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Annual Report 2014–2015

Chester F. Carlson CENTER for IMAGING SCIENCE

contents

FOREWORD

By David W. Messinger, Ph.D.

On behalf of the faculty, staff, and students of the Chester F. Carlson Center for Imaging Science at RIT, I am pleased to present our Annual Report for the 2014-15 Academic Year. I hope you enjoy reading about all the exciting research and educational activities of the Center over the past year.

During the past academic year the Center has continued to be a leader at RIT in research focused on undergraduate and graduate education. The Center was awarded almost $5.5M in externally sponsored research funds during this period! The represents a significant amount and allows us to continue our excellence in broad, multidisciplinary approaches to solving problems with imaging systems. The graduate program has over 100 students pursuing either MS or Ph.D. degrees in Imaging Science. Our undergraduate program also continues to be strong with over 50 undergraduates enrolled in the BS degree program.

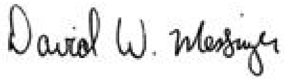
Additionally, our undergraduate and graduate students, as well as our faculty, continue to be recognized for their accomplishments. In this past year, Rose Rustowicz, who graduated with her BS in May, received a Fulbright Scholarship to travel to Iceland to work with a research team from the University of Iceland to conduct remote sensing at the Hekla volcano. Liz Bondi, who will be a senior in 2015-16, received a very prestigious Goldwater Scholarship. At the faculty level, Jan van Aardt was awarded the RIT Trustees Scholarship Award for his outstanding research portfolio. Also, a journal paper published by Dr. Aaron Gerace and Dr. John Schott in the Journal of Applied Remote Sensing was designated as one of the most downloaded papers published by JARS in the past year.

Other research highlights include Dr. Grover Schwartzlander's work for NASA in using "glitter" as a mirror to formulate images, Dr. Maria Helguera's work to use ultrasound technology to create tiny blood vessels needed to nourish organs, and Drs. Naval Rao and Hans Schmitthenner's work in photo-acoustic imaging for prostrate cancer detection. Not to mention our Freshman Imaging Project and Ph.D. graduate lab projects developing novel imaging systems for transient light imaging and crime scene investigation as part of our experiential learning program!

Our summer programs continue to be a major success, at both the High School and undergraduate levels. Our NSF Research Experience for Undergraduates program in "Imaging in the Physical Sciences" continues to provide real, hands on research experience across many imaging science applications to undergraduates from around the country. Our High School intern program provides a unique research experience for rising seniors to come into the Center for several weeks during the summer and learn about Imaging Science. Additionally, the High School intern program has once again contributed to the growth of our incoming freshman class, with 3 incoming students in the Fall of 2015 having been interns in the summer of 2014!

This has been an exciting year, and I hope you enjoy reading this Annual Report and learning about the activities of the Chester F. Carlson Center for Imaging Science. Please contact us for more information or if you have other ideas for Imaging Science!

David W. Messinger, Ph.D.
Professor and Director
Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology



IMAGING SCIENCE UNDERGRADUATE PROGRAM

Program Coordinator's Comments By Dr. Maria Helguera

As soon as I came back from sabbatical I stepped back into my responsibilities as the Undergraduate Program Coordinator. Like Carl Salvaggio, I am totally devoted to our program and I am sure that for both of us it is difficult to step aside. I thank him for the seamless transition.

This past year marked the fifth installment of our year long Innovative Freshman Experience. A total of 14 students from Imaging Science and Motion Picture Science were enrolled. This year the class was tasked with building a transient imaging system based on the work developed at the University of British Columbia (UBC). As always, the project seemed overwhelming to begin with. As always, the students proved themselves to be capable of surmounting every challenge along the way. We were fortunate to recruit Dr. Matthias Hullin -the original developer of the system in UBC- to come for a visit. Our students enjoyed a couple of days in his company and had a chance to ask many questions and learn what was needed of them in order to be successful. They presented their working prototype in ImagineRIT in May. They got invited to participate in the Rochester Museum and Science Center's Year of Light celebration.

Thanks to our combined efforts, Carl and I managed to get the first semester of this wonderful experience to be recognized as general science, meaning that university students can now take Imaging Science courses as their general education concentration.

We started the academic year with a very small Imaging Science class, six students. However, throughout the year four students switched their majors to Imaging Science and three more intend to pursue a double major in combination with Imaging and Photographic Technology, and Motion Picture Science.

As always, we continue to adapt and renew our undergraduate curriculum. We want our students to be competitive in the market and be solidly prepared if they choose to pursue graduate studies.

This past year we adapted/created two courses, Probability and Statistics for Imaging is a sophomore year course. As the title implies our students will not only learn the mathematical foundations but will apply concepts to imaging, image analysis, etc. Imaging Systems Analysis is a four credit course in the junior year. This course will teach students about the physical factors that affect the spatial and temporal response properties of optical, electronic, and biological imaging systems, and the mathematical methods that have been developed for describing these properties.

We continue to offer our National Science Foundation sponsored Research Experience for Undergraduates (NSF-REU) in Imaging in the Physical Sciences. This year the following student have joined us:

Christian Cammarota, from RIT working in optics with Prof. Swartzlander

Matthew Portman, from University of Texas, Dallas working in astronomy with Prof. Kastner

Merlin Hoffman, from Oberlin College working in MRI with Prof. Hornak

Klemens Gowin, from University of Rochester working in optics with Prof. Qiao

Daniel Morgen, from University of Rochester working in optics with Prof. Qiao

Vikie Ngan, from Wellesley College working in remote sensing with Dr. Gerace

Laure Morehouse, from Cornell University working in devices with Prof. Ninkov

Bruce Jones from RIT working in crime scene with Prof. Dube

Aviriana Follet, from Monroe Community College working in crime scene with Prof. Dube

Caroline Trier from Washington University in St. Luis working in biomedical imaging with Prof. Linte.

This past year I renewed my connections with Monroe Community College and have met with the Optical Advisory Board. We do have an articulation agreement in place and a few students have already expressed their interest in pursuing a 2 + 2 program. I am looking forward to continuing this collaboration.

Student Body

Our program continues to be small with about 45 students. We do have students pursuing double majors with Industrial Engineering, Applied Mathematics, Motion Picture Science and Imaging and Photographic Technology.

More and more students are pursuing internships and co-ops as well as benefitting from REU programs all over the country. Some of the places receiving them include Colorado State University, Ball Aerospace, Exelis, University of Buffalo, Wellman Center for Photomedicine at Massachusetts General Hospital, University of Rochester, NASA JPL, United Technologies Aerospace Systems, NGA, OGSystems, Boeing, Farm Crisp, Army Research Lab, Vencore, QVI, several labs in CIS-RIT, etc.

We were lucky to have a very active and engaged senior class. Throughout the year some of them volunteered in the executive committee of the Imaging Science Club (ISC) organizing weekly meetings, some worked as teaching assistants (TA), and resident assistants (RA). During these past four years they really used every opportunity they could to expand their knowledge and improve their academic experience. Several of them spent at least one semester abroad and all of them where involved in internships.

ISC organized a min-symposium on May 19 in which the seniors presented the results of their capstone projects. The experience was so successful that the faculty members of the Undergraduate Curriculum Committee have decided to assume responsibility and organize the event in the years to come. Stay tuned; you will be receiving an invitation when the time comes. This will be an excellent opportunity to meet our talented students.

Overall, the 2014-2015 academic year was a great success as you will see from our students' accomplishments below. We would love to hear from you, whether it is by providing an internship, co-op, visiting campus and talking at our seminar series on Wednesday afternoon or to the student-run Imaging Science Club on Friday afternoon.

Awards/Recognitions

<u>RIT Outstanding Undergraduate Scholar Award</u>

Elizabeth Bondi

<u>RIT College of Science—John Wiley Jones Scholarship</u>

Ryan LaClaire

<u>RIT Women in Computing Hackathon—Most Novel Hack</u>

Victoria Scholl
Elizabeth Bondi

<u>Chester F. Carlson Center for Imaging Science—Carlson Scholarship</u>

Ryan Connal
Nathan Dileas
Sara Leary
Ryan Hartzell
Makayla Roof
Dylan Dang
Zach Mulhollan
Kevin Sacca
Victoria Scholl

<u>Chester F. Carlson Center for Imaging Science—Fitz Scholarship</u>

Amy Becker

<u>Chester F. Carlson Center for Imaging Science—Hughes Scholarship</u>

Matthew Casella

<u>Chester F. Carlson Center for Imaging Science Faculty Award Celebrating Excellence</u>

Megan Iafrati
Rose Rustowicz

<u>SPIE Optics and Photonics Scholarship</u>

Kevin Sacca

<u>Fulbright Fellowship</u>

Rose Rustowicz

<u>Barry Goldwater Scholarship</u>

Elizabeth Bondi

<u>American Society for Photogrammetry and Remote Sensing (ASPRS) Student of the Year</u>

Elizabeth Bondi

<u>United States Geospatial Intelligence Foundation (USGIF) GEOINT Hackathon</u>

Briana Neuberger
Dan Simon

<u>Alpha Sigma Lambda Honorary Society</u>

Rose Rustowicz

<u>UNYTE—Hitting the Accelerator: Health Research Innovation through Data Science. Best Student Poster Award</u>

Rose Rustowicz

Publications, Conference and Poster Presentations

Hitchner, A., Vodacek, A. "Accessing the Accuracy of Cloud Height Measurements using Landsat 8 Images", *2014 RIT Undergraduate Research Symposium*

Jermyn, A., O'Dea, C. "Infrared Observations of Low-luminosity Radio Galaxies", *2014 RIT Undergraduate Research Symposium*

Bondi, E., Easton, R. "Spectral Image Processing Applied to Manuscripts of Cultural Importance from the Museo del Tesoro del Duomo in Vercelli, Italy", *2014 RIT Undergraduate Research Symposium*

Rustowicz, R., Schultz, M., Pow, J, "Do Innovative Curricula Actually Improve STEM Retention: A Case Study", *2014 STEMtech Conference, Denver, Colorado, United States*, November (2014).

Peck, D. S., Schultz, M., Bachmann, C. M., Ambeau, B., Harms, J. "Influence of density on hyperspectral BRDF signatures of granular materials," *Proc. SPIE 9472*, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXI, 94720F (May 21, 2015), http://dx.doi.org/10.1117/12.2177455.

Qiao, J., Travinsky, A., Ding, G., **Dang, D.**, Dorrer, C. "A differential wavefront sensor based on binary pixelated transmission filters", *2014 NASA Mirror Technology Workshop*, Albuquerque, New Mexico, 18–20 Nov, 2014

Iafrati, M., Rustowicz, R., Helguera, M. "RAM: Remotely Accessible Microscope", *UNYTE—Hitting the Accelerator: Health Research Innovation through Data Science*, University of Rochester, May 28, 2015.

Díaz, G., Binaee. K., **Smith, A., Griffo. C.**, Gopinathan, R. "Evaluation of a Phantogram Groundplane for the Study of Visually Guided Walking Behavior", *Annual Meeting of the Vision Science Society*, St. Pete's Beach, Florida (May 2015)

Dang, D. N., Linte, C.A., Otani, N.F. "Reconstruction and Visualization of Action Potential Wave Propagation Patterns in Cardiac Tissue". Accepted for oral presentation *2015 Computer methods in Biomechanics and Biomedical Engineering conference, Montreal, Canada,* Sept. 2015.

Senior Projects

Our graduating class worked on their senior project as part of the requirements for degree completion. Capstone projects prepare them for a specialty within imaging science or for graduate school in the coming year. As you can see from the list below, their interests are wide and varied.

Student

Daryl Schwarz

Advisor

Jie Qiao

TITLE
Chromatic Autofocus Method for Automated Video Metrology Systems

Abstract: Automated video metrology systems rely on accurate axial positioning of the imaging sensor to enhance performance of sensing algorithms, e.g. edge detection. Traditional autofocus methods rely on a contrast sweep through the imaging systems depth of field. The sweep inherently produces a lag in inspection throughout which correlates to fewer parts per hour. U.S. Patent 7 812 971 B provides the intellectual property to use an apparatus in which an illumination source with discrete wavelengths are incident on an object and the individual focal planes coincide with a lens designed with chromatic aberration. The various contrast response of the lens-illumination configurations provide a tool to increase the depth of field of the imaging system and discrete contrast responses. An algorithm to decipher the focal axis position and/or comparison of focal positions of various sources and method is proposed. The algorithm is intended to significantly increase throughput while maintaining positional accuracy for various sensing methods.

Students

Megan Iafrati
Rose Rustowicz

Advisor

María Helguera

TITLE
Remotely Accessible Microscope (RAM)

Abstract: Biologists and other research professionals have a need for an inexpensive, easy-to-use microscope with image processing and analysis capabilities. Although the applications for this type of microscope may be endless, the motivation for developing this technology comes from the desire to view cell samples within an incubator over time. In current technologies, the cells must be fixed and destroyed before viewing under a microscope. Samples must be transported to a microscope each time they are observed, risking sample contamination and interruption of cell processes. To mitigate the need for sample transportation, a remotely accessible microscope was developed. A successful system requires optics, electronics, and image processing. By adapting a Makeblock XY-Plotter kit as an XY motor stage, utilizing the optics from an Adafruit USB microscope, and taking advantage of the capabilities of a Raspberry Pi and it's compatible camera board, components were integrated into one fully functional system. Graphical user interfaces (GUIs) were developed for motor control and image processing. Image processing features were developed specifically for biologists needs and include field flattening, adaptive histogram equalization, and segmentation for cell counting. To further improve the capabilities of the system, future work is anticipated.

Student

Ryan LaClair

Advisor

Zoran Ninkov

TITLE
Development of Control Hardware for the Audine CCD Camera

Abstract: The Audine CCD camera kit is a package that allows the user to assemble a camera on his or her own - giving the user a better understanding of how the imaging system works, how to repair any potential problems, and eliminating any cost associated with purchasing an already assembled camera. The standard interface and software used to control the camera is outdated, and only works with old computers running Microsoft Windows 95. This project developed a new USB controller interface for the Audine camera that can be used with modern computers, as well as software that can be used to perform basic image capture. The prototype for the system was built using a Texas Instruments TIVA TM4C1294 micro-controller that provides communication between the camera and the users computer. The controller receives a signal from the users computer, sends the necessary clock signals to the sensor, reads the digitized signal from the camera, and sends the collected information back to the computer. The completed package can be used by RIT students who build the CCD camera in the laboratory, and can be distributed for use by others in the imaging community who build their own Audine camera.

Student

Christian Taylor

Advisor

Carl Salvaggio

TITLE
Radiometric Calibration of a Modified DSLR for NDVI

Abstract: Silicon CCD detectors found in commercial DSLR cameras are responsive far out into the Near Infrared wavelengths. These cameras typically have an Infrared block filter built in to more closely resemble the human visual system. This paper proposes a method for radiometric calibration in order to extract NIR and RED Radiance bands from a Canon 300D with the IR filter removed. With these spectral bands a single exposure NDVI measurement can be pro-

duced for each pixel in an image for identification of live green vegetation.

Student

Andrew Hitchner

Advisor

Anthony Vodacek

TITLE

Cloud Height Data from Landsat 8 Thermal Images

Abstract: One of the major sources of error in climate models is the lack of information about how clouds interact with the climate around them. To improve climate models, a method for determining cloud heights at a high resolution is needed. This project presents a proof of concept for determining cloud heights using the thermal images from the Landsat 8 satellite. The method involves using mutual information image registration to find the parallax shift between clouds in the Band 10 and Band 11 images, and then uses this shift, along with newly available look angle data for each band, to determine the cloud height. This method is a viable method, however there are some sources of error and uncertainties that need to be addressed and considered before creating an automated method to generate cloud height data.

Student

Doug Scott Peck

Advisor

Charles Backmann

TITLE

Influence of Density on Hyperspectral BRDF Signatures of Granular Materials

Recent hyperspectral measurements of composite granular sediments of varying densities have revealed phenomena that contradict what radiative transfer theory would suggest. In high-density sands where dominant constituents are translucent and supplementary, darker grains are present, bidirectional reflectance distribution function (BRDF) measurements of high density sediments showed reduced intensity when compared to lower density counterparts. It is conjectured that this is due to diminished multiple scattering from the darker particles which more optimally fill pore space as density increases. The goal of these experiments is to further expand upon these earlier results that were conducted primarily in the principal scattering plane and only at minimum and maximum densities. In the present study, the BRDF of granular composites is compared along a gradient of densities for optically contrasting materials. Systematic analysis of angular and material dependence will be used to develop better models for multiple scattering effects of the granular materials. The measurements in this experiment used the recently constructed, laboratory and field-deployable Goniometer of the Rochester Institute of Technology (GRIT), which measures BRDF for geometries covering 360 degrees in azimuth and 65 degrees in zenith. In contrast to the previous studies limited to the principal scattering plane, GRIT provides a full hemispherical BRDF measurement.

Student

Cicely DiPaulo

Advisors

Joel Kastner, Charles Backmann

TITLE

3D Perspective on Visible Light & X-rays from Planetary Nebulae: From the Ant to the Eskimo

There are millions and millions of stars in our sky each with their own unique makeup and morphology. Planetary nebulae are formed by low to intermediate mass stars that swell up when they reach the end of their lives forming cool, red giants, expelling their outer layers and beginning the transformation into white dwarfs. To gain insight into 3D perspective of planetary nebulae, we have used HST and Chandra data along with SHAPE, a modeling program, to demonstrate similarities in morphology.

Student

Susan Kratzer

Advisors

Jan van Aardt, David Messinger

TITLE

Assessing Linear Unmixing Algorithms and their Performance on Low and High Spatial Resolution Hyperspectral Data

Hyperspectral unmixing utilizes pure pixels' spectra as endmembers (i.e. each pixel contains only one cover type) to unmix the fractions, or abundances, of a mixed pixel. Linear hyperspectral unmixing often relies on ground truth data to assess the accuracy of the unmixing model. In the case where ground truth data do not exist, research is done to evaluate if the unmixing model follows statistical logic. This project qualitatively evaluated the produced abundances utilizing data of two different spatial resolutions and two different linear hyperspectral unmixing algorithms. We found the same cover types fell in the same groups of under-mixed and over-mixed. These over- and under-mixtures were attribute to spectral BRDF variation.

Student

Malachi Schultz

Advisor

Charles Backmann

TITLE

NASA Algodones Experiment

By examining the shape of the angular distribution of the hyperspectral reflectance curve, or BDRF, we can get a better understanding of the geophysical properties of sand, such as density, grain size distribution, and moisture content. In this research we are measuring BRDF of varying sand compositions, moisture content, density, and grain size distributions in both the field and the controlled conditions of a laboratory where each geophysical variable can be independently controlled. Based on the discrepancy between the model and the real world we can refine Hapke's model to more accurately predict the geophysical properties of sand in aerial and satellite imagery.

Student

Andrew Smith

Advisor

Gabriel Díaz

TITLE

Evaluation of a Phantogram Groundplane for the Study of Visually Guided Walking Behavior

A phantogram is a two-dimensional projection that, when looked upon from the proper angle, appears three-dimensional to an observer. The concept is the same as for the recently popular street chalk drawings, where the artist appears to draw a large chasm in the ground or something similar. Our implementation builds on this concept by computationally re-rendering the groundplane in real-time according to the subject's physical head position. The result is a very realistic illusion, where virtual objects lying on the ground appear real to the subject.

Two CIS Undergrads On Winning GEOINT Hackathon Team

Developers challenged to produce predictive analysis of disease in West Africa

Nearly 30 developers and data scientists turned out for the first USGIF GEOINT Hackathon June 12-14.

Participants were tasked to determine why certain areas of West Africa were unaffected by the Ebola outbreak as well as predict where additional outbreaks might occur. However, this was their secondary goal—the primary goal was to expose their team's thinking and build in hooks so another team working with another geography or outbreak could modify the solution to a new set of conditions.

"It was a fabulous event," said Dr. Darryl Murdock, USGIF's vice president of professional development. "The judges learned as much as the participants did and we can't wait to host another hackathon."

The first-place team included four student interns and was aptly named "Team Intern." Their solution focused on travel and revealed an "Ebola superhighway" along the coast of West Africa. They were awarded the $15,000 grand prize as well as complimentary registration to USGIF's GEOINT 2015 Symposium, to be held next week in Washington, D.C. Team Intern members are:

R. Blair Mason, a member of the U.S. Naval Academy class of 2016 and a double major in computer science and aerospace engineering. Mason is currently interning with the Naval Research Laboratory.

Briana Neuberger, a soon to be senior at Rochester Institute of Technology (RIT) double majoring in imaging science and industrial systems engineering. Neuberger is a SMART scholar and intern with the National Geospatial-Intelligence Agency (NGA).

Dan Simon, a rising senior at RIT and intern at OGSystems.

Paul Warren, a rising junior at Stanford University majoring in computer science as well as an OGSystems intern.

"We developed an open-source python library to model the spread of disease as it's carried by contagious people through a network of nodes and edges using network theory," Warren said.

Simply put, Team Intern's library aimed to capture where sick people travel and why.

"Once we came up with results, we developed a way to visualize them so they could make meaningful sense," Mason said.

The team attributed Neuberger for helping "expose the way they think by figuring out how they think."

The second-place team produced what it calls "non-historic" predictive analysis and was awarded complimentary GEOINT 2015 registration. "Team Flo Hacks" members are:

Boris Polania of Hollywood, Fla., a software engineer with post-graduate studies in economics who moved to the U.S. from Venezuela six years ago. Polania recently helped found small software consulting firm V/F.

Armando Umerez of Boca Raton, Fla., who recently moved back to the U.S. from Venezuela and is also a partner in V/F. Umerez is an electronic engineer with post-graduate studies in marketing, management, and sustainable development.

"The standard approach of predictive analytics is to go to old data sets and do standard clustering to make generalizations," the team said in its presentation. "We didn't want to do more of the same, so we did a completely new approach."

The third-place team developed an easy-to-use graphical user interface based on sanitation data such as access to water. They were awarded complimentary registration to GEOINT Foreword, the pre-GEOINT symposium science and technology day held June 22. "Team Agile" members are:

Nathan Currier, an incoming senior at Colorado State University, Fort Collins majoring in computer science as well as an intern with Stinger Ghaffarian Technologies (SGT).

Jesse Pai, a rising sophomore majoring in computer engineering at the University of Maryland, College Park. Pai is also an SGT intern.

Team Agile described their solution as "a lightweight web app" that would be ideal for doctors working in environments with limited connectivity. Both Currier and Pai are new to geospatial intelligence.

"The main thing that I liked about this experience was the fact that I was forced out of my comfort zone," Pai said. "I was given a new task and objective, and I had to learn a new set of information and tools in order to understand the task and produce a result. This hackathon allowed me to experience what it felt like to develop for another part of the computing industry."

The GEOINT Hackathon was sponsored by DigitalGlobe, Esri, and OGSystems, and included judges from USGIF, NGA, DigitalGlobe, Esri, and OGSystems.

—See more at: http://trajectorymagazine.com/got-geoint/item/1967-student-interns-win-first-geoint-hackathon.html#sthash.6C1TbIU2.dpuf

Motion Picture Science Program

Prof. David Long, Chairperson

2014-2015 marked another wonderfully successful year of collaboration between undergraduate students in RIT's Motion Picture Science (MPS) and Imaging Science programs. In particular, students studying in MPS as part of the School of Film and Animation continue to reap the benefits of world-class classroom and laboratory opportunities in CIS. On a campus with so many imaging-centric degree programs in the sciences and arts outside of Imaging Science, the rigor and quality of education shared with our students by CIS faculty gives them a unique advantage in the marketplace. The cinema industry continues to take advantage of this bright new talent. And we are motivated to make these bonds even tighter!

Whenever prospective students and families from high school come to visit me, I'm excited to tell the stories of the strong engineering and research opportunities available to MPS students at RIT. And quite of few of them are just a little bit surprised to hear about all we do here. Students contemplating MPS are quite unique. They are drawn to film and to the art of cinema but every one of them has technical talent and a desire to keep their left brains fully engaged in school. I joke with many of them that the motion picture industry is a lot like another CIS favorite, NASA. So much technology developed for the space program spawned products and systems that engineers and scientists continue to take out to the rest of the world today. For imaging systems, the motion picture marketplace is that same high-tech playground. Cameras, displays, computer graphics, computational photography—they all have roots in the cinematic arts. This is what makes RIT so fun for students in both programs. And the collaboration is so infectious that we actually now have three students on campus earning both degrees!

There is much to be proud of from the work of MPS and CIS students on campus this year. For the second year, the full freshmen classes from both programs joined to participate in the year-long Freshmen Imaging Project. This year's team was tasked with building a transient imaging system capable of capturing light in flight. The team did some amazing work in both engineering and software development and showed the world's first ever stereo simulation of light in flight at Imagine RIT. In fact, the experience of past MPS students constructing a low-cost stereoscopic projection system was key to this year's success. Project management, communication and research skills gained here will form a great foundation for all of these students navigating the remainder of their undergraduate careers.

Upperclassmen also contributed to some impressive research both as members of select research groups within CIS and through their capstone engineering projects. Work ranged from high dynamic-range video system design to psychophysical modeling of human response to varying framerates in cinematic exhibition. Several papers were submitted for conferences as a result of research efforts. On an extra-curricular front, members of the student chapter of the Society of Motion Picture and Television Engineers designed and built a video system for capturing live-action virtual reality content and produced a short film that they showed off at Imagine RIT. The demonstration was a hit and a testament to the energy our students can bring to fun side projects. The team was even extended a personal invitation to present their work at the 2015 SMPTE Technical Conference in Los Angeles.

In May, 11 MPS students completed their degrees and officially joined the real world. Three will be attending graduate school in color science and computer science while the rest head off to new careers. Most have landed positions in the motion picture industry but a few will also be starting with non-cinema imaging firms. Again, we have always been very proud that the CIS connection permits our students to contribute immediately to many different kinds of imaging groups, not just the movie-making ones. So look out for MPS alums in New York and Hollywood for sure, but don't be surprised to find them in Milwaukee, Denver and Boston this year, too.

Abstracts taken from sample MPS Senior Projects

Sean Cooper

A Psychophysical Approach to Modeling Temporal Texture in Cinema

The current cinema industry is on the cusp of innovation, and one of the most impactful elements being explored is the deviation from the century-long tradition of 24 fps capture and exhibition. Recent tests into the high frame rate (HFR) domain have resulted in a flurry of passionate response from professionals and the general public alike. The term "soap-opera look" has once again entered into the public's vernacular to describe the percept. Frame rate has clearly proven to be a pivotal aspect of an observers perception of cinema content, and yet the underlying causes of this perception are unknown. This research hopes to take the first step towards a veridical approach to modeling this response in a high-order manner with respect to motion pictures to help inform future decisions in the creative story telling industry and future human temporal vision research.

Matt Donato

Towards Standardizing a Reference White Chromaticity for High Definition Television

Emerging high definition displays exhibit great spectral variance with respect to their unique illuminant technologies. As a result, their spectral power distributions differ. When calibrating these spectrally unique displays, calibration instruments claim chromaticity matches while film industry professionals (naturally diverse in their color perception) experience chromaticity mismatches. This was not an issue when early phosphor-based displays in use were spectrally similar to one another. Both a simulation and psychophysical test are developed in an attempt to quantify differences in color perception between classic phosphor-based displays and emerging high definition displays. The proposed method can be used to effectively determine a mean visually-corresponding chromaticity offset from a given standard white point chromaticity for both LED and OLED displays to satisfy a greater population of observers. While this offset may be satisfactory for a greater number of observers, a single observer model cannot accurately predict metameric matches for an entire population of diverse observers. This issue is magnified as three-primary color rendering becomes increasingly monochromatic.

Carly Cerquone

Green Screen Shootout

The purpose of this project is to determine the effectiveness of various green screen materials (both professional and consumer grade) in multiple difficult-to-composite situations. In total, five different green screen materials (three professional and 2 consumer), six different lighting scenarios, and three cameras at five quality settings were tested. In the end, it is the hope that this project will be successful in aiding student filmmakers (particularly those in the RIT School of Film and Animation) in their decisions to shoot for visual effects by showing them the pros and cons of the cameras they so often choose, and the materials they should be looking into using.

Jordan Westhoff

The Cerberus Project

As the age of cinema has progressed, technology has become more advanced. Today, systems exist that promise images that are both incredibly large and also exceptionally detailed. Images are now being recorded in 2K, 3K, 4K and 6K resolutions in RAW formats, which has proven to exceed the processing power of the workstations designated to manipulate them. Although processing and GPU power has continued to climb, it is still a major undertaking to import and process the complex images that are generated, often in proprietary format, by each major motion picture camera manufacturer.

Executing these workflows has always added an additional level of complexity to the post production workflows for the companies and directors that choose to implement them. The conversions from truly RAW encoded formats to viewable and editable formats in the correct color spaces is a process that is often crippling both in complexity and cost.

This project attempts to tackle multiple hardware and distributed computing technologies simultaneously with beneficial implications for both independent and low-budget filmmakers. The underlying goal of the project aims to provide sound image processing from an imaging science perspective while providing an elegant, scalable hardware solution. This combination builds the foundation of the project and aims to make it marketable for enterprise adaptation.

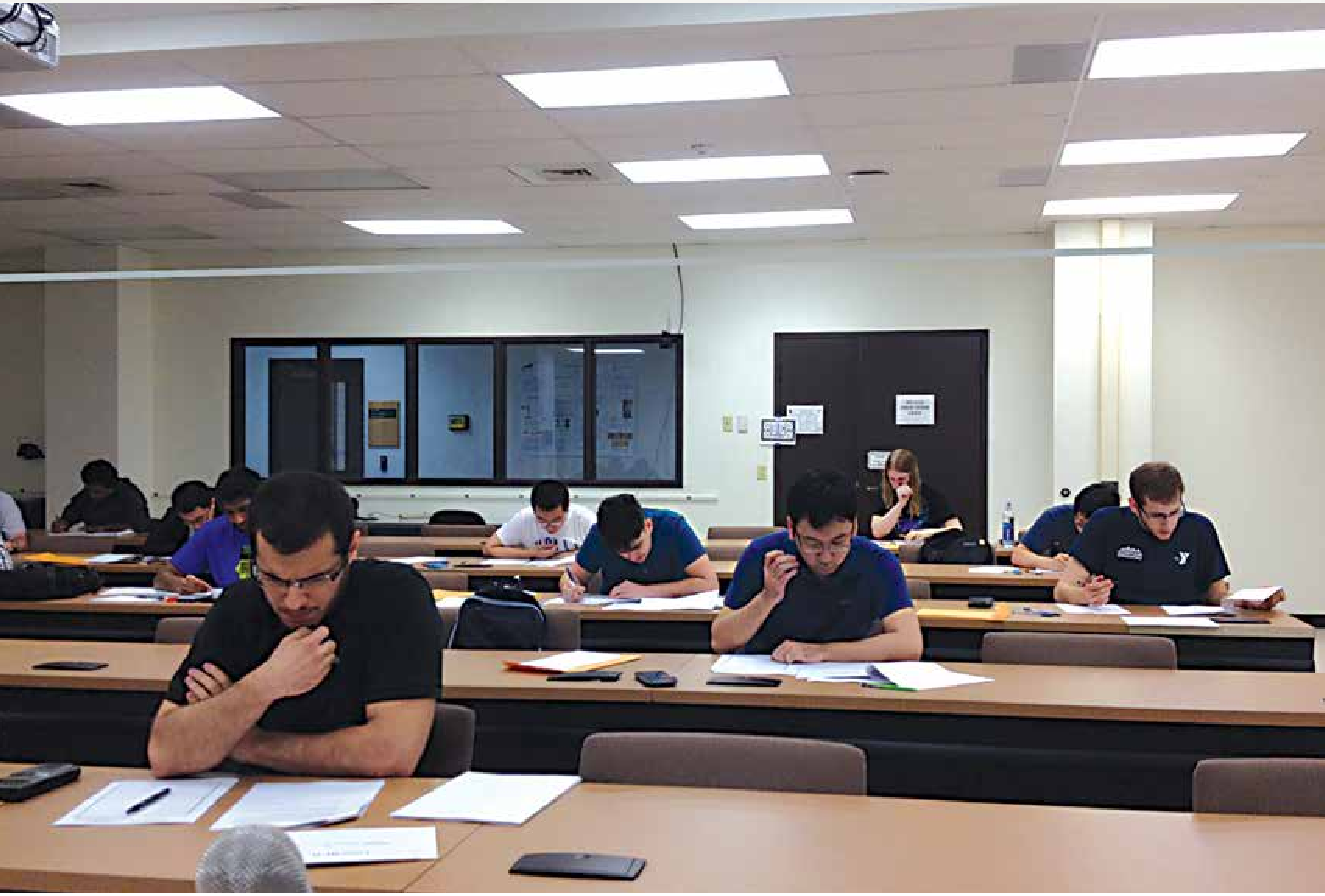
Miscellaneous Awards

Elizabeth Pieri

- RIT Outstanding Undergraduate Scholar

Matt Donato & Victoria Scholl

- Society of Motion Pictures and Television Engineers Lou Wolf Scholar



First year graduate students taking a test in one of their core imaging science classes.

IMAGING SCIENCE GRADUATE PROGRAM

Program Coordinator's Comments By Dr. John Kerekes

The Imaging Science graduate program continues to be highly regarded by our peers and prospective employers. Our graduates remain in high demand and are finding employment in industry, government, nonprofits and universities.

The first year graduate students won the prestigious 'Sponsor's Award' for their work on multispectral crime scene imaging at the annual Imagine RIT Innovation and Creativity Festival.

For the second time under the new semester calendar, we took advantage of the extended break in January with faculty and graduate students offering a number of short courses free of charge to our students. These courses ranged from practical introductions to the technological alphabet soup of LaTeX, MODTRAN, C++, and DIRSIG, to the higher math behind Graph Theory as well as even courses on Entrepreneurship for Scientists and Principles and Techniques to Enhance Your Presentations. These sessions were all well attended and enjoyed by many.

Also for the second year, we welcomed our new graduate students in the fall with an "Imaging Science Immersion" orientation program. Occurring just prior to the start of classes, we exposed the incoming students to the imaging chain through lectures, demonstrations, and lab tours. The program wrapped up with a social gathering where the new students had an opportunity to get to know the faculty.

We look forward to the continued success of our nation's unique graduate program in Imaging Science. The following is a summary of activities, changes, and student highlights over the 2014-15 academic year.

Graduate Program Faculty

This was a quiet year of little change in our graduate faculty with the notable exception of the move by Center Director Professor Stefi Baum to a new position as Dean of the Faculty of Science at the University of Manitoba. Prof. Baum remains engaged advising our graduate students as a Research Professor here in the Center.

As of the end of the 2014-15 academic year there are a total of 51 members of the CIS Graduate Program Faculty. Seventeen are tenured, or tenure-track, with the Center as their primary appointment. Another twenty-five have a primary appointment in one of thirteen other departments centers, programs or laboratories with which the Center is affiliated. The Center is the home to nine Research Faculty. There are five Program Allied Faculty who hold positions at other organizations outside of RIT.

Curriculum Development

With two years now completed under the semester calendar we have just about stopped saying "quarter" when referring to the academic term! Kidding aside, the transition has been smooth and the students seem to be benefiting from the slower pace as well as the additional material included in each course.

One minor change to our curriculum was a renaming of the graduate "Digital Image Processing" course to "Image Processing and Computer Vision." This change reflects the fact that nearly all image processing is digital these days, and that we have been introducing computer vision topics into the course to expose our students to an increasingly common application of imaging science. The course was taught this year by Prof. Nathan Cahill, a member of our Graduate Program Faculty from the School of Mathematical Sciences, and proved to be very popular.

New special topics courses were taught this year by two of the faculty who have recently joined our program. Associate Professor Charles “Chip” Bachmann taught “Introduction to Radiative Transfer in Media” in the fall. This course explored the physics and mathematics behind light scattering in random media and helped prepare the students for more advanced research under the guidance of Prof. Bachmann. Associate Professor Jie Qiao taught “Optical Component, System Design, and Performance Evaluation” in the spring. This course was centered on the use of the ZEMAX optical modeling software and provided the students practical experience in the design and analysis of optical systems. Both classes were well received by our students.

This was the second year for our new yearlong PhD laboratory course led by Prof. Roger Dube. Seventeen first-year PhD students were challenged to design and build a multispectral imaging system to document a crime scene, with the Imagine RIT festival held in May as a deadline. The students organized themselves along subsystems developing requirements, designs, and then building and demonstrating the system, named Crime Scene Investigation System (CRISIS). Their project for the second year in a row won a first place sponsor award at the festival. Congratulations!

Prof. Dube also continued to refine our use of the Matterhorn video capture system now used to automatically record nearly all graduate course lectures. This system continues to be used not only by our online M.S. students, but also by our on-campus students who have found it useful to review lectures.

Graduate Student Body

At the beginning of the 2014-15 academic year there were a total of 117 graduate students pursuing degrees in Imaging Science. There were 28 resident M.S. students, 7 online M.S. students, and 82 Ph.D. students including one who is pursuing the degree online.

The incoming class that started in the fall of 2014 included 8 M.S. and 17 Ph.D. students. In this group of students there are two US Air Force officers (1 M.S. and 1 Ph.D.) and one Canadian Forces officer (M.S.). Except for the Air Force officer, all Ph.D. students received an assistantship covering full tuition and a stipend, while two of the M.S. students also received an assistantship covering tuition and stipend. Ten of the new students were from the United States, with the balance being international including five from China, three from India, two from Nepal, two from Israel and one each from Canada, Iran, and Slovakia.

Student Awards

Our graduate students continue to be recognized through a variety of awards, scholarships and other forms of recognition. The following is a sampling of awards received by imaging science graduate students during 2014-15.

- *IEEE Western New York Image and Signal Processing Workshop Best Remote Sensing Paper*: Jie Yang
- *RIT 2015 Graduate Student Delegate and College of Science Commencement Speaker*: David Kelbe
- *SPIE Travel Scholarship*: Garreth Ruane
- *Wallonie-Bruxelles International Scholarship for Excellence*: Garreth Ruane

Student Publications and Presentations

Imaging science graduate students are strongly encouraged and provided opportunities to broadly disseminate their research by publishing journal articles, presenting and publishing at scientific conferences, and interacting with sponsors at meetings and workshops. The following is a partial list of publications authored or coauthored by our graduate students in 2014-2015.

Selected Journal Articles with Graduate Student Authors (student author underlined)

- Basnet, Bikash; Vodacek, Anthony, Tracking Land Use/Land Cover Dynamics in Cloud Prone Areas Using Moderate Resolution Satellite data: A Case Study in Central Africa, *Remote Sensing, 7, pp. 6683-6709* (May 26, 2015)
- Easton, Jr., Roger L.; Kelbe, David, Statistical Processing of Spectral Imagery to Recover Writings from Erased or Damaged Manuscripts, *Manuscript Cultures, 7, pp. 35-46* (February 06, 2015)
- Meng, Lingfei; Kerekes, John P., An Analytical Model for Polarimetric Imaging Systems, *IEEE Transactions on Geoscience and Remote Sensing, 52, 10, pp. 6615-6626* (October 2014)
- Pahlevan, Nima; Lee, Z; Wei, J; Schaaf, C; Schott, John R.; Berk, A, On-Orbit Radiometric Characterization of OLI (Landsat-8) for Applications in Aquatic Remote Sensing, *Remote Sensing of Environment, 154, pp. 272-284* (November 30, 2014)
- Ruane, Garreth J.; Swartzlander, Grover A.; Slussarenko, Sergei; Marrucci, Lorenzo; Dennis, Mark R., Nodal areas in coherent beams, *Optica, 2, 2, pp. 147-150* (2015)
- Ruane, Garreth J.; Watnik, Abbie T.; Swartzlander, Grover A., Reducing the risk of laser damage in a focal plane array using linear pupil-plane phase elements, *Applied Optics, 54, 2, pp. 210-218* (2015)
- Uzkent, Burak; Hoffman, Matthew J.; Vodacek, Anthony; Chen, Bin, Feature Matching with an Adaptive Optical Sensor in a Ground Target Tracking System, *IEEE Sensors Journal, 15, 1, pp. 510-519* (2015)
- Vantaram, Sreenath R.; Piramanayagam, Sankaranaryanan; Saber, Eli; Messinger, David W., Spatial segmentation of multi/hyperspectral imagery by fusion of spectral-gradient-textural attributes, *SPIE Journal of Applied Remote Sensing, 9, 1, pp. 1-37* (March 31, 2015)
- Zhang, Jiashu; Kerekes, John P., An Adaptive Density-based Model for Extracting Surface Returns from Photon-counting Laser Altimeter Data, *IEEE Geoscience and Remote Sensing Letters, 12, 4, pp. 726-730* (April 2015)

Selected Conference Proceeding Papers with Graduate Student Authors (student author underlined)

- Bandyopadhyay Madhurima; van Aardt, Jan; van Leeuwen, Martin, Modeling individual trees in an urban environment using dense discrete return LiDAR, Proc. SPIE 9465, *Laser Radar Technology and Applications XX, and Atmospheric Propagation XII, 94650J* (May 21, 2015)
- Concha, JA; Schott, John R., In-water component retrieval over Case

2 water using Landsat 8: Initial results , *Geoscience and Remote Sensing Symposium 2014 IEEE International, IGARSS 2014, July 13 - 18, 2014, pp. 4458-4461, Quebec, Quebec, Canada* (July 13, 2014)

- Cui, Zhaoyu; Kerekes, John P.; DeAngelis, Chris; Brown, Scott D.; Nance, C. Eric, A Comparison of Real and Simulated Airborne Hyperspectral Imagery, *Western New York Image and Signal Processing Workshop, pp. 19-22, Rochester, New York, United States* (November 07, 2014)
- Dangi Shusil; Ben-Zikri, Kfir; Schwarz KQ, Cahill Nathan; and Linte, Cristian A., Endocardial left ventricle feature tracking and reconstruction from tri-plane TEE data for computer-assisted image guidance and cardiac function assessment. *Proc. SPIE Medical Imaging—Image-guided Procedures, Robotic Interventions and Modeling.* Vol. 9415. pp: 941505-1-9. 2015.
- Dorado-Munoz, Leidy; Messinger, David W., Schrodinger Eigenmaps for Spectral Target Detection, *Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXI, Defense Sensing + Security, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXI, 9472, 947211, pp. 1-12, Baltimore, Maryland, United States* (2015)
- Jin, Can; Bachmann, Charles M., Modeling and Mitigating Noise in Graph and Manifold Representations of Hyperspectral Imagery, *Proc. SPIE 9472, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXI, 94720W* (May 21, 2015)
- Qiao, Jie; Travinsky, Anton; Ding, Gaozhan; Dorrer , Christophe, Optical differentiation wavefront sensor based on binary pixelated transmission filters, *Proceedings of SPIE, Photonics West, 2015, LASE, 9356, 935608, pp. 1-8, San Francisco, California, United States* (October 15, 2014)
- Sun, Jiangquin; Messinger, David W., Streaming analysis of track data from video, *Geospatial Informatics, Fusion, and Motion Video Analytics V, Defense Sensing + Security, Geospatial Informatics, Fusion, and Motion Video Analytics V, 9473, 947302, pp. 1-15, Baltimore, Maryland, United States* (May 21, 2015)
- Vaidyanathan, Preethi B.; Pelz, Jeff B.; Alm, Cecilia; Shi, Pengcheng; Haake, Anne, Recurrence quantification analysis reveals eye-movement behavior differences between experts and novices, P*roceedings of the Symposium on Eye Tracking Research and Applications, Symposium on Eye Tracking Research and Applications (ETRA), pp. 303-306, Safety Harbor, Florida, United States* (2015)
- Yang, Jie; Kerekes, John P., A Combined Approach for Ice Sheet elevation Extraction From Lidar Point Clouds, *Western New York Image and Signal Processing Workshop, pp. 15-18, Rochester, New York, United States* (November 07, 2014)
- Yao, Wei; van Leeuwen, Martin; Romanczyk, Paul; Kelbe, David; van Aardt, Jan, Assessing the Impact of Sub-pixel Vegetation Structure on Imaging Spectroscopy Via Simulation, *Proc. SPIE 9472, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXI, 94721K* (May 21, 2015)
- Yang, Jie; Kerekes, John P., A Combined Approach for Ice Sheet elevation Extraction From Lidar Point Clouds, *Western New York Image and Signal Processing Workshop, pp. 15-18, Rochester, New York, United States* (November 07, 2014)
- Ziemann, Amanda; Messinger, David W., An adaptive locally linear embedding manifold learning approach for hyperspectral target detection, *Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXI, Defense Sensing + Security, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXI, 9472, 947200, pp. 1-15, Baltimore, Maryland, United States* (May 21, 2015)

Graduates

During academic year 2014-2015 the Center conferred 14 Ph.D. degrees and 13 M.S. degrees.

The following students received a Ph.D. in Imaging Science.

- Madhurima Bandyopadhyay, *Quantifying the Urban Forest Environment Using Dense Discrete Return Lidar and Aerial Color Imagery for Segmentation and Object-level Biomass Assessment, Advisor*: Jan van Aardt
- Tyler Carson, *Signature Simulation and Characterization of Mixed Solids in the Visible and Thermal Regimes*, Advisor: Carl Salvaggio
- Bin Chen, *Multispectral Image Road Extraction Based Upon Automated Map Conflation,* Advisor: Anthony Vodacek
- Monica Cook, *Atmospheric Compensation for a Landsat Land Surface Temperature Product,* Advisor: John Schott
- Rey Garma, *Image Quality Modeling and Characterization of Nyquist Sampled Framing systems with Operational Considerations for Remote Sensing,* Advisor: John Schott
- Shea Hagstrom, *Voxel-based LIDAR analysis and Applications*, Advisor: David Messinger
- David Kelbe, *Forest Structure from Terrestrial Laser Scanning—In Support of Remote Sensing Calibration/ Validation and Operational Inventory,* Advisor: Jan van Aardt
- Kimberly Kolb, *Single Photon Counting Detectors for Low Light Level Imaging Applications*, Advisor: Donald Figer
- Paul Romanczyk, *Extraction of Vegetation Biophysical Structure from Small-footprint Full-waveform Lidar Signals,* Advisor: Jan van Aardt
- Katie Salvaggio, *A Voxel-Based Approach for Imaging Voids in Three-Dimensional Point Clouds*, Advisor: Carl Salvaggio
- Saugata Sinha, *Photoacoustic Image Analysis for Cancer Detection and Building a Novel Ultrasound Imaging System*, Advisor: Navalgund Rao
- Jiangqin Sun, *Temporal Signature Modeling and Analysis*, Advisor: David Messinger
- Oesa Weaver, *An Analytical Framework for Assessing the Efficacy of Small Satellites in Performing Novel Imaging Missions,* Advisor: John Kerekes
- Jiashu Zhang, *Analytical Modeling and Performance Assessment of Micropulse Photon-counting Lidar System*, Advisor: John Kerekes
- Amanda Ziemann, *A Manifold Learning Approach to Target Detection in High Resolution Hyperspectral Imagery,* Advisor: David Messinger

The following students received an M.S. in Imaging Science.

- Viraj Adduru, *Ultrasound Guided Robot for Human Liver Biopsy Using*

High Intensity Focused Ultrasound for Hemostasis, Advisor: Maria Helguera

- Sean Archer, *Empirical Measurement and Model Validation of Infrared Spectra of Contaminated Surfaces,* Advisor: John Kerekes
- Kevin Bloechl, *A Comparison of Real and simulated Airborne Multisensor Imagery,* Advisor: John Kerekes
- Gregory Fertig, *Evaluation of MOSFETs for Terahertz Detector Arrays*, Advisors: Emmett Ientilucci and Zoran Ninkov
- Colin Fink, *Glint Avoidance and Removal in the Maritime Environment,* Advisor: Michael Gartley
- Katherine Grzedzicki, Advisor: Carl Salvaggio
- Michael Harris, *Supervised Material Classification in Oblique Aerial Imagery Using Gabor Filter Features,* Advisor: David Messinger
- Matthew Heimbueger, Advisor: John Schott
- Christian Lewis, *The Development of a Performance Assessment Methodology for Activity Based Intelligence: A Study of Spatial, Temporal, and Multimodal Considerations,* Advisor: David Messinger
- Ming Li, *Building Model Reconstruction from Point Clouds Derived from Oblique Imagery,* Advisor: John Kerekes
- Matthew Murphy, *Statistical Study of Interplanetary Coronal Mass Ejections with Strong Magnetic Fields,* Advisor: Roger Dube
- Jordyn Stoddard, *Toward Three-Dimensional Reconstruction from Cubesat Imagery: Impacts of Spatial Resolution and SNR on Point Cloud Quality*, Advisor: David Messinger
- Xingchao Yu, *Studies of Gas Absorption in Infrared Spectra of Carbon-rich AGB Stars*, Advisor: Joel Kastner

The following are post-graduate plans for some of the students who graduated during 2014-2015.

- Sean Archer, UTC Aerospace Systems
- Kevin Bloechl, U.S. Government
- Bin Chen, OmniVision Technologies
- Monica Cook, Los Alamos National Laboratory
- Greg Fertig, U.S. Air Force
- Colin Fink, U.S. Air Force
- Rey Garma, U.S. Air Force
- Katherine Grzedzicki, National Geospatial-Intelligence Agency
- Shea Hagstrom, Johns Hopkins University Applied Physics Laboratory
- Michael Harris, Exelis
- Matthew Heimbueger, Laboratory for Laser Energetics, University of Rochester
- David Kelbe, Oak Ridge National Laboratory
- Kimberly Kolb, U.S. Army Research Laboratory
- Christian Lewis, U.S. Air Force
- Matthew Murphy, U.S. Air Force
- Paul Romanczyk, Aerospace Corporation
- Saugata Sinha, Visvesvaray National institute of Technology
- Jordyn Stoddard, U.S. Air Force
- Oesa Weaver, U.S. Air Force
- Jiashu Zhang, Aptina Imaging
- Amanda Ziemann, Los Alamos National Laboratory

First year CIS graduate student co-author on a Nature magazine cover article

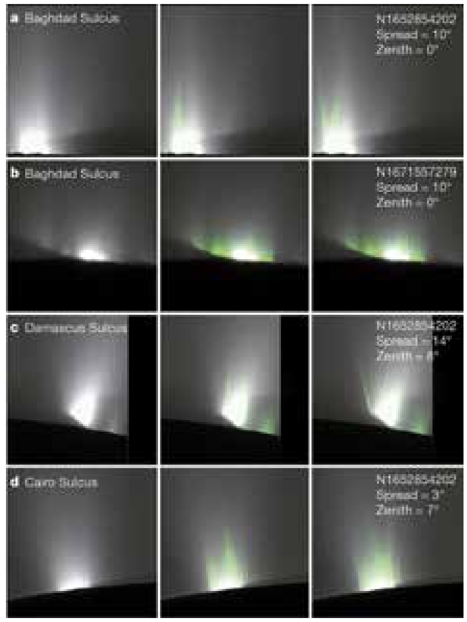
Emily Berkson is co-author on article titled "Curtain eruptions from Enceladus' south-polar terrain"

Curtain Eruptions From Enceladus' South-Polar Terrain

Joseph N. Spitale, Terry A. Hurford, Alyssa R. Rhoden, Emily E. Berkson & Symeon S. Platts

Nature 521,57–60 (07 May 2015), doi:10.1038/nature14368
Received 05 August 2014, Accepted 27 February 2015, Published online 07 May 2015

Abstract:
Observations of the south pole of the Saturnian moon Enceladus revealed large rifts in the south-polar terrain, informally called 'tiger stripes', named Alexandria, Baghdad, Cairo and Damascus Sulci. These fractures have been shown to be the sources of the observed jets of water vapour and icy particles[1, 2, 3, 4] and to exhibit higher temperatures than the surrounding terrain[5, 6]. Subsequent observations have focused on obtaining close-up imaging of this region to better characterize these emissions. Recent work7 examined those newer data sets and used triangulation of discrete jets3 to produce maps of jetting activity at various times. Here we show that much of the eruptive activity can be explained by broad, curtain-like eruptions. Optical illusions in the curtain eruptions resulting from a combination of viewing direction and local fracture geometry produce image features that were probably misinterpreted previously as discrete jets. We present maps of the total emission along the fractures, rather than just the jet-like component, for five times during an approximately one-year period in 2009 and 2010. An accurate picture of the style, timing and spatial distribution of the south-polar eruptions is crucial to evaluating theories for the mechanism controlling the eruptions.



Left-hand column, reference images are shown with no overlays. Middle column, simulated vertical collimated curtains are overlain. Right-hand column, simulated curtains with the indicated spreading and zenith angles are overlain. On Baghdad and Damascus Sulci, the shape of the shadows are more consistent with a spreading curtain than a collimated curtain. In every case, the shape of the observed curtain is consistent with a spreading with altitude. On Damascus Sulcus, the horizontal shadow right of centre is consistent with a fracture not seen in the base map, but which appears in a different Cassini image.

References:

1. Porco, C. C. *et al.* Cassini observes the active south pole of Enceladus. *Science* 311,1393–1401 (2006)
2. Hansen, C. J. *et al.* Enceladus' water vapor plume. *Science* 311, 1422–1425 (2006)
3. Spitale, J. N. & Porco, C. C. Association of the jets of Enceladus with the warmest regions on its south-polar fractures. *Nature* 449, 695–697 (2007)
4. Hansen, C. J. *et al.* Water vapour jets inside the plume of gas leaving Enceladus. *Nature*456, 477–479 (2008)
5. Spencer, J. R. *et al.* Cassini encounters Enceladus: background and the discovery of a south polar hot spot. *Science* 311, 1401–1405 (2006)
6. Howett, C. J. A., Spencer, J. R., Pearl, J. & Segura, M. High heat flow from Enceladus' south polar region measured using 10–600 cm^{-1} Cassini/CIRS data. J. *Geophys.* Res. 116,E03003 (2011)
7. Porco, C. C., DiNino, D. & Nimmo, F. How the geysers, tidal stresses, and thermal emission across the south polar terrain of Enceladus are related. *Astron.* J. 148, 45 (2014)
8. Porco, C. C. *et al.* Cassini imaging science: instrument characteristics and anticipated scientific investigations at Saturn. *Space Sci. Rev.* 115, 363–497 (2004)
9. Roatsch, T. J. *et al. in Saturn from Cassini-Huygens* (eds Dougherty, M. Esposito, L. &Krimigis, S.) 763–781 (Springer, 2009).

Laboratory Director's Comments By Dr. Jan VanAardt

A Year of Exciting Research: Overview

The 2014-2015 academic year was full of exciting developments and activities for the faculty, staff, and students of the Digital Imaging and Remote Sensing Laboratory (DIRS) in the Chester F. Carlson Center for Imaging Science...

DIRS secured significant funding from especially NASA, but also from other agencies and institutions to further remote sensing science via our "imaging chain" approach, i.e., projects that encompass systems, algorithms, and applications.

DIRS activities spanned a range of notable activities; building upon ongoing research in understanding the radiometric behavior of materials through bidirectional reflection distribution function (BRDF) measurements, significant support to the Landsat satellite program for NASA and USGS, and detailed system modeling with our Digital Imaging and Remote Sensing Image Generation (DIRSIG) model plus more. New avenues of research have begun to open looking at imaging applications in the exciting arena of Unmanned Aerial Systems (UAS).

Wiedman Professor in Imaging Science, Dr. Chip Bachmann, in his second year at DIRS has gone from strength-to-strength in bi-directional reflectance distribution function (BRDF) modeling projects. Dr. Bachmann again exposed students to exciting field trips while deploying the GRIT (Goniometer at RIT)—more on that later—and is developing the second generation GRIT, which will include significant refinements in terms of processing power, data acquisition, and portability. A new addition to our team, Dr. Matt Montanaro (Imaging Science alum previously from NASA Goddard) together with Dr. Aaron Gerace, furthered the NASA Landsat and related mission support and calibration work started by Dr. John Schott. Dr. Schott is transitioning to retirement status, but still maintains an active role in the group, thus ensuring continuity in project and expertise related to especially the Landsat project legacy. Much of this work is underscored by a stalwart, ongoing project in DIRS, namely the Digital Imaging and Remote Sensing Image Generation (DIRSIG) tool under the leadership of Dr. Scott Brown.

As has been the case since the inception of DIRS, our students continue to be highly sought after by government and industry alike, with recent MS and PhD alumni obtaining employment in organizations such as the National Geospatial-Intelligence Agency, the National Reconnaissance Office, Exelis, Oak Ridge National Laboratory, Los Alamos National Laboratory, Johns Hopkins Applied Physics Lab, Aerospace Corporation, etc. Discussions also are ongoing with the National Geospatial Intelligence Agency (NGA) and Department of Homeland Security (DHS) to further research collaboration between the various groups and employment opportunities at such institutions. Finally, a variety of DIRS graduate students received prestigious recognition or awards for their research or graduate outputs while at RIT. Dave Kelbe (PhD) was selected as the graduate student commencement speaker for the College of Science, while Jie Yang (PhD) was awarded the Best Remote Sensing Paper during the IEEE Western New York Image and Signal Processing Workshop.

Our faculty and staff did their part in maintaining a high profile locally and internationally. Dr. Emmett Ientilucci served as chair for the local IEEE Geoscience and Remote Sensing Society, Dr. John Kerekes served as ad-com member for the same society, but at the international level, and a variety of faculty and staff served on review panels and science teams for the NSF, IEEE, NASA, etc. Especially notable is that Dr. Matt Montanaro, Ms. Nina Raqueño, Dr. John Schott, and Dr. Aaron Gerace won the "Robert H. Goddard Award for Exceptional Achievement for a Science Team" from NASA for their contributions to the Landsat Calibration/Validation Team, thus flying the DIRS flag as far as Landsat calibration activities are concerned. Dr. Schott also received the John R. Pecora Team Award from the American Society for Photogrammetric Engineering and Remote Sensing (ASPRS) in November 2014, while Dr. Anthony Vodacek was elected as a Senior Member of the IEEE. And then of course, the science itself—by last count and inclusive of summer 2014-May 2015—DIRS has published 15 peer-reviewed journal articles, 25 conference proceedings papers, and four peer-reviewed conference proceedings papers... not a bad tally for an active group.

The following specifically summarizes some of key research activities of DIRS

DIRSIG: Simulating Scenes and Sensors for Remote Sensing Applications

DIRSIG is a first-principles, physics-based simulation environment that is used by government agencies, academic institutions, and companies alike for system development and assessment, algorithm development and refinement, and in general, furthering remote sensing as a science. Dr. Scott Brown and Dr. Adam Goodenough are the main developers of DIRSIG and continuously are immersed in improving on an already highly-valued tool in the remote sensing community. The National Reconnaissance Office (NRO) is supporting the development of a next generation DIRSIG (DIRSIG Version 5), which will boast refined radiometry, an improved user interface, and optimized implementation protocols. This is an exciting development for us as group, especially given the multitude of graduate student projects and related science initiatives that benefit from DIRSIG. Figure DIRS1 shows an example DIRSIG rendering of a power plant as viewed by a panchromatic visible (Pan/VIS), Near Infrared (Near -IR) , and Longwave Infrared (LWIR) sensors.

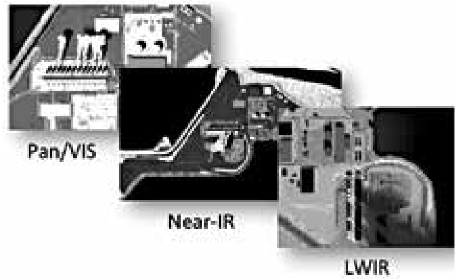


Figure DIRS1: DIRSIG simulation of a power station scene as viewed by three different sensors

GRIT: Measuring Light Reflecting Properties of Materials

The GRIT Laboratory, led by Dr. Bachmann, has had a busy year. In November 2014, Dr. Bachmann presented a keynote address entitled "Hyperspectral Remote Sensing and Characterization of the Coastal Zone," at the University of Sydney's Institute of Photonics and Optical Science IPOS'14 Conference, and an invited talk in September on "Coastal Characaterization from Remote Sensing" at the University of Houston's NSF National Center for Airborne Laser Mapping.

In March 2015, Dr. Bachmann and his students (graduate students Justin Harms and Brittany Ambeau, seniors Doug Peck and Malachi Schultz, and Dr. Carl Salvaggio's graduate student Tyler Carson) participated in a multi-institution calibration and validation experiment, led by South Dakota State University (SDSU) and NASA Goddard in the Algodones Dunes in southern California (Figure DIRS2). Dr. Bachmann and his students fielded GRIT, a hyperspectral goniometer system developed in his laboratory, to record calibration and validation data. GRIT measurements support the development of improved methods to retrieve geophysical parameters which are important to remote sensing; specifically, observed angular dependence of spectral signatures or bi-directional reflectance distribution function (BRDF).

Figure DIRS2. RIT CIS team which participated in the NASA Algodones Dunes experiment in March 2015. (Right) CIS mobile lab provided a base of operations for the hyperspectral GRIT and geotechnical instruments used to record and relate geophysical measurements to GRIT BRDF. (Left) The NASA Goddard G-LiHT sensor overflies the RIT GRIT while GRIT scans a white Spectralon reference panel.

Fixing a Stray Light Problem on the Landsat 8 Thermal Imager

The Thermal Infrared Sensor (TIRS) on board Landsat-8 suffers from a stray light problem that adversely affects image products from the instrument. Work performed at RIT (through a NASA grant) has led to the development of a stray light correction algorithm that drastically reduces the stray light artifacts in the final image products (see Figure DIRS3). The algorithm is a result of a major imaging science effort by RIT personnel to understand the physics and geometry of the problem and to derive a practical solution to be used to correct Landsat images operationally. The RIT algorithm has been implemented into the official United States Geological Survey (USGS) Landsat ground system for testing and will be made operational shortly. An example of stray light correction is shown in Figure DIRS4. The details of the algorithm have been published in the following journal article, "Toward an operational stray light correction for the Landsat 8 Thermal Infrared Sensor", which was published in Applied Optics (Vol. 54, pages 3963-3978) by authors Montanaro, Gerace, and Rohrbach.

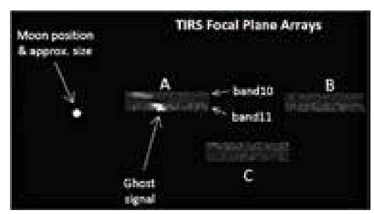


Figure DIRS3: special data collection from the TIRS instrument in which the moon was scanned in the out-of-field area of the instrument and stray light (ghost) signals were detected on the focal plane arrays. [Image credit: Montanaro, M., Gerace, A., Lunsford, A., & Reuter, D. Stray Light Artifacts in Imagery from the Landsat 8 Thermal Infrared Sensor. Remote Sensing, 6, 10435-10456 (2014).]

RIT researchers continue to investigate this approach as well as others to gain a better understanding of the sources of stray light in TIRS and further refine the stray light correction. These investigations address tradeoffs in radiometric accuracy and operational complexity. One approach considers the use of near contemporaneous data from other satellites such as NOAA's GOES or NASA's MODIS to provide high fidelity estimates of stray light contributions to the TIRS signal.

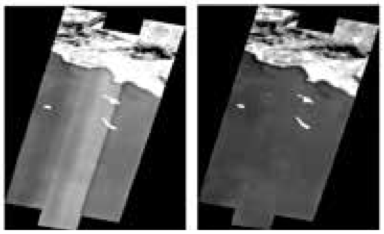


Figure DIRS4: Early example of TIRS imagery with RIT's stray light correction, original (L), corrected (R) . [Image credit: Montanaro, M., Gerace, A., Lunsford, A., & Reuter, D. Stray Light Artifacts in Imagery from the Landsat 8 Thermal Infrared Sensor. Remote Sensing, 6, 10435-10456 (2014).]

Using DIRSIG to better understand the NASA SOLARIS sensor platform

NASA Goddard's SOLARIS (Solar, Lunar for Absolute Reflectance Imaging Spectroradiometer) sensor is the calibration demonstration system for CLARREO (Climate Absolute Radiance and Refractivity Observatory), a mission that addresses the need to make highly accurate observations of long-term climate change trends. The SOLARIS instrument will be designed to support a primary objective of CLARREO, which is to advance the accuracy of absolute calibration for space borne instruments in the reflected solar wavelengths. Dr. Aaron Gerace's work focuses on the development of a simulated environment to facilitate sensor trade studies to support instrument design and build of the SOLARIS sensor. Details of the results to date have been published in the following conference proceedings paper, "The development of a DIRSIG simulation environment to support instrument trade studies for the SOLARIS sensor" (Proceedings of SPIE 9472, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXI, May 21, 2015), by authors Gerace, Goodenough, Montanaro, Yang, McCorkel, and Ong.

Calibration and Assessment of the Landsat Sensors Thermal Calibration Automation

The Landsat program represents the longest continuous record of observations of the Earth from space. As a result the Landsat data represents a unique ongoing opportunity to study both the current conditions and the evolution of the Earth over Landsat's 42 years history. If effectively calibrated this allows us to look at not only the state of the planet but also to study processes taking place over time. We don't have to start a study today and wait 20 or 30 years for the study site to evolve. Rather, we can look back in time and look at what the impact of various forcing functions has been.

A fundamental critical enabler for these types of study is a consistent calibrated data set. The Digital Imaging and Remote Sensing (DIRS) laboratory at the Rochester Institute of Technology (RIT) has been helping to calibrate Landsat Instruments since the 1980's. Over that period RIT's vicarious thermal infrared calibration methods have evolved to provide more accurate and less field intensive approaches. Most recently this has focused on the development of semiautonomous approaches to thermal calibration that utilize moored ocean buoys coupled to in-water thermodynamic and atmospheric radiative transfer models to produce top of the atmosphere (TOA) sensor reaching radiance estimates. These values can then be compared to satellite observed radiance values and used to evaluate and, if necessary, correct the instrument calibrations. RIT derived calibration approaches have been used to support calibration of Landsats 4, 5, 7 and 8.

This task continues research into the automation of thermal band calibration for the Landsat archive and the operational satellites. It focuses on increasing the number of NOAA buoys used in the process, the stability of a calibration analysis tool, and application of the analysis tool to monitor data from the buoys.

For more than 15 years RIT has provided the NASA/USGS Landsat Calibration Team with critical data on the their thermal instrument performance. This year RIT has continued to monitor the performance of the Landsat 7 and 8 instruments using an automated buoy calibration process that utilizes NOAA's existing buoys for water temperature truth. The extensive array of buoys used for calibration is illustrated in Figure DIRS5.

Throughout it's 16 year lifespan, Landsat 7 thermal band has proven to be a reliable and extremely stable instrument. The average error between buoy truth and Landsat predicted is 0.1 Kelvin with a standard deviation of 0.4 Kelvin.

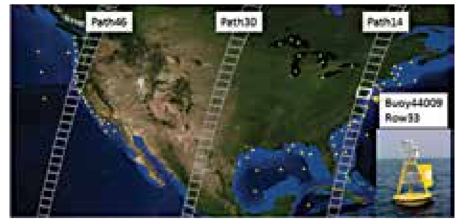


Figure DIRS5: Array of buoys used for thermal calibration of Landsat

Measuring Land Surface Temperature from Space

Land Surface Temperature (LST), in a simple sense, is how hot the ground feels to the touch. People involved in weather prediction, climate research, or even agriculture could benefit from a product or archive that provides the LST at any point in the world at any time, dating back as far as possible.

Currently, the LST process has been validated for Landsat 5 for North American sites, with a mean error of -0.267 Kelvin for cloud free scenes. Validation on a global scale and for more recent Landsat instruments (7 and 8) are underway. An example scenario is shown in Figure DIRS6 for a buoy on Lake Ontario. Another goal is to be able to provide a confidence metric that will indicate how trustworthy the LST results are, which will mostly depend upon cloud cover because it often causes Landsat to predict erroneously low temperatures. Once all these steps are completed and the process continues to show low error levels, it will be combined with an emissivity product produced by NASA JPL so that LST maps for every Landsat scene can be generated and accessed by the public.

Figure DIRS6. An example of a Landsat image of Lake Ontario with a buoy in the scene (the red triangle indicates the buoy location). The temperature at the buoy location is estimated using the LST process and is compared to the buoy measurement that was taken at the time of acquisition.

Retrieval of color producing agents in Case 2 waters using Landsat 8

This project, sponsored by USGS, takes advantage of Landsat 8's features for the retrieval of color producing agents (CPAs: chlorophyll-a, colored dissolved organic matter (CDOM) and sediments (TSS)) over inland and coastal waters. Landsat 8 provides an improved signal-to-noise ratio (SNR) and a new spectral coastal aerosol band in the blue. A look-up-table (LUT) and spectrum-matching methodology was implemented to simultaneously retrieve CPAs, taking advantage of Landsat 8's new features. A LUT of spectral remote-sensing reflectances (Rrs) with different concentration of CPAs was produced using the in-water radiative transfer model Hydrolight. A model-based empirical line method (MoB-ELM) algorithm was developed to atmospherically correct the Landsat 8 imagery and allow direct comparison with the LUT of Rrs. The retrieval algorithm was applied over two Landsat 8 scenes and shows a root mean squared error (RMSE) as a percentage of range of about 10% for Chlorophyll-a and total suspended solid (TSS), and about 5% for colored dissolved organic matter (CDOM) when compared with ground-truth data. The CPA concentration maps exhibit expected trends of low concentrations in clear water and higher concentrations in turbid water. Figure DIRS7 shows a concentration map for TSS over the Rochester Embayment for the Landsat 8 image acquired on 09-29-2013. Red areas indicate areas of elevated TSS concentrations in ponds relative to the open waters of Lake Ontario.

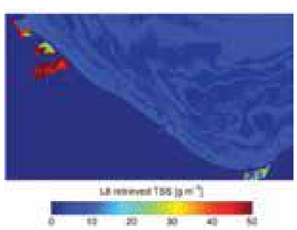


Figure DIRS7: concentration map for TSS over the Rochester Embayment for the Landsat 8 image acquired on 09-29-2013

Evaluation of multi-sensor constellations for long term resource monitoring

Moderate resolution remote sensing data offers the potential to monitor the long and short-term trends in the condition of the Earth's resources at finer spatial scales and over longer time periods. With improved calibrations (radiometric and geometric), free access (Landsat, Sentinel, CBERS), and higher-level products in reflectance units makes it easier for the science community to derive biophysical parameters from these remotely sensed data. In spite of all these improvements, a number of issues still affect the analysis of multi-temporal data sets. These are primarily due to the process of imaging from multiple sensors. Some of these undesired or uncompensated sources of variation includes variation in view angle, variation in the illumination angle, atmospheric effects, sensor effects such as Relative Spectral Response (RSR) (for more than one sensor). The complex interaction of these sources would make this type of study extremely difficult with the real data. The approach is to build a synthetic scene (forest canopy) using DIRSIG model. The anisotropic reflectance characteristics of forest canopy can be defined by its bi-directional reflectance distribution function. Using DIRSIG, the forest canopy's BRDF can be measured and modeled using existing canopy reflectance models. An example of forest scene modeled in DIRSIG is shown in Figure DIRS8. To understand the significance of the sources of variation and their relative magnitude, a factorial design experiment will be designed using DIRSIG as the experimental engine. Using the response surface methodology, the relative sensitivity of the observed reflectance to the sources of variation will be analyzed.

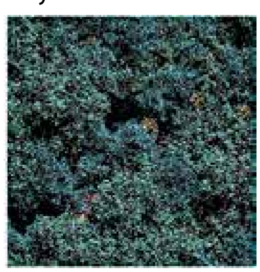


Figure DIRS8: Synthetic image of trees modeled DIRSIG as viewed by a sensor from 12 degree zenith when sun was at 23 degree zenith with approximate ground resolution of 10cm.

Sentinel II + Landsat Data Modeling

RIT is currently studying the impact sensor/acquisition differences between Landsat and the European Space Agency's Sentinel II would have on analysis of data from such a constellation. The current work focuses on detailed modeling of the spectral and bidirectional reflectance properties of forest canopies. The modeling of the canopy and the sensors (including spatial, spectral and radiometric properties) is performed with the Digital Imaging and Remote Sensing Image Generation (DIRSIG) model. The model allows the inclusion of illumination, atmospheric, orbit and acquisition geometry effects, as well as, a wide range of detector element specific variations associated with actual sensor systems (e.g. spectral, gain, and bias variation and drift and noise)

This task includes a wide range of land cover types and puts emphasis of the impact of spectral and BRDF variability on analysis of data from a Landsat-Sentinel II Constellation. To accomplish this, Hyperion spectral data is merged with MODIS BRDF data and topographic data to generate DIRSIG scenes. The high resolution spatial data (e.g. DigitalGlobe) will be used for land cover classification and texture mapping, while BRDF model coefficients derived from MODIS BRDF product will be used in combination with hyperspectral data for estimating spectral BRDF model coefficients. Once a scene is assembled, Sentinel II and Landsat 7 & 8 sensors can be "flown" over the scene and simulated data with varying illumination, atmospheric and view geometries can be acquired. These data can then be used to develop and test algorithms designed to normalize/remove the differences due to sensor view and spectral response differences. Figure DIRS9 illustrates the the synthetic image process using different datasets (DEM, texture image, hyperspectral data, MODIS BRDF product, classification map).

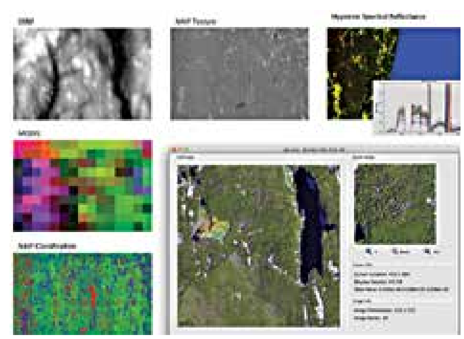


Figure DIRS9: The synthetic image generation process using different datasets

Next Generation Land Remote Sensing Systems Engineering Support

This project assists the Landsat program office with the modeling and analysis of various concepts for Land Imaging using the DIRSIG simulation tool. The goal is to bridge the gap between instrument/satellite concepts and understanding their efficacy for various applications. This systems engineering support will aid in the development of system requirements, analysis of various concepts, and evaluation of issues during hardware development. Figure DIRS10 shows a DIRSIG simulation of Lake Tahoe with additional target patterns inserted to evaluate the effects of design parameters of future Landsat sensors.

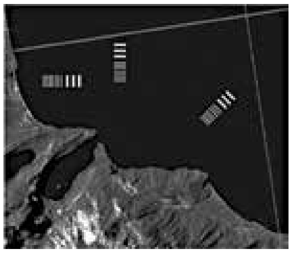


Figure DIRS10: Synthetic DIRSIG image of Lake Tahoe with patterned targets inserted to study future Landsat design performance

Out of Africa... using time series of pan-sharpened Landsat data for agricultural development projects in Rwanda

One of the oldest application areas of remote sensing is agricultural monitoring. Estimating crop yields is often the goal that is achieved by combining time series data of remotely sensed vegetation health, rainfall, temperatures, etc. in predictive models. However, yield modeling for the futures market is very difficult in many tropical developing countries with small plot sizes, hilly terrain, seasonal cloudiness, a wide variety of crops, and little access to ancillary data. Here, the goal of development impact monitoring is to quantify the impact of the money spent on development projects for understanding the highest impact interventions. In Rwanda, Dr. Anthony Vodacek has been collaborating with a World Bank group to assess the use of remote sensing in monitoring agricultural development projects. PhD student Bikash Basnet has been using pan-sharpened Landsat-8 data to observe change at one of the World Bank supported projects. Some example images of the project site demonstrate the potential for monitoring these sites (Figure DIRS11). Another World Bank supported project in Rwanda is the building of rural feeder roads to provide farmers better access to markets. MS student Donath Uwanyirigira, who is from Rwanda, will investigate this application of pan-sharpened Landsat data for his MS research.

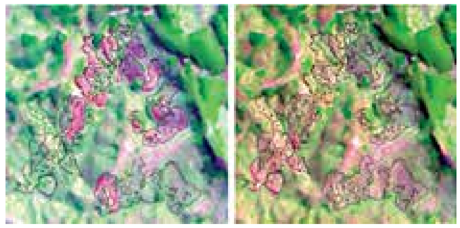


Figure DIRS11. Landsat-8 false color images of an irrigation project in western Rwanda during terrace construction. Black lines are GPS generated ground truth for project boundaries obtained from a project manager. The left image was obtained 13 June 2013 and the right image was obtained 1 August 2014. Dark green is trees, light green is crops, and magenta is soil or other bare land including bare soil near concentrated dwellings. The progression of the construction of the terraces can be found by comparing the two images.

Trees in 3D—our involvement with the National Ecological Observatory Network (NEON)

Dr. Jan van Aardt and a brain trust of graduate students have been extensively involved with NEON in building data processing chains, investigating structural algorithms, and developing calibration-validation tools for NEON's Airborne Observation Platform (AOP) waveform light detection and ranging (lidar) instrument. To this end the group has published numerous conference and peer-reviewed papers, have received NEON funding for two post-doctoral researchers at RIT to spearhead this effort, and have three PhD current/past projects and two past MS projects aligned to the work, based on complementary NSF and NASA funding. Past students William Wu (PhD; processing chain development for waveform lidar; now with Apple Inc.), Joe McGlinchy (MS; extracting structural vegetation components from waveform lidar; now with ESRI), and Diane Sarrazin (MS; species classification based on fusion of imaging spectroscopy and lidar data; now with Canadian Air Force) have laid the groundwork for our NEON-related research. This work has been solidified by efforts from Dr. Kerry Cawse-Nicholson (post-doctoral researcher; understanding how waveform lidar signals propagate through the canopy), Dr. Martin van Leeuwen (post-doctoral researcher; extracting leaf properties from waveform lidar), Dave Kelbe (PhD; terrestrial lidar algorithms for forest structure), and Paul Romanczyk (PhD; simulation of waveform lidar towards measuring forest canopy structure). Examples of this structural of 3D research are shown in Figure DIRS12.

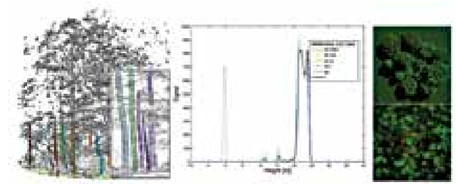


Figure DIRS12. Examples of our 3D structural assessment work in support of NEON activities. (L) a TLS point cloud is used by Dave Kelbe (PhD) to extract tree stems, after which multiple scans are registered to each other based on stem tie points. This research will aid in forest inventory, calibration-validation of airborne remote sensing assessments, and to develop virtual scenes, based on real scans, for use in DIRSIG simulations. (R) Paul Romanczyk, a PhD student, is using DIRSIG to better understand the structural complexity that can be assessed via waveform lidar signals.

Continuing the DIRS legacy in remote sensing for improved disaster response

In the 2009-2010 timeframe, DIRS developed a NSF Partnerships for Innovation (PFI) project with the intent to bridge the gap between disaster response practitioners and researchers. RIT was able to respond to the 2010 Haiti earthquake based on networks, skill sets, and imaging science expertise developed during the grant. This PFI project has led to approximately $1.7m of directly- and indirectly related spin-off projects, among which a NSF Science Master Program (SMP), a Google grant, and a Department of Homeland Security (DHS) award, among others. The latest example is our collaboration with Rensselaer Polytechnic Institute (RPI; Dr. José Holguin-Veras), where Dr. Jan van Aardt's students are working on remote sensing assessments of disaster-impacted infrastructure, and RPI is using our inputs for trafficability modeling—the goal is improved access restoration, or in other words, enabling emergency responders to reach people in need via either existing routing options, or by opening new routes via optimized selection. PhD student Colin Axel is using high spatial resolution imagery and discrete return lidar data to automatically extract roadways, assess their condition, map and quantify debris, and also assess building damage (see Figure DIRS13). The output maps then serve as inputs to RPI's network modeling research. This applied research effort has led to multiple research, application, and training opportunities.

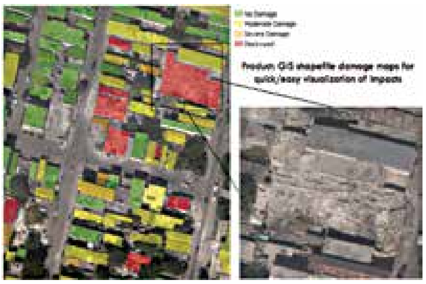


Figure DIRS13. Examples of disaster response products that Colin Axel (PhD student) is developing using the fusion of high spatial resolution color imagery and discrete lidar sensing. (Top) A building damage assessment map, developed using lidar metrics

3D Building Model Extraction from Imagery

Building on past innovations from the DIRS lab, a current effort is underway to improve and streamline the extraction of three dimensional building geometries from a suite of different co-registered imaging data sources, such as optical, LiDAR, or graphical maps. These disparate data sources will be displayed in an immersive virtual reality environment, allowing users to navigate, explore, and even query data on individual buildings on an intuitive and accessible platform like Google Earth. The ability to co-register different imagery sources allows a user to toggle between thermal and optical displays, for example, in order to extract as much information as possible from a scene. The building models created with this technique can also provide the necessary input data for DIRSIG, a program developed here at RIT for generating simulated scenes using different modalities, lighting, or atmospheric conditions.

This technology promises to aid both the intelligence and disaster communities. For example, individual building characteristics, such as structure elevation and construction material, can be automatically assessed and collected across an entire region. These data can be used to improve predictive catastrophe models and aid post-disaster response efforts. Figure DIRS14 shows a schematic rendering of three-dimensional building models generated from imagery data. Note that the scene excludes terrain and foliage. The orange highlighted structures demonstrate the capability to automatically identify building characteristics.

Figure DIRS14: Schematic rendering of three dimensional building models generated from imagery data.

Fuel Consumption and Carbon cycling in northern peatland ecosystems: Understanding vulnerability to burning, fuel consumption, and emissions

Peatland ecosystems represent 3-5% of the land surface, but sequester 12-30% of soil organic carbon. Current trends and climate models predict a general pattern of decreased water availability as a likely outcome of climate change. These climate changes can lead to increased amplitude of water table variation, including large mid-summer declines in water table height. Although peatlands have conventionally been considered resistant to wildfire due to their relatively wet soil conditions, recent studies have shown that the extent of wildfires in boreal North America, where peat fuels are common, has been steadily increasing in recent decades. Our role in this research was to quantify the radiant and convective heat release from these fires and to obtain an estimate of combustion efficiency by measuring the ratio of CO_2/CO in the fire.

The last of the prescribed fires associated with this project were conducted in the upper peninsula of Michigan at the 90,000 acre Seney National Wildlife Refuge (SNWR). Six to ten instrument packages, built entirely at RIT by undergraduate students, were deployed on the fires mounted on 5.5m tall aluminum masts. We are still correlating the results of these experiments with other data inputs to determine the relationship between fuel moisture, sub fuel moisture, fire effects and fire penetration in the boggy areas and uplands. Figure DIRS15 shows some initial radiant flux density data obtained at two widely different vegetation and fuel loading sites within the fireground.

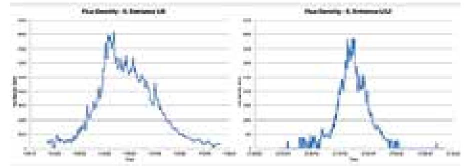


Figure DIRS15: Plots of the surface-leaving total flux density for a bog (left) and upland (right) site at SNWR. The forested plot had twice peak flux density and about 3 times the total energy compared to the peat bog area. This is to be expected considering the fuel loads and moisture in the different areas of the fireground.

Benchmarking LiDAR Fuel Load Estimates, Heat Release and Ground-Measured Fuel Loads

A general and systematic approach of evaluating fuel treatment effectiveness is still to be built and applied as a guideline for the services in charge of conducting these activities in the field. The project will addresses a series of general questions:

a. What changes do fuels management treatments cause to three dimensional structure and loading?

b. What defines effective fuel reduction with regard to fire intensity?

c. What techniques or methods effectively cause a change in fire behavior that would increase forest safety in the wildland urban interface using a minimum of resources?

RIT's mission in this 3 year experiment was to:

- o Collect and analyze airborne infrared and visible imagery using the WASP data collection system, provide airborne LIDAR before and after the fire to assess changes in forest structure, fuel loading and arrangement
- o Measure the radiant and convective energy flows at many (~12) locations in the fire ground
- o Measure the vertical temperature profile in active fire to better define the convective flows and coupling to fire-atmosphere weather models
- o Install the equipment in the fireground.
- o Provide ground support during the fire as part of the ignition and control team.

The 'Ex3' fire this year was planned to be of moderate intensity and all the instruments and airborne systems performed well. Additionally, we constructed and deployed 12 fire-triggered video cameras. These cameras were used by other researchers to record ember distribution and pre-frontal ignition, fire spread rate and behavior, and to observe the rising smoke plume. Several mosaic frames of infrared imagery are shown in Figure DIRS16. This is the last planned deployment of the WASP camera system, having successfully collected data for 31 fires. We believe that we have the largest collection of highly time-resolved high spatial resolution infrared imagery in the world, and we plan to exploit this data set in the future.

Figure DIRS16—Two long-wave infrared images of the Ex3 fire taken with the WASP instrument. [L] is early in the fire with active fire (brighter red/white) while [R] is a creeping ground fire that resulted from ignitions on several sides of the fire control line.

Unmanned Aerial Systems

DIRS is in the forefront of the emerging application area of Unmanned Aerial Systems (UAS). We are witnessing an explosive growth in the use of UAS for personal and commercial applications driven by a confluence of technical capabilities and market forces that rivals the early days of the personal computer and cellular phone.

In addition to the technology required for UAS flight operations, imaging systems and information derived from imagery are the most prominent enablers to applications using UAS platforms. Practically every UAS produced carries an imager of some kind for some purpose.

DIRS is currently engaged in research for using UAS imaging for a variety of applications including determining the characteristics of construction materials and precision agriculture. For sure there will be more to report on this in next year's report.

In Conclusion

Hopefully this summary provided you as reader with a good overview of what we have been up to as faculty, staff, and students within the Digital Imaging and Remote Sensing Laboratory here in the Chester F. Carlson Center for Imaging Science during the 2014–2015 period. There are many exciting developments, ranging from Unmanned Aerial Systems (UAS) and DIRSIG V.5 activities, to projects specific to each individual investigator. We look forward to collaborating within the Center and College of Science, across RIT colleges, and with external researchers towards advancing the field of remote sensing, from sensors… to algorithms… to applications!

Professor Zoran Ninkov and his students in their lab.

LABORATORY FOR ADVANCED INSTRUMENTATION RESEARCH (LAIR)

Laboratory Director's Comments By Dr. Zoran Ninkov

The Laboratory for Advanced Instrumentation Research is dedicated to;

(a) the development of novel and innovative instruments for gathering data from a wide variety of physical phenomena

(b) the training of the next generation of instrument scientists who will occupy positions in government, industry and academia.

LAIR utilizes the excellent infrastructure facilities available at RIT including the Semiconductor and Microsystems Fabrication Laboratory, the Center for Electronics Manufacturing and Assembly, and the Center for Detectors.

A wide variety of instruments have been developed at RIT over the last twenty years including digital radiography systems, liquid crystal filter based imaging systems for airborne (UAV) mine detection, a speckle imaging camera for the WIYN 3.6 meter telescope, a MEMS digital micromirror based multi-object spectrometer, and an X-ray imaging systems for laser fusion research. This research has been funded by NASA, the NSF, NYSTAR and a variety of corporations such as Exelis, ITT, Kodak, Moxtek and ThermoFisher Scientific.

Graduate Students 2014-15:

Dmitry Vorobiev
Greg Fertig
Kevan Donlan
Chao Zhang
Katie Seery
Sahil Pravin Bhandari
Ross Robinson
Bryan Fodness
Kyle Ryan
Jack Horowitz
Anton Travinsky

Undergraduate Students 2014-15:

Ryan LaClair

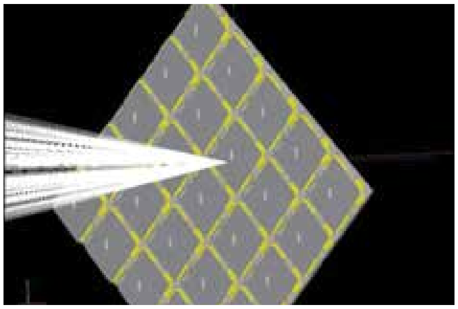
Lauren Morehouse (REU)

Descriptions of some of the current research projects are listed below:

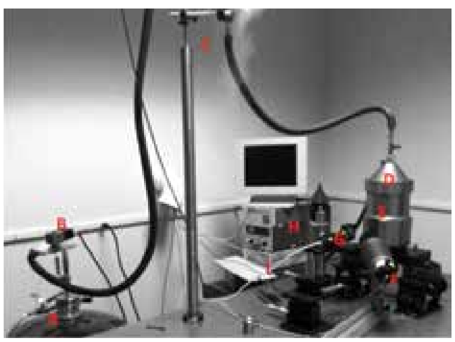
1. Studies of the optical properties of TI DMDs and the development of a multi-object spectrometer

The Digital Micromirror Device (DMD) built by Texas Instruments is the device used as the optical slit mask in the RITMOS Multi-Object Spectrometer. RITMOS was designed to record the spectra of multiple stars within the field of view. The instrument has been improved, with newly written software and a new imaging camera. The 2010 Astronomy Decadal Survey's leading suggestion for space instrumentation is a wide field IR Space Telescope which will require a multi-object spectrograph to accomplish its science goals. Other space based missions requiring multi-object spectroscopy capability have been proposed, including for the ultraviolet. There have been four key aspects of the performance of DMDs that have been questioned for use in a MOS for space. We have attempted to address each of these.

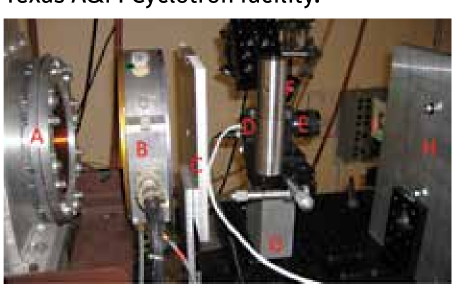
(1) To assess the light scattering properties of DMDs. a spot scanning system has been assembled that accurately translates a spot of light across the DMD and measures the scattered light across the mirror, at the central via, and at the edges of the individual mirrors.



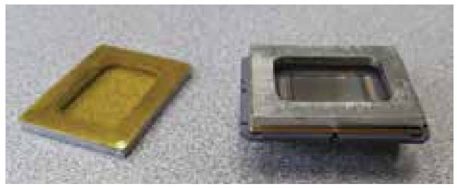
(2) For use in the infrared it is required that DMDs operate at cooled temperatures. The test configuration seen below in the laboratory at RIT showed that normal operation of these devices was able to carried out to a temperature of 130K. This was the limit of how cold the DMD could be cooled by the configuration and did not reflect a failure on the DMD.



(3) The radiation hardness of the DMD. Tests were conducted using the Lawrence Berkeley National Laboratory 88" Cyclotron to irradiated the DMDs with high energy protons. The tests showed that the DMDs worked well when exposed to a dose equivalent to that found at an L2 orbit over a period of five years. A picture of the test configuration at the end of the proton beam line is shown in the figure. Further radiation tests using heavy ions are planned at the Texas A&M Cyclotron facility.

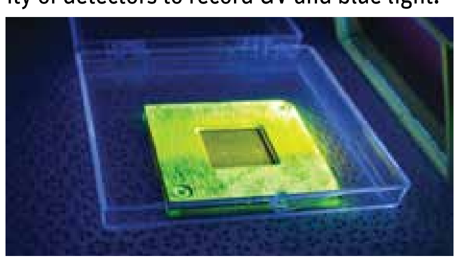


(4) The DMDs are supplied by Texas Instruments with a protective borosilicate glass window. This glass limits the range of wavelengths that the device can be used for. We are currently working on removing these windows and repacking the devices with windows that are transmissive in the ultraviolet. Initially we are using magnesium fluoride and HEM Sapphire as the replacement window material A DMD with part of the protective package removed is shown below. The window material on the right is kapton and that on the left is a thin commercial pellicle.

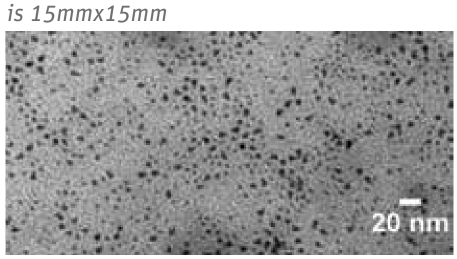


2. Enhancing Focal Plane Array Quantum Efficiency with Quantum Dots

There are many interesting things to see in the ultraviolet (UV). Lithography for integrated circuit production is exposed with 193nm light, honey bees' view of flowers include the UV region and analytical instruments use UV emissions to identify materials. Current silicon CMOS or CCD based detectors used in standard digital cameras do a poor job of recording UV images. The ability to detect UV light may be improved by switching to exotic materials or by polishing the detector until it is so thin that it is flexible and almost transparent. Both of those options are very expensive to fabricate. A different approach is to apply a coating of nanometer-scale materials to the surface of a detector chip to convert the incoming UV light is to visible light which is more readily recorded by standard detector chips. This research has developed a method of coating detector arrays with nano materials and applied it to improve the ability of detectors to record UV and blue light.



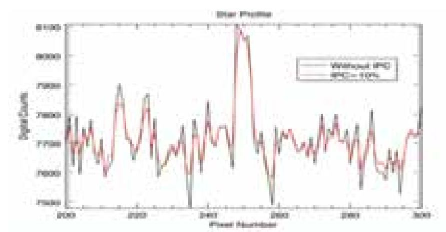
Quantum Dot coated detector in aluminum mask under UV illumination. The active area is 15mmx15mm



TEM image of thin quantum dot film showing well distributed individual dots on an array.

3. The effect of IPC on Astronomical Imaging Systems

The effect of interpixel capacitance (IPC) on images captured by infrared sensors was first identified by a PhD student at RIT, Drew Moore. Now that this effect has been characterized, research has focused on investigating how IPC affects photometry. IPC acts as a smoothing filter, by spreading out the signal of each pixel into the neighboring pixels and also affects the normal assumptions about the relationship between noise and signal. Astronomers commonly use a method of photometry called aperture photometry which is compromised by IPC effects. For isolated stars the effect is small. Continuing research will explorer IPC effects on diffraction limited imagery, such as on the James Webb Space Telescope, as well as in crowded fields.



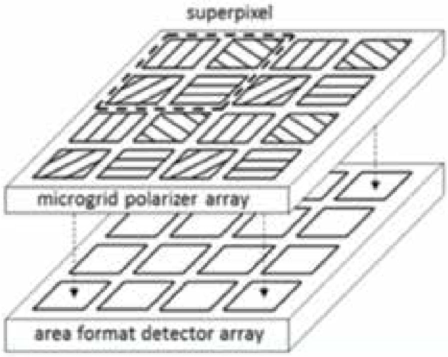
Shows the smoothing features of an IPC coupling at 10% on star and image noise (dark dominated).

4. Imaging Polarimetry

Imaging polarimeters utilizing the division-of-focal technique present unique challenges during the data reduction process. Because an image is formed directly on the polarizing optic, each pixel "sees" a different part of the scene; this problem is analogous to the challenges in color restoration that arise with the use of Bayer filters.

Although polarization is an inherent property of light, the vast majority of light sensors (including bolometers, semiconductor devices and photographic emulsions) are only able to measure the intensity of incident radiation. A polarimeter measures the polarization of the electromagnetic field by converting differences in polarization into differences in intensity. The microgrid polarizer array (MGPA) divides the focal plane into an array of superpixels. Each sub-pixel samples the electric field along a different direction, polarizing the light that passes through it and modulating the intensity according to the polarization of the light and the orientation of the polarizer.

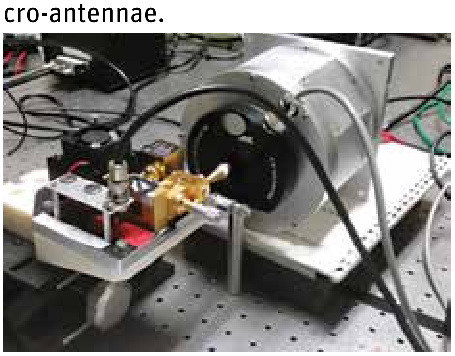
We are actively looking at techniques for hybridizing microgrid polarizer arrays to commercial CID, CCD and CMOS arrays.



A polarimeter using an MGPA. The light passing through a single polarizer is collected by a single pixel.

(5) THz Imaging

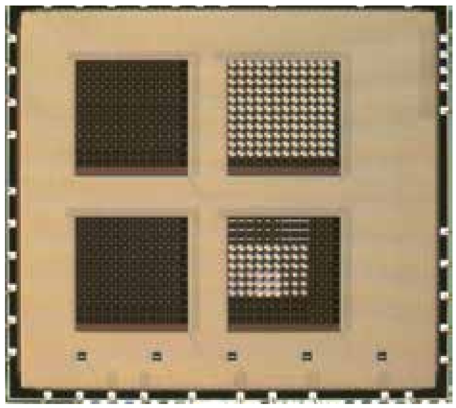
A silicon CMOS based array purposed for the terahertz regime has promising applications for many fields including security screening, manufacturing process monitoring, communications, and medicine. Current systems mainly consist of bulky technology, including large pulsed laser systems and are primarily laboratory based setups. A silicon CMOS based technology was chosen in order to eventually develop a compact, portable, practical imaging system. A large amount of recent research has been conducted regarding the detection of terahertz using silicon MOSFETs. The THz focal plane technology being tested is uncooled and employs direct overdamped, plasmonic detection with silicon CMOS MOSFETs that are each coupled to an individual micro-antennae.



A photo of experimental setup is shown above. The Gunn Diode source is on the left(1), followed by the shutter(2), and the test enclosure(3). The enclosure is mounted on XYZ and rotation stages for alignment of the MOSFET of interest with the source. Response is viewed in real-time for alignment with a source measurement instrument, or a lock-in amplifier (Drain bias current, Id not available when using the lock-in.

Chip Description

The chip used in these experiments was a custom designed and fabricated in a 0.35 μm silicon CMOS process using the MOSIS facility. On the chip are four test imager arrays and five test transistors. These 'test' transistors can be connected directly to outputs for characterization without clocking electronics. Our work has focused on characterizing the response from these five test transistors. The figure below shows a micrograph of the test chip with the test transistors located on the bottom edge.

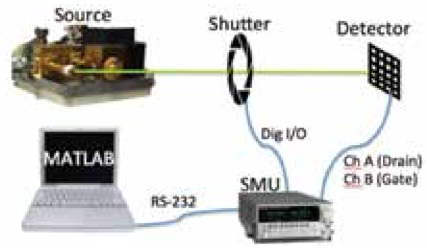


Current generation MOSIS devices. Five test structures are seen along the bottom.

MOSIS test chip on fan-out board mounted in test housing.

Test Description

The transistors were biased using a Keithley 2602 Source Measurement Unit (SMU) which connects to the test enclosure via low noise shielded twisted pair cables. The enclosure creates a Faraday cage around the fan-out board and test chip, and the connections are fed through the box with feed-through capacitors to reduce as much RF noise as possible. A removable high resistivity silicon window on the front of the enclosure precedes a high speed shutter which is controlled via digital I/O from the Keithley. The enclosure is mounted on XYZ and rotation stages for alignment purposes. The Keithley is commanded via a MATLAB serial interface for applying bias sweeps and relaying data. The radiation source is a ≈ 5 mW 188 GHz Gunn diode from Virginia Diodes. An illustration of the experimental setup is shown below.



Schematic of laboratory experimental setup

Patent

Robinson R. and Ninkov Z. [2010]

Enhancing Focal Plane Array Quantum Efficiency with Quantum Dots

US Patent Application Serial Number 12/655,350

PCT International Patent Application Number PCT/US10/62159

Sample Publications

1. Optical simulation of terahertz antenna using finite difference time domain method

Chao Zhang (Carlson Center for Imaging Sci., Rochester Inst. of Technol., Rochester, NY, United States); Ninkov, Z.; Fertig, G.; Kremens, R.; Sacco, A.; Newman, D.; Fourspring, K.; Lee, P.; Ignjatovic, Z.; Pipher, J.; McMurtry, C.; Dayalu, J. Source: Proceedings of the SPIE, v 9483, p 94830D (11 pp.), 2015

2. Transmission imaging measurements at 188 GHz with 0.35μm CMOS technology

Sacco, A.P. (Exelis Geospatial Syst., Rochester, NY, United States); Newman, J.D.; Lee, P.P.K.; Fourspring, K.D.; Osborn, J.H.; Fiete, R.D.; Bocko, M.V.; Ignjatovic, Z.; Pipher, J.L.; McMurtry, C.W.; Xi-Cheng Zhang; Dayalu, J.; Seery, K.; Chao Zhang; Bhandari, S.; Ninkov, Z. Source: Proceedings of the SPIE, v 9483, p 94830U (7 pp.), 2015

3. Design, fabrication and characterization of a polarization-sensitive focal plane array

Vorobiev, Dmitry (Rochester Institute of Technology, Center for Imaging Science, 54 Lomb Memorial Dr, Rochester; NY, United States); Ninkov, Zoran Source: Proceedings of SPIE -

The International Society for Optical Engineering, v 9403, 2015

4. Design, fabrication and characterization of a polarization-sensitive focal plane array

Vorobiev, D. (Center for Imaging Sci., Rochester Inst. of Technol., Rochester, NY, United States); Ninkov, Z. Source: Proceedings of the SPIE, v 9403, p 94030A (12 pp.), 2015

5.Polarization in a snap: Imaging polarimetry with micropolarizer arrays

Vorobiev, Dmitry (Center for Imaging Science, Rochester Institute of Technology, 54 Lomb Memorial Drive, Rochester NY, 14623, United States); Ninkov, Zoran; Gartley, Michael Source: Proceedings of SPIE - The International Society for Optical Engineering, v 9099, 2014, Polarization: Measurement, Analysis, and Remote Sensing XI

6. T-ray detection in 0.35-µm CMOS technology

Fertig, Gregory J. (Rochester Institute of Technology, Carlson Center for Imaging Science, Rochester, NY 14623, United States); Ninkov, Zoran; Bocko, Mark F.; Dayalu, Jagannath; Fourspring, Kenny D.; Ignjatovic, Zeljko; Lee, Paul P. K.; McMurtry, Craig W.; Newman, J. Daniel; Pipher, Judith L.; Sacco, Andrew P.; Zhang, Chao Source: Proceedings of SPIE - The International Society for Optical Engineering, v 9102, 2014, Terahertz Physics, Devices, and Systems VIII: Advanced Applications in Industry and Defense

7. THz imaging Si MOSFET system design at 215 GHz

Sacco, Andrew P. (Exelis Geospatial Systems, Rochester NY 14606, United States); Newman, J. Daniel; Lee, Paul P. K.; Fourspring, Kenneth D.; Osborn, John H.; Fiete, Robert D.; Bocko, Mark F.; Ignjatovic, Zeljko; Pipher, Judith L.; McMurtry, Craig W.; Zhang, Xi-Cheng; Dayalu, Jagannath; Fertig, Gregory J.; Zhang, Chao; Ninkov, Zoran Source: Proceedings of SPIE - The International Society for Optical Engineering, v 9102, 2014, Terahertz Physics, Devices, and Systems VIII: Advanced Applications in Industry and Defense

MULTIDISCIPLINARY VISION RESEARCH LABORATORY

Laboratory Director's Comments By Dr. Jeff Pelz

The MVRL continues to grow as Dr. Christopher Kanan joins the group this Fall. The Kanan Lab focuses on the development and application of brain-inspired algorithms for machine perception.

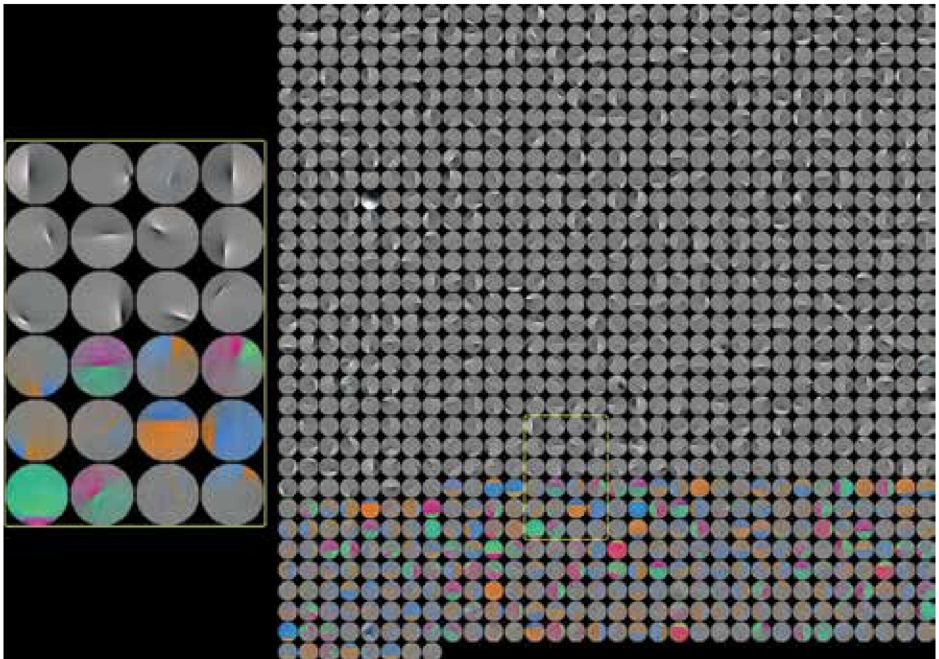
The goal is to identify the algorithms that underlie human perception and to leverage these algorithms for the purpose of computational image understanding and fine-grained object recognition. A central theme of Dr. Kanan's research has been studying how humans move their eyes during goal-directed activities. By analyzing eye movements, he can estimate various parameters of the user's mental state, and use this information to predict where the user is most likely to look next. In addition, Dr. Kanan has created computer vision algorithms that make simulated eye movements to improve their ability to recognize, detect, and track objects in images.

Much of Dr. Kanan's recent work has involved applications of deep hierarchical neural networks to problems in computer vision. With CIS Ph.D. student Mohammed Yousefhussien, he has been developing the Smooth Pursuit tracking algorithm, which uses deep learning with saliency maps to track multiple targets of interest in videos. Saliency maps are a topologically organized maps of what is interesting in a scene and are a model for human attention. Their algorithm's performance rivals or surpasses state-of-the-art tracking algorithms at tracking targets in video captured by an aerial vehicle.

Dr. Kanan is also engineering new techniques to allow machines to reason about images. Computer vision has often assumed that to understand an image means to attribute each pixel in an image to particular object category. In contrast, humans selectively process their visual environment in a way that is heavily influenced by the current task and goals. This observation has motivated Dr. Kanan, in collaboration with CIS Ph.D. student Kushal Kafle, to focus upon the study of visual question and answer systems. These systems take as input a text based question (the goal) and an image. In return, the algorithm generates a text-based answer to the question.

Prior to coming to CIS, Dr. Kanan was a member of the Maritime and Aerial Perception group at NASA's Jet Propulsion Laboratory/California Institute of Technology, where he helped build vision systems for autonomous robots. He earned a Ph.D. in computer science at the University of California, San Diego, working with Dr. Gary Cottrell at the intersection of computer and cognitive science. He received an M.S. in Computer Science at the University of Southern California, working with Dr. Michael Arbib, professor of computer science, biological sciences, biomedical engineering, neuroscience, and psychology.

Most algorithms for object recognition process the image in one-shot. Instead, Dr. Kanan adopted an active approach in which a simulated eye looks at multiple regions of the image. During each fixation, the model extracts foveated features from a local region of the image. As more fixations are acquired, the model's confidence in what it is observing increases.



Each circle represents a filter that is applied to regions fixated during simulated visual search. These filters are not engineered, but result from the application of machine learning techniques to natural images. These artificial neurons share properties with neurons in the human primary visual cortex: Gabor-like filters with red-green, blue-yellow, and dark-light opponency.

Newly funded research aims to investigate national trends in health-related Internet usage and patient-reported outcomes among deaf and hard of hearing individuals

Dr. Poorna Kushalnagar is a Research Associate Professor in CIS. She was recently awarded R15 and an R01 grants, totaling around 2 million dollars over 3 to 5 years. Both grant projects will include developing and testing visually accessible applications in American Sign Language and English that can be used by people from diverse backgrounds. Both projects will include a large team of Deaf/HH undergraduate student researchers in psychology, information technology, and science. Collaborating institutions include Gallaudet University, Institute for Public Health and Medicine at Northwestern University Feinberg School of Medicine, and University of Arkansas for Medical Sciences.

R15 grant: National Cancer Institute's Health Information National Trends Survey (NCI-HINTS) is heavily dependent on English, which present serious language barriers to Deaf patients who use American Sign Language (ASL). The availability of HINTS in ASL and English and such that is valid for users of accessible technology and services will provide important insights on understanding the trends in Deaf people's use of the Internet for health-related purposes and improving health communication models that will lead to better personal and public health within the underserved deaf population. The research plan builds on Dr. Poorna Kushalnagar's prior research on health communication with Deaf signers. Expected findings will support improvement and refinement of health websites that utilize ASL cancer health videos for Deaf consumers, with goals of maximizing effectiveness of dissemination for health-related purposes.

R01 grant: This project plan builds on Dr. Kushalnagar's prior research on quality of life outcomes with deaf and hard of hearing (DHH) population. This project will be conducted by a research team that includes: an early career investigator with expertise in quality of life outcomes in DHH population, a senior investigator with expertise in patient reported outcome measures (the creator of the FACIT fatigue QoL measure), a psychometrician with experience in conducting IRT and psychometric analyses for patient reported outcome measures, an audiologist with expertise in (re)habilitative audiology and hearing related outcomes, and an ASL translation expert. Results from this study will provide a better understanding of the mechanisms that may contribute to poor quality of life frequently observed for individuals with hearing loss.

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BIOMEDICAL AND MATERIALS MULTIMODAL IMAGING LABORATORY

Laboratory Director's Comments By Dr. Maria Helguera

Mission:

To develop innovative ways to visualize, analyze, and characterize biological tissues and synthetic materials by means of multimodal medical imaging devices.

Staff

Dr. María Helguera is the principal investigator. The lab facilities are used as well by Dr. N.A.H.K. Rao.

Research in the lab was conducted and supported by a number of students:

- Amy Becker, Imaging Science, **"Structure Analyses of Artificial Tissues"**. In collaboration with Biomedical Engineering Department, University of Rochester
- Megan Iafrati, Rose Rustowicz, BS Imaging Science, **"Remotely Accessible Microscope".**
- Kfir Ben-Zikri, MS Candidate Imaging Science, **"Image-Based Quantification and Analysis of Longitudinal Lung Nodule Deformations"**. Sponsored by NIH.
- Viraj Adduru, PhD Candidate Imaging Science, **"Lesion Segmentation and Relapse Prediction Using Longitudinal MS Data"**. Sponsored by Geisinger Health System.
- Golnaz Jalalahmadi, PhD Candidate Imaging Science, **"Design of a Comprehensive Protocol for the Diagnosis and Prevention of Abdominal Aortic Aneurisms"**. In collaboration with Geisinger Health System.

Research Projects

"Structure Analyses of Artificial Tissues", Amy Becker, María Helguera in collaboration with Eric Comeau and Dr. Diane Dalecki, Biomedical Engineering Department, University of Rochester.

A texture analysis software tool was used to quantify the structures in engineered tissues. This was done using a three dimensional Gray-Scale Co-occurrence Matrix (GLCM) and a Gray-Level Run Length Matrix (GLRLM) analyses. The software tool was modified to output nine orientations of the GLCM analysis. Test images were designed and used to determine the optimal parameters from this analysis. It was determined that Contrast, Homogeneity, Long Run Emphasis, Gray-Level Non-Uniformity, and Run Percentage were the most indicative parameters from the analyses.

Ultrasound standing wave fields have been used to organize living endothelial cells in a collagen gel, with cells collecting at the nodes of the standing wave. The frequency and the pressure of the ultrasound wave determine the structure of the tissue that is grown. For this project, vasculature (blood vessels) were grown. When endothelial cells were placed in a collagen gel, an ultrasound standing wave field was applied to organize the cells into distinct bands. When the banded cells were set in an incubator and allowed to grow, vessel sprouts formed in between the bands. The sprouts connect the bands to create a complex structure of vessels. Engineered tissues must be irrigated to ensure viability upon implantation.

Samples were exposed to 1 MHz ultrasound standing wave fields of different pressures. The pressures used in this project were 0.1 MPa, 0.2 MPa, and 0.3 MPa. It has been observed that the pressure of the ultrasound wave affects the final structure of the bands and the sprouts. Representative examples are shown in Figure 1, showing the effects of 0.1 MPa in the left, 0.2 MPa in the middle, and 0.3 MPa in the right.

"Remotely Accessible Microscope", Megan Iaftrati, Rose Rustowicz and María Helguera. This project won the 2014-2015 CIS Faculty Award Celebrating Excellence and the UNYTE - Hitting the Accelerator: Health Research Innovation through Data Science. Best Student Poster Award.

We designed and built a portable, low cost, WiFi accessible microscope (20X to 200X) that fits inside an incubator for live cell screening in real time. The system is based on a Raspberry Pi microcomputer and can hold two cell culture plates for simultaneous scanning and time-lapse studies.

user selects the desired position by the click of the mouse. The motors move the microscope/camera unit to the desired position while a window displays the field of view. Fine position adjustments can be done using the arrows in the keyboard. This GUI also controls the illumination system, mounted on the microscope/camera unit, to be turned on-off to avoid photo-bleaching and photo-toxicity. A screen shot of the GUI is shown in Figure 4.

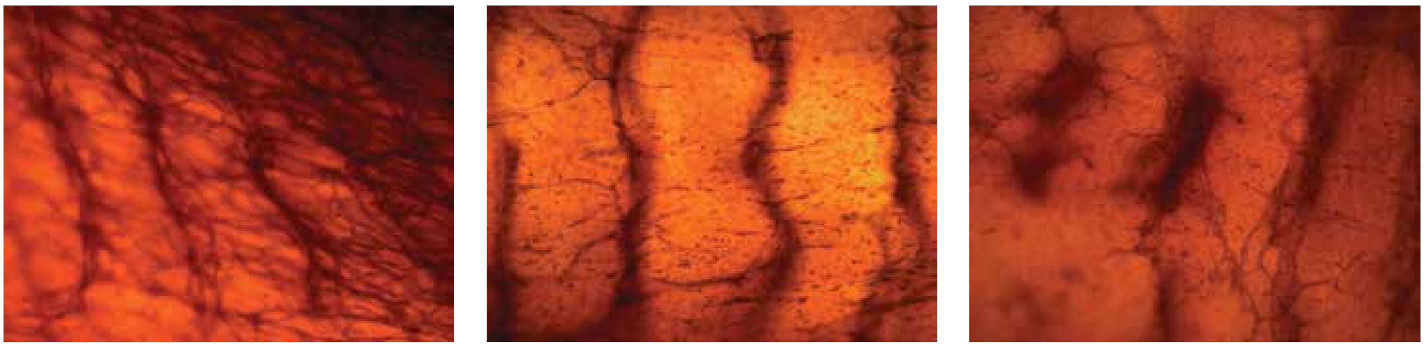


Figure 1. Band formation and sprouting after exposure to 1 MHz ultrasound standing wave fields with 0.1 MPa in the left, 0.2 MPa in the middle and 0.3 MPa in the right. Images taken with 5x magnification

Low Gray-Level Non-Uniformity → **Low Gray-Level Non-Uniformity**

Figure 2. Microscopy representative images for which GLNU ranged from lowest to highest value.

Synthetic images reproducing some band and sprout formations were created to validate the experimental results.

Among the parameters for the GLCM analysis, it was concluded that homogeneity and contrast were the two most indicative. Homogeneity and contrast are essentially opposite measures. Homogeneity is a measure of smoothness and contrast is a measure of business in an image. For the images taken at 5x magnification, the homogeneity increased with an increase in pressure used to create the bands.

Among the parameters for the GL-RLM analysis, it was concluded that Gray-Level Non-Uniformity (GLNU) was best characterizing the texture, as is shown in Figure 2.

The system can be adapted to perform 2D or 3D scans, still images or video, gray scale or color. With such a system in place there is no need to manipulate the samples and the risk of contamination is greatly reduced. A block diagram of the system is shown in Figure 3.

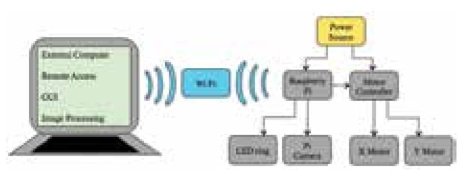


Figure 3. Block diagram showing the external computer controlling the system.

Ad hoc control and image processing software have been created in Python. The control graphical user interface (GUI) shows an image of the cell culture plates on which the

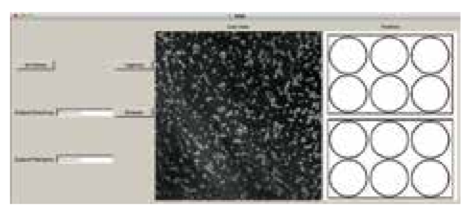


Figure 4. Screen shot of the control GUI showing the field-of-view in the selected tray-well.

Image processing algorithms to enhance, segment and count cells are available through another GUI. The GUI displays the image to be processed and a drop down menu provides options for enhancing contrast, sharpening, reducing noise, flattening the illumination field, etc., as well as a default setting. This preprocessing stage is used to precondition the image. A dialog window asks the user whether he/she is satisfied with the image. If the answer is yes, segmenting and counting of cells will start. This quantitative analysis stage runs behind the scenes without any further input from the user. The resulting segmented image highlighting the cells will be displayed and the count of cells will be shown.

Other quantitative analyses protocols may include gray-scale textural and volumetric analyses, cell tracking, etc. The system is easily customized for different applications.

To reduce contaminants and over-heating, the power supply, power distribution circuits, and motor drivers are located outside of the incubator.

The students involved in the project are seen in the pictures below discussing their project and proudly showing their certificates. Megan Iafrati is on the top and Rose Rustowicz on the bottom.

"Image-Based Quantification and Analysis of Longitudinal Lung Nodule Deformations", Kfir Ben-Zikri, María Helguera and Nathan Cahill, School of Mathematics, RIT, in collaboration with Kitware, and Mark Niethammer, University of North Carolina.

Lung cancer is the leading cause of cancer related-deaths in the US, accounting for 28% of all cancer-related mortality in 2012, and having a 16% five-year survival rate. If lung cancer is diagnosed at an early stage when the cancer is still localized in small lesions or nodules, the five-year survival rate improves to 52%. It is impractical and risky, however, to biopsy every lesion that may be found in a computed tomography (CT) scan. To mitigate this risk, longitudinal scans are collected to determine the growth rates of individual lesions in order to determine if they are consistent with growth rates of known types of malignancies. Ground glass opacity (GGO) lesions are especially difficult to analyze, as they feature a variety of non-solid components that may be influenced by lung deformation. Four cases are shown in Figure 5. Compensating for background lung deformation across longitudinal scans (via image registration) is vital to enable accurate estimation of lesion growth rate. We demonstrate on four clinical cases that registration over a region of interest (ROI) centered around the lesion yields lower target registration errors (TRE) than registration over the entire lung. Results are shown in Figure 6.

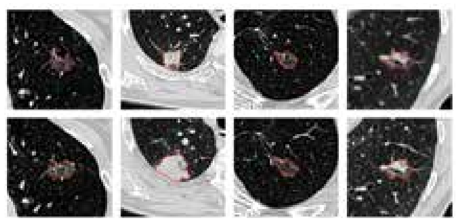


Figure 5. Four longitudinal clinical cases are shown. Earlier (prior) images top row and current images bottom row.

Results of these experiments suggest that registration based on lesion ROIs has the potential to more accurately account for deformations in GGO lesions than registration based on lung ROIs. In 3 of 4 cases for lesion ROIs, the median TRE was less than 1mm. This is less than the variability in the fiducial point locations selected by the radiologist.

Registration based on lesion ROIs had better performance in 3 of 4 cases, suggesting that a limited ROI enables registration algorithms to converge to the correct global minimum. One possible reason for this is that the use of a larger ROI may increase the number of local maxima in the similarity measure. It was found that affine registration outperformed rigid registration in all four cases, both when lung and lesion ROIs are used.

By visually inspecting the registered lesions, it appears that registration with lesion ROIs involved alignment of both the lung and nodule boundaries, while registration with lung ROIs only involved alignment of the lung boundary.

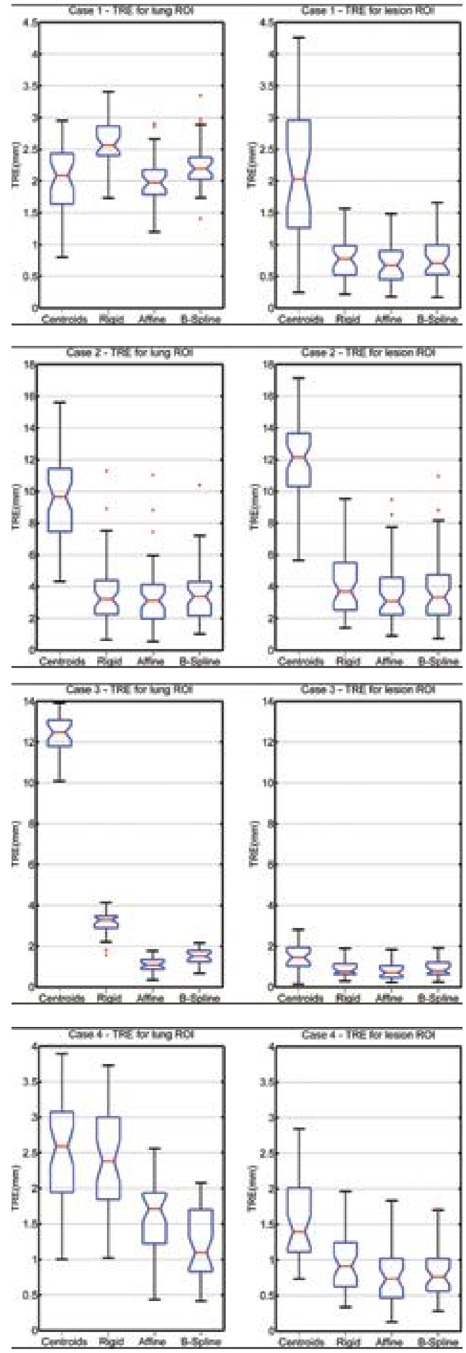


Figure 6. Target Registration Errors (TRE) (mm) for Cases 1–4 after different registration algorithms were applied to lung versus lesion ROIs

"Lesion Segmentation and Relapse Prediction Using Longitudinal MS Data", Viraj Adduru and María Helguera in collaboration with Andrew Michael, Geisinger Health System.

Multiple sclerosis (MS) is a chronic disease of the central nervous system characterized by inflammation, demyelination, and axonal degeneration. The onset is with a neurological disturbance, known as clinically isolated syndrome (CIS) and the patients experience unpredictable episodes of clinical relapses and remissions followed by continuous progression of disability over time in most instances, leading to clinically-definite MS (CDMS). However, about 20% of CIS patients do not convert to MS after two decades, even if they have an abnormal brain scan at onset. Magnetic Resonance Imaging (MRI) is one of the diagnostic imaging methods for MS. MRI's of MS patients primarily exhibit focal and less often diffuse WM lesions in the brain and spinal cord. Typically the images are visually assessed for qualitative analysis and lesions are manually marked if a quantitative analysis is required. Manual marking of lesion-boundaries is a very time consuming and has a high inter and intra-subject variability.

For the past two decades many segmentation algorithms have been developed to detect MS lesions in structural MRI images but no approach is widely preferred due to poor generalization capability across images acquired from various sites. This is mainly because of the inter-subject and inter-site variability in tissue intensities. Moreover very limited studies are available on the prediction of the relapse and used simple machine learning like SVM on the patient demographics and basic lesion properties like size and distance from center. However the structural features of the lesions and their multimodal intensities along with temporal lesion progression can be exploited to learn much more robust machine learning algorithms for lesion segmentation and relapse prediction.

The purpose of this project is to explore better lesion segmentations methods for MS and use machine learning to predict the occurrence of relapse. To achieve these goals we will use the large dataset of longitudinal MRI scans and demographics of the patients collected over time using Geisinger's unique data resources and information technology capabilities. The main aims of the project are:

1. Observe the data and design preprocessing pipelines for noise removal and normalization.
2. Extract useful features by using the information from preprocessed images, patient demographics and clinical exams.
3. Investigate machine learning methods for relapse prediction.

We have developed automatic image processing pipelines for preprocessing the multimodal (FLAIR, T1 and T2) MS brain MR images. The preprocessing steps include Brain extraction (removal of non-brain tissue), image cropping (removal of background voxels), bias correction (correcting for changes in magnetic intensity), and intensity standardization (scaling voxel intensities to a standard range). The pipeline is developed in python using Nipype libraries which provided tools for package integration (allowed usage of various neuroimaging tools in one place) and parallel-processing on a multi-core processor. This simplified the algorithm execution and reduced the computation time significantly.

The preprocessed images free of non-brain tissues and inter-subject intensity variability are divided into test, training and validation sets. 3D patches containing lesions from training sets are selected from each channel (T1, T2 and FLAIR). The machine learning algorithm will be trained with these patches and evaluated for its performance using the validation and test sets. Care will be taken to balance the number of lesion to the healthy tissue voxels to prevent skewing.

"Design of a Comprehensive Protocol for the Diagnosis and Prevention of Abdominal Aortic Aneurisms", Golnaz Jalalahmadi and María Helguera, in collaboration with Aalpen Patel, Geisinger Health System.

Abdominal aortic aneurysm (AAA) is an abnormal dilation which causes an expansion at least 1.5 times of the normal diameter. It is known as the 13th reason for death in the United States and the reason for mortality for 2-4% in elderly. In 2009, the Society for Vascular Surgery (SVS) proposed for more investigations toward the rupture risk factors and the treatment methods for abdominal aortic aneurysms.

The main reason for AAA is not known yet completely but the growing weakness in the aortic wall has been introduced as the main reason which might be affected by different types of factors. For decades, the maximal diameter (Dmax) was considered as the main factor for this growth and in the process of clinical follow up and needs for surgery or repair for the patients. However, recent studies demonstrated that the Dmax is not a sufficient factor for the rupture since patients with smaller diameter have gone through the rupture by a range of 1% of rupture per year. It was indicated that demographic factors like age and gender, geometrical- and shape-related factors like diameter and volume, and biomechanical factors such as peak wall stress are the factors which might influence the growing weakness in the aortic wall as well as the rupture risk. Therefore, surgery only based on the AAA's diameter might end up in remarkable clinical and financial efforts which for a notable portion of patients seem to be unwarranted with high risk of death after all.

The overall goal of this work is to develop an inclusive model that incorporates geometrical and mechanical factors, as well as physiological and demographic patterns. With such a methodology in place, data for new patients will be assessed to evaluate the probability of rupture. After all, there is an increasing need for more reliable and accurate methods for the prediction of the rupture risk and the treatment of AAA.

Selected Publications and Conference Presentations

1. Mercado, K.P. *, **Helguera, M.**, Hocking, D.C., Dalecki, D. "Non-invasive Quantitative Imaging of Collagen Microsctructure in Three-Dimensional Hydrogels using High Frequency Quantitative Ultrasound", Tissue Engineering, Part C: Methods. DOI: 10.1089/ten.TEC.2014.0527, 12/2014.
2. Mercado, K.P., Langdon, J., **Helguera, M.**, McAleavey, S.A., Hocking, D.C., Dalecki, D., "Scholte wave generation during single tracking location acoustic radiation force impulse imaging of engineered tissues", submitted to Journal of the Acoustical Society of America Express Letters, March 2015. Accepted.
3. Ben-Zikri, K.*, **Helguera, M.**, Fetzer, D., Chittajallu, D., Aylward, S., Niethammer, M., Cahill, N. "Longitudinal Registration of Ground Glass Opacity Lessions in CT Scans", International Symposium on Biomedical Imaging (ISBI), April, 2015
4. Rustowicz, R.**, Iafrati, M. **, **Helguera, M.**, "Remotely Accessible Microscope (RAM)", UNYTE, May 2015. Winner of Best Student Poster Award.

* Graduate Student, ** Undergraduate Student

Grants and Research Funding

Funding was provided by NIH, and FINCyT (Peru).

Additional research in the Biomedical Imaging Laboratory is dedicated to:

(a) The development of a new imaging modality called Photoacoustic (PA) Imaging. Focus is on implementing novel methodologies for PA imaging.

(b) Building internal and external collaborations to assist the biomedical research community in addressing cancer diagnosis, prognosis and disease management challenges. This is being done by pragmatically using imaging technologies, image analysis and development of cancer cell targeted contrast agents as biomarkers for molecular imaging.

We have made significant progress in each of these two major areas. Both were highly interdisciplinary in nature with scientists representation departments other than Center for Imaging Science at RIT and University of Rochester.

We were successful in generating over a million dollars in research grants last year. Three major grants where the BIL personnel were directly involved are listed below:

(1) R15 EB 019726-01 –(PI-Rao) Agency: NIH
$436,000 02/01/2015 –01/31/2018

Project title: Development of Photoacoustic and ultrasound transrectal probe for prostate biopsy.

(2) R15 CA 192148-01- (PI: Schmitthenner, Co-I: Rao) Agency: NIH
$440,000 09/01/2014 - 08/31/2017

Project title: Targeted Molecular Agents for Photoacoustic Imaging of Prostate Cancer

(3) CDMRP PCRP Exploration Hypothesis Award (PI:Dogra, Co-I: Rao) Agency: DOD
$100,000 04/01/2014 –03/31/2015

Project Title: In vivo photoacoustic imaging of prostate cancer using targeted contrast agent

Student Participation: Students and research associates involved in the projects were, Saugata Sinha (Ph.D. completed), Viraj Adduru (MS completed), Zichao Han (Ph.D. student), Arjun R. Rajanna (EE MS student), Jacob Wirth (Ph.D. student), Mathew Casella, Michaela Piel, Amy Becker (BS student), Nicholas Brown, Pedro Vallejo, Tess Jacobs (BS optics U of R), Bhargava Chinni (former RIT MS graduate, now research associate, U of R), Shalini Singh, Ph.D. (Research Associate, U of R).

Project-1: Advancement in Acoustic Lens Design Methodology for PA Imaging Camera

Collaborators: B. Chinni, W. Knox, V. Dogra, J. Bentley (U of R) and R. Ptucha (RIT)

In last year's report we described the realization of an innovative acoustic lens focusing based camera for PA imaging. A large study encompassing more than 100 freshly excised human prostate and thyroid tissue samples was conducted. Preliminary data analysis of PA signal from histology proven areas designated as normal or cancer showed better than 85% accuracy for cancer diagnosis. Further studies with neural network based data analysis are in progress.

The image quality of PA camera can be improved with improvement in acoustic lens design. An innovative idea to use optical lens design software called Code V from Synopsys to first evaluate and optimize lens performance was adopted by simply changing the medium velocity from that of light to sound in water. A material commonly available for three dimensional printing was chosen with refractive index of 0.58. The bi- concave lens diameter was 32 mm, radii of curvature 33 mm and the working focal length f ~ 40 mm. Fig.1 shows the ray tracing at 4f configuration and Fig.2 is the modulation transfer function (MTF) for on-axis point in red and extreme off-axis point in blue. Clearly we are close to the diffraction limited performance on-axis with a MTF value of 0.3 at 0.7 cycles/mm but significantly worse for off-axis points. Optimization efforts demonstrated that this is the best we can do using a singlet lens system.

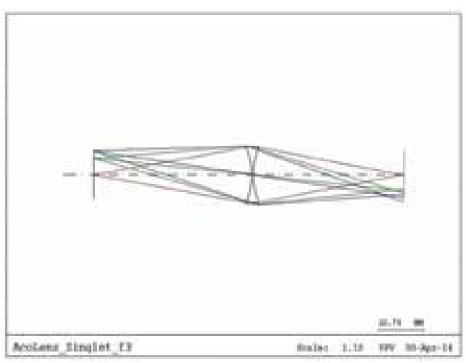


Fig. 1. Ray tracing through singlet lens in Code V optical design software.

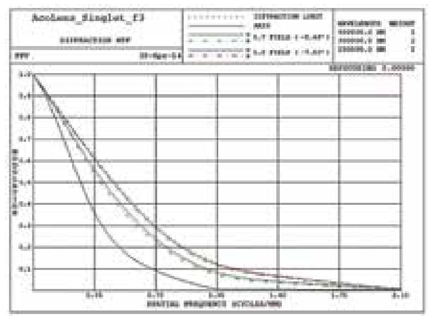


Fig. 2. Singlet lens MTF for on- and off- axis points.

A comprehensive two dimensional (2D) simulation model (see Fig.3) of the 4f configuration was developed that incorporates realistic PA signal generation, acoustic wave propagation from source to transducer element including the focusing through the lens and the transducer frequency response. Snapshot of the propagating PA signal wave-front at different times after the laser pulse firing is shown in Fig.3. PA point source is located at pixel number 113. A diverging wave-front is shown near pixel number 350. At a later time the lens located at pixel number 512 has started to focus the wavefront shown near pixel number 700. The final image plane (the sensor position) is located at pixel number 900. Focused waves are detected at each array elements as a radio- frequency (RF) time signal (A-line data). Only the slowly varying envelope of RF signal is used for generating 2D display of the PSF as a B-scan image in Fig. 4. The middle and the right panel show how the PSF might change when the point source is moved off-axis to 2.5 mm and 5 mm distance respectively.

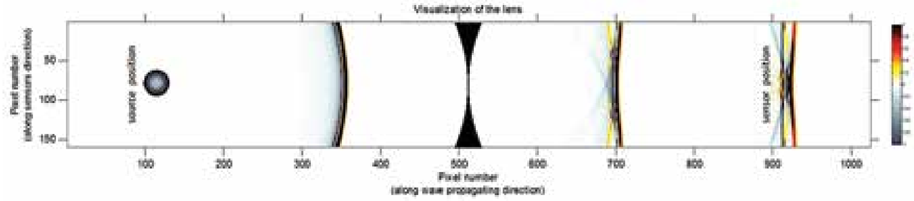
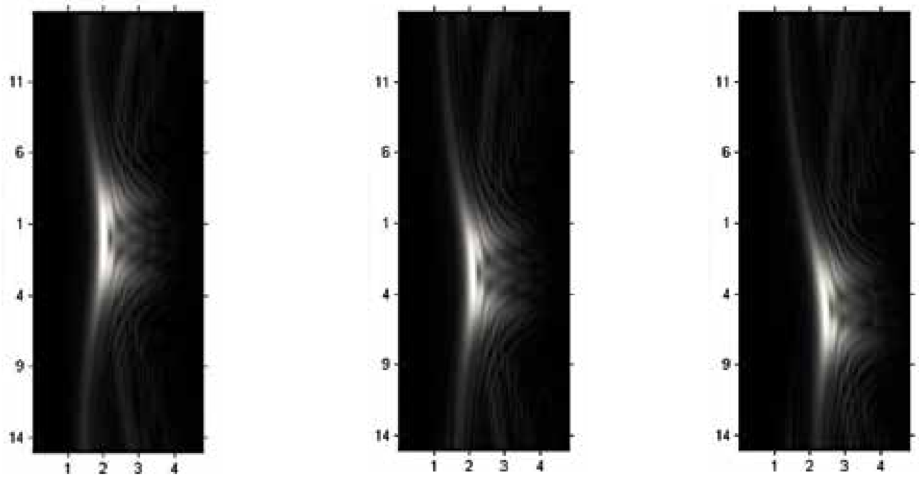


Fig. 3. Photoacoustic wave simulation using MATLAB software.



(a) On axis (b) 2.5mm off axis (c) 5.0mm off axis

Fig. 4. Simulation results: PSF slices for on and off axis points, where the horizontal and vertical axis respectively corresponds to the distance from the center of the pattern and sensor in the center (in mm).

An interdisciplinary team has successfully integrated ray tracing based optical lens design with full wave theoretic simulation of the resulting PSF. Using this methodology we have fabricated and tested a first generation prototype PA imaging camera that can take 1 cm×1cm 2D B-scan images in l second and 2D slices of C-scan images in less than 2 minutes. The innovative element of the system is a single lens acoustic focusing element. A complete system simulation modeling, design and fabrication methodology has been described. Improvement in image quality using optical lens design methodologies are currently under investigation.

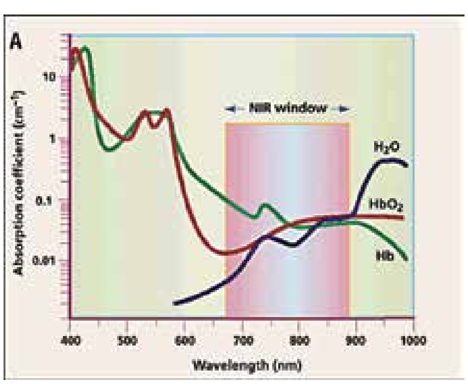


Fig. 5. Biological imaging near-infrared window.

Project-2: Development of targeted Contrast Agents for Prostate Cancer PA Imaging

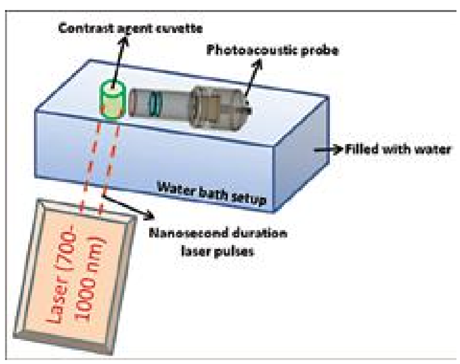


Fig. 6. Spectral analysis of near-infrared dyes. Contrast agents in a cuvette have been examined for a photoacoustic signal using the laser from 700 nm to 1000 nm wavelength.

Collaborators: B. Chinni, S. Singh, K. Nastiuk, J. Krolewski, V. Dogra (U of R), H. Schmitthenner (RIT)

Limitations of endogenous contrast agents for prostate cancer diagnosis. While pre-clinical testing of prostate resection slices indicates that Photoacoustic Imaging (PAI) has higher sensitivity and specificity than TRUS, imaging depth is limited, and chromophores such as de-oxyhemoglobin (dHb) and oxyhemoglobin (HbO2) have two limitations: i) their small absorptivity factor (extinction coefficient) leads to weak PA signals, limiting the depth of tumor detection as well as the minimal detectable tumor size; and ii) endogenous molecules have little specificity for cancer. In order to improve depth penetration and image quality, exogenous chromophores can be employed to enhance sensitivity relative to endogenous agents. This approach has been demonstrated in the use of a near infrared fluorescent (NIRF) dye, IR800CW conjugated to a peptide that targets the neutropilin-1 receptor for the PAI of breast cancer. Excitation of cells can be optimized by use of a laser tuned to the maximum wavelength of NIR dyes with absorptivity factors two to three orders of magnitude greater than those of endogenous agents. Unlike fluorescence imaging with light as the input and backscattered radiation as the output, PA imaging uses light as the input source for excitation but detection and image formation use ultrasound waves generated by the tissue. Since ultrasonic waves scatter much less than light in the tissue, PAI can produce higher resolution imaging deep in tissue, compared to fluorescent detection. For greater tissue depth penetration and sensitivity, PAI utilizes dyes that absorb in the 'biological NIR window' between 700-900 nm. The optimal NIR window is designed to circumvent the strong absorbance of Hb, HbO2 and H2O as shown in Fig. 5. NIR dyes related to ICG including Cy7, Alexa750 and IR800CW are ideal and offer a dramatic increase in sensitivity.

Identification of IRDye800CW as an exogenous contrast agent for PAI. To quantify the PA signal generated with tunable laser excitation in the 700-1000 nm range of endogenous or exogenous dye components, algorithms have been developed to de-convolute the individual chromophore PA images. Five dyes (IRDye800CW, AlexaFluor750, Cy7-NHS-ester, Cy7-sulfo and Dylight800) were tested using our acoustic lens based device at 100 micromolar (µM) concentration. A water bath setup (Fig. 6) was used to determine the photoacoustic spectra of these five dyes. Each contrast agent was interrogated in the NIR region in a five step-interval range and PA signals recorded using our PAI probe. These recorded PA signals were further processed to find the absorption maxima for each exogenous contrast agent across the NIR region. The PA absorption spectra of each dye have been plotted as shown in the Fig. 7.

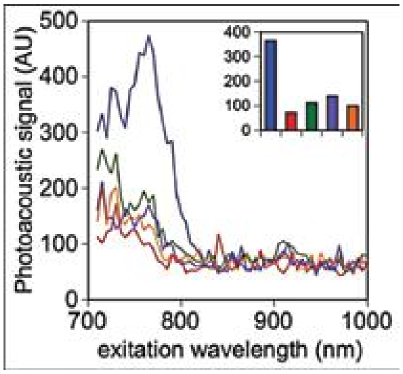


Fig. 7. PA spectra of five contrast agents. IRdye800CW (blue); AlexaFluor750 (red); Cy7-NHS-ester (green); Cy7-sulfo (orange); Dylight800 (purple).

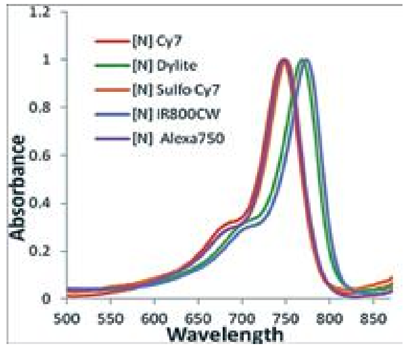


Fig. 8. Optical absorption spectra of five contrast agents. IRdye800CW (blue); AlexaFluor750 (purple); Cy7-NHS-ester (red); Cy7-sulfo (orange); Dylight800 (green).

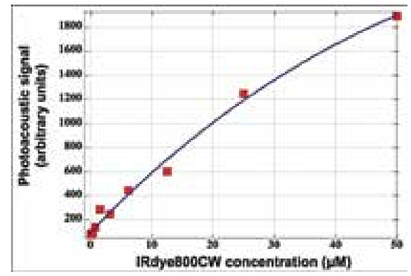


Fig. 9. Sensitivity of IRDye800CW using our PAI device. IRDye800 concentration varied from 90 nM to 50 µM. Each red square represents the corresponding IRDye800CW concentration and its PA signal intensity.

As expected from the reported peak intensities (lambda max) in the ultraviolet-visible spectra, the Alexafluor 750 has a peak PA signal when irradiated at 750 nm, Cy7-NHS-ester at 760 nm, Cy7-sulfo at 755 nm, Dylight800 at 785 nm and the dye IR800CW has a peak signal at 775 nm. When the targeted molecular imaging agents (TMIAs) are injected into the blood stream and PA imaging is conducted during wash out period, the image signal will be the linear sum of signal from all the underlying dominant chromophores (dHb, HbO2 and NIR dye). It is important to create separate images of individual chromophores to obtain the signature related to only the specific biomarker. This task requires input data from the PA signal spectrum of endogenous or exogenous dye components and algorithms have been developed to de-convolve the individual chromophore images to determine i) their sensitivity by comparing their PA yield (PA signal per micro molar solution), and ii) their spectra shape. Among the five contrast agents/dyes we investigated, IRDye-800CW was chosen based on photoacoustic spectrum analysis as determined by the highest intensity achieved relative to the other agents and because the peak absorption is well separated from endogenous tissue constituents, as shown in Figure 7. NIR fluorescence imaging was also performed for the five contrast agents/dyes and the optical absorption data correlated to PA spectroscopy data as shown in Figure 8.

Sensitivity of IRDye800CW using our PAI device. The IRDye800CW was diluted from 50 µM to 90 nM concentrations and photoacoustic signal measured to obtain the sensitivity of the IRDye800CW. Each red square in the plot represents the corresponding IRDye800CW concentration on the x axis and its PA signal intensity on the y axis. PA signal from the dimethyl sulphoxide and de-ionized water has been subtracted from each recorded value and PA signal from the dye alone has been plotted. Using our current PAI system, 90 nanomolar (nM) was determined to be the threshold for signal above noise (Fig. 9).

PAI of PCa cells using IRDye800 conjugated with A10.3 aptamer bonded to PSMA. We have received a 1-year seed grant from Department of Defense Prostate cancer research program to develop and test PAI imaging agents. As shown in Fig. 7, we identified a NIR dye (IRDye 800CW), which generates a strong PA signal, conjugated it to the PSMA-directed A10-3 aptamer and initiated testing in cell cultures. Prostate cancer cells lacking (PC3) and presenting (C4-2) the PSMA cell surface protein were used for testing the PA signal from IRDye-800CW conjugated to the A10.3 aptamer (dye-aptamer) that binds to PSMA. These two PCa cell lines were incubated with 4 µM dye-conjugated aptamer, washed thoroughly and centrifuged. The pellets are mixed with agarose, producing a uniform gel phantom for imaging. As shown in Fig. 10, we prepared a total 9 agarose gel phantoms: three with agarose-only; three with (PSMA-) PC3 cells stained with dye-aptamer, and three with (PSMA+) C4-2 cells stained with dye-aptamer, all in a multi-well plate. Initially, the gel phantoms were imaged using a commercially available fluorescence imaging system (IVIS spectrum) at 770 nm to confirm the dye aptamer binding to PSMA (Fig. 10B, D). Once the binding was confirmed, the phantoms were removed from the multi-well plate and placed on the imaging stage as shown in the photograph (Fig. 10A). The PAI scanning procedure (of the yellow square area) was similar to that used in the ex vivo imaging of tissue slices, using the prototype instrument. Fig. 10C shows a PA C-scan image of the gel phantoms. The PA signal intensity was increased in the ROI surrounding the C4-2 gel phantoms, demonstrating the presence of IRdye800CW conjugated with A10.3 aptamer bound to cell surface PSMA. Image processing algorithms using MATLAB software were used to reduce the spatial variability and enhance the PA signal intensity throughout the image. Each gel type area was considered as the ROI for obtaining the averaged PA intensity (in future experiments we will determine the signal for individual gels, in order to assess reproducibility). The average PA intensity of the C42 gels was ~4 fold higher than either empty phantoms or PC3 cell containing phantoms, and was highly correlated with the fluorescence data obtained by scanning in an IVIS spectrum (Fig. 10D).

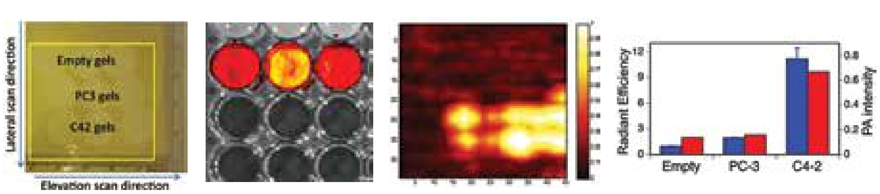
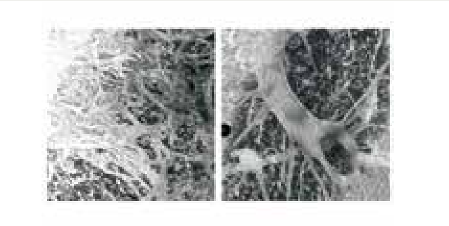


Fig. 10. PAI of PCa cells embedded inside agarose gels. (A) Digital photograph of imaging platform, with 3 gel types (3 of each, in cylinders). The yellow boxed area was scanned. (B) NIRF (770 nm) IVIS image of the scanned area (C) Photoacoustic image of the scanned area. (D) Average NIRF signal for each cylinder (blue columns) +/-SE, and smoothed averaged PA intensity within an ROI defined by the 3 cylinders of each gel type.

RIT scientist collaborates with UR colleagues to advance artificial tissue development

Maria Helguera contributes ultrasound techniques, image processing to NIH-funded project



The beginnings of artificial vascular networks created with ultrasound waves. The frequency and intensity of the waves organize the cells into position.

Circulating oxygen-rich blood through artificial organs and tissues is a bioengineering conundrum without an easy answer. The problem is in the plumbing. Biomedical teams around the world are working on different solutions to the problem of creating a synthetic vascular system.

Scientists at Rochester Institute of Technology and the University of Rochester are looking to ultrasound technology to create tiny blood vessels needed to nourish organs and tissues grown for reconstructive and surgical applications.

Developing complex vascular systems with high-frequency ultrasound waves is the goal of RIT imaging scientist Maria Helguera '99 (Ph.D., imaging science), and UR's Diane Dalecki, professor of biomedical engineering, and Denise Hocking, associate professor of pharmacology and physiology. The UR-led project is funded by the National Institute of Biomedical Imaging and Bioengineering, part of the National Institutes of Health.

Helguera provides the team an expertise in ultrasound imaging and image processing through high-frequency ultrasound techniques and quantitative analysis of microscopy images of the tissue samples.

"We can use ultrasound in every stage of the process while creating artificial tissue," said Helguera, an associate professor at RIT's Chester F. Carlson Center for Imaging Science. "Ultrasound is a clean way of doing things in the sense that we are not delivering any harmful radiation. We can manipulate the cells and image them without hurting the samples."

Ultrasound standing wave fields are generated in a tissue-culture plate containing endothelial cells embedded in collagen. Endothelial cells form the insides of blood vessels. Pressure from ultrasound standing wave fields nudges the cells into predetermined positions. The frequency and intensity of the waves organize the cells and control the density and spacing of cell bands. Samples are then polymerized in an incubator and locked into place. Their close positioning encourages cells to signal to each other and sprout three-dimensional blood vessels.

Tissue constructs are visualized with multiphoton microscopy, a technique that captures specimens in three-dimensional sections.

"Distinct and interesting formations can be seen depending on the frequency and intensity of the ultrasound stationary wave fields," Helguera said. "We decided to quantitatively analyze these three-dimensional data sets to extract parameters characteristic of each exposure regime."

Imaging science Ph.D. student Mohammed Yousefhussien developed an image-processing tool for evaluating the structures of the blood sprouts. Third-year imaging science student Amy Becker is modifying the tool to capture details that will help manipulate the sprouts' growth. Determining the preferred direction in which the vessels branch outward will lead to networks resembling the vascular system within an organ.

"The goal is to design a quantitative protocol that will allow us to create a more complicated structure that is closer to a real system," Helguera said.

MAGNETIC RESONANCE LABORATORY

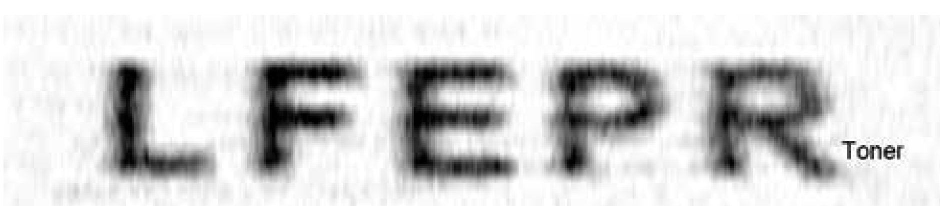
Laboratory Director's Comments by Dr. Joseph Hornak

The RIT Magnetic Resonance Laboratory is a research and development laboratory devoted to solving real world problems with magnetic resonance. This past year we continued our work on low frequency electron paramagnetic resonance (LFEPR) spectroscopy and imaging which is highlighted in this report.

LFEPR-Imaging

One addition to our LFEPR spectrometer this past year was a 3 mm surface coil. A surface coil is a radio frequency transmitter and receiver antenna that can detect the electron paramagnetic resonance (EPR) signal from a surface adjacent to it. This coil enables us to measure non-invasively and non-destructively the EPR and electron magnetic resonance (EMR) signal from paramagnetic and ferri/ferromagnetic materials on a flat surface such as in a painting or illuminated manuscript. By rastering signal bearing surface under the surface coil we are able to image the spatial distribution of the paramagnetic or ferri/ferromagnetic material on the surface. By placing the surface coil over a specific point on the surface we can record an EPR spectrum of the paramagnetic material in the region and allow spectral identification of a material.

We demonstrate this ability by imaging the distribution of EPR signal from the #72 Arial font letters LFEPR stenciled on a vinyl sheet with 2,2-diphenyl-1-picrylhydrazyl (DPPH) in epoxy, and the EMR signal from the same letters electrophotographically printed on paper. DPPH has a single, narrow peak in the EPR spectrum, while toner contains a broad non-descript signal. Fixing the magnetic field on the peak and rastering the lettered surface under the surface coil allowed us to produce the following images of the DPPH and toner.



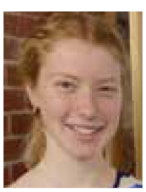
Many pigments used in paintings and illuminated manuscripts contain paramagnetic or ferri/ferromagnetic materials and possess either an EPR or EMR signal. A non-destructive and non-invasive technique which can determine the composition and spatial distribution of a pigment may be of use to curators and collectors who need to determine the authenticity and provenance of a work of art, and to art historians who may like to determine the temporal and geographic changes in the use and availability of pigments.

Staff News

Amy Becker, a second year BS Imaging Student at RIT, has worked on measuring the hydrogen NMR relaxation rates for the lipid-water phantom and the targeted contrast agent projects.

Wyatt Brown, a third year BS Chemistry major at RIT, is working on LFEPR of spectra of paramagnetic complexes as a function of firing temperature and instrument characterization.

Merlin Hoffman, a fourth year BS Physics major at Oberlin College, was a summer REU student in the lab. He worked on the LFEPR spectra of paramagnetic complexes as a function of firing temperature and instrument characterization.

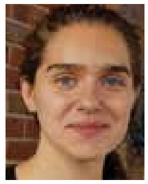


Emma Hornak is a first year high school student at the Harley School. She studied the LFEPR spectra of iron in RedArt clay as a function of firing temperature.

Dr. Joseph Hornak, Professor of Chemistry, Materials Science and Engineering, & Imaging Science finished his second year as Chairman of RIT's Graduate Council.

William Ryan, an adjunct faculty member in the Department of Chemistry, is working on a LabView interface for the lab's low frequency electron paramagnetic resonance (LFEPR) spectrometer.

Dr. Hans Schmitthenner, a Research Scientist in the Center for Imaging Science and Lecturer in the Department of Chemistry, is working on targeted contrast agents for magnetic resonance imaging.



Lauren Switala has been working in the lab for the past two years on a variety of projects ranging from instrument design and interfacing to examining the LFEPR signal from items with cultural heritage significance. She graduated this year from RIT Magna Cum Laude with a BS in Chemistry.

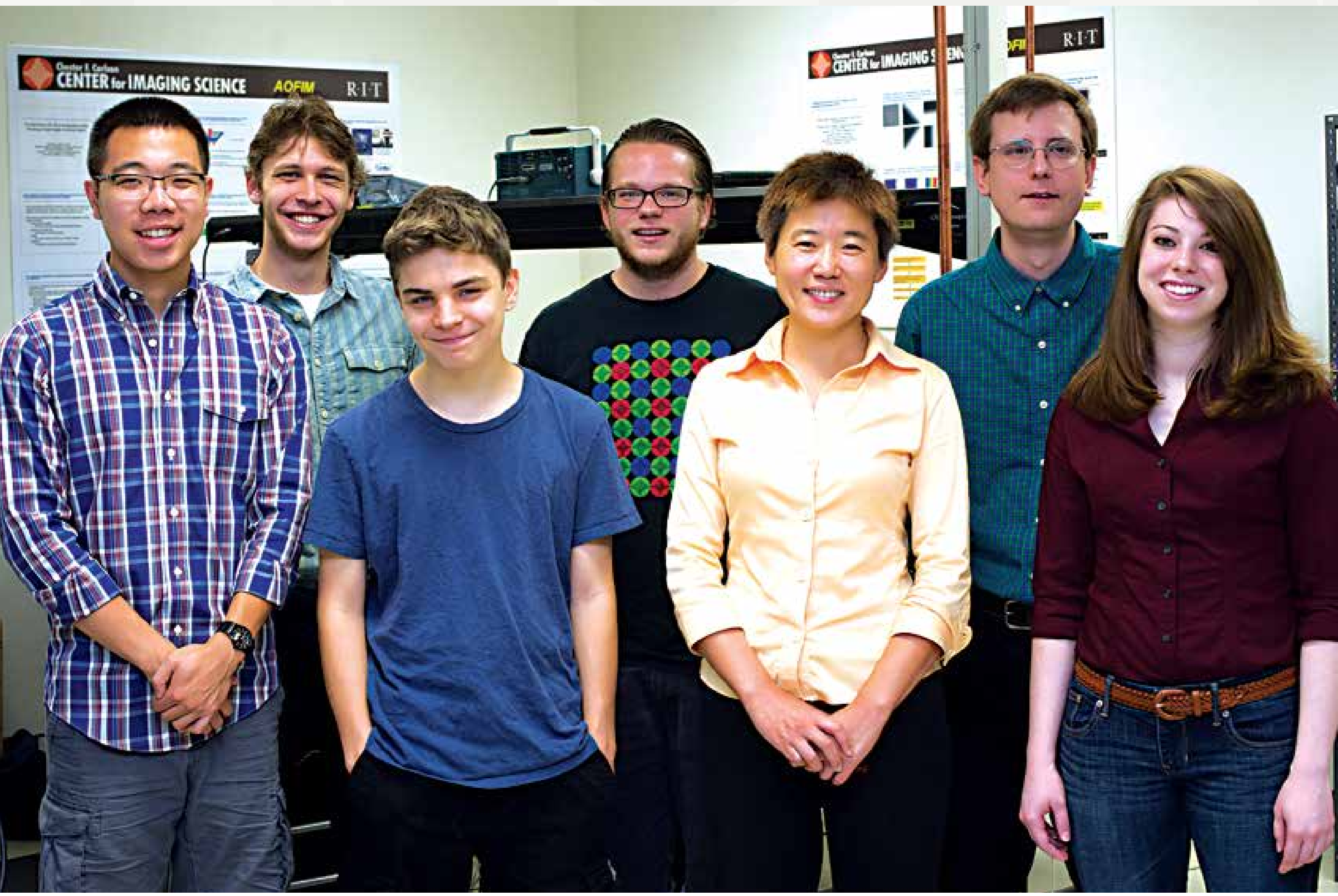
Dr. Nicholas Zumbulyadis, a retired Research Scientist from Eastman Kodak and an expert on Meissen's Blue and White Porcelain continued working with the lab on the identification of ceramics by LFEPR.

Conference Presentations

1. N. Zumbulyadis, W.J. Ryan, L. Switala, J.P. Hornak, Low Frequency EPR: A Novel, Non-invasive, Spectroscopic Approach to Studying Ceramic Objects. Gordon Research Conference: Scientific Methods in Cultural Heritage Research. Newry, ME, Jul 27-Aug 4, 2014.
2. L. Switala, E.I. Hornak, W.J. Ryan, N. Zumbulyadis, J.P. Hornak, A Low Frequency Electron Paramagnetic Resonance Spectroscopy Study Of The Firing Temperature Of Redart Clay. Rochester Academy of Science 41th Annual Fall Scientific Paper Session, Rochester, NY November 2014.
3. N. Zumbulyadis, L. Switala, W.J. Ryan, J.P. Hornak, Low Field EPR in Cultural Heritage Science: the Non-Destructive Characterization of Large Intact Objects and Spin Dynamics at Low Fields. 56th Experimental NMR Conference, Asilomar, CA, April 2015.
4. L. Switala, E.I. Hornak, W.J. Ryan, N. Zumbulyadis, J.P. Hornak, A Low Frequency Electron Paramagnetic Resonance Spectroscopy Study Of The Firing Temperature Of Redart Clay. 60th Rochester Section of the American Chemical Society Undergraduate Research Symposium, Geneseo, NY, 2015.
5. J. Schmitthenner, I. Evans, J.P. Hornak, Modular Synthesis of Peptide-based Single and Multi-modal Targeted Molecular Imaging Agents. World Molecular Imaging Congress, Honolulu, HI, September 2015.

Publications

1. Y. Qiu, WC.E. Kwok, J.P. Hornak, A method of switching the signal in an MRI phantom based on trace ion currents. J. Magn. Reson. 245: 171-176 (2014).
2. Y. Qiu, W. Yao, W-C.E. Kwok, J.P. Hornak, A Circuit for Synchronizing External Stimuli and Events to the Pulse Sequence of a Clinical Magnetic Resonance Scanner. Concepts in Magn. Reson. 44B:50-52 (2014).
3. W.J. Ryan, N. Zumbulyadis, J.P. Hornak, The Potential of Low Frequency EPR Spectroscopy in Studying Pottery Artifacts and Pigments. MRS Proceedings, mrsf13-1656-pp03-03 doi:10.1557/opl.2014.708 (2015).


CENTER for IMAGING SCIENCE
AOFIM
R·I·T

Laboratory Director's Comments By: Director Dr. Jie Qiao

The laboratory for Advanced Optical Fabrication, Instrumentation and Metrology (AOFIM) at the Chester Center for Imaging Science conducts research in the areas of…

(1) Ultrafast Lasers for advanced optics fabrication including integrated photonics and freeform optics (2) Optical Metrology for phase imaging and wavefront sensing, which can be used for charactering astronomical telescopes, laser beams or retina imaging. (3) Coherent phasing of segmented large-scale gratings and adaptive optics for next-generation telescopes or laser systems.

The vision for the AOFIM Laboratory is to conduct frontier research in the aforementioned three areas and provide coherent, integrated, and closed-looped research and educational experiences to directly engage undergraduate and graduate students to work on a diverse set of real-world projects in Optical Science and Engineering. The mission is to train young researchers on how to frame research problems, acquire relevant knowledge, test hypotheses, demonstrate concepts, and provide solutions.

Dr. Qiao, Associate Professor, leads the AOFIM Laboratory where two PhD students, three undergraduate students, one high school intern, one visiting scholar, and one post-graduate researcher have been conducting their research projects during the past academic year.

Research projects:

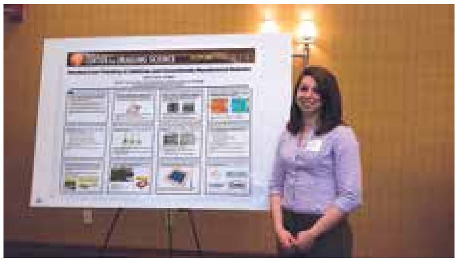
1. Ultrafast Lasers for advanced optics fabrication including integrated photonics and freeform optics

Ultrafast lasers are transforming the way that optics are being manufactured. They provide a more cost effective, time effective, and environmentally friendly solution for fabricating integrated photonics, freeform optics, and micro optics, and optoelectronic packaging.

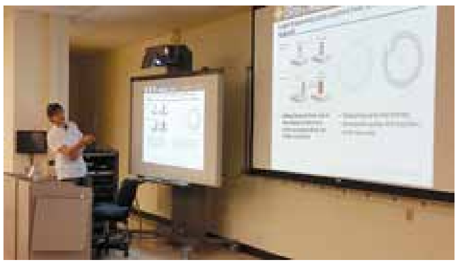
AOFIM Lab conducts fundamental research on the theoretical modeling and experimental demonstration of ultrafast lasers and matter interaction. This project investigates the phenomena, mechanism, systems, and metrology of non- thermal ultrafast-laser welding, polishing, and cutting of various optical materials, which will allow for the connection of different optics/glass materials and enable more compact, and better integrated photonics circuits with different functions.

Project team

Prof. Qiao was working with Lauren Taylor (Ph.D) and Daniel Morgen (NSF REU student) on a laser beam delivery system for ultrafast lasers for advanced optics and integrated photonics fabrication.

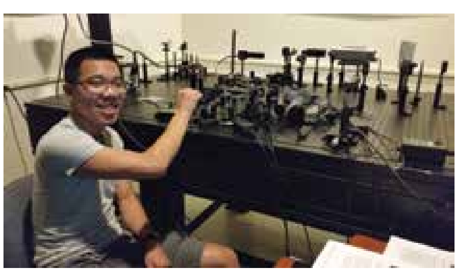


Third-year PhD student Lauren Taylor presented her research on laser polishing experiments at the 2015 University Technology Showcase by CEIS. Lauren has also been working on the theoretical interaction modeling to determine the optimum laser processing parameters.



NSF-REU student Daniel Morgen, rising senior from the Institute of Optics, University of Rochester conducted summer research on "Optical design and performance analysis of a trepanning system for laser material processing" at the AOFIM lab and he presented the work to his fellow REU students.

Dr. Jun Qiao, Professor of College of Materials Science and Metallurgy, the University of Science and Technology Liaoning, China, has joined AOFIM lab as a visiting scholar since May 2015. He brings in material science expertise to this ultrafast lasers and material interaction project and he will be conducting collaborative research in the following academic year.



NSF-REU student Klemens Gowin, a rising junior from the Institute of Optics, University of Rochester conducted summer research on "Freeform Surface Generation Using a Deformable Mirror and Grating Compressor Modeling" at the AOFIM lab. He also did a literature review on Freeform Metrology and presented his work to his fellow REU students.

2. Optical Differentiation wavefront sensor (OWDS) for freeform metrology and phase imaging

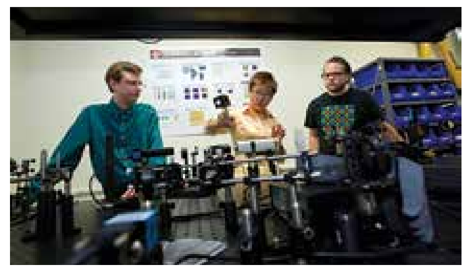
High-resolution wavefront sensors are of great interest for laser engineering and astronomy. The optical differentiation wavefront sensor allows for high signal-to-noise ratio broadband characterization of the spatial phase of optical waves. When a filter with a field transmission that is linear with respect to a spatial coordinate is located in the far field of the optical wave, the spatially resolved wavefront slope along that coordinate can be recovered from the near field of the filtered wave. The complete spatially resolved wavefront is recovered from a set of two orthogonal wavefront-slopes maps. Experimental reconstruction of the wavefront of a HeNe laser with Cr-on-glass pixelated binary transmission filters has been demonstrated. The trade-off between pixel size, filter size, beam parameters, and wavefront reconstruction accuracy has been studied.

The PI Dr. Qiao has provided an invited talk "Performance analysis of an optical differentiation wavefront sensor and its application to the metrology of freeform optics" at the Imaging and Applied Optics Congress in June, 2015 in Arlington, VA.

Project team

Zachary Mulhollan, a rising senior at the Chester Center for Imaging Science, RIT conducted summer research "the Modeling and Tolerance Analysis of an Optical Differentiation Wavefront Sensor" at the AOFIM lab. He presented his work at a group meeting.

Matthieu Chalifour, a high school intern from Brighton High School, worked on "The Analysis and Comparison of Single to Noise Ratio for Shack-Hardmann and ODWS sensors in the summer of 2015. He presented his work at a group meeting.



Prof. Qiao, Zachary Mulhollan (CIS undergraduate), and Dr. Aaron Schweinsberg (post-graduate research assistant) were working on the experimental demonstration of the ODWA sensor

Students across levels have active interactions:

Matthieu Chalifour (high school intern) and Klemens Gowin (NSF-REU student) were working together on a numerical model MATLAB.

The ODWS showed excellent self-consistency using two sets of orthogonal filters, achieving a difference of less than 1/20th of optical wave (one wave: 633nm), as shown in Figure 1.

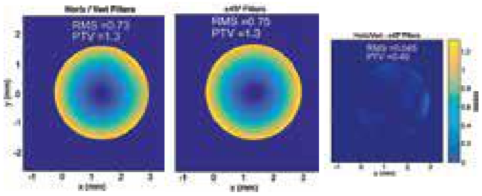


Figure 1. Left: measured wavefront using a pair of far-field filters with orthogonal linear transmissions in horizontal and vertical directions. Middle: measured wavefront using a pair of far-field filters with linear transmissions in two orthogonal 45-degree directions. Right: The difference of the two sets of measurements is less than 1/20th of optical wave.

The progress of this work has also been presented at the 2015 SPIE Photonics West conference (Jan. 2015 San Francisco, CA) and 2015 CLEO/OSA conference (May 2015, San Jose, CA).

3. Coherent phasing of segmented large-scale gratings for next-generation telescopes or laser systems.

This line of research effort builds on Dr. Qiao's experience and publication credentials in the high-energy laser field. As part of this effort, Dr. Qiao has finished the design and modeling of an innovative deformable–grating which can be used for both lasers and astronomical telescopes. She has submitted a journal paper to Optics Express. As the PI, Dr. Qiao Dr. Qiao has conceived the concepts and developed the proposal "Investigation and Demonstration for the Coherent Phasing of Transmissive Diffractive Optical Elements (DOE) for Large Lightweight Space Telescopes". This proposal was submitted to the NASA APRA program in March 2015. The objective of the proposal is to apply transmissive diffractive optical elements (DOE) into UV telescope systems and to study the coherent phasing of DOE subapertures to support continued development of lightweight space telescopes providing large collecting area and high angular resolution. The proposed work include modeling and laboratory demonstration of the coarse and fine phasing of a nominal segmented powered DOE telescope. This proposal includes collaborations with co-PI Dr. Joel Kastner, Exelis Inc. (now Harris Corp.), NASA Goddard Space Flight Center, Aktiwave LLC, and Patchwork Optical Consulting LLC.

Journal Publication (2014 - 2015)

(1) C. Dorrer, A. Consentino, D. Irwin, **J.Qiao**, J. Zuegel, OPCPA Front End and Contrast Optimization for the OMEGA EP Kilojoule, Picosecond Laser," accepted to appear in Journal of Optics, 2015, Article reference: JOPT-101628

Conference Publication / Presentation (proceeding / summary / abstract) (2014 - 2015)

(1) (Invited) **J. Qiao**, A. Travinsky, and C. Dorrer, "Performance Analysis of an Optical Differentiation Wavefront Sensor and its Applications to the Metrology of Freeform Optics," in Imaging and Applied Optics 2015, OSA Technical Digest (online) (Optical Society of America, 2015), paper FTh2B.2. (abstract only)

(2) J. Qiao, A. Travinsky, and C. Dorrer, "Optical differentiation wavefront sensor based on binary pixelated transmission filters," in CLEO: 2015, OSA Technical Digest (online) (Optical Society of America, 2015), Paper STu2N.1.

(3) J. Qiao, A. Travinsky, O. Ding, D. Dang, C. Dorrer, Optical differentiation wavefront sensor based on binary pixelated transmission filters, SPIE Proceedings, Paper 9356-6, SPIE Photonics West, San Francisco, CA, 7–12 Feb., 2015

(4) J.Qiao, X.Liu, and J. Papa "Actuator-Position Optimization and Holographic Correction for Large-Scale Deformable Gratings", 2014, International Ultrahigh Intensity Lasers Conference, Paper Tu2-P65, Goa, India, 12–17 October, 2014 (one-page abstract)

(5) J.Qiao, X.Liu, "Design and Actuator-Position Optimization for a Large-Scale Adaptive Grating", Frontiers in Optics, Paper FTu2C4, Tucson, Arizona, 19–23 October, 2014

Additional Conference Presentations

(6) J. Qiao, A. Travinsky, G. Ding, D. Dang, C. Dorrer, "A differential wavefront sensor based on binary pixelated transmission filters", 2014 SPIE NASA Mirror Technology Workshop, Albuquerque, New Mexico, 18–20 Nov, 2014 (poster)

(7) L. Taylor, J. Qiao, Ultrafast laser polishing offers flexible, high-precision finishing for conventional and additive manufacturing, University Technology Showcase, Center for Emerging and Innovative Sciences (CEIS), University of Rochester, Rochester, NY, 16 April, 2015 (poster)

GRANTS

(1) PI, NYSTAR CEIS, Development & Investigation of an Integrated Laser-based Optics Polishing System, July 01, 2014 - July 30, 2015, $30,000, Awarded

(2) PI, NYSTAR CEIS, Ultrafast laser Polishing for Additive Manufacturing, July 01, 2014 - June 30, 2015, $30,000, Awarded

(3) PI, OptiPro Systems LLC, Investigation of an Integrated Laser-based Optics Polishing, July 01, 2014 - June 30, 2015, $30,000 cash plus $30,000 equipment, Awarded

(4) PI, the Dean's Research Initiation Grant (COS), An innovative optical differentiation wavefront sensor based on binary pixelated transmission filters, August 01, 2014 - August 01, 2015, $15,000, Awarded

(5) PI, ADVANCE RIT/National Science Foundation (NSF), Advance RIT Connect Grant (RIT Internal Grant), $9,600, Awarded

(6) PI, NASA-National Aeronautics and Space Administration, Astrophysics Research and Analysis (APRA) Program: Investigation and Demonstration for the Coherent Phasing of Transmissive Diffractive Optical Elements (DOE) for Large Lightweight Space Telescopes, submitted on 20 March, 2015, $999,720, Pending

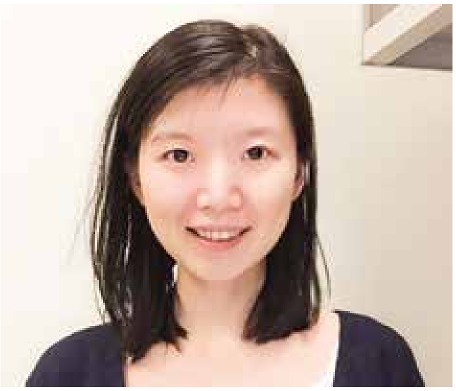
PhD candidate Garreth Ruane with NASA Administrator Charles Bolden.

Laboratory Director's comments by Dr. Grover Swartzlander

The laboratory enjoyed a productive year developing diverse areas related to imaging and optical physics.


Alexandra Artusio-Glimpse


Christian Cammarota


Xiaopeng Peng

The work was supported by the National Science Foundation, NASA, and others. The research spanned the areas of exoplanet research, radiation pressure for future space propulsion, computational imaging, and future space telescopes. Prof. Swartzlander leads a team of three graduate students (listed by seniority: Alexandra Artusio-Glimpse, Garreth Ruane, and Xiaopeng Peng), one visiting scholar (Dr. Lingyu Wan, Guangxi University), one undergraduate student (Christian Cammarota), various RIT collaborator faculty (Dr. Alan Raisanen, CAST; Dr. Michelle Chabot, SoPA; Dr. Mario Gomes, KGCE). External collaborators included scientists from Jet Propulsion Laboratory, US Naval Research Laboratory, NASA Marshall Space Flight Center, University of Liege, and University of Bristol. He also continues as Editor-in-Chief of the Journal of the Optical Society of America—B, which will begin celebrating a 100 year history in the coming year.

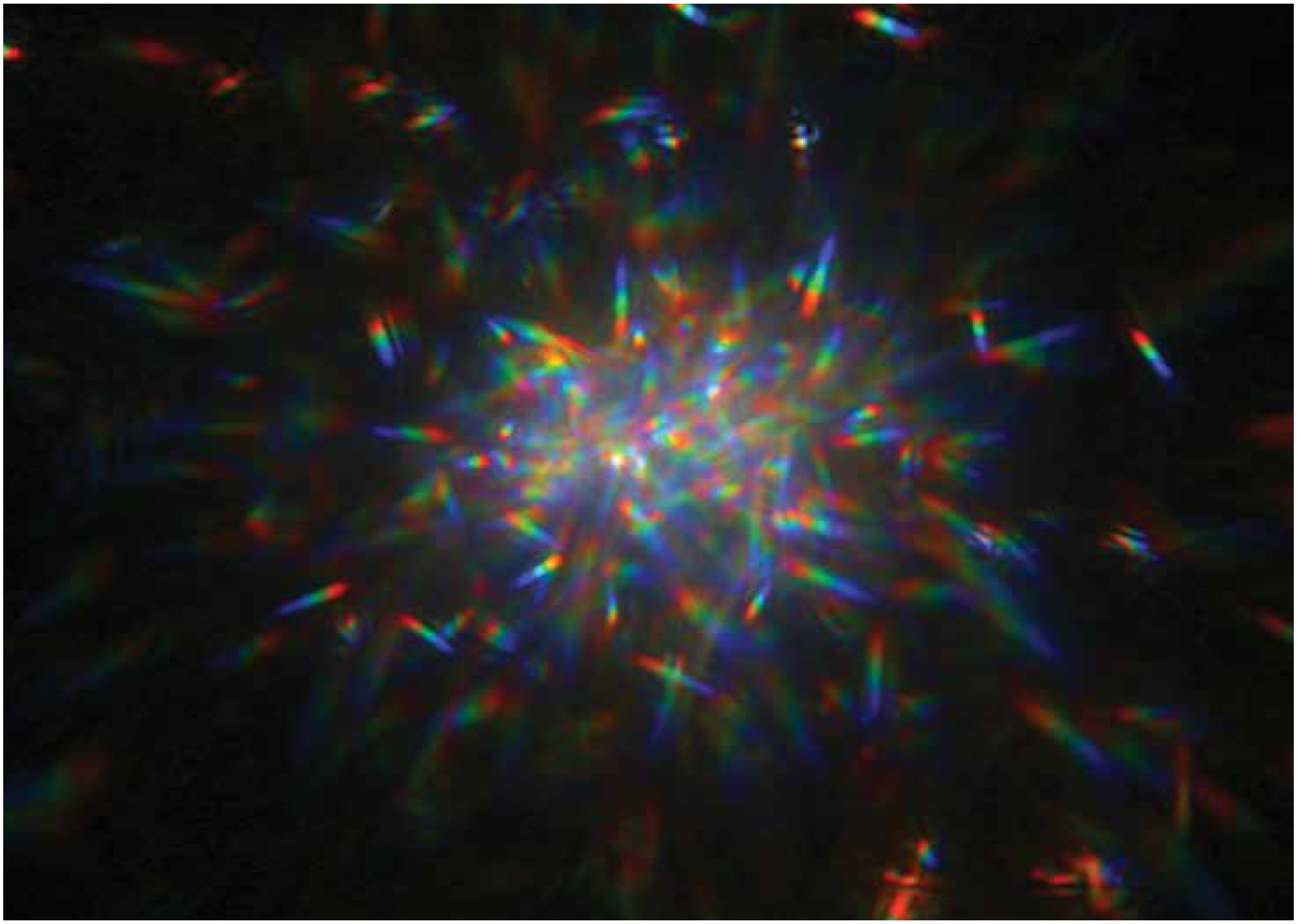
Research highlights includes a collaboration with the Jet Propulsion Laboratory to explore the shaping of a cloud of small reflective bodies into a large space telescope. Using computational imaging techniques, the RIT team demonstrated imaging using craft store glitter. The team continues to explore how space based lasers may be used to orient the reflective optics with non-contact forces. A separate collaboration with a European Space Agency group based in Belgium is developing a diamond optical vortex coronagraph to help astronomers image exoplanets with large ground based telescopes. An additional collaboration with NRL seeks to use computational imaging schemes to protect optical sensors from damaging laser beams.

Projects (additional RIT team members)

- Radiation Pressure Torsion Oscillator (Artusio-Glimpse, Raisanen, Chabot, Gomes)
- Optical Vortex Scatterometer (Ruane, Wan)
- Optical Vortex Coronagraph (Ruane)
- Granular Space Telescope (Peng, Ruane, Artusio-Glimpse)
- Radiation Protection (Ruane)

Publicity Highlights:

- National Public Radio All Things Considered, Joe's Big Ideas
- YouTube, Light Matters
- The Economist, Space Telescopes, A Glittering Prize
- RIT Press Release
- JPL Press Release



This image shows white light reflected off of a glitter mirror onto a camera sensor. Researchers tested this in a laboratory as part of the concept of "Orbiting Rainbows," a low-cost solution for space telescope mirrors. Credit: G. Swartzlander/Rochester Institute of Technology

Patent Awarded:

- Optical lift apparatuses and methods thereof (2014)

Recent Publications:

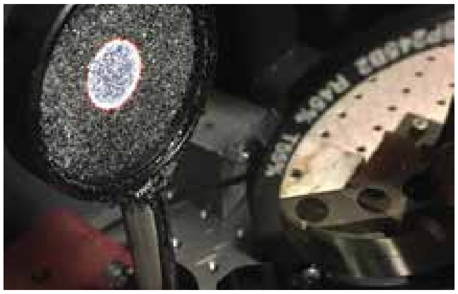
- "Nodal areas in coherent beams," Ruane, Swartzlander, Slussarenko, Marrucci, Dennis, Optica (2015)
- "Reducing the risk of laser damage in a focal plane array using linear pupil-plane phase elements," Ruane, Watnik, Swartzlander, Applied Optics (2015)
- "Nonlinear response and stability of a 2D rolling semi-cylinder during optical lift," Schuster, Gomes, Artusio-Glimpse, Swartzlander, Nonlinear Dynamics (2015)
- "Image restoration from a sequence of random masks," Peng, Ruane, Artusio-Glimpse, Swartzlander, SPIE Proceedings (2015)
- "Mirror swarm space telescope," Peng, Swartzlander, IEEE Proceedings (2014)
- "An Overview of Solar Sail Propulsion within NASA," Johnson, Swartzlander, Artusio-Glimpse, chapter in Advances in Solar Sailing (2014)
- "Thrust Efficiency on an Idealized Deformable Sail," Artusio-Glimpse, Swartzlander, chapter in Advances in Solar Sailing (2014)
- "Rocking motion of an optical wing: theory," Artusio-Glimpse, Schuster, Gomes, Swartzlander, Applied Optics (2014)
- "Vortex-phase filtering technique for extracting spatial information from unresolved sources," Ruane, Kanburapa, Han, Swartzlander (2014)
- "Zernike amplitude pupil apodization for vortex coronagraphy with obscured apertures," Ruane, Swartzlander, arXiv (2014)
- "Vortex-phase filtering technique for extracting spatial information from unresolved sources," Ruane, Kanburapa, Han, Swartzlander, arXiv (2014)

Glitter Cloud May Serve as Space Mirror

What does glitter have to do with finding stars and planets outside our solar system? Space telescopes may one day make use of glitter-like materials to help take images of new worlds, according to researchers at NASA's Jet Propulsion Laboratory in Pasadena, California.

Standard telescopes use solid mirrors to image far-away objects. But the large, complex mirrors needed for astronomy can be quite expensive and difficult to construct. Their size and weight also add to the challenges of launching a space telescope in the first place.

A concept called Orbiting Rainbows seeks to address these issues. Researchers propose using clouds of reflective glitter-like particles in place of mirrors to enable a telescope to



Researchers made a mirror surface out of glitter to test the idea of using a cloud of reflective particles as a space telescope mirror. They took images of two light sources using this mirror in a laboratory at Rochester Institute of Technology. Credit: G. Swartzlander/Rochester Institute of Technology.

view stars and exoplanets. The technology would enable high-resolution imaging at a fraction of the cost.

"It's a floating cloud that acts as a mirror," said Marco Quadrelli from

JPL, the Orbiting Rainbows principal investigator. "There is no backing structure, no steel around it, no hinges; just a cloud."

In the proposed Orbiting Rainbows system, the small cloud of glitter-like grains would be trapped and manipulated with multiple laser beams. The trapping happens because of pressure from the laser light -- specifically, the momentum of photons translates into two forces: one that pushes particles away, and another that pushes the particles toward the axis of the light beam. The pressure of the laser light coming from different directions shapes the cloud and pushes the small grains to align in the same direction. In a space telescope, the tenuous cloud would be formed by millions of grains, each possibly as small as fractions of a millimeter in diameter.

Such a telescope would have a wide adjustable aperture, the space through which light passes during an optical or photographic measurement; in fact, it might lead to possibly larger apertures than those of existing space telescopes.

It would also be much simpler to package, transport and deploy, than a conventional space telescope.

"You deploy the cloud, trap it and shape it," Quadrelli said.

Nature is full of structures that have light-scattering and focusing properties, such as rainbows, optical phenomena in clouds, or comet tails. Observations of these phenomena, and recent laboratory successes in optical trapping and manipulation have contributed to the Orbiting Rainbows concept. The original idea for a telescope based on a laser-trapped mirror was proposed in a 1979 paper by astronomer Antoine Labeyrie at the College de France in Paris.

Now, the Orbiting Rainbows team is trying to identify ways to manipulate and maintain the shape of an orbiting cloud of dust-like matter using laser pressure so it can function as an adaptive surface with useful electromagnetic characteristics, for instance, in the optical or radar bands.

Because a cloud of glitter specks is not a smooth surface, the image produced from those specks in a telescope will be noisier—with more speckled distortion—than what a regular mirror would generate. That's why researchers are developing algorithms to take multiple images and computationally remove the speckle effect from the glitter.

To test the idea, co-investigator Grover Swartzlander, an associate professor at the Rochester Institute of Technology in New York, and his students spread glitter on a concave lens in the laboratory. His team used lasers to represent the light from a double star system. They pointed the speckled mirror at the simulated stars, then used a camera to take pictures. With many exposures and lots of processing, an image of the two "stars" emerged using the glitter mirror.

"This is a major achievement," Quadrelli said. "This demonstrates a highly controlled experiment in which we were able to do imaging in the visible light spectrum."

The technology could be used more easily for radio-band signals. Because the wavelength is so much longer (about one centimeter, compared to nanometers in visible light), the mirror grains don't have to be as precisely controlled or aligned. This opens up Earth science applications such as earthquake detection and remote sensing of water and other phenomena. JPL's Darmindra Arumugam is investigating possible mechanisms for remote sensing with Orbiting Rainbows.

The JPL optical design team, including Scott Basinger and Mayer Rud, has been working on the adaptive optics techniques that would be needed by an Orbiting Rainbows telescope. So far, the team has been exploring reflective, refractive and diffractive versions of a telescope based on Orbiting Rainbows, with maximum sensitivity to one specific frequency.

Orbiting Rainbows has not yet been demonstrated in space. For a test in low-Earth orbit, the researchers would deploy a telescope with a small patch of particles, no larger than a bottle cap, to show that it can be trapped and shaped to reflect light. The next step would be to make many of these patches and synthesize an aperture with which to do imaging.

The project represents a new application of "granular matter," materials such as dust grains, powders and aerosols. Such materials are very light, can be produced at low-cost and could be useful to the space exploration community. In this particular project, the "glitter" may be tiny granules of metallic-coated plastic, quartz or some other material.

Orbiting Rainbows is currently in Phase II development through the NASA Innovative Advanced Concepts (NIAC) Program. It was one of five technology proposals chosen for continued study in 2014. In the current phase, Orbiting Rainbows researchers are conducting small-scale ground experiments to demonstrate how granular materials can be manipulated using lasers and simulations of how the imaging system would behave in orbit.

NIAC is a program of NASA's Space Technology Mission Directorate, located at the agency's headquarters in Washington. JPL is managed by the California Institute of Technology for NASA.

For a complete list of the selected proposals and more information about NIAC, visit:

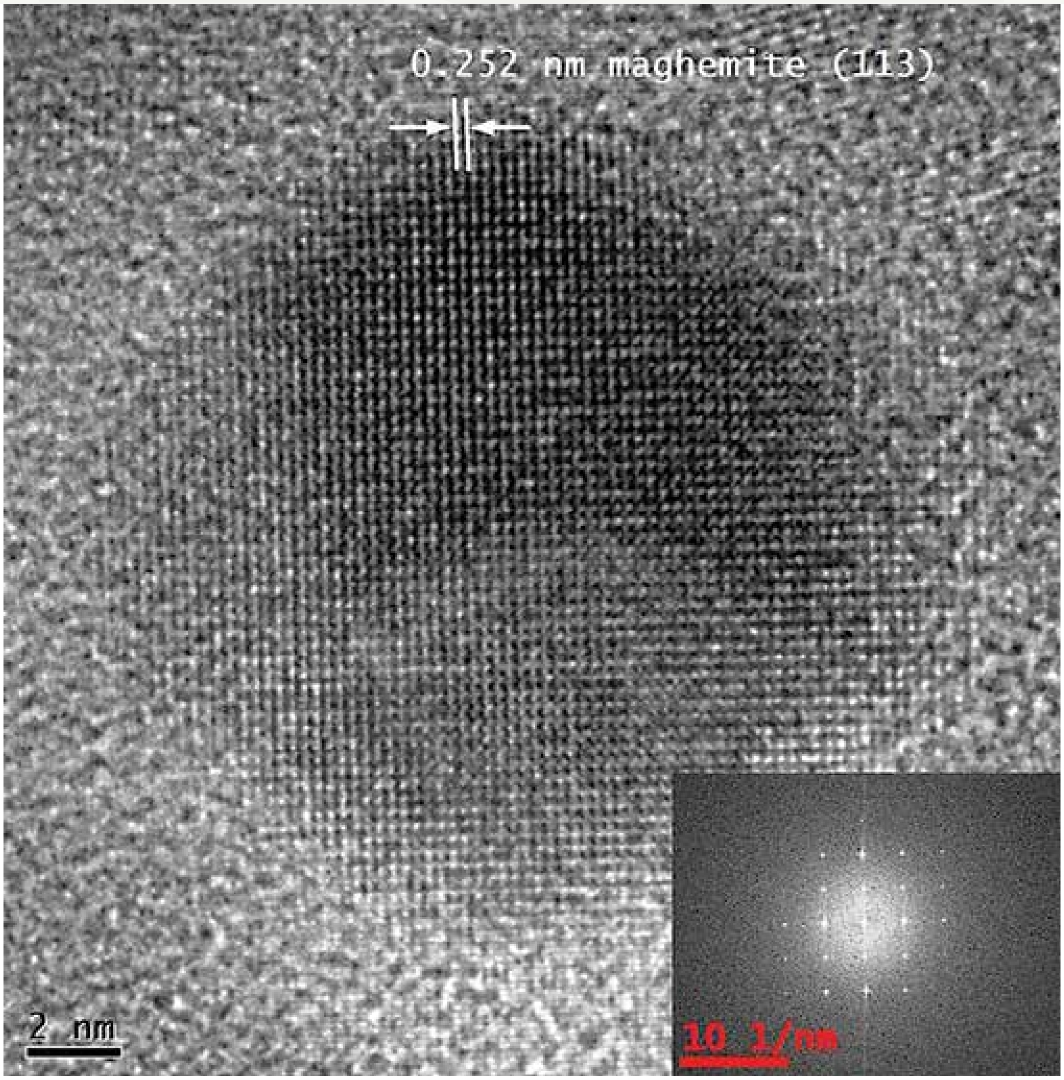
http://www.nasa.gov/niac

For more information about the Space Technology Mission Directorate, visit:

http://www.nasa.gov/spacetech

Glitter Mirror

Researchers made a mirror surface out of glitter to test the idea of using a cloud of reflective particles as a space telescope mirror. They took images of two light sources using this mirror in a laboratory at Rochester Institute of Technology. Credit: G. Swartzlander/ Rochester Institute of Technology

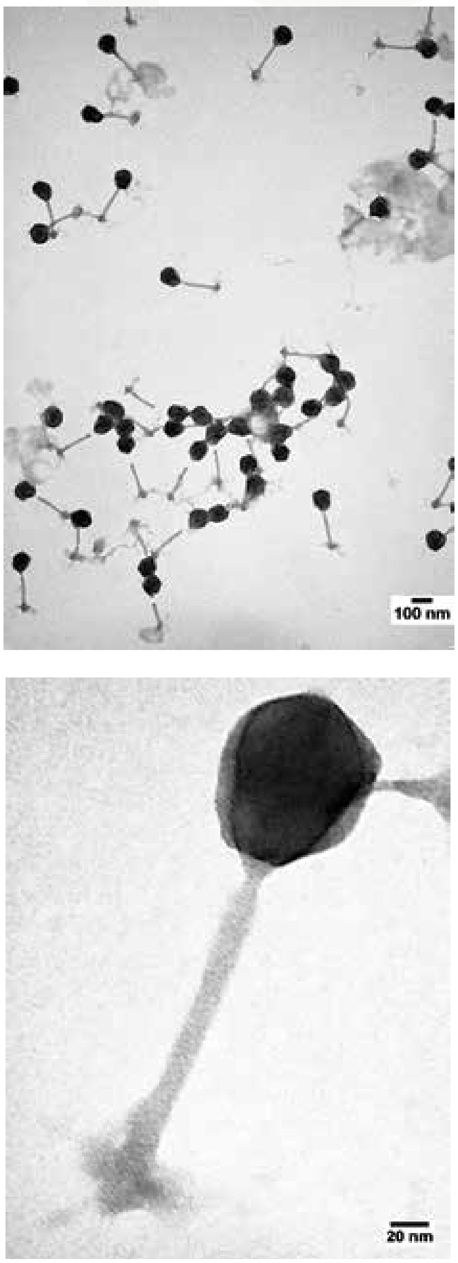


A high-resolution TEM image of a maghemite (γ-Fe_2O_3) nanocrystal. The individual columns of atoms can be seen in the crystal and the spacing between columns is indicated. The inset is a Fast Fourier Transform of the image and represents the electron diffraction pattern of the nanocrystal. The spacing between spots allows the determination of crystal structure and confirms that the crystal is maghemite.

NANOIMAGING RESEARCH LABORATORY

Laboratory Director's Comments By Professor Rich Hailstone

The NanoImaging Laboratory has continued to grow in the diversity of materials imaged at the micro and nanoscale as part of collaborations with other RIT research groups and our industrial partner.



Phage Imaging. Phages (or more correctly bacteriophage) are biomaterials that have a specific affinity for bacteria. They inject their genetic material into the bacterium following infection and can cause the bacteria to synthesize phage nucleic acids and proteins. This is a joint project with Professor Julie Thomas, a phage researcher in the School of Life Sciences, to support her research, as well as the phage workshop she teaches in the Spring semester.

Currently we are focused on determining the optimal pathway to preparing the phage for imaging in the transmission electron microscope (TEM). It is required to preserve the phage material in its natural state, but still be compatible with the vacuum of the electron microscope. Figure 1 shows both an overview of the phages, as well as a magnified view of one phage, showing its capsid and the tail used to penetrate the bacterium. Contrast is enhanced by staining the material with phosphotungstic acid. At this point the preparation is less than optimal, as the capsids are too dark.

Imaging Polymer Blends. This is a project with Professor Carlos Diaz-Acosta in Packaging Science. He is blending three biodegradable polymers in effort to make the packaging more "green," but still possess the requisite physical properties for the intended packaging. The goal of the project is to connect the nano- and micro-structures seen in the electron microscope with macroscopic physical properties. Figure 2 shows TEM images of the polymer blend, indicating at least two phases—the darker structures and the more or less continuous background.

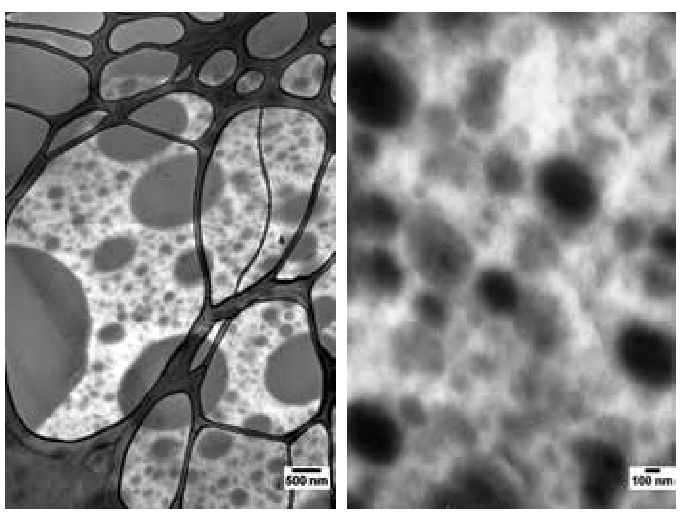


Fig. 2. Left, TEM image at low magnification of the polymer blend. The darker "stringy" structures are from the lacey carbon support that the polymer cross section is resting on. Right, a higher magnification view of the polymer blend.

Fig. 1. TEM images of wild type phage.

We have also looked at these blends in the scanning electron microscope (SEM) and an example is given in Fig. 3. These cross-sections of the polymer blend are prepared by a freeze-fracture technique. On the left is an indication that there are at least two phases present because of the brighter pseudo-circular structures on the darker background. On the right is a higher magnification view in which the contrast has been enhanced. This image may indicate there are three phases present. The larger white structures or the very dark features where the larger white structures once were located comprise one phase. But the gray background may also indicate two phases—small darker features on a lighter continuous background. This possibility is being explored in future work.

Laser-Aided Manufacturing. One of Professor Jie Qiao's research group's interest is in using ultrafast lasers to enhance manufacturing capabilities. The CIS Microscopy Facility is being used to characterize laser-matter interactions. Using samples prepared by CIS PhD student Lauren Taylor, we imaged the material in the SEM. An example is shown in Fig. 4. Circularity and depth of the laser-produced hole are important attributes in this test and the SEM images are critical in quantifying the laser-matter interaction.

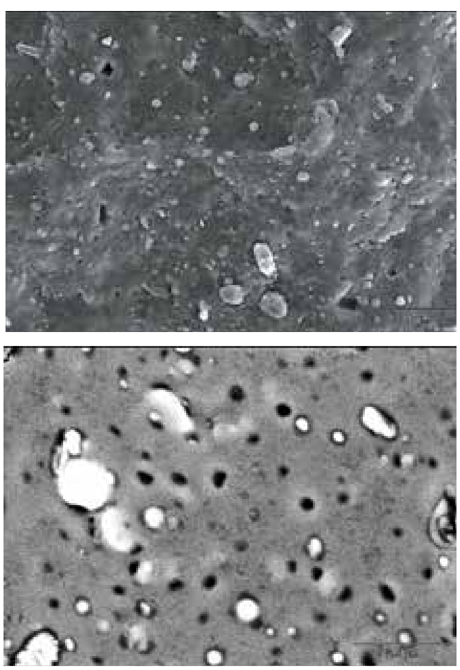


Fig. 3. Top, SEM image at low magnification of the polymer blend. Bottom, a higher magnification view of the polymer blend with contrast enhanced.

Analysis of Pt Particles in SrTiO3. Professor Michael Pierce (Physics) and MS&E MS student Joshua Goodman have synthesized Pt nanoparticles on a SrTiO3 substrate. After annealing in H2, the particles are about 100 nm in height and widths varying between 10's and 100's of nanometers, as shown in Fig.5. The figure on the left indicates most nanoparticles have a large bright area and one or more edges have a darker area. The latter could indicate the nanoparticles have a varying composition. The right-hand image indicates that the nanoparticles have a height around 100 nm.

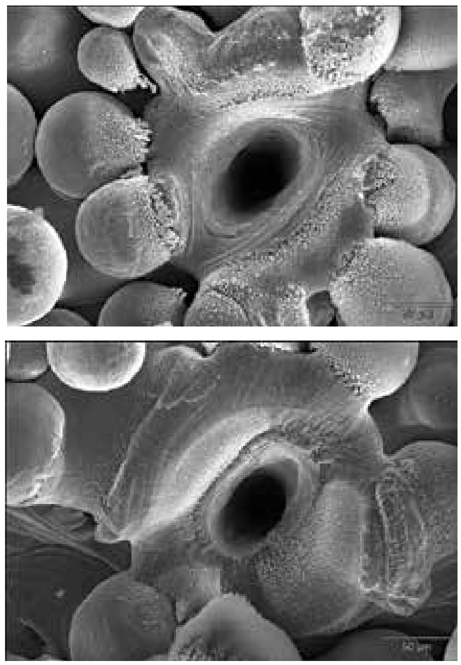


Fig. 4. SEM images of a Ti alloy which has been exposed to a high-power laser. Top: 500k pulses over 15 s. Bottom: 2000k pulses over 15 s.

To check the composition of the nanoparticles we used EDS in linescan mode. EDS (energy dispersive spectroscopy) uses the x-rays emitted by the sample when exposed to the high-energy beam electrons. The energy of these x-rays is characteristic of the element that emitted them, so this becomes a way to spatially determine the elemental composition of the nanoparticles. As shown in Fig. 6, the bright area of the particle is Pt, but the darker area has the composition similar to the substrate. The Sr signal does not go to zero when the beam is on the Pt phase of the particle because the beam electrons are energetic enough to penetrate through the Pt and excite Sr x-rays in the substrate. This ability of the beam electrons to penetrate the Pt phase was confirmed by Monte Carlo simulations

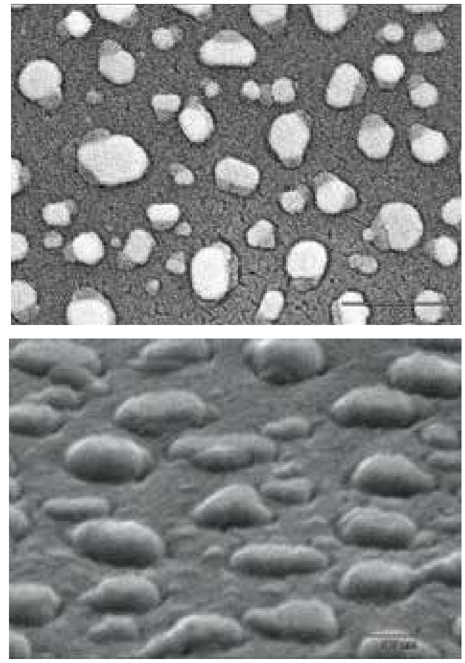


Fig. 5. SEM images of Pt nanoparticles on SrTiO3 substrate. Left: Image looking perpendicular to nanoparticles. Right: Image with sample tilted 70 degrees to normal to reveal sides of the nanoparticles.

of the electron trajectory. From these results it appears that the synthesis of the Pt nanoparticles and/or the subsequent anneal in H2 is also disturbing the substrate.

Alkali-Activated Materials as Substitutes for Portland Cement. The world uses large volumes (4.18 billion metric tons in 2015) of Portland cement every year in the manufacture of concrete, with huge effects on energy and greenhouse gas production. In the latter case it is estimated that 5% of total anthropogenic emissions of CO2 come from cement production. Alkali-activated materials are cementitious materials that can be produced from industrial by-products, with less impact on energy and greenhouse gas emissions.

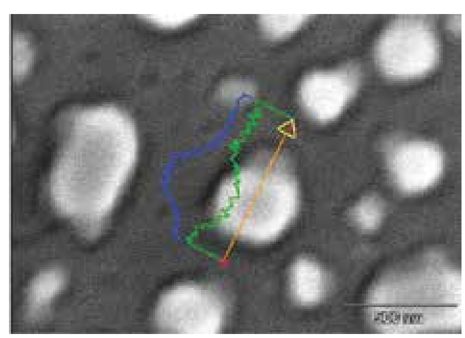


Fig. 6. Linescan elemental analysis of a Pt nanoparticle along the direction indicated by the yellow arrow. Superimposed on the linescan arrow are the x-ray signals from Sr (green) and Pt (blue).

The purpose of this joint project with Professor Varela in Mechanical Engineering and CIS MS student Najat Alharbi is to explore possible correlations of the nano- and micro-structure of the produced cements with the physical properties of the material, especially compressive strength. Currently, we are studying blast-furnace slag as a substitute. The slag material is predominately composed of the oxides of calcium and silicon, with minor constituents of the oxides of aluminum and magnesium.

One of the possible factors affecting the physical properties of cement is the pore size and its distribution. Traditionally this property is measured with N2 adsorption-desorption in an experiment called "BET." As an alternative, we directly measured the diameter of the pores using TEM images of the material such as those shown in Fig. 7. A comparison of pore size distribution measured by the two techniques is shown in Fig. 8 and suggests that the two techniques are measuring a similar property. The advantage of using TEM is that it images the pores directly, rather than indirectly as with the BET method.

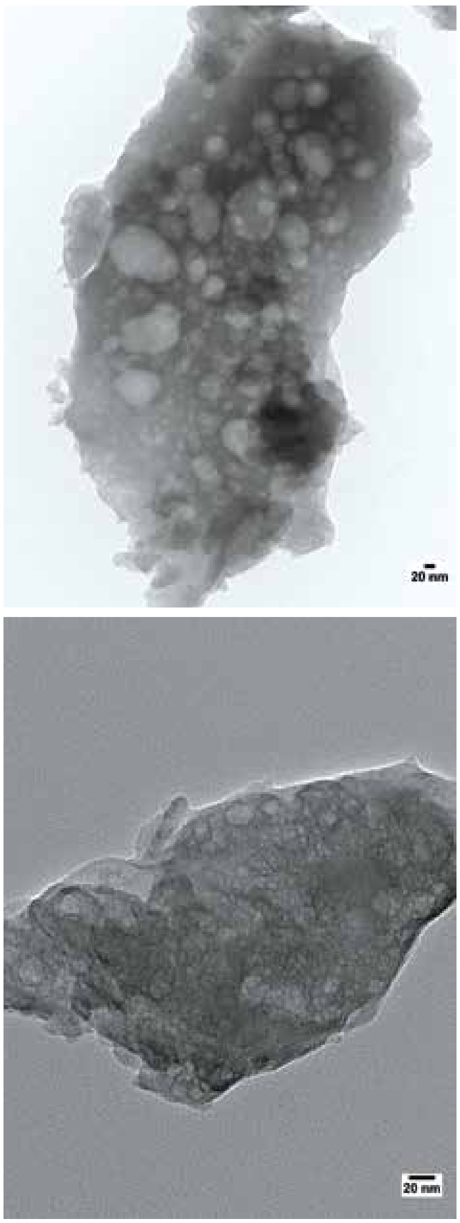


Fig.7. TEM images of slag-based cement. The lighter shapes are examples of voids or pores in the material. Their diameter was measured to produce the histogram in Fig. 8.

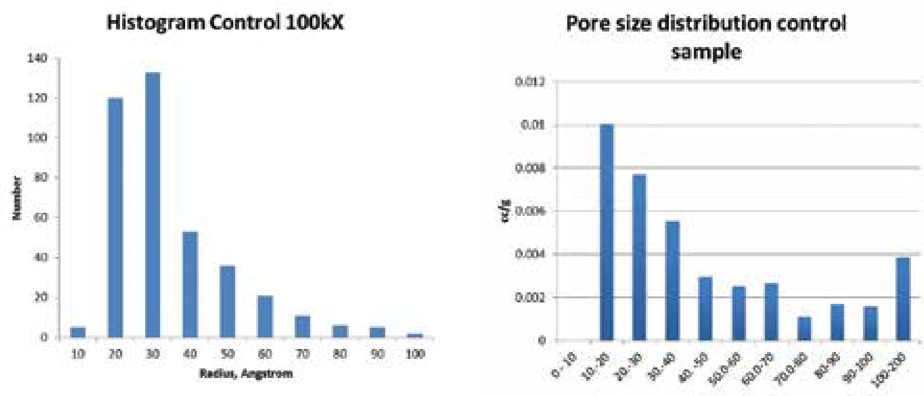


Fig.8. A comparison of pore distribution as measured from TEM images, left, and from the standard BET measurement, right.

Another aspect of the cement material is the extent of cracking in the cured material. This property could be correlated with the material's compressive strength. Figure 9 is a comparison of SEM images of the control material and an improved version with higher compressive strength obtained by omitting one of the raw material components. The total crack length of the control measured over five randomly chosen fields of view was more than twice that for the improved version.

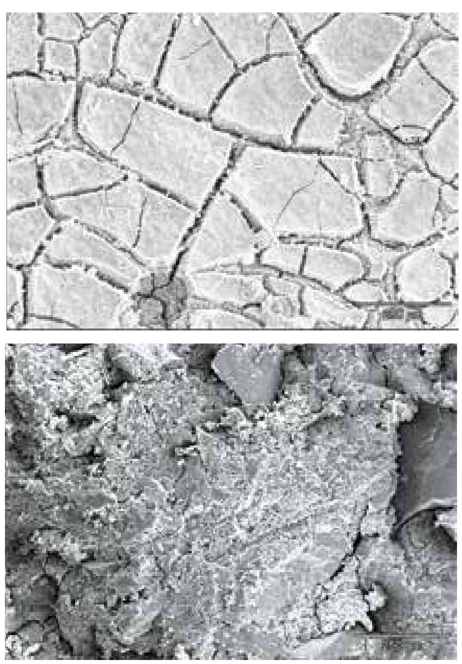


Fig.9. SEM images of the cement material after curing. Left, control, right, improved version with higher compressive strength by omitting one of the raw materials.

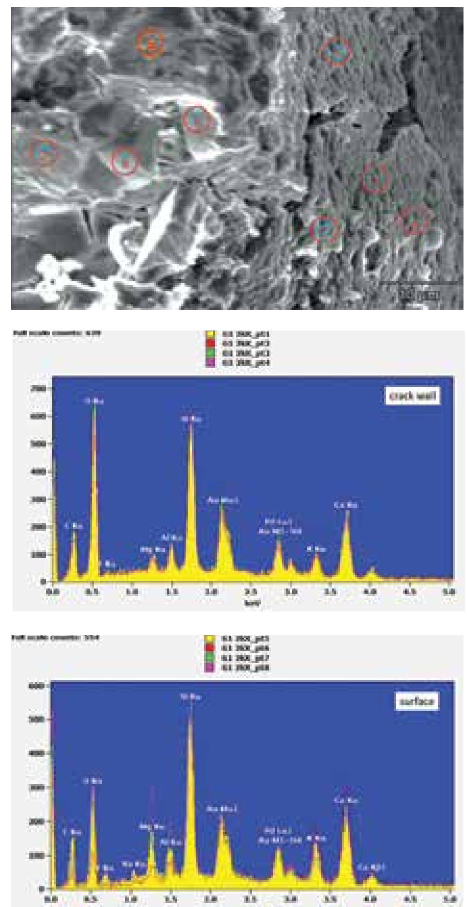


Fig. 10. Top, SEM image of a crack wall (right-hand side) and the adjoining surface (left-hand side). Numbers indicate regions where x-ray spectra were collected. Middle, EDS spectrum of the crack wall at the four different locations indicated in the SEM image. Bottom, EDS spectra of surface wall at the four different locations indicated in the SEM image. Au and Pd are from the sputter-coated film applied to make the sample electrically conductive.

We are also interested in studying the elemental distribution in the cement, and in particular within the cracks. Figure 10 shows an SEM image of a crack and the adjoining surface f one of the improved versions. The numbered circles indicate where x-ray spectra were collected, and these are shown in the lower part of the figure for both the crack wall and the surface. The most obvious difference is that of the O peak. It is much lower at the surface, as well as being more variable between the different locations. At this time it is not clear what this might mean.

Publications, Patent Applications, Patents Issued, Invention Disclosures, and Conference Presentations 2014-2015

1. A. G. DiFrancesco, R. K. Hailstone, K. J. Reed, and G. R. Prok (2014). Cerium-Containing Nanoparticles, U. S. Pat. App. 14/537,161
2. A. G. DiFrancesco, R. K. Hailstone, K. J. Reed, and G. R. Prok (2014). Cerium-Containing Nanoparticles, U. S. Pat. App. 14/537,993
3. A. G. DiFrancesco, R. K. Hailstone, A. Langner, and K. J. Reed (2014). Method of Preparing Cerium Dioxide Nanoparticles, Japanese Pat. No. 5462627
4. A. G. DiFrancesco, R. K. Hailstone, K. J. Reed, and G. R. Prok (2014). Cerium-Containing Nanoparticles, U. S. Pat. No. 8,883,865 B2
5. R. Hailstone, K. Reed, T, Allston (2015) Oxidation Resistant, Structured, Hexagonal Plate Nanoparticle Conductive Ink. RIT Invention Disclosure 2015-007
6. R. Hailstone, K. Reed, T, Allston (2015) Oxidation Resistant, Structured, Spherical Nanoparticle Conductive Ink. RIT Invention Disclosure 2015-008
7. R. Hailstone, K. Reed, T, Allston (2015) Oxidation Resistant, Structured, Cubic Nanoparticle Conductive Ink. RIT Invention Disclosure 2015-009
8. R. Hailstone, K. Reed, T, Allston, A. Cannella, S. Reed (2015). Facile, Low Temperature Synthesis of Metallic Nanoparticles. RIT Invention Disclosure 2015-019.

Grants and Contracts 2014-2015

Cerion Advanced Materials, $28k

Other Income 2014-2015

Microscopy Facility $30k

Facilities

Microscopy: JEOL 6400V scanning electron microscope with a LaB6 electron gun and energy dispersive X-ray analysis for elemental detection. JEOL 2010 transmission electron microscope with energy dispersive X-ray analysis for elemental detection. JEOL 100CX II transmission electron microscope. Reichert Jung ultramicrotome for cross-section preparation. Nikon 9000 Film Scanner.

Dr. Dube and undergraduate researcher Cailtin Kavanaugh discuss specific results of the neural network forecasts of space weather storms.

Laboratory Director's Comments By Dr. Roger Dube

The Space Weather lab develops technologies to ensure sustainable colonies on the Moon, Mars and other interplanetary bodies by developing advanced early warning systems that forecast the arrival of deadly space weather storms at the colony location.

Severe space weather storms can also bring down the power grid and disable or even destroy satellites orbiting around Earth due to the high electromagnetic pulse that often accompanies storms of this nature. In order to assure the survivability of a human colony on the moon or Mars, there remains a critical need to develop a predictive capability that will monitor various precursor events on the sun and develop a high-confidence prediction that a coronal mass ejection will erupt at a future time. Moreover, such a system should include forecasting awareness of planetary and spacecraft positions so that warnings may be issued to appropriate human operations in multiple places within the solar system. The amount of advanced warning is clearly important, since the first wave of radiation (X-rays) and very high-energy particles (> 100 mev protons) will strike the Earth (for example) eight minutes and Mars 12 minutes after eruption. The extent to which a reliable predictor with high confidence can be developed that provides in excess of hours of advanced notice before a CME eruption will determine how much preparation time Earth and a colony on Mars have before being struck by the first wave of radiation. This early warning should provide any affected populations to take protective actions, thereby assuring survivability of their effort.

Today we have about a 30-minute warning before such a high speed storm strikes the earth and our infrastructure. This is insufficient time to prepare spacecraft orientations, protect astronauts in interplanetary travel, and, ultimately, to protect colonists on the moon or Mars. Our work is directed towards extending this warning time.

Our current research employs an artificial intelligence (AI) system that we hope will identify precursors to the storms so that we can get an early warning. Matthew Murphy, a master's student in Imaging Science, is completing his thesis using this tool. His work has validated the ability of the AI to correctly model the functional behavior of these storms as a function of certain parameters. His work has duplicated published results of space weather research with high accuracy.

Our next phase will be the extension of this tool to identifying other parameters that can act as reliable indicators for storms.

Staff

One full time faculty member, Dr. Roger Dube of Imaging Science, anchors the lab. With earlier seed funding by NASA, the Space Weather lab works closely with NASA on advanced predictive algorithms that monitor solar data for signatures that can reliably predict a subsequent eruption.

Research in the lab has been and continues to be conducted by:

- Matthew Murphy, MS candidate to graduate in the summer of 2015

Summer REU students have included:

- Alicia Lazore
- Alexis LaBoy
- Ivana Molina
- Stephen Chow
- Andrew Ferris
- Caitlin Kavanaugh

Outreach

Dr. Dube's role as a Native American faculty member, combined with his mentoring of students in the local chapter of the American Indian Science and Engineering Society (AISES), provided multiple opportunities to attract members of various underrepresented minority groups to the project. In particular, during the past 3 years, the project has included:

- 3 Native Americans
- 3 African Americans
- 5 women

Press Coverage

Since its inception, the project has enjoyed a good deal of press coverage, ranging from front-page local newspaper coverage to Space Coalition and Mars Daily websites.

Democrat and Chronicle—front page: http://rocnow.com/article/local-news/20109130331

Azo Sensors: http://www.azosensors.com/Details.asp?NewsID=130

Mars Daily.com: (we didn't know there was such a thing!) http://www.marsdaily.com/reports/Early_Warning_System_Would_Predict_Space_Storms_on_Mars_999.html

PlanetStewards.net: http://planetstewards.net/a919727-early-warning-system-would-predict-space.cfm

The Space Coalition: http://spacecoalition.com/blog/nasa/danger-mars-colonists-need-for-predicting-space-storms

PR Web: http://www.prweb.com/releases/RIT_Roger-Dube/space_storms_Mars/prweb3808924.htm

Softpedia News: http://news.softpedia.com/news/How-to-Forecast-Space-Storms-on-Mars-138729.shtml

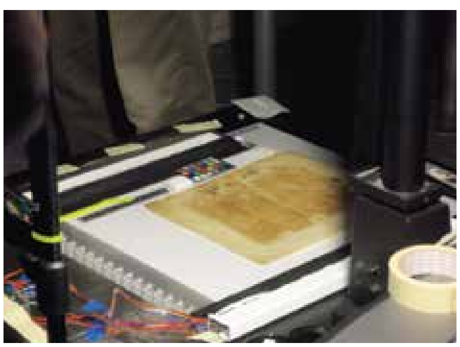
Collages before imaging by infrared thermography at Thermal Wave Imaging, Ferndale MI, May 2014

HISTORICAL MANUSCRIPT IMAGING

Laboratory Director's Comments By Dr. Roger Easton

In the past year, the Laboratory for Historical Manuscript Imaging was engaged in a wide variety of research efforts involving both new manuscripts and new technologies.

Dr. Gregory Heyworth and Dr. Roger Easton with imaging system in the Vatican Library, August 2014



Leaf from the Codex Vercellensis in place for imaging at the Museo del Tesoro del Duomo in Vercelli, Italy, July 2014.

The success achieved in these tasks has led to invitations to image more new items in the coming year. Dr. Roger Easton collaborates with faculty and staff at other institutions, including Dr. Gregory Heyworth of the University of Mississippi, Michael Phelps of the Early Manuscripts Electronic Library, and Dr. Daniel Stoekl Ben Ezra of the *École Pratique des Hautes Études*. The students participating in this work include David Kelbe, Liz Bondi, and Kevin Sacca.

In May 2014, Dr. Easton traveled with Dr. Heyworth to *Thermal Wave Imaging* in Ferndale MI (near Detroit) to use infrared thermography techniques to image a pair of collages evidently made by Juan Gris. The goal was to find indications of hidden writing.

In the summer of 2014, Dr. Easton and Liz Bondi traveled to Vercelli, Italy to participate with the team that imaged the *Codex Vercellensis* (also known as *Codex a*) at the *Museo del Tesoro del Duomo*; the team also included Dr. Heyworth, Michael Phelps, Dr. Keith Knox (then of the USAF Research Lab on Maui), Dr. Ira Rabin of the *Technische Universität Berlin*, Kenneth Boydston of Megavision, Inc., and several undergraduate honors students from the University of Mississippi. This significantly damaged long manuscript (more than 600 leaves) is believed to be the earliest manuscript of the Old Latin Gospels, dating from the late fourth century. Immediately following, Dr. Easton traveled to Rome along with Dr. Knox, Ken Boydston, and Michael Phelps, where they met with David Kelbe for imaging and processing of a palimpsest in the collection of the Vatican Library.

In August, Dr. Easton participated in imaging of a world map by Henricus Martellus Gemanus in the collection of the Beinecke Rare Book and Manuscript Library of Yale University. This project, funded by the National Endowment for the Humanities and led by map scholar Chet Van Duzer, included Dr. Heyworth, Ken Boydston, and Michael Phelps. This large map (approximately 2 m wide and 1.25 m tall) of the world was made c. 1491 and likely was consulted by Christopher Columbus before his travels to the new world. The map was painted in tempera over a base of paper made backed by a large canvas. The writings are in several different colors on several different colors of background, which is a considerably different situation compared to that for manuscripts, which are usually in one or two colors of ink over bare parchment. The writings on the map have so faded over time that very few texts remain readable to the unaided eye. The images were processed to reveal much text that had not been read for hundreds of years. These writings confirmed that much of the text on the 1507 printed world map by Martin Waldseemüller (which was imaged in 2007) had been copied from this map or from its sources. This project received a considerable amount of press attention, including a one-page article in the June 2015 issue of *Smithsonian Magazine*.

In September 2014, Dr. Easton traveled to Paris with Dr. Heyworth and Michael Phelps to present an imaging workshop at the *École Pratique des Hautes Études*, which is associated with the Sorbonne. This week-long workshop was attended by approximately 20 participants from several institutions in France and led to the proposal for a project to image the damaged manuscripts from the Cathedral at Chartres.

Together with Michael Phelps and Dr. Heyworth, Dr. Easton traveled to Tbilisi in March 2015 to propose pilot projects to image manuscripts at the Georgia *National Center for Manuscripts* and the *Georgia State Archives*. These proposals were accepted and a team will be traveling there in July-August of 2015 to demonstrate capabilities prior to proposing full projects

Throughout the year, the team worked on processing of images of the palimpsests in the collection at St. Catherine's Monastery in Sinai and of the David Livingstone diaries in the collection of the David Livingstone Center in Blantyre and the National Library of Scotland in Edinburgh.

Dr. Easton traveled to Udupi, India in May 2015 with Dr. P.R. Mukund of the RIT Department of Electrical Engineering and Dr. Knox to propose a new *Center for the Preservation of Manuscripts* at the *Shri Madhwa Vadiraja Institute Of Technology & Management*, which is intended to establish the imaging capability to preserve the writings on palm leaf manuscripts in India. This proposal was accepted and Dr. Easton now serves on the advisory board of the new organization.

Presentations:

27 June 2014: Talk at Dartmouth College

12, 14 August 2014: Two talks at the Beinecke Rare Book and Manuscript Library

15-19 September 2014: workshop to *EPHE* in Paris

18 October 2014: talk at Brick City Weekend

Ken Boydston (Megavision) and Dr. Gregory Heyworth (University of Mississippi) adjust the frame holding the Martellus Map before imaging (August 2014)

The c.1491 map of the world by Henricus Martellus Germanus being prepared for imaging at the Beinecke Rare Book and Manuscript Library at Yale University, August 2014. Project Director Chet Van Duzer in the foreground.

The Shri Madhwa Vadiraja Institute Of Technology & Management in Udupi India after presentation of proposal for the Center for the Preservation of Manuscripts

Imaging Science Undergraduate's AMA Reaches Reddit Front Page

Fourth-year student Kevin Sacca's "Ask Me Anything" (AMA) about multispectral imaging of historical documents proved highly popular on social network reddit

Jun. 16, 2015

Imaging Science senior Kevin Sacca is spending his summer working with Dr. Roger Easton Jr. capturing and processing multispectral images of historic documents. In response to public curiosity about the nature of his work, Sacca set up an AMA ("Ask Me Anything") interview session on social networking website reddit. The session proved to be wildly popular, racking up over 350 comments and even making it to the front page of reddit. Here's a summary of the interview, taken from amahighlights.com:

I am a scientist who utilizes multispectral imaging to recover and preserve information from old documents. AMA!

My short bio: My name is Kevin Sacca and I am an senior undergraduate student researcher at the Rochester Institute of Technology (**R.I.T**) working in the **Chester F. Carlson Center for Imaging Science**. I work with Dr. Roger Easton Jr. and his multidisciplinary team of scientists and scholars who share a common passion for preserving the information and cultural heritage that is inherent in antique manuscripts, paintings, palimpsest, scrolls, etc.

Personally, I have been working on the **Archimedes Palimpsest**, the **Martellus Map of 1491**, and various unknown documents from the St. Catherine's Monastery in Mount Sinai. My job is to use the raw multispectral imagery, perform statistical image processing routines, and generate imagery showing much more clearly the text, diagrams, or figures that have been almost lost due to fading or "palimpsesting".

My Proof: It's hard to show my proof because I can't disclose 99.9% of my work, and an image of me holding a card with my reddit username won't help much... So here's a press release of a scholarship I was awarded this year for my contributions to the field of Imaging Science and Photonics from SPIE. Press Release

[Edit]: I should mention that the reason for this AMA is due to a number of people requesting it after I posted on this front-page TIL thread: *http://www.reddit.com/r/todayilearned/comments/39xhr8/til_of_a_monk_who_had_taken_an_old_book_written/*

What was the (persumabely) oldest document you ever recovered?

I know my colleagues have worked on the Dead Sea Scrolls, which I'm pretty sure are as old as they come. But personally, the Archimedes Palimpsest is the oldest document I've worked on.

I'm new to this whole world and gave both The Dead Sea Scrolls and Archimedes Palimpsest a Google. Your job is the coolest ever and so is this AMA. Can you ELI5 the findings on both of those?

Wow thank you! While I'm not sure of the significance of the findings for the Dead Sea Scrolls or the Archimedes (in terms of history, culture, or the translations), I do know that so far, there have been many successful recoveries on both documents. I am not literate in the languages of the text I try to reveal, so unfortunately I can't read as I go, I pass along my data to the experts who can.

Getting successful recoveries is the best outcome because:

1) The information is now preserved digitally and won't fade over time, so it can be studied for an indefinite period of time.

2) We are able to reveal text that hasn't been looked at in over 2000 years... We hope that the text is significant in terms of it's content, and if it is, it can literally change what we know about our world's history.

So you just focus in on the actual process of uncovering the info, not the analysis?

Yeah, in other words, I really just try to provide useful images to those who can read and make sense of the information.

Was there ever a document you were working on that completely infatuated your interest outside of the technical details of uncovering hidden text? Like, a piece of history that really interested you in all ways?

Yes, absolutely. The Martellus Map really grabbed my attention, and I was pretty desperate to start working on it. I bugged my advisor for a very long time before I started working with him. And while I know there are millions of people who know more about history and maps than I do, I think it's so interesting to learn first-hand what the educated people in the 15th century thought about the world.

Scattered all around the map are these legends and cartouches which contain text that very briefly describe the land there. They can be pretty funny to us now, but it's really interesting to see how our knowledge of the world progressed to what it is now.

Digital information doesnt fade but formats/filesystems change so rapidly that you can quickly find yourself without any data that is readable. *https://en.wikipedia.org/wiki/Digital_dark_age*

On top of storing our images in multiple file formats, uncompressed and compressed, we store copies of them in multiple places! I don't think that we are concerned about not being able to read them.

Are there any dangers involved during the processing of ancient manuscripts? Could a misstep lead to a portion of a text being lost, and has this ever happened?

Yes there is significant risk in removing some of the documents from their casing and exposing them to intense light. However, my group is very conscientious about how we expose the target. Previous imaging teams used broad-spectrum light which exposed the targets to way more light than they should have, and that resulted in heat transfer and the loss of ink/pigment.

We use LED light sources which emit a very narrow bandpass, which dramatically reduces the light energy incident upon the target to the point where there is almost no risk.

I can't imagine a job where I could get fired for turning the lights on too bright... What's the worst thing you'll admit to screwing up?

Well, I've honestly been quite good about not screwing things up. The worst I've done so far is forget which hard drive (of like 80 4TB hard drives that surround me) I stored my data on. So, I had to start over, which is fine, but all that data took some time to process again.

Wow. Move over Hillary Duff. I'll be stealing the spotlight today. Thank you so much! To have so many people ask me questions about the stuff I spend so much time doing is actually really nice!

Can you walk us through the general practices of finding the overwritten text?

Well, we capture high-resolution, narrow-band multispectral imagery using tunable LED light sources and color filter wheels in combination with our multispectral camera.

We then take our massive data products into ENVI, a software package from Exelis Inc., which is very useful for image processing. Usually used for Remote Sensing purposes, ENVI also contains statistical processing routines that are invaluable for our research task too!

Within ENVI, we simply use combinations of statistical processing routines, like Principal Component Analysis, Independent Component Analysis, and spectral math to generate imagery whose contents are visually enhanced.

Can you talk a little more about these instruments? Makes and models. Just curious to see the equipment.

I'm not positive of the model (maybe the EV?), but check out MegaVision! MegaVision — Cultural Heritage Division

We most often use a MegaVision multispectral camera for our imaging, mainly because we have a colleague who works for them, but also because their equipment is top!

I actually worked on a competitor's multispectral & hyperspectral image processing tools for remote sensing about a decade ago. I'd like to second a request for more info on the hardware and frequencies used since I only really worked with the software end.

The wavelengths of light we capture at are 365 to 940 nanometers in steps of ~50nm. Then we perform fluorescent ultraviolet imaging, which uses ultraviolet light, but not at specific wavelengths.

In your estimation, is the image science research community working at a sufficient rate to preserve our great libraries before the books are inevitably lost? How much longer do the Martellus Map of 1491 and other artifacts like it stand to survive in their present cozy, climate-controlled environments?

Well, considering the amount of text that was lost on the Martellus in the 500 years since it was painted, and also considering the fact that the documents that many people want imaged are much, much older than 500 years old, we need to act as soon as we can to try to preserve as much as possible.

In my opinion, I think not. We need a larger community working on this type of research. The imaging science community is surprisingly small considering its applications in almost every other field in the world. While that kind of job security should make me happy, it actually worries me that we aren't putting enough resources into preserving our history and culture when it's sitting in museums doing nothing but deteriorating.

Has Google been of any help with delicate works? I know their main effort has been more of a feed-into-a-machine-and-go, but they could do wonders with their ability to charge forward on a project and make the information so widely accessible.

I'm not aware of the efforts Google is making in this field, but I'm sure they have their chip in the dip (Is that a saying? I don't know. Maybe I just made something up.) as they so often do.

That being said, Google translate has been super helpful to me working in the lab, to help me figure out if the words I recover mean anything!

I'm fascinated with Martellus Map. Do you have the source for a high resolution version of it? I tried to google it and the biggest image have only 2800px wide and I can't read anything.

A huge reason why you can't read anything is because most of the text has faded! Chet van Duzer is leading the Martellus project with Yale, so please check out his article(s) on the map, and consider buying his new book.

I have a copy of the book, which includes sections of the map after processing, and you would be amazed at how much text you can see clearly afterwords.

What has been your most interesting find so far?

Cartouches are treasure troves of hidden text. On the Martellus map, I've found text in small sections of the map where there was thought to be no text (or no recoverable text). Written in these cartouches are some pretty interesting passages by Martellus himself.

Why can't you disclose your work?

Well… funding for our research is typically from private donors, museums, and, in the case of remote sensing, the government or government contractors. While maybe it's okay to show you guys stuff, I wouldn't take a chance disclosing any of my work that could result in some legal shitstorm that could affect my career or the careers of my friends who I work with.

Has there ever been anything surprising you've come across while imaging documents?

Yes, the craziest thing is when you find an entire layer of text below text you can see clearly. It makes you wonder all sorts of things about the limitations of our human visual system, and that there is much more than meets the eye.

How was the original writing in these old documents erased? Was it painted over or some such?

Many times the ink was washed off with water or chemicals, other times the ink was scraped off. Then, the cleaned paper is reused and written/painted over. Otherwise, the text is faint due to natural aging and fading of pigments.

How accurate was National Treasure I and II, and why were they very accurate?

Not accurate. They had a very whimsical interpretation of document imaging techniques. Great movies though.

Would you consider National Treasure the Jurassic Park or Indiana Jones of your career? Also on a related and more serious note, do you consider yourself an archaeologist? You are in essence recovering ancient artifacts for the study of cultures past, even if your methods of excavating and far from traditional.

I'd love to haphazardly travel across the world uncovering the dark secrets of history, so I'd totally try National Treasure out. I'm afraid of dinosaurs, loved the new movie, but I'll have to say no to dinosaurs. My boss is Indiana Jones, so I can't.

I don't consider myself an archaeologist, I don't actually uncover the documents. I am proud to be part of a team who leads an effort into preserving cultural heritage! But I think the more scholarly colleagues of mine are more suited to the title of archaeologist.

What file format do you store the images

in? Something standard (TIF, PDF) or something proprietary?

We store the images in multiple file formats, tiffs because they are lossless, jpegs because they can be convenient for viewing, PDFs for use in documents and articles, and finally, .img files for working in ENVI.

So, when you are imaging a document, are you capturing reflective photons, transmissive, or both? Are you looking for florescence in any of the target materials?

All of the above. We capture transmissive, reflective, and fluorescence from both sides of the parchment. We have images of both sides because sometimes, the ink can stain through the layers and not fade as much as the surface layer.

What guides/books/websites would you reccomend where I can learn about the basics of image processing? I am about to take a course on image processing and eager to get started!

Excellent! I recommend you check out the software ENVI if you can, as it is an environment where you can learn about a lot of different image processing routines.

In terms of books… I'd check out Gonzalez and Woods book, Digital Image Processing. Any edition will do. I see their books everywhere in my building at school.

I do a lot of image processing in Python, so if you're new to programming, I recommend CodeAcademy.com to learn the basics of programming, and then I'd check out any documentation for image manipulation in python using scipy or spectral libraries!

Is it possible to check work that didn't use this technology to see if we've missed anything? I realize that certain pieces are almost untouchable but I think it's amazing knowing that we could be sitting on new information and never know it.

Yes it is entirely possible, and highly recommended that we do so soon! The longer we wait, the more time that aging and fading has to destroy the evidence!

There is a huge call to museums and universities to get their important artifacts imaged using multispectral/hyperspectral techniques!

Some pieces are much better candidates to put the time and resources into imaging them, but I know that if we had all the time and money, my team would image every document in the world.

I work in these materials daily (Dead Sea Scrolls, Codex Ephraemi Syri Rescriptus, etc.). I presumed St. Catherines had been thoroughly raked through by now. Is there anything of historical religious significance (say before 4th century) that you expect will soon see the light of day?

Yes, we have been planning more imaging this summer at St. Catherines. There are very old copies of the Bible (presumably), and other materials that may contain undertext of a completely different nature.

What inspired you to want to study imaging science? How did you end up where you are?

Long story, I changed my major a handful of times (even before arriving at R.I.T) from International Business, Physics, Film & Animation, and finally Imaging Science.

I knew I wanted to study math and physics, but I wanted a specialized curriculum, so I looked into Imaging Science because I had the connection with the Film & Animation program.

I attended a presentation given by a PhD student who worked on the palimpsest research project, and it was so interesting that I decided to switch. And I switched my first week of freshman year and have loved it since.

So you switched from business into physics and eventually imaging science? You give me hope that wall street is yet not able to steal away all of the best minds.

Yeah, I've thought a lot about what it meant to switch my major so drastically, and the career paths that open up (and close) by doing so, and to be summarized simply:

I ended up here because I'm studying something I genuinely think is interesting, something that I can do for a career that can help others, the people around me every day are amazing, and I'm happy where I am in life. I think as long as those remain true, I can accomplish what I want to.

If you could inspect any document that exists in the world today what would it be?

Fun question! Okay, well I don't know about specific documents, but I'm an aspiring treasure hunter, and I'd absolutely love to image old treasure maps! That would be SO COOL. Very National Treasure-like.

If you could inspect a document that no longer is know to exists, or can't be proved to have existed but is rumored to have, what would it be?

I think the Lost Library of Alexandria exists, and I hope we are able to uncover some text that proves it's existence, or best-case scenario, where it is! You never know!

In terms of your hours and free time, what is a general work day for you?

Well during the academic year, I work mainly on weekends. This summer, however, I work full-time on processing data.

My typical work day starts with checking my email, looking for requests from my scholar colleagues for processing specific images that have grabbed their attention.

I have a long long list of documents to process, and so I take the scholar's requests as priority, slowly checking things off the list.

I usually spend around four hours on one image, as that's about the time it takes for me to finish all of my processing routines in my arsenal. Then, I take the best results and create a psuedocolor rendering of them and send them off to the scholars for interpretation. Many times they are able to read entire words that they could not see or read before!

In terms of free time, there's honestly so much work to be done that there is never really any free time. However, while the computer is chugging through the processing, I have time to look into new statistical processing methods, and try them out on samples to see if they work or not! All in the effort to improve the results!

I have plans to go abroad to Germany this summer to image documents from the bombing in Dresden, so that will be about a week or so.

Links to any papers that explain the results you've obtained? Any data you've worked with that we can play with?

My first co-authorship paper will be finished and hopefully presented at the IEEE conference in Rome this year, so I don't have a paper explaining my personal results. But please check out Roger Easton's website which I have linked in the original post. He has plenty of stuff to look at.

I can't give out any of my data right now, because I don't want to somehow get into any trouble. But! I encourage you to Google for RIT Archimedes data or RIT Martellus data or anything of the like, because I know there is some posted online that you can download yourself! Because if you find and download it yourself, then that's A-okay!

My uncle has a journal from a Civil War soldier that he rescued in the 1960s from a refuse pile (a small local museum that was clearing out stuff they didn't find important) that he wishes to preserve. What's something I could tell him to do to preserve it? At lease until the point he passes it onto his daughter (a curator of old documents). It's still readable, if that tells you anything.

I am not too knowledgeable on this matter, but I do know this: Keep it in a dust/dirt/water free container out of the light. Light is a big player in fading the text.

If you're a fellow RIT student, you might know about the Carey Collection at the Wallace Library. They would be EXCELLENT people to go talk to about just this. Please, please talk to them.

The team in which you work with –have you lot ever encountered a document which unveiled information which broke new grounds and changed the perception of what we know of the history of that period? If so, what was it and how did you (and the team) feel?

While I've been a part of the team, no, nothing ground-shattering.

However, in the recent past, the whole foundation for this type of research was, in all seriousness, accidentally stumbled upon. The main goal I believe was simply to enhance the text that we could already see a little, but they ended up finding a palimpsest, so an entirely new layer of text under the existing text.

I know the efforts at the St. Catherines Monastery have been quite fruitful as well. There's been talk about possibly discovering Shakespeare's 13th signature or more Archimedes works, it's all so amazing!

What are some texts or papers you would recommend as "required reading" for multispectral imaging? I'm hoping to begin an engineering project at work that will involve multispectral imaging of tissue for medical purposes.

Well for starters, the best book for any kind of spectral imaging work is Schott's book, Remote Sensing: An Imaging Chain Approach. Because honestly, we are always doing remote sensing, but on a smaller scale.

For a multispectral medical imaging focused book, check out Dr. M. Ali Roula's book. I know I've seen it around before, and it might hit the nail on the head for you.

Also find this book: Introduction to Medical Imaging by Nadine Barrie Smith. My classmates used this book for a medical imaging physics class and said it was amazing.

Do you think we'll ever get consumer/commodity hyperspectral imagers? Something akin to the FLIR One? Are there any hacks that allow cheap hyperspectral imagery? What spectral ranges are useful? Is polarization also a useful signal at all?

Yes! I think that is very possible! In the near future too! This technology is relatively new, but it's advancing so fast, so I foresee this technology being rapidly available!

Spectral imagery is achieved by simply collecting photons of a small bandgap of wavelengths with a sensitive detector. So, if you had a light source that emitted at all in a given wavelength, you could place a wavelength-specific filter over your detector and, if the exposure is right, you have yourself a spectral imager. Multi and hyperspectral are terms used to describe the spectral resolution of your system. I don't foresee hyperspectral technology being readily available just yet, but definitely multispectral. (multispectral: ~tens of bands — hyperspectral: ~hundreds of bands)

Also curious about polarization detection. It is a relatively simple technique which has seen many applications in biophysical fields and can easily be combined with hyperspectral imaging.

Yes! Polarization is an incredibly useful method to isolate the important signal. While I'm not aware of the measures we take to polarize our light for document imaging, as an Imaging Science student, we study polarization a lot, and there is some incredible research into polarization being done by a few graduate students I know!

Were some scientific discoveries in those documents, of which we didn't thought people had it back then? Or were there even discoveries we didn't make, but learned about trough the documents?

Well I know as a kid we were taught that people in the 14th and 15th century thought the world was flat, and that Columbus was going to sail off the edge of the Earth.

This is a myth, and proven over and over again. Educated people back then knew the Earth was round, and evidence from the Martellus backs it up.

I'm a big fan of old documents myself. Whats the best way for someone to get into this field of research?

This research was what made me change my major into Imaging Science. After I switched, I bugged my advisor for over two years before he hired me and I got to start working on this stuff.

The best thing to do is actively contact people in the field. Let them know you are interested, and study up on the subject so if an opportunity presents itself, you can demonstrate that you are a useful person to have helping!

Is there a way to tell if document is "recycled" or not?

If the document shows signs of undertext when illuminated by infrared, ultraviolet fluorescent light, then the document may have been recycled and is a good candidate for multispectral imaging.

How would a school or researcher go about getting your team to preserve some documents?

They should contact Dr. Roger Easton at easton@cis.rit.edu

Another good resource is R.I.T's Cary Collection They could offer insight in the best way to preserve documents, and they would easily be able to contact our team for imaging.

Do you currently have any technology or techniques that could see text that has been sharpied over? Like redacted information from CIA reports? Perhaps the 29 pages about the Saudis and 9/11.

Honestly, probably. I imagine that back in the day, before knowledge of spectral reflectance was less understood in industry, sharpie markers didn't absorb all wavelengths of light, so perhaps to some wavelengths of light, it would look like the sharpie wasn't even there.

I'm sure it's possible to recover at least some classified text like that. If you never hear from me again, you can be assured that it's true.

How are you able to keep from falling in love with every woman scientist you see in the lab? It's been all over the news that girls are bad for science because everyone apparently falls in love and no work gets done.

Easy. I'm the only person working in my lab this summer. I get my work done with (relatively) few distractions!

LABORATORY FOR MULTIWAVELENGTH ASTROPHYSICS

Laboratory Director's Comments By Dr. Joel Kastner

RCH

1. Summary

A subset of the faculty, staff and students from the Center for Imaging Science (CIS) and Department of Physics within the College of Science at Rochester Institute of Technology participates in the Laboratory for Multiwavelength Astrophysics (LAMA). LAMA exists to foster the utilization and advancement of cutting-edge techniques in multiwavelength astrophysics by RIT faculty, research staff, and students, so as to improve human understanding of the origin and fate of the universe and its constituents. *Calendar year 2014 marked LAMA's "coming of age" as a designated research lab at RIT: CY 2014 constituted, by far, LAMA's most prolific year thus far in terms of dissemination of research results.* Specifically, LAMA faculty, postdocs, and students were lead or co-authors of *over 30 refereed papers and nearly 50 conference presentations and other non-refereed publications—roughly double our CY 2013 publication totals.* A significant fraction of these (82) publications resulted from projects in which LAMA personnel play leading roles within national and international teams of astrophysics researchers. In 2014, LAMA-affiliated PIs held or obtained 28 external grants, mostly from NASA and the NSF. LAMA PI grant expenditures totaled approximately $805K, yielding roughly $42.5K in overhead recovery return to the lab. These numbers were down by ~20% relative to CY 2013, perhaps reflecting the tightening NASA and NSF astrophysics budgets and the resulting increasingly competitive astrophysics funding environment. Expenditures by the research center account totaled approximately $20.4K. In 2014, LAMA continued its highly successful summer student research programs, again in association with (and in support of) the Center for Imaging Science (NSF-sponsored) Research Experience for Undergraduates program. LAMA also continued its investments in RIT's astrophysics research infrastructure, and maintained its administrative and software support. Overall, LAMA continued to play a leading role in support of RIT's thriving community of astrophysics researchers and educators, and served to boost the profile and reputation of RIT astrophysics on national and international levels.

2. Mission Statement

LAMA's Mission. The mission of LAMA is to foster the utilization and advancement of cutting-edge techniques in multiwavelength astrophysics by RIT faculty, research staff, and students, so as to improve human understanding of the origin and fate of the universe and its constituents.

LAMA exists to support the following major astrophysics activities at RIT:

- exploitation of existing and forthcoming national and international ground- and space-based astronomical observing facilities/missions;
- exploitation and mining of the present and forthcoming generations of

multiwavelength data archives;

- development of scientific requirements for future astronomical observing facilities/missions and future data archival and mining methods;
- analysis and modeling of multiwavelength astronomical and astrophysical data.

Goals & Objectives. Support of the four major activities listed above drives LAMA's primary goals and objectives. Specific LAMA goals and objectives include:

(1) obtain external funding sufficient to maintain a healthy cadre of student and postdoctoral scholars pursuing research in multiwavelength astrophysics;

(2) widely disseminate the research results of LAMA-affiliated faculty, postdocs, and students;

(3) promote a highly dynamic, interactive astrophysics research environment at RIT and bolster national and international astrophysics collaborations involving RIT;

(4) strategically invest in novel astrophysics research initiatives and in new astrophysics research infrastructure in both the instrumentation and software domains, within and beyond RIT.

Progress Toward Goals & Objectives. In 2014, LAMA's fourth year as a designated research laboratory at RIT, LAMA-affiliated faculty, postdocs and students made the following progress toward these goals and objectives:

- *CY 2014 was, by far, LAMA's most prolific year thus far in terms of dissemination of research results.* LAMA faculty, research staff, and students were lead or co-authors of over 80 refereed papers and conference presentations, with a significant fraction of these publications resulting from projects that have succeeded as a direct result of LAMA's leadership of large national and international teams of astrophysics researchers.
- LAMA-affiliated PIs obtained or maintained 28 grants, with total CY 2014 expenditures of approximately $805K.
- In summer 2014, in association with (and in support of) the Center for Imaging Science (NSF-sponsored) Research Experience for Undergraduates program and the School of Astronomy & Physics AST Ph.D. program, LAMA continued its highly successful summer student research program.
- LAMA contributed to RIT's investment in the WIYN 0.9 m telescope consortium via direct payment of membership fees and student travel support.
- LAMA continued to use some of its discretionary funds for support of student travel to conferences, publication page charges, and general RIT astrophysics community-building activities.

3. Personnel & Finances

Participating Faculty: Stefi Baum (CIS), Roger Dube (CIS), Joel Kastner (CIS; LAMA Director), Jacob Noel-Storr (CIS), Chris O'Dea (Physics), Michael Richmond (Physics), Andrew Robinson (Physics)

Research Staff (Postdoctoral Researchers): Preeti Kharb, Rupal Mittal, Benjamin Sargent

Graduate Students: Triana Almeyda, Kevin Cooke, Marcus Freeman, Davide Lena Dave Principe, Kristina Punzi, Valerie Rapson, Sravani Vaddi, Billy Vazquez (all AST Ph.D.)

Undergraduate Students: Cicely DiPaolo (Imaging Science), Alyssa Hunter (Physics), Kaitlin Schmidt (Physics), Lucas Shadler (Physics)

Finances. A total of 28 external grants were maintained by LAMA faculty and research staff PIs during calendar year 2014. The vast majority of this funding came from NASA and the National Science Foundation. Expenditures in CY 2014 totaled approximately $805K, and overhead return to LAMA in CY 2014 totaled $42,538. These numbers were down by ~20% relative to CY 2013, with this decrease likely reflecting tightening NASA and NSF astrophysics budgets and the resulting increasingly competitive astrophysics funding environment. Expenses in CY 2014 totaled $20,428. Details concerning LAMA grants, grant expenditures, and lab account income and expenses for CY 2014 are available upon request.

4. Student Support and Community Building

Immersive Summer Undergraduate Student Research Program. In summer 2014, LAMA continued its RIT summer undergraduate student research program, in association with (and in support of) the Center for Imaging Science (NSF-sponsored) Research Experience for Undergraduates (REU) program and the School of Astronomy & Physics AST Ph.D. program. As in previous summers, our LAMA-supported student (Physics major Alyssa Hunter) was seamlessly integrated into the larger summer astrophysics student research community of grant-supported CIS and Physics undergraduates and visiting REU students involved in summer astrophysics research, all with the support and encouragement of our LAMA-sponsored AST graduate students. Small working groups, organized around research themes and data analysis techniques, developed naturally. Biweekly group meetings were held in which the LAMA fellows and REU students (along with AST grad students and LAMA faculty and postdocs) gave research status reports and shared results with each other. These LAMA-inspired and LAMA-supported summer student projects led to several student presentations at the 2014 RIT Summer Undergraduate Research Symposium. Some students also presented at the Jan. 2015 American Astronomical Society meeting, and a few projects are developing into papers for refereed journals.

RIT Astrophysics Community Building. Via hospitality support in 2014, LAMA again facilitated informal interactions between visiting RIT astrophysics colloquium speakers and RIT's community of AST and CIS graduate students and postdocs. These informal gatherings over lunch or dinner are very popular with the students, as they serve as opportunities to make connections and ponder career choices. LAMA also provided pizza and drinks for the weekly RIT astrophysics lunch talk series, whose typical audience consists of 5-10 graduate students from the AST Ph.D. program and another half-dozen researchers from all three RIT astrophysics research labs (LAMA, CCRG, CfD).

ImagineRIT. As in the previous three years, LAMA's Valerie Rapson led the development and organization of the AST graduate program's exhibit at the May 2014 edition of ImagineRIT. All of our LAMA-sponsored AST graduate students played essential roles in this effort.

LAMA graduate students: outreach within and beyond Rochester. In January 2014, LAMA graduate student Valerie Rapson was inducted into the American Astronomical Society's Astronomy Ambassadors program. This is a select group of early career scientists who are actively involved in astronomy education and public outreach (EPO), and want to continue to improve the effectiveness of this public outreach. Valerie attended professional development workshops to improve her EPO skills. She continued to conduct a variety of outreach activities n the Rochester area. Most prominently, she served as President of the Astronomy Section of the Rochester Academy of Sciences, the area's foremost amateur astronomy society. She also published a paper in the Communicating Astronomy with the Public Journal detailing her experiences in astronomy education for senior citizens (Fig. 1).

Fig. 1: In 2014, Valerie Rapson continued her programs of astronomy education for senior citizens, such as this opportunity to view sunspots and limb darkening on the disk of the Sun using a small telescope and solar filter.

Kristina Punzi planned and participated in various local outreach fairs, including Super Science Saturday at Victor Intermediate School, Family Science Day at the University of Rochester, and Celebrate Science for Brick City Weekend. Additionally, she volunteered for public outreach for the Insight Lab and WISE and at local K-12 schools.

Davide Lena and Sravani Vaddi participated in the 2014 Science and Technology Entry Program (STEP). STEP is an Imaging Science fair for middle school students and their parents. Davide and Sravani showed models of the core of a main sequence star and post-main sequence star, simulation models of galaxy interactions, and introduced the students to Star Walk and other guides to the night sky.

Outreach abroad. Astronomers around the world study the same sky, making international collaborations common. LAMA faculty and students are engaged in wide-ranging research programs that usually involve international teams and interests. Examples:

- Michael Richmond has been working with scientists in Japan since his days as a post-doc on the Sloan Digital Sky Survey in the 1990s. His colleagues at the University of Tokyo have recently upgraded the camera on a telescope at the Kiso Observatory, in the mountains of central Japan. Richmond helped to write some of the software which analyzes images taken by this camera, which is currently scanning large sections of the sky in survey mode. In September, 2014, as the Kiso Observatory celebrated its 40th anniversary, Richmond travelled to Japan to participate in the event, which brought together scientists, administrators and members of the Kiso community. As part of the after-dinner entertainment, Richmond stepped onto the stage to deliver an address in Japanese (Fig. 2), much to the amusement of the audience.
- As CY 2014 ended, Joel Kastner was hard at work as co-Chair of the Scientific Organizing Committee of International Astronomical Union Symposium #314, "Young Stars & Planets Near the Sun," to be held in Atlanta, GA in May 2015. Quoting from the IAUS 314 website (http://youngstars.gsu.edu/): "Research over the past two decades has led to the discovery of hundreds of young stars within 100 parsecs of the Sun. Many of these stars have been classified as members of kinematic "moving groups", whose ages range from an extremely youthful (by astrophysical standards) 8 million years, up to a still very young 200 million years. Because these groups represent the closest young stars to the Earth, they constitute the best sample available to investigate the early evolution of low-¬mass to intermediate-mass stars. Their members represent the most convenient targets with which to obtain direct information on the conditions and timescales associated with the evolution of circumstellar disks, and the subsequent formation and early physical and dynamical evolution of planetary systems. This symposium of the International Astronomical Union (IAU) will bring together scientists working on nearby young stars from multiple research perspectives, and from all over the world. The meeting will feature sessions on the identification, ages, and origins of nearby young stars, new constraints these young stars put on theories of early stellar evolution, the dispersal of protoplanetary disks and the origins of debris disks, and the early evolution of planetary systems. Scientists will also discuss the prospects for advances in the study of nearby young stars and planets resulting from new and future large astronomical observatories on Earth and in space (e.g., ALMA, GAIA, GPI, SPHERE, JWST)."

Fig. 2: Michael Richmond addressing the audience, in Japanese, on the occasion of the 40th anniversary of the University of Tokyo's Kiso Observatory.

5. Selected Research Highlights

Michael Richmond

Stars that explode in brilliant fireworks at the end of their lives are called supernovae. Astronomers find hundreds each year, but almost all occur in the far reaches of the universe. Every few years, however, one of these giant explosions occurs in a relatively nearby galaxy, with the Milky Way's neighborhood. Michael Richmond uses the RIT Observatory's small telescopes to study these uncommon events. On July 27, 2013, he was observing an ordinary star when an e-mail announced the discovery of supernova 2013ej in the galaxy M74; he quickly shifted his attention to the new object. Between July and December, 2013, he measured the brightness of this star on almost every clear night through several different filters. The resulting light curves (Fig. 3) show that this star had a large and massive envelope of hydrogen when it exploded: it takes several months for much of the energy generated at the center of the star to fight its way out through the envelope. The results are published in Journal of the American Association of Variable Star Observers, vol. 42 (2014).

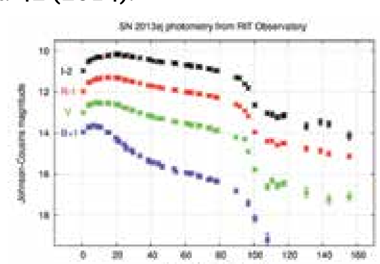


Fig. 3: Light curves of supernova 2013ej in the galaxy M74, obtained at the RIT Observatory.

Valerie Rapson

In April of 2014, graduate student Valerie Rapson, Professor Joel Kastner and their international team of astronomers won time on the new Gemini Planet

Imager on Gemini South to image a planet-forming disk around a nearby young star. Their observations tested the limits of the dimmest objects capable of being observed with GPI, and were spectacularly successful. An example image from GPI is exhibited in Fig. 4, and shows scattered light off dust grains in the disk around the young star V4046 Sgr. This image, combined with previously published sub-mm data, suggests that multiple planets may be forming and carving out rings in the disk (Rapson et al., 2014).

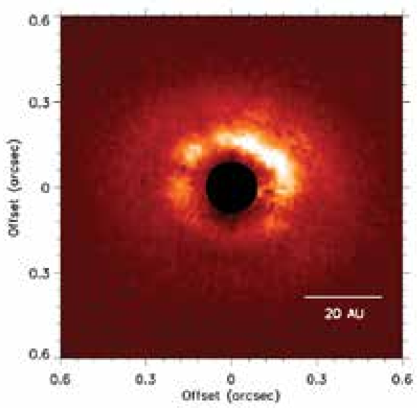


Fig. 4: Near-infrared coronagraphic/polarimetric image obtained with the Gemini Planet Imager, showing scattered light off small dust grains in the planet-forming disk around V4046 Sgr.

Valerie was also among 31 winners (including Kevin Cooke; see below) chosen from nearly 450 students who entered the Chambliss student poster presentation competition at the 223rd American Astronomical Society meeting in Washington, D.C., in January 2014. The Chambliss awards recognize exemplary research by undergraduate and graduate students who present posters at the society meetings. Rapson won an Honorable Mention for her poster on infrared spectroscopy of the V4046 Sgr protoplanetary disk.

Marcus Freeman

As a part of The Chandra Planetary Nebula Survey (ChanPlaNS), Marcus Freeman, as well as Professor Joel Kastner, continued to explore X-ray emission from several planetary nebulae within 1.5 kpc of the Sun. The survey was designed to place constraints on the X-ray properties of planetary nebulae and their central stars, and give us insight into the evolution of these objects.

ChanPlaNS began with Chandra Cycle 12 observations and archival data, and continued into 2014 with Cycle 14 observations. Analysis of this new data with the previous observations (found in Freeman et al. 2014) revealed that more than half of the surveyed nebulae had some sort of X-ray emission. We found that ~27% hosted diffuse X-ray emission related to hot bubbles within the nebulae, while ~36% hosted point-source X-ray emission related to the central stars.

Furthermore, we detected diffuse X-ray emission for the first time from NGC 1501, NGC 3918, NGC 6153, and NGC 6369 (Fig. 5).

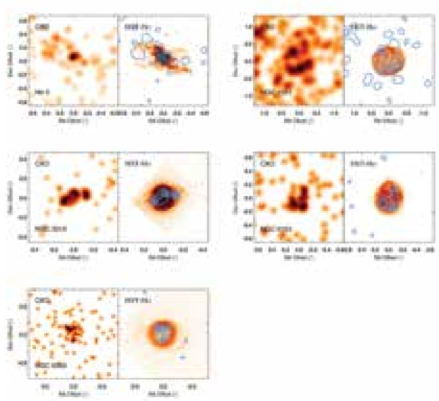


Fig. 5: Chandra X-ray Observatory (CXO) vs. Hubble Space Telescope (HST) images of five planetary nebulae newly imaged in X-rays by CXO as part of the Chandra Planetary Nebula Survey (ChanPlaNS). Images reproduced from Freeman et al. (2014).

Kristina Punzi

In May 2014, Kristina Punzi attended the National Radio Astronomy Observatory's 14th Annual Imaging Synthesis Workshop in Socorro, NM. In June 2014, she attended and presented the results of her radio spectroscopic survey of the protoplanetary disk orbiting the young star LkCa 15 at the International Symposium on Molecular Spectroscopy in Champaign-Urbana, IL in the special mini-symposium entitled: Astronomical Molecular Spectroscopy in the Age of ALMA. Kristina was awarded an RIT Research and Creativity Grant to attend the conference.

Ben Sargent

Spectra of a small sample of T Tauri stars—young stars with orbiting dust and gas disks that may evolve into planetary systems—show emission in Spitzer Space Telescope Infrared Spectrograph (IRS) 5–7.5 micron wavelength spectra from water vapor and absorption from other gases in these stars' protoplanetary disks. For some, the spectral absorption signatures are consistent with gaseous formaldehyde (H2CO), and, for others, they are consistent with gaseous formic acid (HCOOH). Modeling of the spectra of stars that show water vapor emission features suggests these gases are present in the inner regions of their host disks, corresponding to the habitable zones of stars at a very early age (a few million years).

Infrared spectroscopy also reveals the composition of the material around dying stars. Spitzer-IRS spectra of red supergiant (RSG) and oxygen-rich asymptotic giant branch (AGB) stars in the nearby Large Magellanic Cloud and Small Magellanic Cloud galaxies and in our Galaxy show emission from amorphous dust grains of silicate composition that were produced by these stars. "Amorphous" means the dust grain lacks long-range crystalline order, though it is still a solid; also, "oxygen-rich" means the abundance of oxygen exceeds that of carbon in the star's photosphere. An analysis of spectra from the Spitzer Legacy program "SAGE-Spectroscopy" (Principal Investigator: F. Kemper), the Spitzer program "SMC-Spec" (PI: G. Sloan), and other archival Spitzer-IRS programs shows differences in the spectral emission features of the amorphous silicate dust from the Oxygen-rich AGB stars versus the amorphous silicate dust from the RSG stars. Radiative transfer modeling suggests these spectral differences are due to differences in the properties of the dust grains themselves. This, in turn, may suggest differences in the circumstellar environments around RSG versus O-rich AGB stars in which the stardust grains are forming.

Davide Lena

For decades it has been known that the nuclei of certain galaxies are characterized by unusually large energy outputs, the presence of radio-emitting jets, outflows and a number of highly energetic phenomena varying on short time-scales (days). Such galaxies are known as active galactic nuclei (AGNs). The key mechanism that keeps them active is believed to be well understood: gravitational potential energy is released in the form of radiation during the accretion of gas on a supermassive black hole (SMBH) residing at the galactic center. Nevertheless it is not yet clear how the gas is funneled from the inner kiloparsec down to the sub-parsec scale accretion disk that fuels the SMBH. Is there a relation between the accretion rate of the SMBH and the presence of outflows?

Davide Lena, Professor Andrew Robinson, and their team have been using the Integral Field Unit (IFU) of the Gemini Multi Object Spectrograph (GMOS), mounted on the 8-m Gemini telescopes, to observe the ionized gas in the nuclear regions of a sample of AGNs. We completed the analysis and modeling of the active galaxies NGC 1386 (Fig. 6) and NGC 1365, a Seyfert 2 and a strongly barred Seyfert 1 respectively. We found that the gas kinematics in the inner kiloparsec of these galaxies can be explained as a combination of rotation in the large-scale galactic disk, inflows and compact outflows along the axis of the AGN "radiation cone".

NGC 1386 was previously observed by Ferruit et al. 2000 with the Hubble Space Telescope (HST). They revealed the presence of a faint bar-like emission extending approximately 150 pc east and west of the nucleus. We found strong evidence that this emission is approximately aligned with the equatorial plane of the AGN torus, and we showed that it is associated with kinematical features suggestive of outflows and/or rotation. Classical AGN unification models do not predict such kinematic in the plane of the torus. Our observations might therefore be providing a new clue to the physical process operating in AGNs.

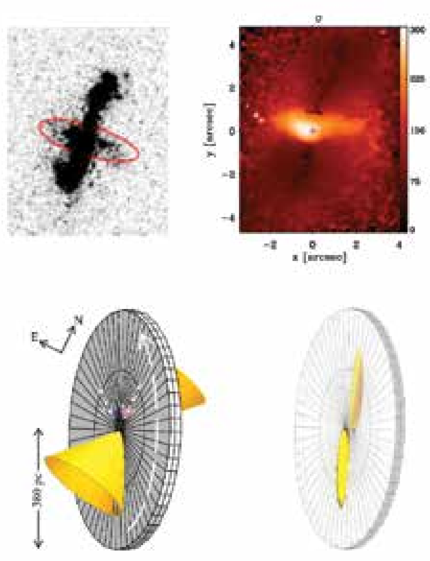


Figure 6. Top left: [OIII] flux map of the circum-nuclear region of NGC 1386 obtained from HST observations (Ferruit et al. 2000). Top center: velocity dispersion (km/s) derived from our observations. Top right: velocity residuals (km/s) derived by subtracting from the observed velocity map a second velocity map representing gas rotating in circular orbits. Bottom: cartoon representing the model proposed to explain the observed features. Most of the gas experiences rotation, and perhaps inflow, in the large-scale galactic disk (left). The AGN radiation cones intersect the interstellar medium rotating in the disk producing the lobes visible in the flux maps (central panel, to be compared with the flux map derived by Ferruit et al.). Along with flux features revealed from the HST observations, the line profiles that we obtained show that gas in the nucleus is outflowing along the axis of the AGN radiation cone (green blobs in the right panel). However, the velocity dispersion map (top center) and the velocity residual map (top right) reveal that the bar-like emission highlighted in the top left panel has a kinematical counterpart which can be interpreted as rotation along the axis of the AGN radiation cone and/or outflow in the equatorial plane of the torus (perpendicular to the AGN radiation cone).

Kevin Cooke

During the 223rd Meeting of the AAS in Washington, D.C. Kevin Cooke won a Chambliss Astronomy Achievement Award for his research poster on brightest cluster galaxies, one of only 6 gold medals awarded to the 150 graduate student posters at the conference. Kevin's poster described his research of line emission indicative of star formation in massive elliptical galaxies.

David Principe

In 2014 David Principe successfully defended his Ph.D. dissertation, entitled “Multiwavelength Observations of Young Stars and Their Circumstellar Disks”. Part of his dissertation was focused on infrared and X-ray observations of the nearby star-forming region L1630 where he characterized magnetic phenomena in ~50 X-ray emitting young stars and their variability over several years. This work was published in the Astrophysical Journal Supplements (Principe et al. 2014). The remaining chapters of his thesis investigate variability in three nearby, star-disk systems using simultaneous multiwavelength observations. Preliminary results suggest that variable obscuration of the stellar photosphere from a disk warp and/or clump viewed nearly edge-on is responsible for the variability. David presented this research at the 224th American Astronomical Society Meeting in Washington, D.C. and at the 18th annual Cool Stars Conference in Flagstaff, AZ. This research is being prepared for publication and will be submitted in 2015.

Chris O'Dea and Stefi Baum

Galaxies grow as stars form amid dense clouds of cold molecular gas. Their growth can stall if this gas is disrupted, expelled from the galaxy, or prevented from forming in the first place. The kinetic and radiative energy liberated as matter falls onto a galaxy's central supermassive black hole is, in principle, large enough to inhibit star formation via some of these mechanisms, perhaps over a significant fraction of cosmic time. Were this indeed the case, black hole feedback could alleviate many problems in our understanding of galaxy evolution, reconciling observations with a theory that would otherwise over-predict the size of galaxies and the star formation history of the Universe. The mechanical energy of jets powered by active galactic nuclei (AGN) can strongly couple to the multiphase gaseous environments through which they propagate. However, we have yet to understand, beyond circumstantial evidence, how black hole feedback might govern the fate of cold molecular gas and the formation of stars within it.

O'Dea and Baum, working with former RIT graduate student Grant Tremblay (now at Yale) have found that a supermassive black hole can act much like a mechanical pump in a water fountain, driving a convective flow of molecular gas that drains into the black hole accretion reservoir, is pushed outward again in a jet-driven outflow, and falls once more back toward the galaxy center from which it came. This molecular fountain has been discovered in the central galaxy of the nearby cool core cluster Abell 2597, using new observations from the Atacama Large Millimeter/submillimeter Array (ALMA). The data reveal giant molecular clouds falling on ballistic trajectories towards the black hole in the innermost 500 parsecs of the galaxy. The black hole accretion reservoir, fueled by these infalling cold clouds, powers an AGN that drives a jet-driven molecular outflow in the form of a 10 kpc-scale, billion solar mass expanding molecular bubble. The molecular shell is permeated with young stars, perhaps triggered in situ by the jet. Buoyant X-ray cavities excavated by the propagating radio source may further uplift the molecular filaments, which are observed to fall inward toward the center of the galaxy from which they came, presumably keeping the fountain long-lived. The results are highly inconsistent with the "hot mode" accretion scenario envisaged by many theorists, and show that both the mass and kinetic luminosity budgets of black hole accretion and feedback can be dominated by the cold molecular phase, suggesting that an AGN can indeed couple to the most important catalyst for galaxy evolution. However, the results also demonstrate that kinetic AGN feedback is not a switch that shuts off star formation, as the fountain consists not only of molecular gas, but young stars as well.

Billy Vasquez

Billy Vasquez has been analyzing the initial results of observations obtained by the Spitzer Space Telescope of the Seyfert Type 1 Active Galactic Nucleus (AGN) NGC 6418 over a timespan of more than a year (Fig. 7). The Spitzer observational campaign and ultimately the publication of this first paper are the results of the efforts of an international collaboration that includes leading experts on AGN. Our team has determined the radial distance to the 3.6 and 4.5 micron characteristic region of the molecular dusty region, known as the torus in the Unified Model of AGN, using reverberation lag time series and cross correlation analysis. The results are consistent with current models of clumpy tori in AGN.

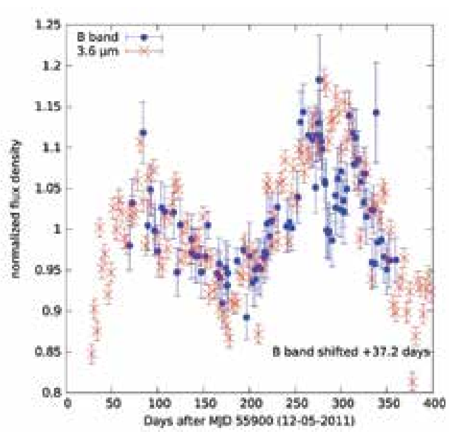


Fig. 7: The 3.6 micron (near-infrared) and time-shifted B-band (visible-light) light curves of NGC 6418, representing the results of the time series analysis conducted by Vasquez et al.

6. Publications

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Comments By Bethany Choate

Outreach efforts for the Center for Imaging Science have historically been manifested in a variety of programs, demonstrations, activities, materials, events, and publications which serve three main audiences: prospective students; the community at large; and alumni.

2014–2015 marked a transition year as outreach organizer and facilitator Bethany Choate, 2006 Imaging Science BS graduate, was reduced to part-time in anticipation of her departure in June 2015.

Prior to her departure, Bethany prepared as her Masters Capstone Project a thorough Strategic Plan for Undergraduate Recruitment specifically for CIS. This plan investigates trends and best practices, benchmarks similar academic programs, details CIS's enrollment and outreach history, includes a full marketing plan and analysis, and provides goals and suggested activities in support of those goals. It is hoped that this strategic plan will guide, inform, and support future outreach endeavors in CIS.

CIS Intern Program

The Center for Imaging Science summer intern program continued for its 15th year in 2014, with some changes to the program. For one, the program was shortened to six weeks due to RIT's conversion to a semester calendar system and the resulting earlier start to the academic year. Additionally, due to the rising costs of maintaining the program, all interns were unpaid for the first time in the program's history. Despite the funding challenges we were able to offer the same high level of experience and extracurricular programming with 15 interns as listed in the chart below:

Intern	High School	CIS Research Lab
Maryam Bahrani	Hotchkiss School (CT)	Perform
Rory Bloechl	Harley	Insight
Jacqueline Chan	Webster Schroeder	Visual Perception
Abraham Glasser	Pittsford Mendon	Remote Sensing
Lindsay Haefner	W. Irondequoit	Astronomical Imaging
Alex Kautz	Brighton	Insight
David Lewis	Wheatland-Chili	DIY Camera Lab
Adam Maier	McQuaid	Biomedical Imaging and Modeling
Emma Pratt	Rush-Henrietta	Insight
Rachel Shadler	W. Irondequoit	DIY Camera
Jimmy Shih	Webster Schroeder	Insight
Wesley Smith	Brighton	Astronomical Imaging
Elizabeth Thrasher	Gates-Chili	Visual Perception
Victoria Thrasher	Gates-Chili	Perform

Madeline Wolters Hilton
DIY Camera

Interns conducted authentic research in several CIS laboratories as outlined in the table above. The program also included a field trip to Mees Observatory and a career exploration luncheon featuring a live Skype session with CIS alumnus and NASA scientist Matthew Montanaro. CIS continued the tradition of weekly cookout lunches organized and coordinated by the interns, which also included team building games and activities. Interns were required to maintain blogs recording their memorable experiences and presented their research at a half day symposium at the end of August. For the second year, we recorded these presentations for later viewing. Meet our 2014 interns, view their presentations, and read their blogs at http://www.cis.rit.edu/2014interns/.

This CIS Intern Program has jump started successful academic and professional careers for 173 participants over fourteen years. The benefits of the CIS intern program are four-fold: to students; to the community; to CIS and RIT; and to STEM (science, technology, education, and math) education in the United States as a whole. Participants benefit from research experience, exposure to a college environment, experientially exploring their academic interests, and learning the responsibilities of a full time job. The intern program is a community builder, as schools and students from across the area participate, and local companies and research centers are showcased through field trips. The program is also CIS's most successful recruitment initiative: ~50% of participants have enrolled at RIT for STEM-related disciplines; and 15% of all past interns have applied to Imaging Science, with 12% ultimately enrolling as students in the Imaging Science program. We are excited to report that three of our 2014 interns have enrolled as undergraduate Imaging Science students for Fall 2015. Lastly, our internships encourage the further pursuit of STEM disciplines by up-and-coming young talent.

K-12 and Community Outreach Events

CIS's in-person programming has been greatly reduced as of 2014, though several select events continue to be supported.

Greece Olympia Project-Lead-The-Way and Optics Classes

Greece Olympia students enrolled in Project-Lead-The-Way and Optics classes toured Sydor Optics and then visited CIS as a field trip. Students were provided an informative and interactive presentation about Imaging Science, complete with a hands-on thermal camera demo.

IYOL Career Day at RMSC

CIS participated in a panel discussion and career fair at the Rochester Museum and Science Center (RMSC) focused on Optics, Photonics, and Imaging. The event was presented to K-12 students as part of the museum's International Year of Light festivities.

Science Saturdays and Light Weekends at the RMSC

CIS presented an exhibit on thermal imaging in a booth at the Rochester Museum and Science Center as part of their "Light Weekends" programming for the International Year of Light. Several objects and materials were available for interaction with the camera including ice, hair dryers, hot and cool liquids, plastic bags, space blankets, glasses, and more. Printed images were available as souvenirs to take home. Additionally, CIS students involved with the RIT SPIE/OSA student chapter participated in Light Weekends by demonstrating a tabletop Schlieren imaging system on a separate Saturday.

New Website

CIS completed overhauled our entire website, www.cis.rit.edu, in 2014. We partnered with the Wallace Center on campus to produce a modern, appealing, highly-functional website that serves the needs of our diverse audiences. We are proud of the results of this significant undertaking and welcome your comments on the new design and functionality.

Imaging Connection Newsletter

We have continued producing the CIS Imaging Connection current events newsletter in 2014-2015 and were excited to unveil a new look and feel with the Spring newsletter. While the intended audience is Imaging/Color/Photo Science alumni, most topics are of general public interest. Content includes: news stories related to CIS; upcoming events; alumni updates; research spotlights; and more. Past issues can be viewed online at http://www.cis.rit.edu/about/newsletter.

The newsletter is e-mailed quarterly to CIS's alumni population. If you are an alumnus and wish to be added to our mailing list, contact Joe Pow at pow@cis.rit.edu.

Social Networking

CIS continues to maintain its social networking sites, which have proven themselves quite successful. Please connect with us on Facebook and Twitter via the username RITimagingsci. Here you can find news and information about the Center; opportunities for potential students, current students, and alumni; links to interesting Imaging-related articles; CIS event announcements; as well as general announcements. We encourage anyone involved with CIS to become a fan, interact with the site, and spread the word to others. There is also a LinkedIn group called RIT Imaging Science and Photographic Science Alumni.

R·I·T

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