe can deliver proton beams a few microns in diameter for a wide variety of imaging applications, ranging from medical physics to materials science and engineering, using proton-induced X-ray emission techniques and digital data acquisition systems.

Prof. Partha Chowdhury’s academic research interests lie in exploring the heavy-element frontier by investigating the structure of the heaviest nuclei that are accessible through gamma ray spectroscopic techniques. He studies the excited states of nuclei with about a hundred or more protons, which help guide theoretical models that attempt to predict the existence and properties of a “superheavy” island of stability. Isotopes of superheavy elements should ordinarily fly apart due to the repulsive forces between the many positively charged protons, but are held together in a delicate balance due to quantum energy gaps in the spectrum of nucleon energy levels. He studies nuclei that are spinning rapidly, and where the nucleons occupy the highest quantum orbits. He is also interested in the physics of high-spin “isomers,” which are long-lived meta-stable states whose comparatively long half-lives arise from special quantum symmetries that occur in non-spherical axially-deformed nuclei. These experiments are conducted at national and international heavy-ion accelerator facilities, with large gamma-detector arrays coupled to electromagnetic separators and/or various particle detection devices. At UMass Lowell, Chowdhury’s applied research interests lie in the development of novel and emerging radiation detectors for neutrons and gamma rays. The detectors are initially tested and characterized at the Radiation Laboratory facilities and subsequently deployed for experiments at the larger national accelerator facilities.

While each individual faculty member has their own specific research interests, many projects tend to be group efforts. Students, both graduate and undergraduate, and post-docs work with faculty as a team and contribute to the success of the necessarily complex experiments. Students, get to learn and hone a variety of hands-on and computational skills, which include detector and accelerator fundamentals, vacuum techniques, and the optics of charged particle beams.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NEUTRON-INDUCEDREACTIONS

Science and Applications

Asst. Prof. Marian Jandel carries out fundamental studies of neutron-induced reactions and their applications relevant to astrophysics, nuclear medicine, stockpile stewardship, nuclear forensics, homeland security and nuclear energy. The high-precision measurements of neutron capture and fission reactions are studied in detail at Los Alamos National Laboratory (LANL) with the Detector for Advanced Neutron Capture Experiments (DANCE). This is an array that consists of 160 barium fluoride detectors with very fast time response that surround the fissioning samples. DANCE enables high-efficiency measurements of gamma rays that are emitted within a narrow time window of a few nanoseconds. The samples at DANCE are irradiated by a pulsed beam of energetic neutrons created by very high energy protons from a particle accelerator which impinge on a tungsten “spallation” source. The neutron incident energy is calculated using a time-of-flight method, and neutron-induced reactions are studied using gamma ray calorimetry. To further study the fission process, Jandel has led the design of the NEUtron Array at daNCE (NEUANCE) to study correlations between gamma rays and neutrons emitted in fission. He has started a collaboration between UML and LANL and new measurements of prompt fission gamma rays from U-235 are under way at the UML research reactor. His students take advantage of opportunities for summer internship at LANL. A graduate and an undergraduate student spent ten summer weeks at LANL to work on DANCE related research.

Jandel’s research spans a variety of arenas and spawns natural collaborations with other research programs. He is collaborating in the development of neutron detectors based on thin film technology developed by the group of Prof. Erno Sajo. This research is spearheaded by graduate students in the medical physics program, where methods are being developed for depositing very thin layers of gadolinium material. This would allow measurements of electric currents induced by neutron reactions on gadolinium, which has a very high probability of capturing neutrons. He is also initiating collaborations with the nuclear physics group (Asst. Profs. Bender and Rogers and Prof. Chowdhury) to for research with neutron-induced reactions at the reactor and accelerator facilities of the Radiation Laboratory.

Graduate student Razvan Stanescu works with the multi-detector setup to measure fission gamma rays from U-235 at the thermal column of the UML Research Reactor.

NEUANCE at the center of the DANCE array. A 2 centimeter thick Li-loaded poly-ethylene shell is installed between NEUANCE and DANCE at Los Alamos Neutron Science Centre, Los Alamos National Laboratory.

Left: Assoc. Prof. Tries with a Canberra alpha/beta air monitor and a Technical Associates radiation monitor. Above: The thermal neutron radiography facility at the UMass Lowell Research Reactor is used as a quality assurance and R&D tool for the non-destructive inspection of mechanical parts, electronics and assemblies.

Growing Need for Radiological Sciences and Protection

Assoc. Prof. Mark Tries uses the UMass Lowell Research Reactor to investigate parameter optimization for high-throughput neutron activation analysis, dose assessment for specialized reactor irradiation facilities, analysis and calibration of radiation detector response for environmental surveillance and leakage rate for the reactor's containment vessel.

Tries has secured funding to construct a thermal neutron radiography facility within the research reactor that can be used for the non-destructive examination of a wide variety of industrial components as well as for biological imaging. In addition, he obtained funding for a major upgrade of the reactor's power and radiation monitors to help ensure the longevity and availability of this facility.

Tries is also part of a team—with Prof. Susan Braunhut in the Department of Biological Sciences and a faculty researcher from the Medical College of Wisconsin—that was awarded two grants by the U.S. National Institutes of Health to develop ways to predict and mitigate injuries resulting from radiation exposure.

The first project identifies and quantifies innovative "biomarkers" that can potentially predict radiation injuries to the lungs, weeks before symptoms become apparent. This will help doctors in deciding on the appropriate treatment and reducing lung injury in victims of a radiological terrorist attack, a nuclear reactor accident or in patients receiving radiation therapy for lung and breast cancers.

The second project studies the use of the anti-hypertension drug lisinopril to mitigate radiation injuries to multiple organs, such as lungs and kidneys, before symptoms develop. The team evaluates the effectiveness of the drug on laboratory test subjects that have been exposed to neutrons and gamma rays that mimic the explosion of an improvised nuclear device.

Tries also has collaborated with faculty researchers in the university's Francis College of Engineering in using radiotracers to measure the residence time distribution for thermoplastics in an extruder and to investigate the diffusion characteristics of a novel cation-exchange membrane.

"The UMass Lowell Research Reactor plays a major role in all these collaborations by providing the radiation fields and producing the radioisotopes necessary for investigations that have wide-ranging impact to society," he says.

From Low-cost Nanofilm Detectors to High-Z Nanoparticle Radiotherapies

Prof. Erno Sajo directs the university's medical physics program. His research interest is the study of fundamental interactions between radiation and biological matter, with particular emphasis on cancer therapy.

The detector setup being developed by Profs. Sajo and Zygmanski and their team. At upper right is a calibrated radiographic image of the pixelated target pattern obtained with the detector. The cost to fabricate the detector array was only about $10.

Medical physicists are concerned with applying physics to medicine, particularly in cancer therapy, diagnostic imaging and nuclear medicine. These areas employ ionizing radiation for the benefit of patients. Another area is medical health physics, which is concerned with radiation safety in a hospital setting. Qualified medical physicists are graduates of accredited programs and are certified in their specific subfields by an appropriate national certifying body.

UMass Lowell's medical physics program offers dedicated master's and doctoral degrees accredited by CAMPEP, the Commission on Accreditation of Medical Physics Education Programs.

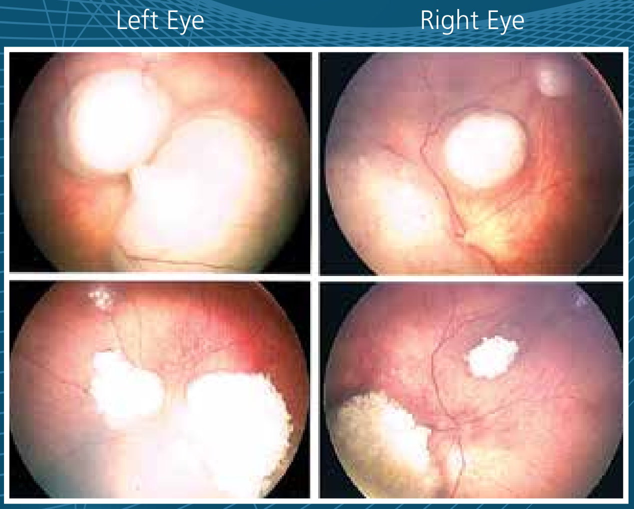
"This is one of the only two nationally accredited program in New England that leads to a doctoral degree in medical physics," says director Prof. Erno Sajo. "We have an active research-centered student-exchange program with Heidelberg University in Germany in which courses and thesis research are mutually accepted. In addition, we have close research and clinical training collaborations with the UMass Medical School and with Harvard-affiliated health-care institutions, particularly Brigham and Women's Hospital (BWH), Dana Farber Cancer Institute, Massachusetts General Hospital and Beth Israel Deaconess Medical Center, where many of their researchers also serve as adjunct faculty in the program."

The UMass Lowell–BWH collaboration, under the direction of Sajo and Asst. Profs. Wilfred Ngwa and Piotr Zygmanski of Harvard Medical School (both also serving as affiliate faculty at UMass Lowell), focuses on the application of nanotechnology to diagnostic imaging and treatment of diseases with the following concentrations.

NANOSTRUCTURED RADIATION DETECTOR DEVELOPMENT

A novel, low-cost nanofilm radiation detector invented by Sajo and Zygmanski uses thin-film sensors to harness the energy of the radiation it detects to power itself. Unlike existing technology, the device does not need external high voltage or signal amplification to operate. It is also flexible, wearable, able to conform to curved shapes while being largely transparent to radiation. The detector's cost per unit area is only a fraction of that of present devices. It can detect the type and intensity of ionizing radiation as well as the location of its emission, and it employs simple electronics to report digital signals that may be wirelessly transmitted. Nanofilms are suitable for new radiation imaging or monitoring devices for many applications, ranging from national security, disaster relief and nondestructive testing to medical imaging and treatment.

"When fully developed, this device carries the potential to be a true in-vivo implantable radiation detector that wirelessly transmits its signal to simultaneously tell its location in the body and the received radiation dose in real time, while the radiation beam is targeting the tumor," Sajo says. "In this way, organ motion will no longer impede targeting precision."



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Profs. Ngwa and Sajo and their research group are investigating the use of nanoparticle-aided radiotherapy to help treat eye cancers, such as retinoblastoma, or cancer of the retina, which afflicts mainly young children. This panel shows retina scans of a patient's left and right eyes with retinoblastoma (white patches) before and after chemotherapy.

HIGH-Z NANOPARTICLE RESEARCH

In recent years there has been a rapid increase in the application of nanoparticles and nano-structures to medicine—from being used as contrast agents for diagnostic imaging to potential dose enhancement in radiotherapy, to name two. The perturbation of the radiation field, resulting in dose enhancement or suppression near high-Z (high-atomic number) materials has been known since almost the dawn of X-ray applications. Gold nanoparticles (GNPs), owing to their biocompatibility, can be delivered to the tumor or its blood vessels without affecting the rest of the body. However, once the nanoparticles reach adequate concentration in the target, they can boost the radiation dose and either inactivate the neoplastic cells or disrupt the tumor's blood supply.

"GNPs have been shown to yield significant radiation-dose enhancement when irradiated with low-energy X-rays," notes Sajo. "Before practical applications could be developed, however, detailed computations and experiments of nanoparticle behavior are necessary."

This includes characterizing the nanoparticles' dose-enhancement properties as well as understanding their transport through the patient's airway, bloodstream, cell membranes, and their overall bio distribution.

"Our research group has developed a deterministic method to compute dose enhancement at the nanoscale and its impact on the radiobiology of cells. This is a particularly difficult task because the computations must be done at disparate scales, spanning seven orders of magnitude," he says. "Separately, we have published a computer code that can predict the coagulation of nanoparticles en route, from the injection site to the target tissue. The significance of this research is that optimal dosimetric scenarios can be found in a methodical way as a function of irradiation conditions and potential biological targets, which will eventually lead to realistic treatment planning methods."

The delivery method of nanoparticles that effectively transports them to the target is an active research area in which Sajo's group has made significant advances. In brachytherapy, radioactive sources are implanted in or near the tumor, giving a high radiation dose to the tumor itself while minimizing exposure in the surrounding healthy tissues.

Asst. Prof. Wilfred Ngwa

"Led by Dr. Ngwa, our group introduced a method of brachytherapy to cancer treatment with in-situ dose painting, in which smart biomaterials containing non-radioactive nanoparticles target both local and metastatic tumors with minimal concomitant radiation toxicity to normal tissue. These biomaterials can also carry drugs, including immunotherapeutic agents and cannabinoids, to increase their therapeutic efficacy. This work utilizes the abscopal effect, in which high radiation dose applied locally, enhanced by the presence of nanoparticles, induce an immune response and have an effect on distant metastatic sites as well."

Dr. Ngwa is also the Director of the Global Health Catalyst at Harvard Medical School, dedicated to catalyzing high impact collaborations and initiatives to reduce healthcare disparities, with focus on cancer and other non-communicable diseases.

Nanoparticle-aided radiotherapy for eye cancers is another application of nanotechnology in which Ngwa and Sajo and their co-researchers have been active. This work investigates the dosimetric feasibility of employing GNPs or carboplatin nanoparticles (CNPs) to enhance the efficacy of radiation treatment for ocular cancers, specifically retinoblastoma and choroidal melanoma, during internal and external beam radiotherapy. The results predict that substantial dose enhancement may be achieved by employing GNPs or CNPs in conjunction with radiotherapy using kilovolt (kV)-energy photon beams. The use of the brachytherapy approach yields higher dose enhancement than the external beam kV-energy devices. However, the latter have the advantage of being non-invasive.

"Our computer simulations as well as experiments suggest that radiotherapy dose to cancer cells may be enhanced via this mechanism by more than 100 percent during concurrent chemo radiation therapy," says Sajo.

uml.edu/medphys

ADVANCED BIOPHOTONICS LABORATORY

Anna N. Yaroslavsky, Ph.D., Saratov State University, Russia, 1999 Biophysics, Medical Physics, Optics, Photomedicine

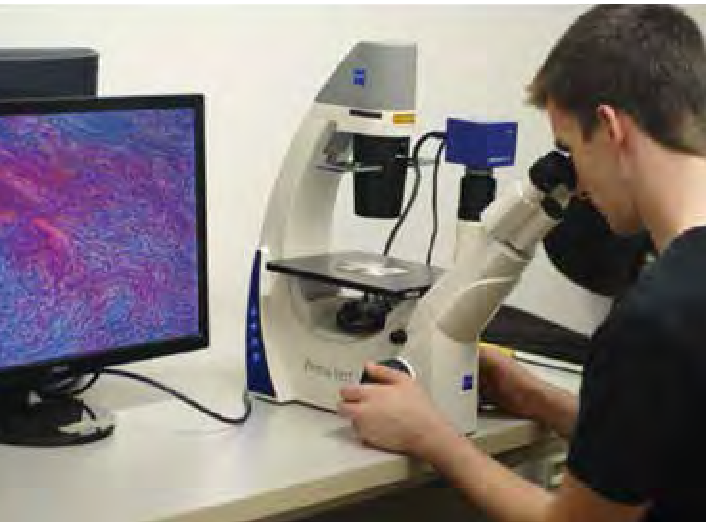
Multimodal Imaging and Spectroscopy for Biomedical Applications

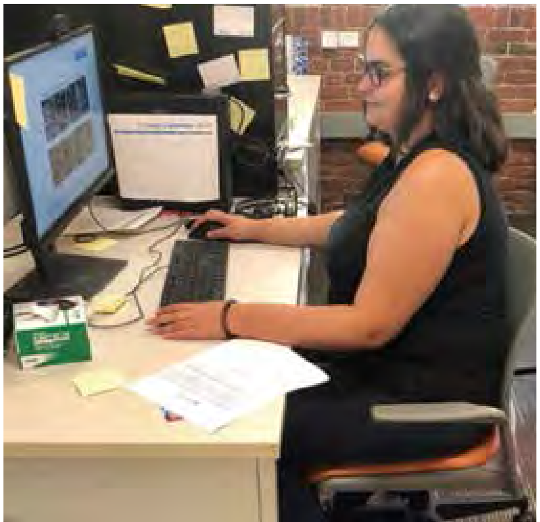
Assoc. Prof. Anna Yaroslavsky is the director of the Advanced Biophotonics Laboratory (ABL) in the Department of Physics and Applied Physics. The major focus of the research effort at ABL is on the development and integration of experimental and theoretical multi-modal technologies and methods for functional and structural characterization of biological tissues and cells, as well as pathology detection and treatment.

The research directions pursued in her laboratory include: 1) Development and integration of multiple optical imaging and spectroscopic approaches (i.e., elastic scattering, polarization imaging, fluorescence and fluorescence polarization imaging and spectroscopy) for monitoring biochemical and physiological processes in real time on spatially different scales. 2) Modeling of light propagation in and interaction with biological tissues, liquids and cells. 3) High-precision quantitative measurements of optical properties of tissues and liquids. 4) Development and clinical translation of all-optical and multi-modal image-guided intervention techniques.

The ABL includes 1,340 square feet of optical engineering and imaging space, a 500 square foot room dedicated to magnetic resonance imaging, 460 square feet of spectroscopic and chemical tissue characterization area with chemical hoods and a wet-bench, 160 square feet photopathology area and 640 square feet of office space. The laboratory is well-furnished with state-of-the-art optical and Nuclear Magnetic Resonance (NMR) spectroscopic and imaging equipment. The ABL is also equipped with several high-performance in-house built instruments including two in vivo multimodal confocal microscopes specifically designed for small animal and human imaging, and an in vivo polarization-enhanced reflectance and fluorescence imager.

sites.uml.edu/abl





‘Green’ Chemistry and Engineering at UMass Lowell

The Center for Advanced Materials (CAM) is a multidisciplinary research and resource facility for the design, synthesis, characterization and intelligent processing of advanced materials in the areas of organic polymers, ceramics, biomaterials, composites, semiconductors and electro-optic materials.

Physics Prof. Jayant Kumar and plastics engineering Prof. Ramaswamy Nagarajan currently co-direct the CAM, which has participating faculty researchers from the Kennedy College of Sciences, Francis College of Engineering and the Zuckerberg College of Health Sciences. The following are areas of active research being conducted by the center:

MOLECULAR AND ORGANIC/INORGANIC HYBRID SOLAR CELLS

Materials for molecular and polymeric solar cells are synthesized and characterized for their electronic and optical properties. Solar cells are fabricated from the materials developed, and the cells’ current-voltage characteristics (efficiency, open circuit voltage and short circuit current) and long-term stability are evaluated.

SYNTHESIS, PROPERTIES AND APPLICATIONS OF ‘SOFT’ MATERIALS POLYMERS

Small molecules and colloidal materials are synthesized and their properties are investigated using a variety of techniques. Properties of interest include optical, nonlinear optical and electronic characteristics (conductivit;y, electron and hole mobility) as well as the organization of the materials in the solid state (crystalline, liquid crystalline or amorphous) or in solution. Researchers are interested in the optical properties of materials for their potential use in fabricating optical elements and devices. Some of the materials are designed to self-organize into micelles or vesicles in solution and have been studied as vehicles for delivering drugs.

SENSOR DEVELOPMENT AND CHARACTERIZATION

“Intelligent” electronic sensors being investigated by CAM researchers are designed to detect chemical toxins in the air (e.g. poisonous gases, nerve agents), water (heavy metals, pathogens) and food supply as well as for health monitoring. The scientists have also been active in developing novel sensor arrays for detecting traces of TNT and other explosives as tiny as one part per trillion, or even smaller.

SYNTHESIS OF NON-HALOGENATED FLAME-RETARDANT MATERIALS

The use of flame-retardant (FR) additives for making commercial flame-resistant polymers exceeds 900,000 tons per year globally. Current FR additives are often toxic and can threaten human health as well as ecosystems. Research is ongoing to develop non-halogenated FR materials based on naturally occurring, sustainable materials that can be utilized as additives wto render textiles and commercially used plastics less flammable.

uml.edu/research/cam

Prof. Jayant Kumar, left, with research chemist Ravi Mosurkal, Ph.D., at the Center for Advanced Materials lab.

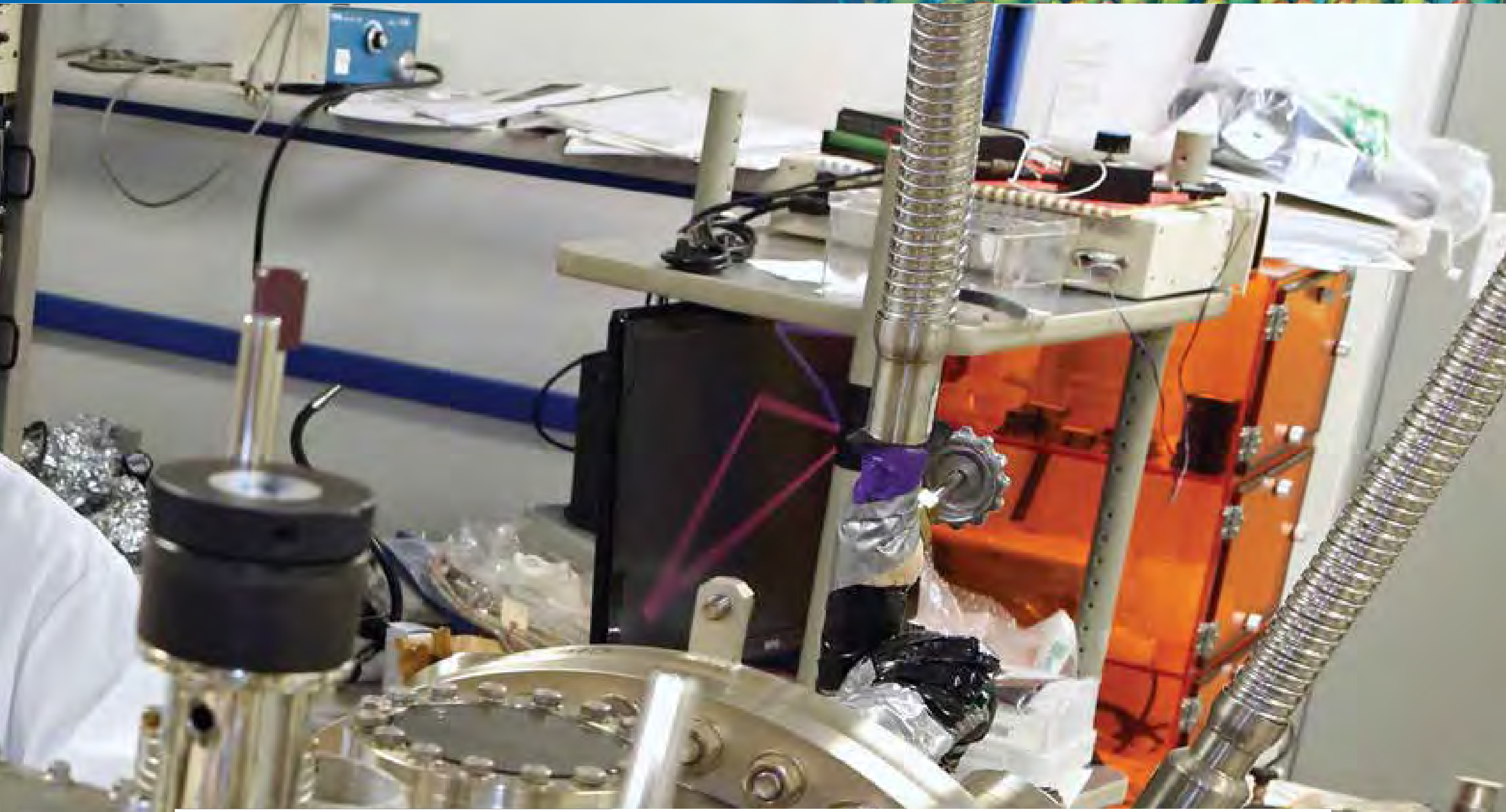
PHOTONICS

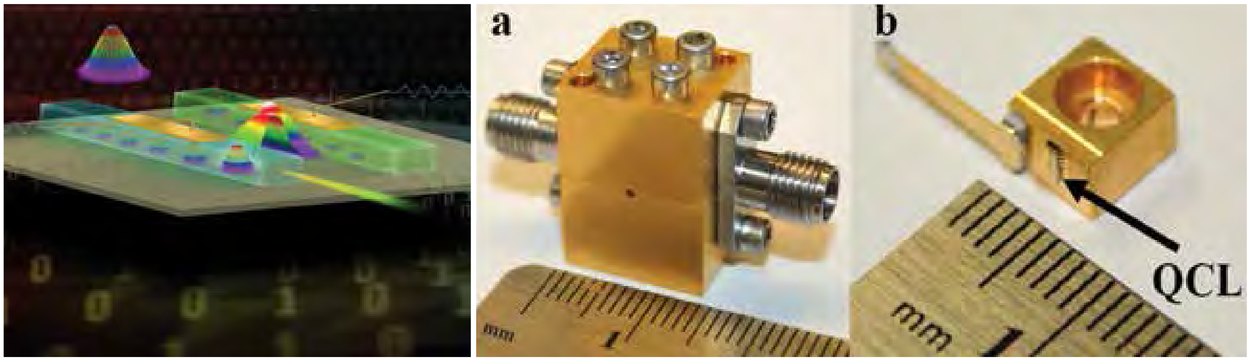
Laboratory for Advanced Semiconductor Epitaxy

Established in 1994 by William Goodhue, now professor emeritus in the Department of Physics and Applied Physics, the Photonics Research Lab (PRL)’s mission is to support government research, regional industries and startup companies, train undergraduate and graduate students and perform industry– and government– sponsored studies. The center’s design and fabrication capabilities support various university initiatives that require innovative semiconductor-based photonic and nanoelectronic device technologies.

The Photonics Research Lab is equipped with state-of-the-art facilities for growing III–V compound semiconductor materials, fabricating devices and characterization research. “Our lab is currently developing a large variety of III–V material-based optoelectronics devices, thanks to the incredible facilities at the Photonics Center,” says Asst. Prof. Wei Guo, the lead of the research group Asst. Prof. Xifeng Qian, the group’s co-leader, adds: “Our devices will have great impact in the areas of solar energy, data centers, medical science and homeland security.”

The center’s research efforts focus on the development and applications of optoelectronics devices, such as various semiconductor diodes laser, modulators. “Semiconductor lasers have various applications that can impact on many areas, such as communications, LiDAR,” notes Guo.





Left: Photonics group researchers, in collaboration with Prof. Viktor Podolskiy's group, developed a novel semiconductor laser that takes advantage of parity-time symetry breaking to precisely design and control lasing action. Center and right: Researchers have grown and fabricated high-performance THz quantum -cascade lasers, or QCLs (shown with arrow), with high operating temperature and large output power.

QUANTUM-CASCADE LASER TECHNOLOGY

Semiconductor quantum-cascade lasers (QCLs), due to their high power and ultra-small footprint, are often used as the sources of choice at mid-infrared and terahertz (THz) frequencies in multitudes of applications, ranging from health-care and pollution monitoring to homeland security. A collaborative project between the Photonics Center and UMass Amherst, NASA's Jet Propulsion Laboratory and the German Aerospace Center aims to build a sensitive, compact coherent THz heterodyne transmitter/receiver system based on THz QCLs and Schottky diode balanced mixers. The UMass Lowell part of the project is directed by physics Lecturer Andriy Danylov and Prof. Emeritus Jerry Waldman. University researchers have demonstrated significant improvement in spatial and temporal coherency of THz QCLs, which opens the door for applications of the system in THz astronomy, imaging, spectroscopy and plasma diagnostics.

Assoc. Prof. Mengyan Shen (right) and graduate student Cong Wang work on the lab's laser setup.

Creating Nanostructures on Solid Surfaces Using Femtosecond Pulsed Laser

"We are using intensive pulsed laser light to study interactions between laser pulses and matter for potential applications in nanoscience and nanotechnology," says Assoc. Prof. Mengyan Shen, head of the Lab's Femtosecond Laser Group. The team utilizes a femtosecond (10^{-15} sec.) pulsed laser at 400 and 800 nanometers to fabricate nanostructures on a solid surface.

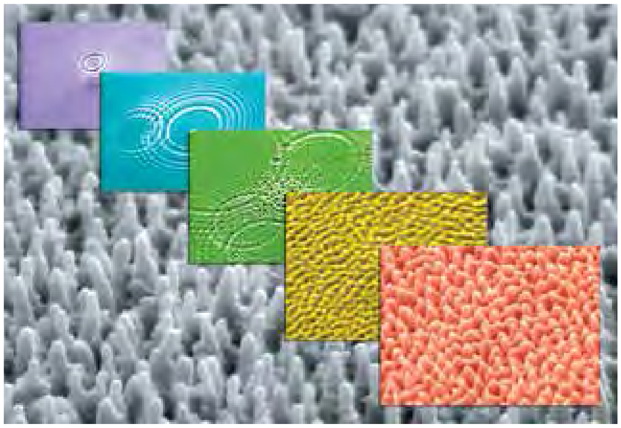
"The technique is highly efficient because it is several orders faster than electron-beam writing and ion-beam etching, and is applicable to different materials," he says. "It has applications in opto-electronics such as high-efficiency photodetectors and solar cells, as well as in biology and medical research such as micro/nano tunnels for low-friction fluidity, and nanostructured metal surfaces for other applications."

The group has successfully developed soft nanolithography to three-dimensionally replicate silicon nanospike structures made by femtosecond laser pulse irradiation to a precision of 5 nm. The replicated nanostructures are being used to manufacture identical chemical and gas sensors at very low cost. This research has been supported by the National Science Foundation.

"With metal nanostructures formed with femtosecond laser irradiation, a natural-like photosynthesis has shown great potential for storing solar energy and saving our environment," says Shen.

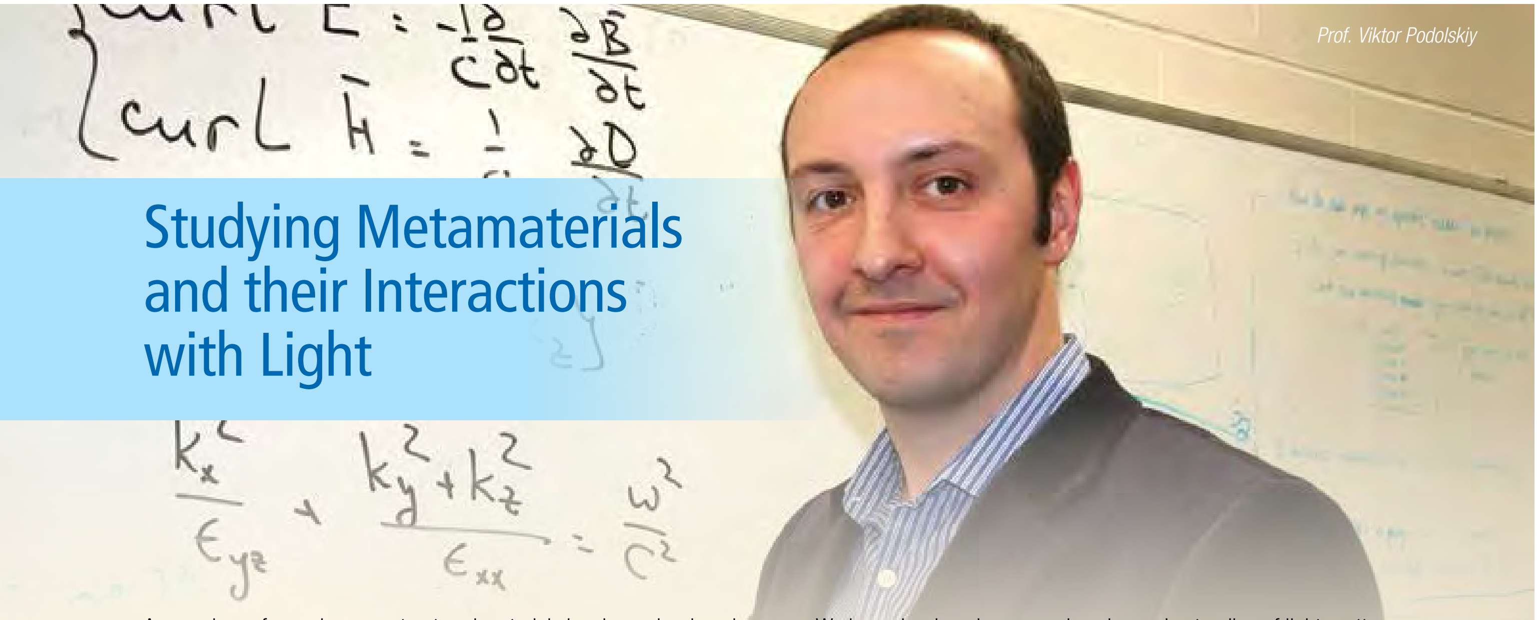
This research has been partially supported by a seed fund from the NSF Center for High-Rate Nanomanufacturing at UMass Lowell.

He says the group is also developing techniques for time-resolved spectra measurements, in the time range from seconds to femtoseconds, for other applications in nanoscience and nanotechnology.



The sequence above shows the formation of silicon nanospikes on a silicon surface irradiated in distilled water by an increasing number (from blue to red) of femtosecond laser pulses. The nanospikes in the background are about 100 nanometers wide and up to about one micrometer high.

MULTISCALE ELECTROMAGNETICS LABORATORY



Prof. Viktor Podolskiy

Studying Metamaterials and their Interactions with Light

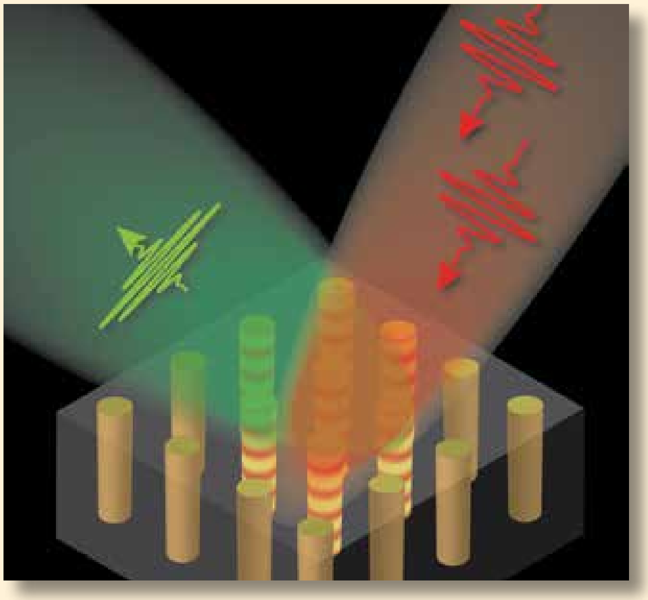
A new class of complex nanostructured materials has been developed over the past decade. Our research focuses on understanding light interaction with these composites through advanced analytical and computational studies. We are interested in confinement and manipulation of optical pulses at the deep subwavelength scale, novel nonlinear optics, and imaging.

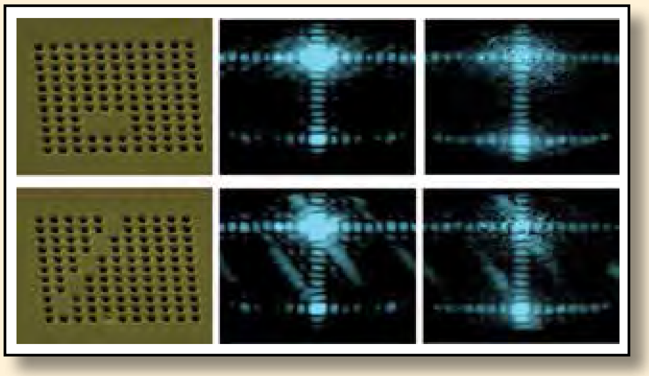
Engineered composites open fascinating opportunities in molding the flow of light at the nano- and micro-scales. Optical properties of these composite structures, metamaterials, depend not only on the electromagnetic properties of their constituents, but also on the arrangement and shapes of their components. Over past several years, our group has closely collaborated with the group of Prof. Zayats from King's College London trying to understand the unusual optical response in metamaterials comprising arrays of aligned metallic nanowires.

We have developed a comprehensive understanding of light-matter interaction in nanowire composites, and demonstrated applications of these materials in biosensing, lifetime engineering, and nonlinear optics. We are exploring new optical phenomena in these and other metamaterials platforms.

Our group also explores the opportunities in development of novel imaging techniques, opened by exponential growth of computations, fueled by Moore's Law. In particular, we are developing the machine-learning diffractive imaging paradigm that enables optical characterization with subwavelength resolution based on far-field measurements. Our research has potential to drastically change imaging and spectroscopy across the electromagnetic spectrum, from ultraviolet, to visible, to infrared, terahertz, and gigahertz frequencies.

faculty.uml.edu/vpodolskiy





Above: Even though each individual hole in the grid is only 100 nm wide (left), the signatures of the missing holes are clearly seen in the diffraction pattern. Algorithms can learn on theoretically predicted spectra (center) to recognize experimental data (right)

Left: Structural nonlinear optics, conversion of two incoming (red) photons into one reflected (green) photon as result of light interaction with multiple nanowires in a metamaterial

SUBMILLIMETER-WAVE TECHNOLOGYLABORATORY

Research Center Offers Breakthroughs in Terahertz Imaging

The Submillimeter-Wave Technology Laboratory (STL) has pioneered terahertz imaging technology to acquire radar signatures using physical scale-modeling techniques. STL has developed a nationally recognized facility whose mission is to develop and advance emerging technologies within the millimeter-wave and terahertz frequency regions of the electromagnetic spectrum.

The laboratory has established itself as a leader in high frequency transmitter and receiver systems, coherent broadband solid-state multiplier sources, high-power ultra-stable CO2 and far-IR lasers, laser/microwave hybrid systems, and dielectric materials characterization. The lab has applied state-of-the-art THz technology in the areas of military surveillance, homeland security, target scattering, imaging technologies, medical diagnostics, and other areas of advanced scientific and academic research.

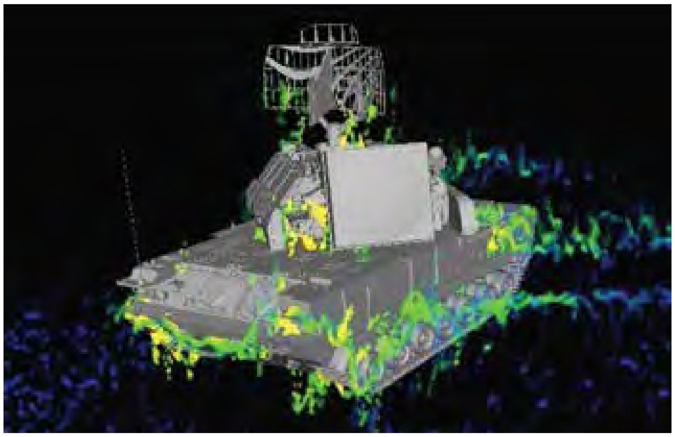
Comprised of a diverse team of technical personnel, STL staff and students share a common goal of producing high quality, thoroughly benchmarked radar signatures with unparalleled reproducibility for government sponsors.

“STL’s greatest asset is its diverse and dedicated team of scientists, engineers, technicians, and students,” says STL director and Assoc. Research Prof. Andrew Gatesman.

By integrating laser-based and solid-state transmitters with coherent receivers, STL produces high-performance indoor compact radar ranges capable of acquiring precise target radar signatures using physical scale-modeling techniques.

With sponsorship from the U.S. Army National Ground Intelligence Center, STL has developed fully polarimetric compact ranges at 6-18 GHz, 100 GHz, 160 GHz, 240 GHz, 350 GHz, 520 GHz, and 1.56 THz for acquisition of archival-quality UHF, C, X, Ku, K, Ka, and W-band radar imagery of 1/16th and 1/35th scale model targets situated in free-space and cluttered environments.

STL also has a strong commitment to developing new remote sensing technologies. A few examples include the utilization of



software defined radio techniques within their radar systems, application of advanced signature visualization technologies, and the implementation of high performance cluster computing to support expanding computational requirements.

“These efforts are enabling STL to develop new programs involving bistatic radar, millimeter-wave Doppler radar, 3D image processing, and novel computational electromagnetic and radar signature visualization tools. All of these areas are of interest to the radar community as well as to potential sponsors,” says Assistant Director Guy DeMartinis.

In addition to its work for the army, the lab has used its unique capabilities to fulfill radar measurement requests from other government agencies and contractors as well as defense-related laboratories and companies, including the Massachusetts Institute of Technology Lincoln Laboratory, Aerospace Corporation, NASA, Combat Capabilities Development Command Soldier Center, Air Force Research Laboratory, and Raytheon.

STL also has a strong commitment to graduate and undergraduate student education at the university. STL has engaged more than 150 students at its research facility working towards their bachelor’s, master’s, and doctoral degrees in physics, electrical engineering, computer science, computer engineering, and mechanical engineering.

“Radar is truly a fascinating field of study and STL’s success is a clear demonstration of what can happen when dedicated staff and students come together with a shared vision of innovation, creativity, and collaborative research.” says Gatesman.

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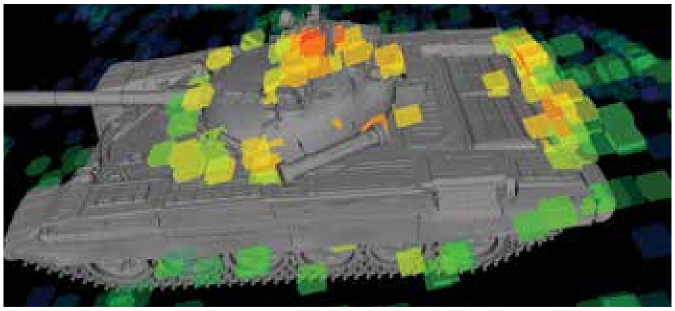
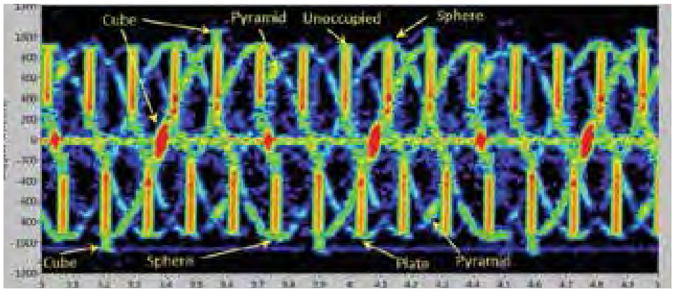
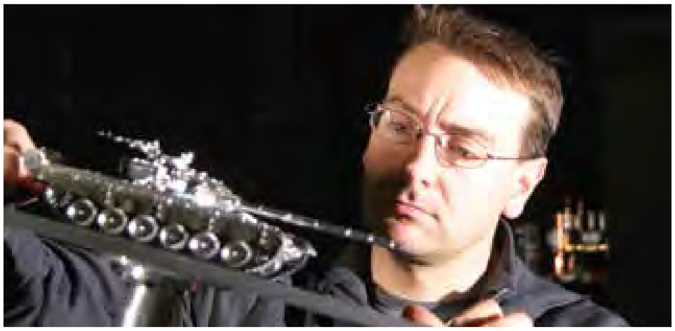
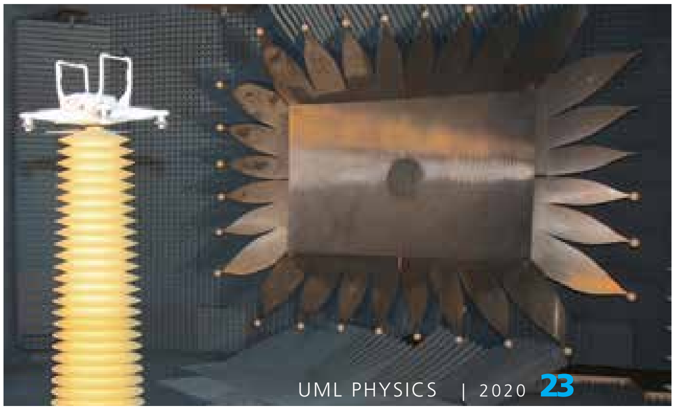








Clockwise from top left: STL computer engineer Brian Soper assembles a custom system controller for a high power CO2 laser; 3D interferometric terahertz radar imagery of an object overlaid with its 3D CAD model (same for next image); Terhertz micro-Doppler imagery of complex rotating object; STL senior electrical engineer Chris Beaudoin prepares to collect terhertz imagery of a ground target; STL’s indoor microwave compact radar range.

BIOMEDICALTERAHERTZ TECHNOLOGYCENTER

Graduate student Jillian Martin works on the BTTC terahertz optical systems used for biomedical imaging.

Developing Innovative Imaging Technology for Cancer Diagnosis

The Biomedical Terahertz Technology Center (BTTC) was established in 2012 with the goal of translating the extensive terahertz technology expertise at UMass Lowell to biomedical applications (see page 16). THz radiation, which lies between the microwave and infrared regions of the electromagnetic spectrum, is highly sensitive to water content in tissues and, unlike X-rays, is non-ionizing. THz imaging has been shown to offer intrinsic contrast—i.e., no external contrast agent is needed—between normal and cancerous tissues, making it well-suited for biomedical imaging, especially for studying colorectal cancer and non-melanoma skin cancer.

Colorectal cancer is the third most common cancer in the United States, with approximately 140,000 new cases each year. Early diagnosis and surgical removal of benign neoplastic lesions is an effective method for reducing a patient's cancer risk and preventing cancer-related death. The current standard for screening is conventional colonoscopy, which relies on visual inspection of the lining of the intestine.

The BTTC, in collaboration with Dr. Karim Alavi in the Division of Colorectal Surgery at UMass Medical School in Worcester, is evaluating the tissues' intrinsic contrast, combining it with the center's existing efforts on THz waveguide development.

"We have shown that polarized THz images can differentiate between healthy and cancerous tissues," notes UMass Lowell physics Prof. Robert Giles, the center's director. "This technique potentially offers surgeons a tool to aid in colon-cancer screening."

GOING MORE THAN SKIN-DEEP

Non-melanoma skin cancer accounts for half of all cancers in the U.S. Of the more than 3.5 million cases diagnosed each year, about 3,000 patients die from the disease. And the cost of treatments exceeds $600 million annually.

The most effective treatment usually involves Mohs micrographic surgery, in which the tumor is removed by excising the tissue layer by layer, with each layer examined under a microscope to help map the diseased area. This ensures the complete removal of the tumor while preserving much of the surrounding normal tissue. While the procedure is effective, it is time-consuming, labor-intensive and costly.

Although THz imaging offers intrinsic contrast, its resolution is limited in wavelength to approximately 0.5 millimeter. Imaging with optical polarized light offers higher resolution (comparable to histology) but lacks the contrast. BTTC researchers are collaborating with UMass Lowell physics Assoc. Prof. Anna Yaroslavsky of the university's Advanced Biophotonics Laboratory (see page 16) to develop a non-invasive multi-modal optical/THz imaging system for non-melanoma skin cancer that would complement current treatment techniques and aid in the demarcation of cancer margins.

The Lowell Center for Space Science and Technology (LOCSST) provides a home for space science and technology research activities on the UMass Lowell campus. The center brings together researchers from physics, science, and engineering, as well as involving industry partners in curriculum, research, projects and proposals/business development, and training the next generation of space scientists, technologists, teachers, business leaders and policy makers. The center provides a wealth of hands-on research experience for undergraduate students. Physics research done at LOCSST includes the following groups:

EXPERIMENTAL ASTROPHYSICS GROUP

Researchers Use Sounding Rockets and Balloons to Explore the Cosmos

A team of scientists, engineers and students in the university's Lowell Center for Space Science and Technology directed by Prof. Supriya Chakrabarti is conducting research to study Earth, Earthlike exoplanets, the Milky Way galaxy and the cosmos.

"The center aims to train the next generation of scientists and engineers through hands-on involvement in all phases of the mission, from instrument development to data analysis," says Chakrabarti. "We will also mentor and train early career professionals in space astronomy and engineering and promote hands-on undergraduate participation in space and technology research."

In 2014, NASA awarded Chakrabarti a grant worth nearly $5.6 million over five years to develop and test an instrument system that could potentially detect young, Jupiter-size planets orbiting other stars in the Milky Way. The team's ultimate goal is to discover Earth-like planets around Sun-like stars capable of supporting life.

The instrument—dubbed the Planetary Imaging Concept Testbed Using a Recoverable Experiment-Coronagraph, or PICTURE C—is scheduled to be launched on two separate flights, in the fall of 2019 and 2020, from the Columbia Scientific Balloon Facility in Fort Sumner, N. M., where it would be carried aloft to the edge of the atmosphere using helium balloons several stories tall.

"PICTURE C will enable us to learn about the disk of dust, asteroids, planets and other debris orbiting the stars and gain a better understanding of the processes and dynamics that formed our own solar system," explains Chakrabarti, who is the principal investigator for the NASA study. "But in order for us to do this, we have to fly the instrument to altitudes of about 120,000 feet to get above most of the Earth's atmosphere. Atmospheric turbulence distorts and blurs our image of the stars."

Asst. Prof. Timothy Cook, right, and post-doctoral associate Christopher Mendillo prepare an earlier version of the PICTURE C payload, which was flown in 2011 aboard a sounding rocket.

Aside from Chakrabarti, the other members of the UMass Lowell team are physics Asst. Prof. Timothy Cook, who is the project's co-investigator; graduate student Kuravi Hewawasam and post-doctoral associates Susanna Finn and Christopher Mendillo. Other collaborators include researchers from NASA's Jet Propulsion Laboratory and Goddard Space Flight Center, Caltech, MIT, the Space Telescope Science Institute and the University of California Santa Barbara.

EMPLOYING CUTTING-EDGE TECHNOLOGIES

Five stars have been selected as test targets for the two missions, representing a wide range of brightnesses, ages, distances and spectral types: Alpha Lyrae (Vega), Sigma Draconis, Epsilon Eridani, Alpha Aquilae (Altair) and Tau Ceti.

The mission will allow PICTURE C to test its coronagraph, a specialized optical imaging system coupled to a 24-inch-diameter telescope designed to "mask," or block out the direct light from the star so that faint objects very close to the star—such as planets, asteroids and interplanetary dust, which otherwise would be hidden in the star's bright glare—can be studied in great detail.

The scientists expect the instrument to be rocked by turbulence in the upper atmosphere. To keep the coronagraph aimed precisely at the target, the instrument is mounted on a special gimbal platform in the balloon's gondola that can compensate for any unwanted movements. PICTURE C will use the platform in conjunction with an onboard active optical pointing control system.

"Chris Mendillo designed and built this fine-pointing system and had validated it on an earlier mission," notes Chakrabarti. "It can provide the coronagraph a pointing accuracy of 5 milliarcseconds, which is comparable to that of the Hubble Space Telescope, or even better."

TO THE THRESHOLD OF SPACE

The researchers have also used sounding rockets to lift instruments weighing more than 1,000 pounds to altitudes of up to more than 900 miles above the ground. These rockets are not powerful enough to boost their payload to orbital speed—after scientific observations have been completed, the payload falls back to Earth, deploying a parachute to slow down its descent and allow for a safe recovery of the payload on the ground.

"Prof. Cook and I have a combined 40 years of experience launching experiments aboard sounding rockets, and we have successfully launched 20 of them during that time span," says Chakrabarti.

For example, in November 2012 Cook launched another NASA-funded instrument, called IMAGER, aboard a sounding rocket to observe the spiral galaxy M101 and measure the properties of its dust. Cook and his team are now analyzing the data from the IMAGER flight to understand how ultraviolet light is absorbed by the dust, how it heats and destroys the dust and how new dust is formed.

Sounding rockets and high-altitude balloons offer a relatively inexpensive way to verify the flightworthiness of the science hardware before they are placed into orbit, which costs tens of millions of dollars per launch. However, scientific observations aboard sounding rockets are limited to about seven minutes or so before the rocket's payload falls back to the ground.

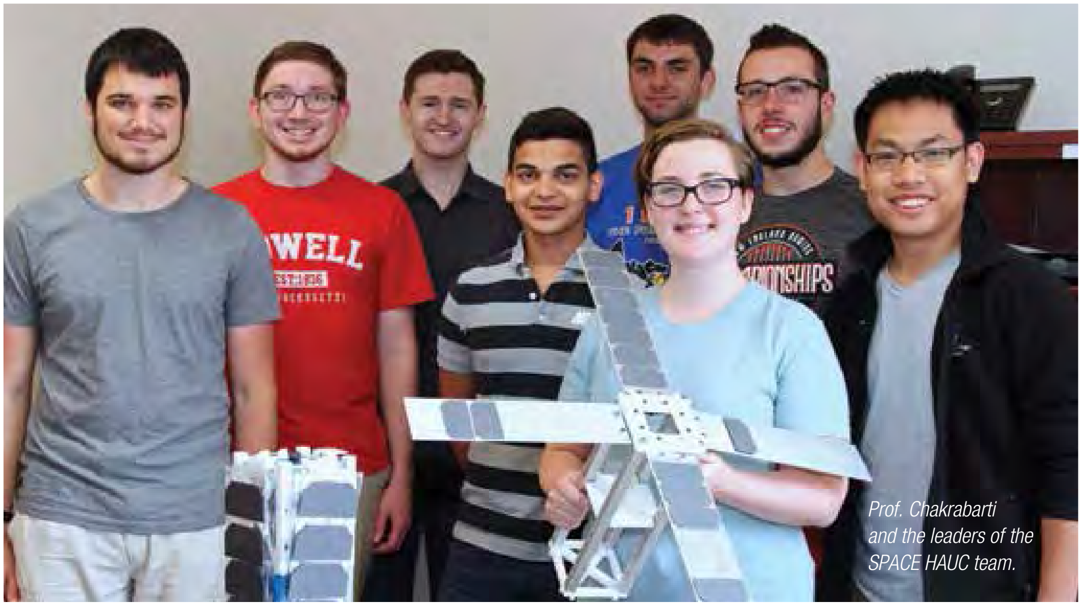
"For some experiments, the several hundreds of seconds of data from above the atmosphere that a sounding rocket provides are just not enough," explains Chakrabarti. "In the case of PICTURE C, a high-altitude balloon offers a better way to lift the instrument to the threshold of space—above 99 percent of the atmosphere—and keep it aloft for hours or days, depending on the weather conditions as well as the launch site, the type of balloon, the time of day, etc."

At the end of the mission, ground controllers would send a command to release the payload from the balloon, and the payload free-falls to the ground. A parachute is then deployed to slow it down and allow the payload to land gently for reuse in the next mission.

uml.edu/research/LoCSST

Left: The new NASA-funded PICTURE C science experiment will be launched into the stratosphere in 2019 and 2020 on two high-altitude balloon flights. They will be the first balloon missions for UMass Lowell. Center: Prof. Cook, fifth from left, poses with Supriya and Joanne Chakrabarti, Meredith Danowski, Christopher Mendillo, Brian Hicks, Jason Martel and Ewan Douglas at the White Sands Missile Range in New Mexico. In the background is the Black Brant IX sounding rocket used in the 2012 launch. Right: The face-on spiral galaxy M101 in Ursa Major, shown in this photo taken by the Hubble Space Telescope, was the target of Cook's rocket experiment in 2012.

SPACE HAUC



Prof. Chakrabarti and the leaders of the SPACE HAUC team.

SPACE HAUC (Science Program Around Communication Engineering with High Achieving Undergraduate Cadres) is an undergraduate 3U CubeSat project selected by NASA for flight in 2020. It is part of the NASA Undergraduate Student Instrumentation Program, that is designed to provide hands-on training in spaceflight missions to multidisciplinary teams of undergraduate students with a goal of developing future space explorers.

SPACE HAUC students presenting the project.

SPACE HAUC will demonstrate high rate data transmission (up to 100 Mbps) which is essential for imaging applications that dominate nanosatellite missions. It operates in the X-band (7.2-8.3 GHz) and uses a 16 element (4 x 4) patch antenna array. The phased array will create a 25 degree (FWHM) beam and will also demonstrate beam steering over ± 45 degrees with less than 5 degree error.

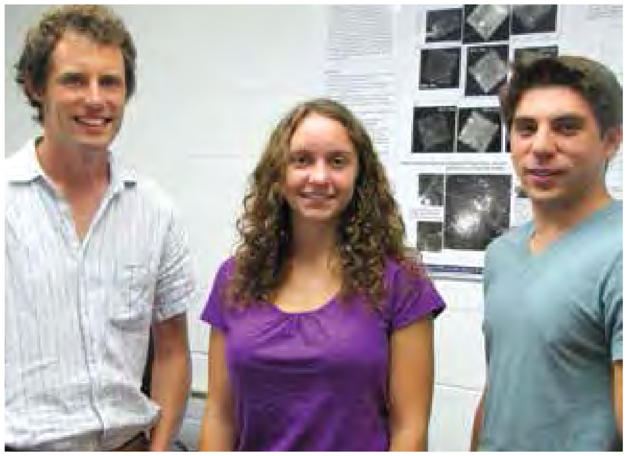
The X-Band communication system consists of Commercial off-the-self transceiver and student-designed patch antennae array, RF Front-end for signal processing and beam steering. The system occupies a 1.5U volume and weighs less than 1 kilogram. Its transmitter and receiver consume approximately 9 watts power each; its radiated power is 1.6 watts with a receiver sensitivity of -115 dBm.

If successful, SPACE HAUC will introduce an important new tool to the CubeSat community developed by undergraduate students. The project has involved approximately 100 undergraduate students from many different UML departments, including physics, mechanical engineering, electrical engineering, computer science, math, computer engineering, as well as students from civil engineering, biomedical engineering, business, and fine arts.

LOWELL CENTER FOR SPACE SCIENCE AND TECHNOLOGY

OBSERVATIONAL ASTRONOMY GROUP

X-ray Binaries as Astrophysical Probes, Multi-Wavelength Observations and Time-Domain Astronomy



The focus of the Astronomy and Astrophysics Group is the multi-wavelength (infrared, optical and X-ray) study of accretion-powered X-ray binaries, or XRBs. These fascinating star systems consist of a compact companion (neutron star or black hole) and a normal star locked in orbit around each other. The normal star is slowly consumed by its companion, whose strong gravity is able to capture gas from the star and then crush it to nuclear density, releasing tremendous amounts of energy in the process. As a result, the compact object shines brightly in X-ray as it feeds.

"By observing the X-ray emission, we can study fundamental astrophysical properties that are unobtainable at other wavelengths," says Silas Laycock, an assistant professor in the Department of Physics and Applied Physics and the group's leader. "Meanwhile, optical spectroscopy enables us to study the stellar companion and trace its orbital motion. X-ray binaries simultaneously probe extreme physics and provide a unique window into stellar and galactic evolution." One of the group's projects is a time-domain survey of X-ray pulsars—spinning neutron stars whose magnetic fields channel the accretion stream to their poles and emit regular pulses as their X-ray beams rotate around the sky.

"Using thousands of satellite observations of about a hundred known X-ray pulsars accumulated over more than a decade, we are building the most comprehensive library of pulse profiles," notes Laycock.

"By developing computer models of the pulsars' beams and matching them to the X-ray data, we will shed light on the structure of the magnetospheres of neutron stars and their dramatic changes over time."

Black holes and neutron stars are the relics of the most massive and short-lived stars—the same stars that die in supernovae—which sculpt and enrich the interstellar medium and create the chemical elements needed to seed life. These natural particle accelerators are visible in X-rays at intergalactic distances. The group is using X-ray astronomy satellites (NASA's flagship Chandra X-ray Observatory and Europe's XMM-Newton) along with optical telescopes (such as the 8-meter Gemini telescope) to discover and monitor X-ray binaries in nearby dwarf galaxies.

"Different galaxies seem to have produced XRBs in large numbers, but at different points in their evolution, and curiously these binaries involve different types of stars and different ratios of black holes to neutron stars," Laycock explains. "By studying galaxies of different ages all the way down to the very youngest—a mere few million years—we are unlocking the secrets of what happens in this brief but influential period of star formation."

Inset: The Astronomy and Astrophysics Group—led by Asst. Prof. Silas Laycock, shown in the photo at left with undergraduate student Kathleen Oram and graduate student Andrew Balchunas—is interested in high-energy astrophysics, time-domain analysis and data-intensive astronomical research. Background: An artist's impression of the Cygnus X-1 binary system. It shows a massive OB or Be star, at left, losing matter to a compact companion (a black hole or neutron star) and forming an accretion disk around the companion. Matter in the inner disk is heated to millions of degrees, generating the X-rays observed from Earth. Illustration courtesy of ESA/Hubble.

COMPUTATIONAL ASTROPHYSICS & SPACE PHYSICS GROUP


NASA's PLEIADES supercomputer

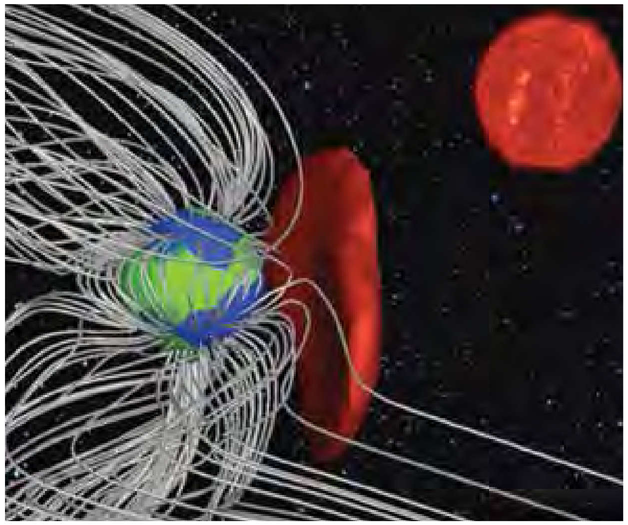
Solar Physics, Heliophysics, Space Weather, Stellar Astrophysics, Exoplanets

The Computational Astrophysics & Space Physics group works on developing theoretical and computer models to study wide range of topics from space and solar physics, heliophysics, astrophysics, planetary science and exoplanets. The common fundamental physics is plasma physics, or the physics of ionized gas and its interaction with electromagnetic fields.

Our group uses and develops sophisticated three-dimensional models to study plasma physics in different applications. These models are computationally intense, and they are run on high-performance supercomputers provided by NASA, the National Science Foundation, as well as the Massachusetts Green High-Performance Computing Center.

The science applications the group studies are extremely diverse and include:

- The solar atmosphere
- The solar wind
- Space Weather
- Stellar coronae and stellar winds
- The space environment of exoplanets
- The atmospheres of exoplanets
- The space environment of the early Earth


Computer simulation of the interaction of M-dwarf planet and its space environment

Our group's research is highly interdisciplinary, and it aims to bridge between heliophysics and planetary sciences, and astrophysics. This provides opportunities for our graduate students to interact with more than one scientific community, and to expand their knowledge and experience beyond a narrow scientific field.

One of the main topics our group is working on is the atmospheres of exoplanets and whether they can be sustained over time. We use computer models of the planets and their interaction with the surrounding space environment in order to estimate the amount of gas the atmosphere may lose over time.

Investigating Space Weather, the Magnetosphere and Ionosphere

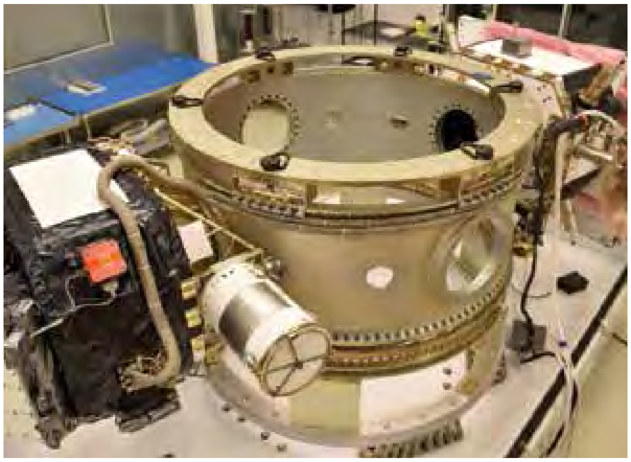
SSL Director Paul Song and Assoc. Director Ivan Galkin work with former doctoral student Meg Noah during a full functional test of the flight software for the UMass Lowell-designed high-power VLF transmitter. The transmitter is flying in Earth's Van Allen radiation belts aboard the Air Force Research Laboratory DSX spacecraft to conduct wave-particle interaction experiments.

Established in 2014, Space Science Laboratory (SSL) continues the heritage of UML scientific investigations in Space Weather, Magnetospheric Physics, Ionospheric Physics, Radio Science. SSL has built major instruments for NASA and U.S. Air Force spacecraft, SSL has developed strong engineering expertise for design of autonomous remote sensing systems for spacecraft platforms. Computer scientists at SSL build intelligent systems for automatic interpretation of acquired data and operate Global Ionosphere Radio Observatory, a worldwide network of sensors bearing the Lowell logo since 1969.

VERY LOW FREQUENCY IN SPACE

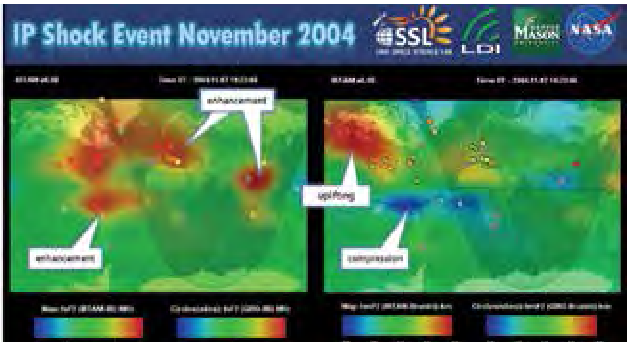
A self-tuning VLF transmitter will drive an 80-meter dipole antenna with 5 kV onboard the USAF DSX satellite to study the effect of space plasma on the radiation process and the effect of the radiation on the trapped electron population. The SSL designed and delivered the power transmitter and a narrow-band receiver for the frequency range from 3 kHz to 750 kHz in cooperation with Southwest Research Institute and Stanford University. The transmit and receive system measures the local plasma density and will automatically tunes the antenna circuit for maximum radiation.

NASA's IMAGE mission (2000 to 2005) flew a UMass Lowell-designed Radio Plasma Imager instrument for remote sensing of Earth's plasma using a unique spinning antenna system with two 500-meter dipoles.



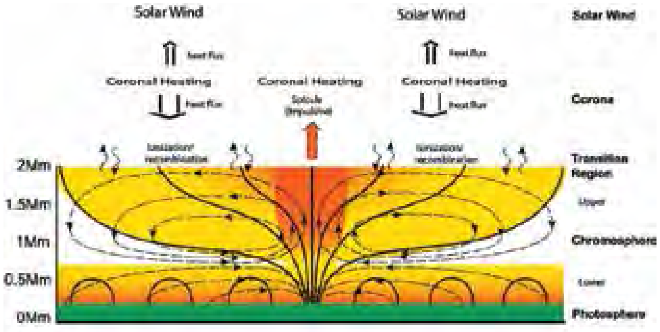
The U.S. Air Force DSX satellite was launched June 25, 2019, carrying a UML- designed 80-meter high-power radio transmitter to conduct space radio science experiments.

The Global Ionospheric Radio Observatory comprises UML-built radio sounder installations in 27 countries with real-time access to observational data from 45 locations, and the Lowell GIRO Data Center holding over 40 million records of remote sensing of the Earth's ionosphere.



SPACE WEATHER IN REAL-TIME

SSL faculty are among the founders of the Space Weather, an emerging discipline of space sciences that applies the knowledge we gained in space physics and space plasma physics to forecast the conditions in space. SSL currently operates the real-time ionospheric condition forecast model for users worldwide.



SOLAR CORONAL HEATING

The surface temperature of the Sun is around 6,000 degrees Kelvin. However, about 70 years ago, observations showed that the temperature of the solar corona, the atmosphere of the Sun, is more than two million degrees. How can a heater of a lower temperature heat up the air to a temperature 100 times higher, apparently inconsistent with the second law of thermodynamics? This problem has puzzled physicists around the world since then. SSL faculty developed a model to answer it.

Plasma modeling and simulation group: Research Prof. Jiannan Tu (project lead)

PLASMA MODELING AND SIMULATION

Ground-based and space-borne observations have established a global picture of the space plasma environment. The complicated and intriguing plasma processes and sparse observation coverage, however, hinder the deterministic understanding. The modeling and simulation, combined with observations, has been proved to be a powerful tool in providing understanding of physical and chemical processes in space plasma and in predicting space weather. The Space Science Lab has been actively undertaking empirical modeling and computer simulation of antenna-plasma interaction, magnetosphere-ionosphere-thermosphere coupling, ionosphere and magnetosphere density distribution, and plasmasphere depletion and refilling.

"KILLER" ELECTRONS

Featured at No. 37 in Discover magazine's "Top 100 Science Stories of 2007," discovery of the physical mechanism responsible for accelerating electrons trapped in the Earth's Radiation Belts to the 'killer' velocities as much as 94% of the speed of light has been credited to the SSL scientists.

Making Positive Change in the Caribbean Nation

From left, Haitian student research interns Dayana Alabre, Ralph Douyon and Elysee Dimanche assist Prof. Robert Giles in installing a new solar panel at the center. Giles is teaching the students about electronics and approaches to affordable solar energy. The students, who assist visiting UMass Lowell engineering teams and provide in-country support for the center's programs, receive research scholarships for their work.

The mission of the university's Haiti Development Studies Center (HDSC) is to engage science and engineering faculty and students in philanthropic research focused on solving life-threatening issues faced by citizens in the world's poorest countries.

"These countries, identified by the international banking system as having Third- and Fourth-World status, suffer from overpopulation, soil erosion, drought and famine," says Prof. Robert H. Giles, the center's director. "However, the lack of potable water and sufficient food supplies are not the only barriers to economic development in the most densely populated regions of the world. Fragmented politically and socially, the general population in these labor-rich countries face environmentally induced health issues due to chemical and biological contaminants in the air, water, soil and locally grown food."

Whether human-caused or naturally occurring, these contaminants are crippling communities in impoverished countries. "They are compromising the health of the indigenous population, defeating foreign investment for positive change and eliminating possible global participation of the local work force," notes Giles. "Only treating the contaminant-induced societal symptoms, international aid agencies developing programs to support public work's projects and medical clinics are often exhausted before sustainable change occurs in the poorest regions."

In response, Giles established the HDSC in 2013 in the port city of Les Cayes in Haiti, which he describes as a Fourth-World country with First-World possibilities. "I believe Haiti has First-World potential by virtue of its geographical location in the Caribbean," explains Giles, who has more than 10 years of experience working in Haiti and is now fairly fluent in Creole. "Having a permanent residence within the community will enable visiting UMass Lowell faculty and student researchers to perform health and environmental assessments across the Southern Department of Haiti."

The HDSC employs a full-time staff of Haitians who are responsible for housekeeping, ground transportation, security and all in-country resource requirements.

Giles advises on projects involving regional and community-based concerns and opportunities while university student interns and their faculty advisers may remain in Haiti over extended periods to gather and document the scientific data.

LIFE-SAVING RESEARCH

With a focus on scalable and sustainable technologies for impoverished regions of the world, faculty and students at the center are developing programs to decrease the impact of environmental contaminants and assess the efficacy of those programs.

Projects being undertaken at the center include:

- Implementing bio-sand water-filtration systems as well as investigating pilot studies to identify biomarkers for recognizing contaminated water;
- Developing low-cost, spectroscopic monitoring techniques and the instrumentation for supporting laboratory analysis;
- Investigating affordable solar energy systems and recycling of combustible waste materials as biomass fuels;
- Establishing a directed-studies, college-preparatory program for select Haitian students in the physical sciences with service-based team training on engineering projects and laboratory skills and
- Conducting an Honors College Seminar Series for science and engineering students focused on impoverished countries and the process of developing international research projects to explore scalable and sustainable solutions that address regional concerns.

"As an at-home and abroad program, internationally collaborative research projects not only challenge the critical thinking skills of our students, but also raise their awareness of socio-economic and regional factors that hinder positive world change," says Giles.

He adds: "Education is central to our mission. For students and teachers, the opportunities to make a difference in people's lives are limitless. The center is a place where research is a pathway to critical change."

For more information on how to help the Haiti Development Studies Center, email Robert_Giles@uml.edu.

Physics Faculty and Expertise

Nishant Agarwal, Ph.D., Cornell University, 2011
Theoretical cosmology

Peter Bender, Ph.D., Florida State University, 2011
Nuclear Structure and Gamma-ray Spectroscopy

Erin Bertelsen, Ph.D., Colorado School of Mines, 2020
Radiochemistry, electrochemical separations, nuclear forensics, nuclear fuel cycle

Supriya Chakrabarti, Ph.D., University of California, Berkeley, 1982
Astronomy and astrophysics

Partha Chowdhury, Ph.D., SUNY Stony Brook, 1979
Nuclear structure, detector development, applied nuclear science

Ofer Cohen, Ph.D., University of Michigan, 2008
Computational plasma physics, magnetohydrodynamics

Timothy A. Cook, Ph.D., University of Colorado, 1991
Astronomy and astrophysics

Andriy Danylov, Ph.D., UMass Lowell, 2010
Photonics

Robert H. Giles, Ph.D., UMass Lowell, 1986
Department Chair
Millimeter-wave and terahertz frequency biomedical spectroscopic imaging applications, energy engineering in developing countries

Wei Guo, Ph.D., Brown University, 2008
Nanomaterial growth, optoelectronic device applications

Marian Jandel, Ph.D., Comenius University, Slovakia, 2003
Nuclear physics, neutron-induced reactions, radiation detectors and nuclear medicine

Cecil Joseph, Ph.D., University of Massachusetts Lowell, 2010
Terahertz imaging, Biomedical optics

Archana Kamal, Ph.D., Yale University, 2013
Quantum physics, quantum information

Jayant Kumar, Ph.D., Rutgers University, 1983
Materials science, optoelectronic properties of materials, optical spectroscopy

Silas Laycock, Ph.D., University of Southampton, 2002
Astronomy

Nikolay Lepeshkin, Ph.D., New Mexico State University, 2001
Undergraduate Program Coordinator
Optics

Noureddine Melikechi, D. Phil., University of Sussex, 1987
Laser spectroscopy of complex systems

Arthur Mittler, Ph.D., University of Kentucky, 1970
Experimental nuclear physics, physics education

Chandrika Narayan, Ph.D., UMass Lowell, 1992,
Thin film processing; physics education

Viktor A. Podolskiy, Ph.D., New Mexico State University, 2002
Graduate Program Coordinator
Electromagnetism, photonics, nanoscience, metamaterials

Xifeng Qian, Ph.D., UMass Lowell, 2009
Photonics

Andrew Rogers, Ph.D., Michigan State University, 2009
Nuclear astrophysics, nuclear structure

Erno Sajo, Ph.D., UMass Lowell, 1990
Medical Physics Program Coordinator
Nuclear science, medical physics

Mengyan Shen, Ph.D., University of Science and Technology of China, 1990
Nanoscience and technology, condensed matter and optics

Paul Song, Ph.D., University of California, Los Angeles, 1991
Space Physics

Nancy Sullivan, Ph.D., UMass Lowell, 1993
Physics Education

Mark Tries, Ph.D., UMass Lowell, 1999
Radiological Science Program Coordinator
Radiological science and protection

Anna N. Yaroslavsky, Ph.D., Saratov State University, Russia, 1999
Biophysics, medical physics, optics, photomedicine

Johannes Zwanikken, Ph.D., Utrecht University, Netherlands, 2009
Condensed matter theory, soft matter

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