R·I·T

Annual Report 2015–2016

Chester F. Carlson
CENTER for
IMAGING
SCIENCE

contents

On the cover: RIT President Bill Destler meets students from the Freshman Imaging Project class during the ImagineRIT Innovation and Creativity Festival in May.

FOREWORD

By David W. Messinger, Ph.D.

Once again, on behalf of the faculty, staff, and students of the Chester F. Carlson Center for Imaging Science at RIT, I am pleased to present the 2015-16 Academic Year CIS Annual Report. It has been another exciting year here in the Center and I hope you enjoy reading about all the research and educational success of the Center.

The Center would like to pass along our congratulations to Dr. Maria Helguera on her retirement from RIT after 16 years of service. Maria will continue to have a research faculty affiliation with the Center and hopes to continue her research program as well as her involvement with our students. Her unending push for excellence in our research and academic programs will be missed. We wish her the best of luck and happiness in her future endeavors, and will always welcome her back when she has time to visit us!

In other faculty news, this completes my first year as the Director of the Center (I was the Interim Director last year). While this represents a challenge and change in my career, it is exciting and I am looking forward to continuing to push CIS to new heights as a premier academic and research organization. We also welcomed Dr. Chris Kanan to the faculty in the fall of 2015. Chris jumped in with "both feet" —immediately starting to work with several students both in CIS and across RIT. Chris' research specialty is Computer Vision, and in particular using machine learning and biologically inspired models to look at problems related to Visual Question Answering, perception systems for autonomous ships, and a host of other problems.

There have been several research breakthroughs and new initiatives in the Center over the past year. Dr. Roger Easton continues to enlighten scholars around the world as his team images historical maps and documents. Last spring they achieved a great success in imaging the Martellus Map (c. 1490) from the Yale University Library Collection, highlighting text on the map that had faded to the point of not being able to be read. Roger has also been working with staff at the Bodleian Library at Oxford University on Hyperspectral Imaging of documents in their collection. This past year, Dr. Jeff Pelz and Dr. Jan van Aardt both had successful sabbaticals, in Copenhagen, Denmark and Hawaii, respectively. Joel Kastner will be on sabbatical next year and will be partially funded by a Carnegie Institution Department of Terrestrial Magnetism Tuve Fellowship. Dr. Zoran Ninkov will also be on sabbatical next year continuing to develop Multi-Object Spectrometers for various NASA projects.

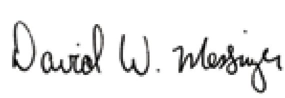
Additionally, as part of the new RIT Strategic Plan "Greatness through Difference", CIS faculty lead a team to win an RIT Signature Interdisciplinary Research Award, one of five on campus. Our proposal relates to Imaging Systems on Unmanned Aerial Systems with a focus on commercial activities such as precision agriculture and property inspection. We have already started acquiring many platforms and sensors and will be collecting a large amount of data in the near future.

Out students continue to be the lifeblood of the Center, and they continue to do great things. This past year, students from our sophomore class, along with some colleagues from across RIT, entered into the SpaceX HyperLoop competition. The students proposed a laser-based subsystem for high speed internet connectivity as the pods move in the tube, as well as a structured light approach to analyzing the tube itself for defects. They were invited down to the main competition in Texas in February and while there won an Innovation Award for their efforts. They are now working with many outside groups, including SpaceX, on developing their ideas further. We also had two successful Freshmen Imaging Projects, a successful first year Ph.D. graduate lab project, and several other publications, presentations, and awards given and / or won by our students. They always continue to amaze us all!

Victoria Scholl, a graduating senior (with a double major in Imaging Science and Motion Picture Science) won a Fulbright Scholarship to spend next year in Switzerland using airborne LIDAR imaging to map forests. This is our second year in a row having a graduating senior win a Fulbright! Also, Javier Concha, who defended his Ph.D. dissertation this past year and is currently working at NASA Goddard, was selected as the College of Science Graduate Delegate for this year's Commencement Ceremony, while Dave Kelbe (now at Oak Ridge National Laboratory) was selected as having the best Ph.D. Dissertation at RIT.

2015–16 has been an exciting year for us in the Center, 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 or stop by when you are in Rochester to see all the excitement in Imaging Science!

Thanks.



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Retiring Undergraduate Program Coordinator, Dr. Maria Helguera, with the graduating students of the Class of 2016.

IMAGING SCIENCE UNDERGRADUATE PROGRAM

Comments By Joe Pow, CIS Associate Director

The leadership of the undergraduate program is currently in transition with the recent retirement of Program Coordinator Professor Maria Helguera after 16 years with the Center.

During that time Professor Helguera distinguished herself as an inspirational teacher, a renowned researcher, and a trusted mentor. Her many contributions to RIT will certainly have a lasting impact on the Institute, the Center, and on the lives of the many colleagues and students that she has touched over the years. We wish her well in her future endeavors, which include teaching and research in both her native Mexico and Peru, as well as establishing a not-for-profit foundation to support STEM education in the community where she grew up. Although she will be gone, she will continue to collaborate with the Center on various projects as a research faculty member.

Associate Director Joe Pow, Director Dave Messinger, and Undergraduate Program Coordinator Maria Helguera at the first annual Rochester Museum and Science Center's STEM Education Awards ceremony.

Professor Helguera left RIT on a high note, as she and Associate Director Joe Pow were (as a team) one of four finalists for a Leadership Award in STEM Education from the Rochester Museum and Science Center. The Leadership Awards in STEM Education are presented at elementary, secondary and university levels. These awards recognize innovative teaching in science, technology, engineering, or math education. Educators are recognized for innovation in inspiring students to understand, appreciate, and apply STEM fields. Candidates must have at least three years of teaching experience.

Professor Helguera's replacement as Undergraduate Program Coordinator is Professor Jim Ferwerda. Professor Ferwerda has been with the Center since 2007. His areas of research include computer graphics, digital imaging, display systems, visual perception, material appearance, low vision, and assistive technologies. Since joining the Center he has taught courses in both the graduate and undergraduate program including Color Science, Imaging Systems Analysis, Appearance of Materials, and Computing for Color Science. Professor Ferwerda, a longtime member of the Center's Undergraduate Curriculum Committee (UGCC), assumed the position of Program Coordinator in July 2016.

CURRICULUM

Throughout the year the UGCC continued to adapt and renew our undergraduate curriculum. They want our students to be competitive in the market and be solidly prepared if they choose to pursue graduate studies. This year the UGCC held a mini-retreat to review the scope and timing of all of our offerings. The meeting started with a course mapping exercise that resulted in rescheduling courses, primarily in the first two years. These changes include:

- In the fall of the freshman year the students will take the Freshman Imaging Project and the Introduction to Imaging and Video Systems (offered by the Motion Picture Science department). In the spring of the first year they will continue with the second semester of the Freshman Imaging Project and Vision and Psychophysics.
- In the fall of the second year the students will take Introduction to

Computing and Control (previously a freshman course). In the spring of the second year they will take Probability and Statistics for Imaging, Fundamentals of Color Science, and Linear and Fourier Methods for Imaging.

— In the fall of the third year students will have an opportunity to take an open elective, along with Geometric Optics, Radiometry, and Image Processing and Computer Vision. In the spring of the third year they will take Physical Optics, Interactions Between Light and Matter, and Imaging Processing and Computer Vision II and a second open elective.

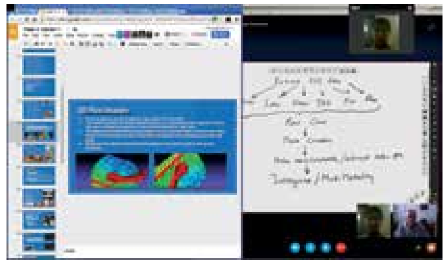
— In the fall of the fourth year the students will take Imaging Systems Analysis, Noise and System Modeling, a course in their chosen track, and Senior Project I. In the spring they will take another course in their track, as well as Detectors and Senior Project II

In the coming years the UGCC will monitor the impact of these changes on student performance and will make additional revisions as necessary.

After a dinner prepared by Dr. Maria Helguera, students practiced for their Preliminary Design Review in Associate Director Joe Pow's kitchen.

The 2015–2016 academic year marked the sixth time that the Center has offered our innovative Freshman Imaging Project course. A total of 25 students from Imaging Science and Motion Picture Science were enrolled at the beginning of the academic year. Although the Center has been actively trying to increase the size of our incoming class, 25 is far too many to assign to a single project. So for the first time we split the group and offered two sections, each working on its own unique project.

Section One was tasked to build a "haptic activity tracker"—a device to



Students used Skype to continue working on their project during a campus shutdown resulting from a February snowstorm.

measure the movement of the joints on a human hand as it manipulates an irregularly shaped object. The device was inspired by the work of Dr. Flip Phillips, a neuroscientist at Skidmore College, who is trying to understand the cognitive connection between visual and haptic interactions through quantitative analysis. Dr. Phillips has used eye-tracking technologies extensively to collect data that confirms that humans visually distinguish objects through identifying and comparing object contours. However, he needed a system that can collect the corresponding quantitative information for haptic activity. The freshmen in Section One made use of the imaging capabilities of the Kinect game system in conjunction with software written by a group of researchers from the Foundation for Research and Technology—Hellas (FORTH) in Greece to make the critical measurements for Dr. Phillips' studies.

Students prepare to collect long wave and medium wave images of a book on the history of Rome dating back to 1535.

Section Two of the Freshman Imaging Project class spent the year building a flash thermography system to reveal illegible texts that were originally written on materials which were subsequently recycled for use in other manuscripts. The students in this section faced several challenges, not the least of which was securing the use of a camera. Most of the researchers in this field have used cameras which capture mid-wave infrared (MWIR) radiation. These cameras are extremely expensive—well beyond the budget available to the class. So the students had to rely on help from two companies, FLIR and Harris, who agreed to loan the class MWIR cameras for their research. Armed with these devices, the students were able to develop both pulsed and lock-in imaging techniques which successfully detected subsurface texts in recycled materials that were used in the inside front cover of a 16th Century book on the history of Rome.

The work of both freshman sections was successfully demonstrated at RIT's annual innovation and creativity festival, ImagineRIT.

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.

Amy Becker and Michaela Piel: Design of a low-cost, Portable Digital Scanning Microscope. Two Applications: Tuberculosis Detection and Diagnosis, and Tissue Engineering.

Advisor: María Helguera

In biological applications there is a need for low-cost, portable digital scanning microscopes that not only collect but quantitatively analyze images. We have built two systems that satisfy those needs.

1. Tuberculosis is a major global health problem, being the second leading cause of death from an infectious disease worldwide, after HIV. Most deaths from tuberculosis are, or should be preventable, therefore the death toll is unacceptable. In countries with scarce resources, sputum smear microscopy has been the primary method for detecting tuberculosis and monitoring treatment response. A patient's ability to be infected is related to the number of bacilli in the sputum. In collaboration with the Pontifical Catholic University of Peru we have designed an automated

bacilloscopy system for the diagnosis of tuberculosis. The system will prepare and automatically diagnose four samples at a time.

2. Tissue engineering holds great potential for saving the lives of thousands of organ transplant patients who die annually while waiting for donor organs. To successfully fabricate tissues and organs in vitro, methodologies that recreate appropriate extracellular microenvironments to promote tissue regeneration are needed.

Endothelial cells are responsible for promoting vascular network formation in 3D tissue constructs, providing a means to supply oxygen and nutrients. Monitoring the structural and biological properties of engineered tissue constructs during fabrication is critical for the development of their intended physiological functionality. Currently, histological and biochemical assays are used to assess the viability of engineered tissues. Unfortunately, these techniques require the samples to be fixed and forbid the capability for real-time and longitudinal monitoring.

Our system can be placed in an incubator for continuous monitoring of the cell processes, and provides automated analyses techniques for cell counting and quantitative assessment of volumetric and textural parameters of the developing tissue structures.

Elizabeth Bondi: Calibration of UAS Imagery Inside and Outside of Shadows for Improved Vegetation Index Computation

Advisor: Carl Salvaggio

Vegetation health and vigor can be assessed with data from multi- and hyperspectral airborne and satellite-borne sensors using index products such as the normalized difference vegetation index (NDVI). Recent advances in unmanned aerial systems (UAS) technology have created the opportunity to access these same image data sets in a more cost effective manner with higher temporal and spatial resolution. Another advantage of these systems includes the ability to gather data in almost any weather condition, including complete cloud cover, when data has not been available before from traditional platforms. The ability to collect in these varied conditions, meteorological and temporal, will present researchers and producers with many new challenges. Particularly, cloud shadows and self-shadowing by vegetation must be taken into consideration in imagery collected from UAS platforms to avoid variation in NDVI due to changes in illumination within a single scene, and between collection flights. A workflow is presented to compensate for variations in vegetation indices due to shadows and variation in illumination levels in high resolution imagery collected from UAS platforms. Other calibration methods that producers may currently be utilizing produce NDVI products that still contain shadow boundaries and variations due to illumination, whereas the final NDVI mosaic from this workflow does not.

Victoria Scholl: Using an Unmanned Aerial System (UAS) to Collect and Study Inland Water in Western New York.

Advisors: Aaron Gerace, Carl Salvaggio

Monitoring the levels of chemical compounds present in polluted waters is of high importance to the environmental and remote sensing communities. Traditional remote sensing platforms such as those integrated into airplanes and satellites typically have significant spatial, temporal, or radiometric limitations. An unmanned aerial system (UAS) platform offers users the potential for flexible temporal collection, customizable spectral sensitivity, and high spatial resolution image data. In this study, a 6-band multispectral VIS-NIR camera array was mounted onto a UAS and used to image inland waters in western New York. An image processing workflow has been developed to estimate levels of chlorophyll, suspended materials, and color-dissolved organic matter from the imagery captured using the UAS platform. This constituent estimation procedure involves the utilization of a water reflectance spectra look-up table (LUT). The LUT was generated using Hydrolight, an in-water radiative transfer model, which incorporated environmental characteristics at the time and location of image collection. Converting each multispectral image pixel into a reflectance signal and searching for the closest match within the LUT enables the estimation of constituent levels. Colorized map products have been produced to allow users to visualize the presence of constituents throughout the region of interest. A comparison of retrieved constituent levels to in-situ water sample ground truth indicates that constituent estimation from UAS imagery is a promising endeavor.

Daniel Simon: Computational Temporal Gaze Modeling

Advisor: Reynold Bailey

Many computer vision algorithms are biologically inspired and designed based on the human visual system. Convolutional neural networks (CNNs) are similarly inspired based on the primary visual cortex in the human brain. However, the key difference between current visual models and biology is how the visual information is gathered and processed. Humans make eye movements to collect information from the environment for navigation and task performance. When searching a stimulus, certain eye movement patterns are correlated with better performance in visual search tasks. Researchers have guided subjects along expert scan paths for improved search task performance. However, it is necessary to have an expert examine the visual stimuli in order to generate these scan paths. In order to extend the idea of gaze guidance to a new unseen stimulus, there is a need for a computational model that can generate expert-like scan path. To develop such a system, we model the scanpath generation process using a convolutional neural network. Due to the temporal nature of eye movement data (scanpath), the network must be recurrent in nature, and have memory of outputs previously processed. We propose using a convolutional neural network and long short-term memory (LSTM) modules to temporally model visual attention to generate expert scanpath on new unseen images for active gaze guidance.

Kevin Sacca: Multispectral Imaging System for the Humanities and Archives (MISHA)

Advisor: Roger Easton

Multispectral imaging systems are costly and are usually designed with a particular application in mind, like astronomical imaging or airborne remote sensing. For document imaging applications, a system that can image from ultraviolet to infrared light is needed, but not readily available for reasons of cost. Document imaging is a field of value to many museums, libraries, and archives, but has not received adequate attention because of the cost of imaging documents. I propose an example of a low-cost, portable multispectral imaging system that can be used for document imaging applications. Using many narrow-spectrum LEDs ranging from 360 to 940nm and an inexpensive digital camera with a monochromatic sensor, this system will be able to image a target with a controlled illumination of selected wavelengths of light. The system's illumination sources were characterized spectrally and the camera has been calibrated radiometrically so various image-derived metrics can be obtained. Included with the system is open-source software to capture and process the multispectral image cubes. In the future this system could be used by students and scholars to perform in-house sampling of documents, perform materials analysis, and characterize documents for further imaging.

Alexander Fafard: Design of a Low-cost Ground-scanning LiDAR

Advisors: Jan van Aardt, Robert Kremens

The use of light detection and ranging (LiDAR) as an invaluable asset to the understanding of the physical world is well established within industry and organizations possessing extensive funding. The use of LiDAR technology in lower level applications has been effectively barred due to the relatively high expense of these systems. Herein is presented a compact LiDAR ground scanning imaging system which has been produced for a small fraction of the price of the most economical commercial systems currently available. This reduction in price can be attributed to the expungement of the economic barrier associated with laser ranging devices with the recent commercialization of low dispersion laser range finders. The price of this LiDAR scanner is further reduced through the use of a gyroscopic design- which removes the need for an expensive rotational optical element. The system possesses an angular spatial resolution of 0.45˚ and is able to cover an azimuthal full 360˚ rotation with a zenith angle spanning 135˚ at ranges of up to 50 meters. The ranging accuracy of the system has been found experimentally to be +/- 0.021 meters. In addition to the scanning characteristics, salient features of the system include the incorporation of an inertial measurement unit (IMU), a GPS and the ability to scan in selective regions at user selected resolution levels.

Alexander Jermyn: Improving Galactic Spectral Classification

Advisor: Joel Kastner

Gathering spectral classifications of young stars is very useful in determining many characteristics including age, mass, and temperature. These stars are often embedded within the dust clouds where they formed, requiring observations in the near infrared. However, classification using near-IR data places T-Tauri M stars 2 subtypes later than when using optical data. This results in the stars appearing colder and older in the infrared region than in the optical region. I provide analysis of 14 potential T-Tauri stars from the GALNYSS survey using medium resolution near-IR spectra from SPEX and optical spectra from DuPont B&C to provide improved characterization of the spectral type discrepancy and convert from one set to the other.

Lindsey Schwartz: Analyzing Gaps in Circumstellar Disks as a Result of Planet Formation

Advisor: Joel Kastner

Theories of the origins of planetary systems, like our own solar system, hold that planets form in disks of gas and dust orbiting newborn stars. The recent discovery of gaps within circumstellar disks has led astronomers to speculate that these gaps are indicative of planets in the act of formation. As protoplanetary disks spin, the materials within begin to combine together to form larger particles. These particles continue to adhere to one another, eventually forming the beginnings of a planet or planetesimal. Ultimately, a planet sized object forms and begins to carve out a path (gap) in the disk. Using various imaging systems, images of the star and surrounding disk can be obtained and analyzed. The size of the gap in the circumstellar disk, determined via image processing, can be compared with planetary models to reveal physical traits of the planet, such as mass and its orbital semi-major axis. This project aims to compare data from the Gemini Planet Imager to existing and new protoplanetary disk models to determine the number, masses, and semi-major axes of planets possibly forming within two specific circumstellar disks (orbiting the stars TW Hydrae and V4046 Sgr AB). We will also examine unique phenomena occurring in the circumstellar disk around V4046 Sgr AB using radial and azimuthal profiles.

Carrie Griffo: The Effect of Grain Size Distribution on Reflectance

Advisor:Chip Bachmann

Modeling the scattering of a granular material can provide insight on how the geophysical properties of said material influence its spectral reflectance. Many models have been explored over the years, and one of the most promising approaches is a radiative transfer model developed by Hapke. While Hapke's model contains terms for multiple variations of scattering, much of his theoretical work assumes that size distributions are narrow and composed of spherical particles from a uniform material. Most granular materials, however, are non-homogeneous and do not follow a power-law distribution. Density and particle size distribution are just some of the geophysical properties that influence each other and the overall observed spectral reflectance. The aim of this study is to better understand how variations in these geophysical properties, in particular, grain size distribution, contribute to the overall reflectance for the purpose of improving a model for a portion of the Algodones Dunes system. Spectral libraries will be created using hyperspectral BRDF measurements acquired with the Goniometer of the Rochester Institute of Technology (GRIT). These spectral libraries will be integrated into a scene constructed with airborne LiDAR data to create a calibration site for Landsat 8.

Zachary Mulhollan: Optical Differentiation Wavefront Sensing

Advisor:Jie Qiao

Wavefront sensors are a fundamental tool that is widely used to measure and characterize aberrations in an optical system. The optical differentiation wavefront sensor (ODWS) uses a gradient transmission filter in the far field of the wave under test to measure the wavefront slopes from intensity measurements made at the observation plane. This sensor has the potential to achieve higher spatial resolution, higher wavefront slope dynamic range, and lower cost when compared to the conventional Shack-Hartmann (SH) wavefront sensor. An ODWS system allows for the detection of finer features in a wavefront's curvature, which could prove to be invaluable for freeform optics metrology. In this project, the aim is toexamine the robustness of wavefront reconstruction in regards to tolerancing of key system components and focal spot size incident on the transmission filter.By introducing a deformable mirror into the input plane, custom wavefronts are generated that enable us to measure the sensitivity and dynamic range of the ODWS and compare its performance to a commercial Shack-Hartman sensor under monochromatic and broadband light.

Matt Casella: Low-cost Thermal Sensors for Ground Based Fire Research

Advisor: Robert Kremens

Every year there are significant naturally occurring events that cause vast amounts of destruction to geographical regions and their inhabitants. Most naturally occurring events are difficult to predict and control. One specific event prevalent in the western United States is wildfire. Fire lines, the outer edge of the region where the fire is burning, can go on for miles so it is difficult for those on the ground to predict how the fire will change. It is therefore necessary to find a way to measure characteristics of the fires to study how they burn so accurate fire models can be created and improved. Currently there are systems that collect data from various sensors from within the fire and from above the fire. Satellite and airborne imaging can be used for this purpose. Airbrone imaging is expensive but provides high spatial and temporal resolution, while satellites can be used with much poorer spatial and temporal resolution. Researches have therefore made instruments to be placed within fires that are relatively low cost and can continually collect data. The goal of this project is to test the effectiveness of a low cost thermal camera for use within the fire. This camera would provide the capability to see the heat of the fire spread and better understand the energy transfer of the fire.

AWARDS AND RECOGNITION

Kevin Kha

- Hughes Memorial Scholarship
- Henry and Mary Kearse Student Writing Award

Rachel Shadler

- Carlson Scholarship

Madeline Wolters

- Carlson Scholarship

Liz Bondi

- Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping Conference Best Paper Award
- Universities Space Research Association (USRA) Thomas R. McGetchin Memorial Scholarship Award 2015

Victoria Scholl

- AGU 2015 Fall Meeting Outstanding Student Paper Award (OSPA) recipient for Biogeosciences section
- Fulbright Scholarship Award - research fellowship at the University of Zurich in Switzerland, mapping vegetation using LiDAR. Grant period begins in September, 2016

PUBLICATIONS

Qiao, Jie; Mulhollan, Z.; Dorrer, C., Optical differentiation wavefront sensing with binary pixelated transmission filters, Optics Express, 24, 9, pp. 9266-9279 (April 11, 2016)

Nalin H. Samarasinha and 48 co-authors including Carlino, S., Results from the Worldwide Coma Morphology Campaign for Comet ISON (C/2012 S1) Planetary and Space Science, Volume 118, 1 December 2015, Pages 127–137

CONFERENCE PROCEEDINGS

Bondi, Elizabeth; Salvaggio, Carl; Montanaro, Matthew; Gerace, Aaron D., Calibration of UAS imagery inside and outside of shadows for improved vegetation index computation,Proceedings of the SPIE, Defense + Commercial Sensing, Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping, Unmanned Aerial Vehicles in Precision Agriculture, 9866, 17, pp. 98660J-1-98660J-7, Baltimore, Maryland, United States (April 19, 2016)

Qiao, Jie; Mulhollan, Z; Schweinsberg, A; Dorrer, C, Performance of an Optical Differentiation Wavefront Sensor based on Binary Pixelated Transmission Filters, CLEO: 2016 OSA Technical Digest, Cleo 2016, SM2M.5, pp. -, San Jose, California, United States (2016)

Easton, Roger L.; Sacca, Kevin; Heyworth, Gregory; Boydston, Kenneth; Van Duzer, Chet; Phelps, Michael, Rediscovering text in the Yale Martellus Map, Spectral imaging and the new cartography, 7th IEEE International Workshop on Information Forensics and Security, 7th IEEE International Workshop on Information Forensics and Security, pp. -, Rome, none, Italy (November 19, 2015)

Iafrati, Megan; Rustowicz, Rose; Dalecki, Diane; Helguera, Maria, Remotely Accessible Microscope, International Symposium on Biomedical Imaging (ISBI), ISBI, pp. -, Prague, Prague, Czech Republic (November 2015)

CONFERENCE PRESENTATIONS

Bachmann, Charles M.; Harms, Justin D.; Ambeau, Brittany; Griffo, Carrie; Peck, Doug; Badura, Greg; Myers, Emily, Retrieval of Sediment Fill Factor from Hyperspectral BRDF Measurements of Coastal Sediments, SPIE, SPIE Defense and Security 2016, Algorithm and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXII, Solid Target Variability I, Baltimore, Maryland, United States (April 17, 2016)

Qiao, Jie; Mulhollan, Z; Schweinsberg, A; Chalifour, M; Dorrer, C, Demonstrations of an optical differentiation wavefront sensor, SPIE, SPIE Photonics West, San Francisco, California, United States (February 2016)

INTERNSHIPS AND CO-OPS

Liz Bondi—Harris

Beth Bogart—HERE (Higher Education Research Experience) at the Oak Ridge National Laboratory in Oak Ridge, TN. Involved in Photogrammetric Registration of Imagery from Manned and Unmanned Systems (PRIMUS) with the Geographic Information Systems and Technologies group. I am specifically doing image registration in the thermal spectrum.

Rose Rustowicz—Air Force Research Laboratory, Dayton, OH. Working with SAL (synthetic aperture ladar). Because SAL development is in the early stages, data must be simulated for analysis and processing. The current simulated images for SAL are created under perfect conditions, which is unrealistic for testing out what algorithms will do to real world data from such a sensor. My task is to add real-world atmospheric effects from phase distortions and turbulence into the simulated images—basically modelling the atmospheric noise into the simulated images.

Victoria Scholl—

- National Ecological Observatory Network (NEON), Boulder, CO. Assessing and Adapting LiDAR-Derived Pit-Free Canopy Height Model Algorithm for Sites with Varying Vegetation Structure
- NASA Goddard Space Flight Center in Greenbelt, MD. Mapping Arctic Melt Ponds using Landsat 8 OLI Multispectral Imagery

Leah Bartnik—Canfield Scientific, Parsippany-Troy Hills, NJ. Working on projects including objective measurement of skin oiliness for applications in acne studies and cosmetic research; oxy/deoxy head imager for applications in skin lesion and melanoma studies; development of backlight imaging method for vellus hair analysis; method validation for commercial analysis software packages; extensive database captures for multiple imaging systems.

The RIT Imaging Science team won the "Special Innovation Award" at the national Hyperloop Design Weekend, sponsored by SpaceX and hosted by Texas A&M University. The multidisciplinary team of sophomores won for their novel structured light approach to track diagnostics for the ultra-high speed ground transportation system, and their creative concept for real-time internet access for passengers in the 700 miles per hour hyperloop pods.

Motion Picture Science Program

Program Director's Comments by Dr. David Long

This May, I had the privilege of attending graduation ceremonies for both the College of Imaging Arts and Sciences, home of the motion picture science (MPS) program and the College of Science, home of imaging science. At these annual events, where the successes of our respective students are celebrated separately, I paused to think how wonderful it is to know our two programs cross these traditional inter-college barriers to form such a strong collaborative community. My main motivation for participating in both ceremonies was to celebrate, in particular, the graduation of Victoria Scholl, the first student to complete

both the MPS and imaging science undergraduate degrees. Victoria is also recipient of a Fulbright Scholarship and will be spending 2016-17 studying in Switzerland. Victoria's achievements are exemplary of the positive impact our shared curricula have. She has also begun an encouraging trend, inspiring two additional undergraduate students to pursue each of the two degrees.

2015–16 was another strong year for MPS. Two separate freshmen imaging project teams, each comprised of both MPS and imaging science first-year students, worked hard to produce successful exhibits at Imagine RIT. The first team demonstrated thermal imaging techniques for revealing damaged or hidden text on fragile cultural artifacts, including some examples from the RIT Cary Graphic Arts collection. The second team researched haptic tracking technologies to permit measurement and visualization of human hands in action manipulating different objects. That work was done in support of visiting scientist, Flip Phillips, who studies hand and eye object detection as part of the Skidmore College Department of Neuroscience. Immersing the freshmen from both of these programs immediately into a real-world engineering environment is key in introducing them to the dynamics of professional technology development. It's also great each year to see the MPS students bring just a little right-brain perspective to the teams.

In October, three different student papers were presented at the annual Society of Motion Picture and Television Engineers (SMPTE) technical conference in Hollywood. The RIT student chapter of SMPTE also took home honors in the first annual SMPTE student film festival for a documentary they produced on their research into virtual reality filmmaking. Perhaps most exciting, though, was to see other papers at the conference presented by MPS alumni. With only six graduating classes in the short history of MPS, RIT is becoming a force in the motion picture community. Also on the alumni front, John Traver (BS '10) lead a team that won one of only 12 Apple Design Awards at the June Apple Worldwide Developers Conference. John is co-founder of frame.io, an online video collaboration company geared towards filmmakers who must work through production and post-production remotely.

Finally in May, 10 additional MPS students joined Victoria Scholl in completing their degrees at RIT. And they are off to post production roles with Imax in Hollywood and Deluxe in New York among others or are already starting research careers at Dolby Labs and Disney. This was certainly another strong group ready to take the RIT name out to the cinema world, with great thanks to the partnership with imaging science setting the technical foundation.

Abstracts taken from sample MPS Senior Projects

Adrian Grey

Color Correction for Stop-Motion Animation: Diagnosis and Reduction of Flicker Artifacts

Flicker artifacts occur in stop-motion animations as a result of small variations in exposure from frame to frame. This project studies the sources of flicker using Fourier analysis to determine whether variability will result in an artifact that is visible to an average observer. Solutions to the flicker, both on set and in post, are also explored and assessed for effectiveness. It was determined that variability in aperture size was the most significant cause from the potential sources examined. This variability can be controlled using a manual lens with no electronic control, or corrected in post using software solutions. A specific algorithm to correct for flicker was developed and implemented to meet this need.

Nathaniel McFarlin and Maxwell Pope

Resolution Enhancement via Display Vibration

The aim of this thesis is to design, build, and test the legitimacy of a display that gives the perception of higher than its native resolution via display vibrations that are both synced with the refresh rate of the monitor and quicker than the human visual system's retinal integration time. Using an image with higher resolution than that of the display, lower resolution copies of the image are made to match the native resolution of the display. Next, these low resolution images (LRIs) are rendered in sequence at a high refresh rate on the display. These refresh rates are then synced with the physical display vibrations to blend the LRIs together, giving off the perception of high resolution.

Victoria McGowen

Automatic Blendshape Creation for Facial Motion Capture

The purpose of this thesis is to create a streamlined program for animators to create blendshapes of their face models for facial motion capture projects. Creating animations by manipulation of vertices or creating blendshapes by hand can be a very tedious process and an impractical one since vertex manipulation causes permanent change to the model. Having a tool to assist in the task and quicken the process will enable modelers to focus more on the actual creation of their characters. This program will be available for animation and 3D design students at Rochester Institute of Technology.

Elizabeth Pieri

The Effect of Frame Rate on the Human Visual System

The motion picture industry today has begun to stray from traditional 24-frame rate capture and display, resulting in an unexpected negative response from viewers. There is no straightforward reason for this strange aesthetic that comes along with higher frame rates and causes the human visual system to respond unexpectedly. Research surrounding this topic is limited, as it is an extremely complex issue that does not affect each person the same way. To tackle a piece of the problem, this vocabulary study aims to reveal which words most aptly describe the percepts of motion as frame rate varies, to eventually be able to determine how small of a change in frame rate humans are capable of detecting. Through experimentation and collaboration, this research hopes to get us one step closer to understanding the way humans interpret motion.

Matt Setlow

Perceived Brightness vs Screen Size

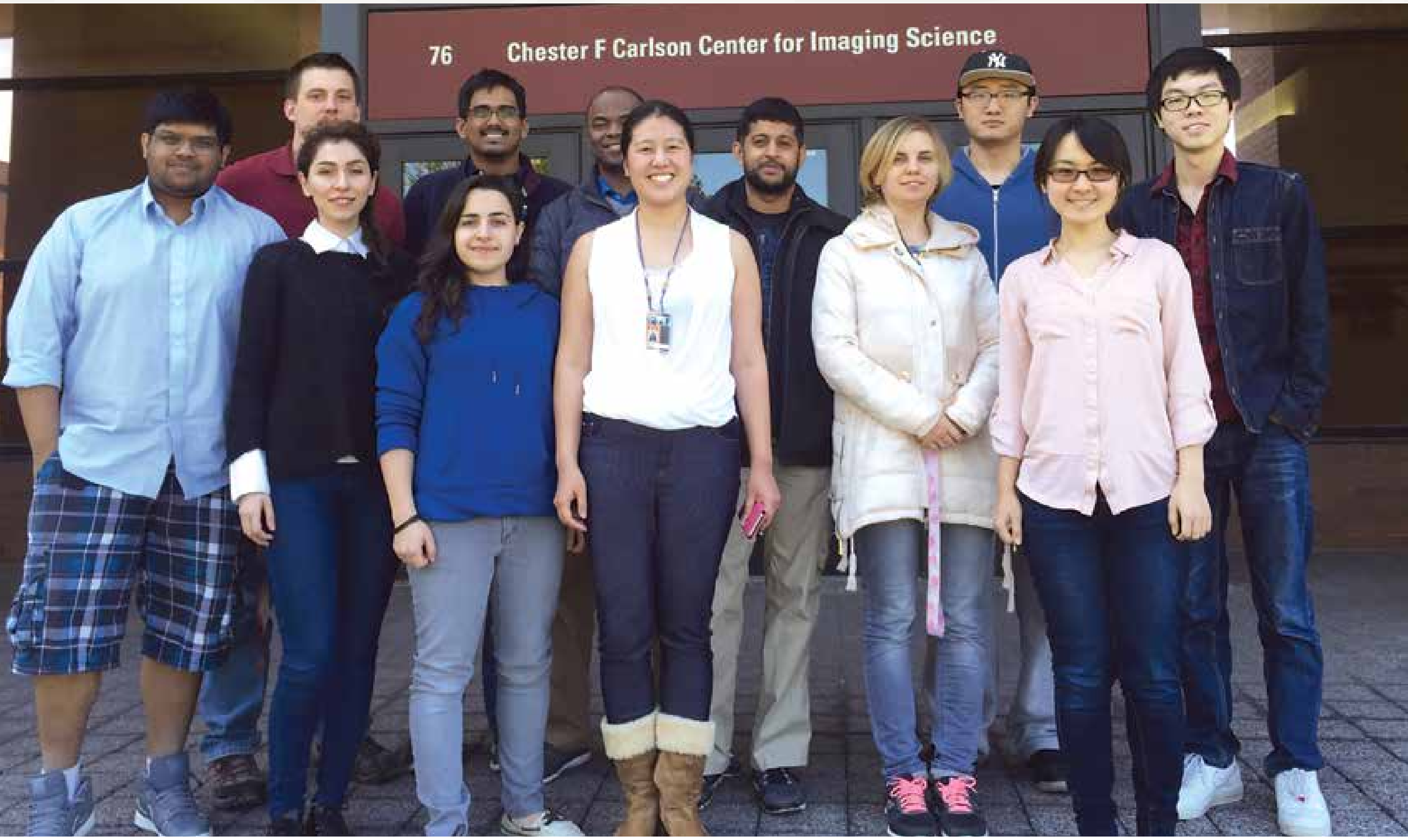
The objective of this project was to define a relationship between the size of the viewing screen and the perceived brightness, lightness, and contrast of the content displayed. The effect was tested using psychophysical methods through two implementations. The first implementation tested perceived brightness versus field of view while the second implementation tested perceived brightness versus physical screen size. Whether these relationships are measurable, observable, or non-existent, the motion picture and television industry can benefit from analytical data of this common anecdotal phenomenon.

Miscellaneous Awards

- Victoria Scholl

  —Fulbright Scholarship

Scholl, a native of Hudson Valley, N.Y., will work in partnership with scientists at the University of Zürich and plans to apply airborne light detection and ranging technology (LiDAR) processing methods to large regions across Switzerland and adapt them for optimal individual tree detection over a 12-month period. LiDAR allows for efficient forest surveying. These findings may then be applied to other forests around the world as a step toward understanding, forecasting and solving global climate change issues.



First-year graduate students for the 2015-2016 academic year.

IMAGING SCIENCE GRADUATE PROGRAM

Program Coordinator's Comments By Dr. John Kerekes

The Imaging Science graduate program continues to play a key role in advanced education and research in the expanding fields of imaging for consumer, defense, and scientific uses. Our graduates remain in high demand finding employment in industry, government, nonprofits and universities.

As we have in previous years under the new semester calendar, we took advantage of the extended break in January with faculty and graduate students offering to our student body a number of short courses free of charge. These courses ranged from introductions to computer languages such as C++, MATLAB, and the typesetting markup language LaTeX, immersions in virtual reality and motion capture, to an industry workshop on trends in spectroscopy. This year there was also an emphasis on communication with a workshop on presentation techniques and a very successful student-led writing retreat.

Also as in previous years, 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 2015–16 academic year.

Graduate Program Faculty

The 2015–16 academic year began with the formal announcement of Prof. David Messinger being appointed as the CIS Director after serving as Interim Director for the previous year. Prof. Messinger has continued to be a strong advocate of CIS, meeting frequently with government and industrial leaders, and working with faculty, staff, and students and the RIT administration to provide the resources necessary to continue our program. His move into the Director's office also opened up a tenure-track faculty position in the remote sensing area, and an international search is ongoing to fill this slot with the new faculty member to be appointed during the 2016–17 academic year.

The beginning of this year also saw the arrival of Assistant Professor Christopher Kanan, a world-class expert in computer vision. Prof. Kanan has hit the ground running by taking on several graduate student advisees and teaching our graduate Image Processing and Computer Vision core course. We look forward to Prof. Kanan contributing to our program for many years to come.

During the year we also welcomed Prof. Ray Ptucha of Computer Engineering as a member of our Graduate Program Faculty.

As the year ended, Prof. Maria Helguera announced her retirement from the RIT faculty, although she will remain active in her research and will continue to be affiliated with RIT. We thank her for her many contributions to our program and wish her the best as she moves to the next stage of her career.

As of the end of the 2015–16 academic year there are a total of 53 members of the CIS Graduate Program Faculty. Eighteen are tenured, or tenure-track, with the Center as their primary appointment. Another twenty-six have a primary appointment in one of thirteen other departments centers, programs or laboratories with which the Center is affiliated. Also, 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

No changes were made to our curriculum during this past year, although we continued to offer our new PhD laboratory course as well as three special topics courses developed by faculty.

This was the third year for our new year-long PhD laboratory course led by Prof. Roger Dube, with assistance from Rolando Raqueno and Don McKeown. Twelve first-year PhD students were challenged to design and build an imaging system to create a computer avatar of a person, 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 Markerless Avatar Rendering System (MARS) which was successfully demonstrated at Imagine.

Assistant Professor Gabriel Diaz taught a new special topics course, "Interactive Virtual Environments," in the spring semester. This course engaged students in hands-on experiences in a project-based real-time immersive virtual reality environment. This was a very popular course and gave the students excellent experience in the programming and hardware of virtual environments. Two special topics courses were taught this year for the second time by faculty who have recently joined our program. Associate Professor Charles "Chip" Bachmann taught "Introduction to Radiative Transfer in Media" in the spring. 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.

Graduate Student Body

At the beginning of the 2015–16 academic year there were a total of 116 graduate students pursuing degrees in Imaging Science. There were 28 resident M.S. students, 7 online M.S. students, and 81 Ph.D. students including two who are pursuing the degree online.

The incoming class that started in the fall of 2015 included 6 M.S. and 14 Ph.D. students. In this group of students there are two US Air Force officers (1 M.S. and 1 Ph.D.) and two Canadian Forces officers (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. Five of the new students were from the United States, with the balance being international including four from India, two from China, two from Canada, and one each from Bangladesh, Congo, Iran, Serbia, South Africa, Taiwan and Ukraine.

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 2015–16.

- RIT 2016 PhD Dissertation Award: David Kelbe
- RIT 2015 Graduate Student Research and Creativity Grant: Anton Travinsky
- SPIE Travel Scholarship: Anton Travinsky
- SPIE Officer Travel Grant: Zichao Han

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 2015–2016.

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

- Carson, Tyler D.; Salvaggio, Carl, Soil signature simulation in the thermal infrared, Optical Engineering, 54, 10, pp. 104102-1-104102-6 (October 2015)
- Carson, Tyler D.; Bachmann, Charles M.; Salvaggio, Carl, Soil signature simulation of complex mixtures and particle size distributions, Optical Engineering, 54, 9, pp. 094103-1-094103-10 (September 2015)
- Kelbe, David; van Aardt, Jan A.; Romanczyk, Paul A.; van Leeuwen, Martin; Cawse-Nicholson, Kerry A., Single-Scan Stem Reconstruction Using Low-Resolution Terrestrial Laser Scanner Data, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 8, 7, pp. 3414-3427 (July 2015)
- Ruane, Garreth J.; Huby, E; Absil, O; Mawet, D; Delacroix, C; Carlomagno, B; Swartzlander, Grover A., Lyot-plane phase masks for improved high-contrast imaging with a vortex coronagraph, Astronomy & Astrophysics, 583, A81, pp. 1-6 (September 18, 2015)

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

- Bachmann, Charles M.; Ambeau, Brittany; Griffo, Carrie; Harms, Justin, Retrieval of Sediment Fill Factor from Hyperspectral BRDF Measurements of Coastal Sediments, Proceedings of SPIE , SPIE Defense and Security 2016, Solid Target Variability I, Baltimore, Maryland, United States (April 2016)
- Bachmann, Charles M.; Peck, Douglas S.; Ambeau, Brittany; Harms, Justin; Schultz, Malachi, Improved Modeling of Multiple Scattering in Hyperspectral BRDF of Coastal Sediments Observed Using the Goniometer of the Rochester Institute of Technology (GRIT), Proceedings of SPIE, SPIE Optical Engineering + Applications, Imaging Spectrometry XX, Surface and Gas Imaging Spectrometry, 9611, pp. 96110J-1-96110J-17, San Diego, California, United States (August 2015)
- Harms, Justin; Bachmann, Charles M., A next generation field-portable goniometer system, Proceedings of the SPIE, SPIE Defense and Security 2016, Solid Target Variability I, Baltimore, Maryland, United States (April 2016)

- Iafrati, Megan; Rustowicz, Rose; Dalecki, Diane; Helguera, Maria, Remotely Accessible Microscope, International Symposium on Biomedical Imaging (ISBI), ISBI, pp. -, Prague, Prague, Czech Republic (November 2015)
- Kothari, Rakshit; Binaee, Kamran; Jonathan S., Matthis; Bailey, Reynold; Diaz, Gabriel, Novel Apparatus for Investigation of Eye Movements when Walking in the Presence of 3D Projected Obstacles, Eye Tracking Research and Applications, pp. -, Charleston, South Carolina, United States (March 14, 2016)
- Qiao, Jie; Taylor, Lauren; Qiao, Jun, Thermal Modeling and Heat Mitigation for Femtosecond-Laser-Based Silicon Processing, CLEO: 2016 OSA Technical Digest, CLEO: 2016 , ATu3K.4, pp. -, San Jose, California, United States (2016)
- Taylor, Lauren; Qiao, Jun; Qiao, Jie, Advanced optic fabrication using ultrafast laser radiation, Proc. SPIE 9740, Frontiers in Ultrafast Optics: Biomedical, Scientific, and Industrial Applications XVI, , 9740, pp. -, San Francisco, California, United States (March 09, 2016)
- Uzkent, Burak; Hoffman, Matthew J.; Vodacek, Anthony, Real-time Vehicle Tracking in Aerial Video using Hyperspectral Features, Workshop on Moving Cameras Meet Video Surveillance: from Body-borne Cameras to Drones, CVPR Workshops 2016, pp. -, Las Vegas, Nevada, United States (2016)
- Wang, Fan; Kerekes, John P.; Wang, Yandong, Adaptive Region Merging Segmentation of Airborne Imagery for Roof Condition Assessment, Imaging & Geospatial Technology Forum 2016, Fort Worth, Texas, United States (April 2016)
- Weaver, Oesa; Kerekes, John P., The Role of Large Constellations of Small Satellites in Emergency Response Situations, International Geoscience and Remote Sensing Symposium, pp. 4200-4203, Milano, Lombardia, Italy (July 2015)
- Williams, McKay D.; van Aardt, Jan A.; Kerekes, John P., Generation of Remotely Sensed Reference Data Using Low Altitude, High Spatial Resolution Hyperspectral Imagery, Algorithms and Technologies fro Multispectral, Hyeprspectral, and Ultraspectral Imagery XXII, Defense and Commercial Sensing, 9840, 98401R, pp. 1-10, Baltimore, Maryland, United States (April 2016)
- Yao, Wei; van Leeuwen, Martin; Romanczyk, Paul A.; Kelbe, David; Brown, Scott D.; Kerekes, John P.; van Aardt, Jan A., Towards Robust Forest Leaf Area Index Assessment Using an Imaging Spectroscopy Simulation Approach, International Geoscience and Remote Sensing Symposium, pp. 5403-5406, Milano, Lombardia, Italy (July 2015)

Graduates

During academic year 2015-2016 the Center conferred 7 Ph.D. degrees and 8 M.S. degrees.

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

- Bikash Basnet, Monitoring Cloud Prone Complex Landscapes at Multiple Spatial Scales Using Medium and High Resolution Optical Data: a Case Study in Central Africa, Advisor: Anthony Vodacek
- Javier Concha Sepulveda, The Use of Landsat-8 for Monitoring of Fresh and Coastal Water, Advisor: John Schott
- Shruti Gopal, Inter-subject Variability Analysis in Blind Source Separation Applications, Advisors: Stefi Baum and Vince Calhoun
- Thomas Kinsman, Semi-supervised Pattern Recognition and Machine Learning for Eye-Tracking, Advisor: Jeff Pelz
- Gareth Ruane, Optimal Phase Masks for High Contrast Imaging Applications, Advisor: Grover Swartzlander
- Abdul Haleem Syed, Segmentation and Classification of Remotely Sensed Images: A Solution to the Scale Selection Problem, Advisor: Eli Saber
- Siyu Zhu, Text Detection in Natural Scenes and Technical Diagrams with Convolutional Feature Learning and Cascaded Classification, Advisor: Richard Zanibbi

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

- Alison Gray, Advisor: Ray Ptucha
- Sanghui Han, Advisor: John Kerekes
- Chao Liu, Advisor: James Ferwerda
- Dengyu Liu, Efficient Space-Time Sampling with Pixel-wise Coded Exposure for High Speed Imaging, Advisor: James Ferwerda
- Ashley Penna, Advisor: Mark Fairchild
- Timothy Smith, Advisor: John Kerekes
- Donath Uwanyirigira, Advisor: Anthony Vodacek

The following are post-graduate plans for some of the students who graduated during 2015-2016.

- Bikash Basnet, Lumen Aero
- Javier Concha Sepulveda, NASA Goddard Space Flight Center
- Abdul Haleem Syed, MathWorks
- Shruti Gopal, University of Miami
- Alison Gray, NVIDIA
- Sanghui Han, Rochester Institute of Technology
- Thomas Kinsman, Rochester Institute of Technology
- Chao Liu, Carnegie Mellon University
- Dengyu Liu, Intel
- Ashley Penna, Dolby Laboratories
- Gareth Ruane, California Institute of Technology
- Donath Uwanyirigira, University of Rwanda
- Timothy Smith, Harris
- Chao Zhang, Rochester Institute of Technology

DIGITAL IMAGING AND REMOTE SENSING LAB

Laboratory Director's Comments By Dr. Anthony Vodacek

During the 2015–2016 academic year the activities in DIRS fit within our standard suite of research into systems, modeling and simulation, algorithms, and applications and the faculty and staff were stable.

Of course students are always a dynamic group by nature and DIRS had its usual large complement of undergraduate researchers (11), MS students including Canadian Forces and USAF officers (12), and PhD students including USAF officers (26). Despite this stability in numbers, change is in the air when considering new DIRS research thrusts. Foremost among these are the projects that emphasize work with new imaging and sensing systems.

Several of these new initiative are based on taking an imaging systems approach to improve the use of image data obtained from unmanned aerial systems. Critical activities in this arena are strongly linked to the needs of specific users:

- In February 2016, RIT announced strategic investment in four research areas. One of these research areas is Remote Sensing with Unmanned Aerial Vehicles. Dr. Carl Salvaggio is taking a leading role in this interdisciplinary team from imaging science, engineering, public policy and mechanical engineering technology to take on challenges facing this industry from integrating UAVs into the national airspace to make better use of the high quality visual data collected in a variety of disciplines.
- RIT joined the Property Drone Consortium as a technology adviser with DIRS playing a central role. This industry consortium is comprised of insurers and aerial imaging providers focused on roof damage assessment, a multi-billion dollar industry concerned primarily with quickly and accurately assessing storm damage.
- Dr. Chip Bachmann (PI), and Co-PIs Dr. Tony Vodacek, and Dr. Matt Hoffman (School of Mathematical Sciences) were awarded a Defense University Research Instrumentation Program (DURIP) grant to purchase an imaging spectrometer for specialized imaging applications in BRDF of sands and vehicle tracking. The grant also included funds for a calibration system and combined with other funds from the College and the UAV strategic investment, a large integrating sphere for radiometric calibration was purchased (see Figure DIRS-1).

With these new opportunities and investments leading the way, the DIRS group has produced a wide variety of remote sensing research projects and activities. The following paragraphs are a selected summary of these projects and activities.

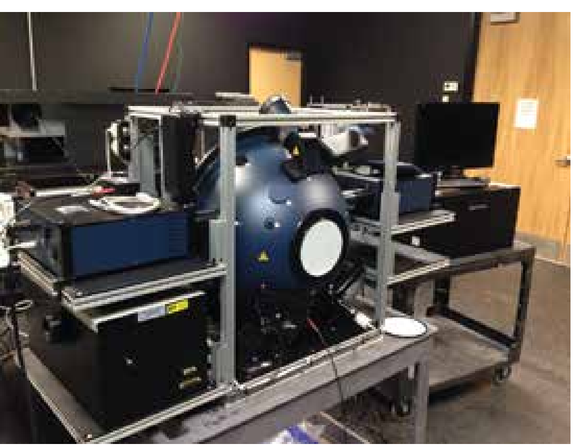


Figure DIRS-1. Integrating sphere system purchased from Labsphere as part of the DURIP funding. The 20 inch sphere has an 8 inch aperture. Two plasma sources are installed to each side of the sphere enable stable illumination approaching solar brightness. Our existing scanning monochromator (vis-NIR-SWIR) is installed below the left plasma lamp.

Unmanned Aerial Systems

One of the most basic remote sensing techniques is the use of red and near infrared signals to estimate vegetation health using the normalized difference vegetation index (NDVI). The use of NDVI is ubiquitous in remote sensing applications because of the importance of mapping vegetation and vegetation health in many application areas. However, producing reliable and repeatable NDVI values requires sensor calibration. Techniques to handle the challenging illumination and viewing conditions for UAS are needed if useful NDVI values are to be derived from these emerging platforms. Dr. Salvaggio and his students are diving headfirst into this problem and gaining experience with remote sensing data collections using cameras on UAS that will help them find a solution for this need. Figure DIRS-2 and DIRS-3 show some of the imaging hardware and imaging techniques used with these new platforms.

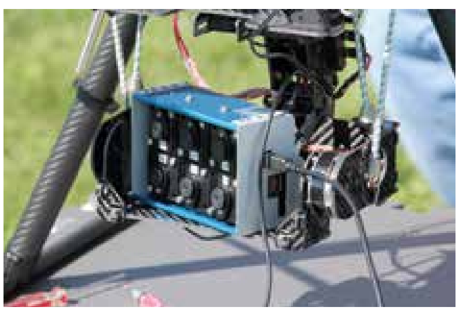


Figure DIRS-2. A 6-band multispectral Tetracam, Inc. camera system installed on a gimbal hanging from an octocopter. The use of red and near infrared filters on two of the cameras allows the calculation of NDVI.

Figure DIRS-3. Left. The use of shadowing on grayscale calibration targets to provide a means of image calibration for improved calculation of normalized difference vegetation index (NDVI) in shadowed conditions by tall trees or buildings or by clouds. This type of calibration adjustment is necessary to fully exploit the ability of a UAS to fly and collect calibrated data under varying atmospheric conditions such as under clouds.

Spectral BRDF

For several years, Dr. Bachmann and students have been addressing the use of spectral BRDF to assess the trafficability and geomorphologic characteristics of unconsolidated sediments (sands, silts, clays). The original instrumentation used for these studies has been updated to the next generation spectral goniometer system: Goniometer of the Rochester Institute of Technology-Two (GRIT-T). GRIT-T was developed by Justin Harms as Ph.D. dissertation research project under Dr. Charles Bachmann (Figure DIRS-4). GRIT-T includes two ASD FR-4 VNIR/SWIR spectrometers for measuring directional spectral reflectance of the surface and skylight simultaneously. Other novel features include an onboard laser for maintaining lock on the same point on the ground, regardless of terrain, and providing a digital elevation model of the surface where the spectral measurements are taken.

Figure DIRS-4. Images of the new GRIT-T deployed in different scenarios. Clockwise from upper left: Laboratory setting with artificial illumination on an engineered sediment, view showing the dual spectrometers used by the system, leveled instrument on a steep dune slope, use on a coastal tidally flooded site, and detail of the leveling legs and articulated probe.

Industrial Facility Modeling

Dr. Mike Gartley is working with Lawrence Livermore National Labs (LLNL) to develop a flexible industrial facility site model for the DIRSIG software. This industrial facility modeling effort leverages the previously built site model of the Trona, CA industrial facility (sometimes referred to as Megascene 2). The scene has been significantly improved to align the ground texture and geometric scene objects. The scene has expanded both the natural and man-made ground clutter for improved realism of such a facility. Once this was accomplished, various configurations of the original desert facility were created so the scene was representative of a suburban site in the summer and winter (see Figure DIRS-5 below). These variations permit LLNL algorithm testing against multiple realistic spectral and geometric backgrounds. To date the project has delivered various multi-spectral image datasets and co-registered LIDAR point clouds of representative commercial platforms.

Figure DIRS-5. RGB DIRSIG renderings of (left) original desert mode of the Trona, CA industrial facility model, (middle) modified summer suburban facility mode and (right) winter suburban facility mode.

Paul and Francena Miller Chair in International Education

In January 2016 Dr. Anthony Vodacek began a 2-year appointment as the Paul and Francena Miller Chair in International Education. This endowed chair rotates among the RIT colleges and is intended to provide support for the development of international experiences for RIT students and faculty. Dr. Vodacek wrote his proposal to the College of Science selection committee around partnership with World Bank funded African Centres of Excellence in Higher Education II (ACE II). These projects at African universities in Eastern and Southern Africa will enhance graduate education and research activity and are slated to begin in Fall 2016 and continue for 5 years. The ACE II projects were required to have international partners and RIT is listed as a partner in 3 funded proposals within the University of Rwanda (UR). The 3 centers are focused on 1) The Internet of Things, UR College of Science and Technology, 2) Data Science, UR College of Business and Economics, and 3) STEM Education, UR College of Education. Dr. Vodacek will be organizing participation of College of Science faculty and students in teaching and research activities in the ACE II projects with an emphasis on projects that use geospatial technologies and spatial reasoning as a critical thinking skill. Figure DIRS-6 shows Dr. Vodacek presenting the RIT M.S. in imaging science diploma to recent Rwandan graduate Donath Uwanyirigira.

Figure DIRS-6. Left to right. Dr. Gaspard Rwanyiziri, Director of the University of Rwanda Centre for GIS and Remote Sensing, Donath Uwanyirigira, Dr. Anthony Vodacek. Taken at the Centre for GIS and Remote Sensing facility in Huye, Rwanda.

Precision agriculture assisted by UAS

In parallel with Dr. Salvaggio's work, Dr. van Aardt is assessing the use of imaging from UAS for precision agriculture. Some of his work has been in collaboration with Cornell University personnel to assess soil fertility and other treatments to increase yields. This effort in precision agriculture relies on imaging to observe crop response to various treatments on the scale of a meter or less to the detail of individual plants. Imaging from UAS may provide a temporal and spatial coverage impossible to achieve from aerial or satellite platforms. Figure DIRS-7 shows a hint of the potential for these systems applied to precision agriculture.

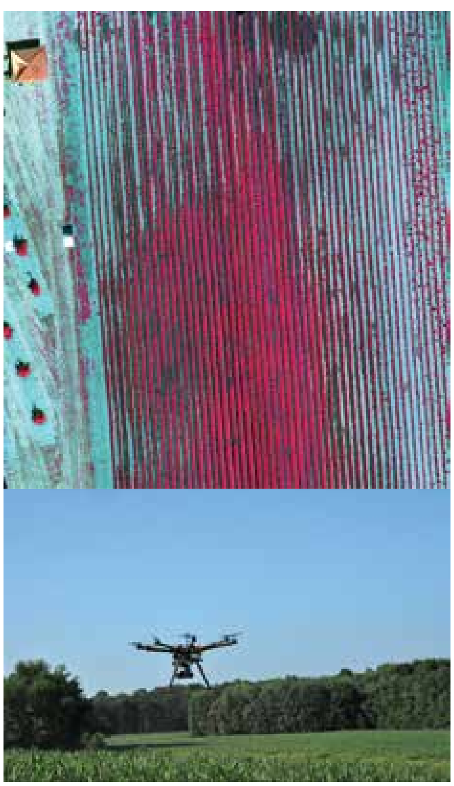


Figure DIRS-7. Left, UAS image (color infrared rendering) of a snap bean field (Cornell University) illustrating growth responses at the plant level. Right, DIRS octocopter at low altitude over an Advanced Biological Marketing (ABM™) cornfield at their facility in Geneva, NY.

DIRSIG 5

Dr. Scott Brown and Dr. Adam Goodenough are working rapidly to implement the significant software updates that will take DIRSIG from version 4 to version 5. DIRSIG 5 will have many significant upgrades that will allow for the faster creation of synthetic scenes of greatly enhanced realism and fidelity. Figure DIRS-8 shows visually the computational improvements for DIRSIG 5 in comparison to DIRSIG 4. The two images were run for 5 minutes for identical conditions except for the version of DIRSIG. The multi-thread capability of DIRSIG 5 enables a very large improvement in computation speed. Figure DIRS-9 illustrates the impact of a much-improved treatment of the atmospheric absorption and scattering by using a segmented ray path during the calculation of the atmospheric signal to produce a more realistic atmospheric phenomenology, especially for this case of extreme oblique viewing.

Figure DIRS-8.

Figure DIRS-9.

Roof Condition Assessment

In keeping with the theme of UAS development, Dr. Kerekes and graduate student Fan Wang have been investigating algorithms for assessing rooftop condition from very high resolution image data such as might be obtained from a low altitude UAS. This project applied computer vision techniques to explore automated assessment of residential roof condition using high resolution imagery (1 inch GSD) provided by Pictometry International. As an initial phase, the research focused on unsupervised segmentation of distinct regions on the roof. Figure X shows an example roof and example segmentation results for three different values of the segmentation compactness parameter. The graph shows a linear model between this parameter and dissimilarity as measured by texture features derived from the gray level co-occurrence matrix (GLCM). Ongoing research is investigating the optimal ways of automatically selecting this parameter and then performing the condition assessment using a support vector machine (SVM) classifier trained from labeled samples.

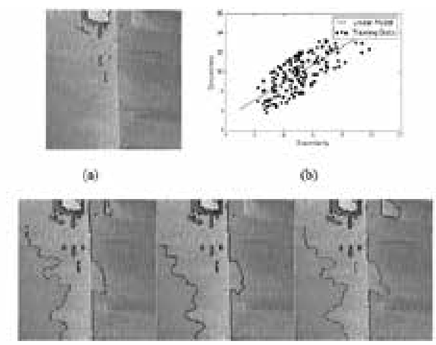


Figure DIRS-10. Example results of automated segmentation of residential roof. (a) Original image; (b) linear model for compactness parameter; (c) - (e) various segmentation results for a range of compactness.

Future Landsat System Studies

Dr. John Kerekes and Dr. John Schott conducted research in support of future Landsat instrument design concepts. In particular, a study was conducted on the impact on measured radiances and the analysis product Normalized Difference Vegetation Index (NDVI) due to the change in spectral response of spectral filters due to off-axis imaging. This study was motivated by future Landsat concepts that may broaden the ground swath to decrease the interval between repeat passes. Results indicted an impact on the radiances ranging from 0.02 to 4.4% with a mean impact on NDVI of 0.5%. In addition a number of synthetic scenes have been generated using DIRSIG to use for further system studies with a goal of exploring the impact on additional analysis products for a range of future instrument design concepts.

Other Activities

In addition to the directed research

activities in DIRS, faculty and staff have continued to expand their contributions to the greater scientific community. Just a few example activities are:

- Dr. Messinger, Co-Chair and Editor for the SPIE Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXII conference at the Defense + Commercial Sensing meeting in Baltimore, April 2016.
- Dr. Ientilucci, Scientific organizing committee for the SPIE Imaging Spectrometry conference and organizing the inaugural Systems and Technologies for Remote Sensing Applications Through Unmanned Aerial Systems (STRATUS) Workshop to be held at RIT in fall 2016.
- Dr. Vodacek, Associate Editor for the Journal of Great Lakes Research.
- Dr. Kerekes, Chair of the IEEE GRSS Modeling in Remote Sensing Technical Committee
- Dr. Schott, Landsat Science Team member
- Dr. van Aardt, Technical Working Group, waveform light detection and ranging (lidar) for the National Ecological Observatory Network (NEON)
- Dr. Chip Bachmann, Organized a winter intersession workshop on Current Applications and New Trends in Spectroscopy

The following citations are for a representative subset of journal articles and conference papers published by the DIRS group in 2015-2016.

Selected Journal Articles

Carson, T.D., Salvaggio, C. 2015. Soil signature simulation in the thermal infrared, Optical Engineering, 54(10):104102.

Doctor, K.Z., Bachmann, C.M., Gray, D., Montes, MJ., and Fusina, R.A. 2015. Wavelength dependence of the bidirectional reflectance distribution function (BRDF) of beach sands, Applied Optics, 54(31):F243-F255.

Kelbe, D., van Aardt, J.A., Romanczyk, P.A., van Leeuwen, M., Cawse-Nicholson, K.A., 2015. Single-Scan Stem Reconstruction Using Low-Resolution Terrestrial Laser Scanner Data, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 8:3414-3427.

Montanaro, M., Gerace, A., and Rohrbach, S. 2015. Toward an operational stray light correction for the Landsat 8 Thermal Infrared Sensor. Applied Optics. 54:3963-3978.

Uzkent, Burak; Hoffman, Matthew J.; Vodacek, Anthony, (2016 Early Access Online) Integrating Hyperspectral Likelihoods in a Multi-dimensional Assignment Algorithm for Aerial Vehicle Tracking, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. doi:10.1109/JSTARS.2016.2560220

Concha, J.A. and J.R. Schott. Available online 13 April 2016. Retrieval of color producing agents in Case 2 waters using Landsat 8. Remote Sensing of Environment. doi:10.1016/j.rse.2016.03.018

Selected Conference Papers

Williams, M.D., van Aardt, J.A., Kerekes, J.P. 2016. Generation of Remotely Sensed Reference Data Using Low Altitude, High Spatial Resolution Hyperspectral Imagery. Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXII, Defense and Commercial Sensing, 9840, 98401R, pp. 1-10, Baltimore, Maryland, United States

Weaver, O., Kerekes, J.P. 2015. The Role of Large Constellations of Small Satellites in Emergency Response Situations. IEEE International Geoscience and Remote Sensing Symposium (IGARSS), pp. 4200-4203, Milano, Italy.

Peck, D.S., Schultz, M., Bachmann, C.M., Ambeau, B., and Harms, J. 2015. Influence of density on hyperspectral BRDF signatures, Proc. SPIE 9472, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXI, 94720F.

Yao, W., van Leeuwen, M., Romanczyk, P.A., Kelbe, D., Brown, S.D., Kerekes, J.P., van Aardt, J.A., 2015. Towards Robust Forest Leaf Area Index Assessment Using an Imaging Spectroscopy Simulation Approach. IEEE International Geoscience and Remote Sensing Symposium (IGARSS), pp. 5403-5406, Milano, Italy.

Bondi, E., Salvaggio, C., Montanaro, M., Gerace, A.D. 2016. Calibration of UAS imagery inside and outside of shadows for improved vegetation index computation, Proc. SPIE, Defense + Commercial Sensing, Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping, Unmanned Aerial Vehicles in Precision Agriculture, 9866, 17, pp. 98660J, Baltimore, Maryland, United States

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. A description of some of the current research projects are listed below.

Graduate Students 2015–16:

Dmitry Vorobiev (AST)

Kevan Donlan (CIS)

Katie Seery (AST)

Ross Robinson (CIS)

Bryan Fodness (CIS)

Kyle Ryan (CIS)

Jack Horowitz (CIS)

Anton Travinsky (CIS)

David Rhodes (CIS)

Tiffany Cable (Manufacturing and Mechanical Systems Integration)

Undergraduate Students 2015–16;

Robert Ichiyama (Chemistry)
Research Projects 2015-16:

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 were performed at the Texas A&M Cyclotron facility (TAMU)

Figure 1: Travinsky, Ninkov and Vorobiev in the control room at the TAMU Cyclotron.

(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. These devices have been successfully shake/shock/vibration tested at the NASA GSFC facility for verification of ability to survive a launch.

Figure 2: Travinsky, Vorobiev and Ninkov next to the shake table at NASA GSFC. The DMDs under test are mounted in a plate on the shake table and the interface cable is seen going to the control board.

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 with future, 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. We use an Optomec Aerosol Jet sprayer to deposit the quantum dots. 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.

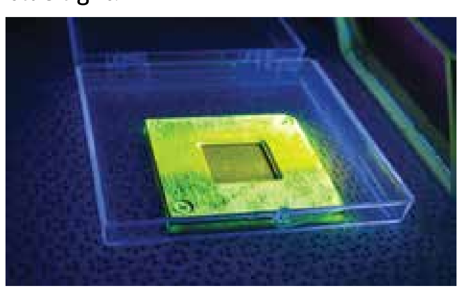


Figure 3: Quantum Dot coated detector in aluminum mask under UV illumination. The active area is 15mmx15mm

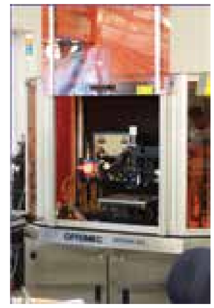


Figure 4: The Optomec Aerosol Jet sprayer used for these experiments at RIT.

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. In addition we have been modeling the source of IPC namely the fringing fields between pixels using the Lumerical Device software.

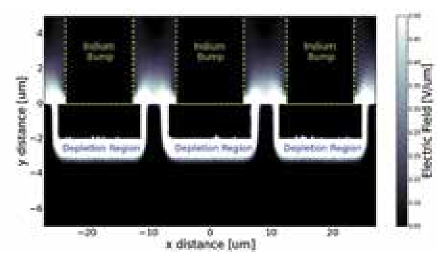


Figure 5: The strength and location of electric filed within pixels of a hybridized array.

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.

We had the opportunity to deploy one of these polarization cameras to the CTIO 1 meter telescope in Chile, South America. Below is an image of Jupiter obtained from that data revealing the polarization signature at the poles.

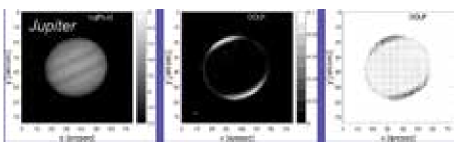


Figure 6: Images of Jupiter in integrated light (left), degree of linear polarization (center) and vector image of polarization (above).

(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.

Figure 7: A photo of experimental setup is shown above. The source is on the right, followed by the shutter, and the test dewar enclosure. 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.

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 is a test imaging array and fifteen 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.

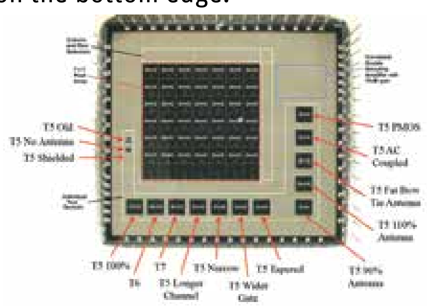


Figure 8: Generation II MOSIS THz devices. Fifteen test structures are seen along the edges.

Test Description

The transistors were biased using SRS power supplies which connect 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. The enclosure is mounted on XYZ and rotation stages for alignment purposes. A SRS 560 current preamplifier is commanded via a MATLAB serial interface for applying bias sweeps and relaying data. The radiation source is a 200–300 GHz tunable source from Virginia Diodes

Patent Pending

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. Extreme Contrast Ratio Imaging of Sirius with a Charge Injection Device

Batcheldor, D.; Foadi, R.; Bahr, C.; Jenne, J.; Ninkov, Z.; Bhaskaran, S.; Chapman, T. [2015] accepted for publication in P.A.S.P 128, 960

2. Extreme Multi-Slit Spectroscopy with GMOX

Robberto, Massimo; Heckman, Tim; Gennaro, Mario; Deustua, Susana; MacKenty, John W.; Ninkov, Zoran; Becker, George; Bianchi, Luciana; Bellini, Andrea; Calamida, Annalisa; Kalirai, Jason; Lotz, Jennifer; Sabbi, Elena; Tumlinson, Jason; Smee, Stephen; Barkhouser, Robert [2015] IAU General Assembly, Meeting #29, id. #2257947

3. Terahertz detection in Si MOSFE T based on thermionic emission

Dayalu, J.B. (Dept. of Electr. & Comput. Eng., Univ. of Rochester, Rochester, NY, United States); Ignjatovic, Z.; Bocko, M.F.; McMurtry, C.W.; Pipher, J.L.; Ninkov, Z.; Newman, J.D.; Sacco, A.P.; Ryan, F.J.; Fourspring, K.D.; Lee, P.P.K. Source: 2015 IEEE International Conference on Microwaves, Communications, Antennas and Electronic Systems (COMCAS), p 1-4, 2015

4. Transmission imaging measurements at 188 GHz with 0.35m CMOS technology

Sacco, Andrew P. (Exelis Geospatial Systems, Rochester; NY, United States); Newman, J. Daniel; Lee, Paul P. K.; Fourspring, Kenneth D.; Osborn, John H.; Fiete, Robert D.; Bocko, Mark V.; Ignjatovic, Zeljko; Pipher, Judith L.; McMurtry, Craig W.; Zhang, Xi-Cheng; Dayalu, Jagannath; Seery, Katherine; Zhang, Chao X.; Bhandari, Sahil; Ninkov, Zoran Source: Proceedings of SPIE—The International Society for Optical Engineering, v 9483, 2015

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

Zhang, Chao (Rochester Institute of Technology, Carlson Center for Imaging Science, Rochester; NY, United States); Ninkov, Zoran; Fertig, Greg; Kremens, Robert; Sacco, Andrew; Newman, Daniel; Fourspring, Kenneth; Lee, Paul; Ignjatovic, Zeljko; Pipher, Judy; McMurtry, Craig; Dayalu, Jagannath Source: Proceedings of SPIE—The International Society for Optical Engineering, v 9483, 2015

6. 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

7. The GMOX science case : resolving galaxies through cosmic time

Mario Gennaro, Massimo Robberto,b, Timothy Heckman, Stephen A. Smee, Robert Barkhouser, Zoran Ninkov, Angela Adamo, George Becker, Andrea Bellini, Luciana Bianchi, Arjan Bik, Rongmon Bordoloi, Annalisa Calamida, Daniela Calzetti,Gisella De Rosa, Susana Deustua, Jason Kalirai, Jennifer Lotz, John MacKenty, Carlo Felice Manara, Margaret Meixner, Camilla Paci, Elena Sabbi, Kailash Sahu, and Jason Tumlisona [2016] Source: Proceedings of SPIE—The International Society for Optical Engineering, v 9908, 160

8. The opto-mechanical design of GMOX: a next-generation instrument concept for Gemini

Stephen A. Smee, Robert Barkhouser, Massimo Robberto,b, Zoran Ninkov, Mario Gennaro, and Timothy M. Heckman [2016] Source: Proceedings of SPIE—The International Society for Optical Engineering, v 9908, 107

9. SAMOS: a versatile multi-object-spectrograph for the GLAO system SAM at SOAR

Massimo Robberto,b, Megan Donahue, Zoran Ninkov, Stephen A. Smee, Robert H. Barkhouser, Mario Gennaro, and Andrei Tokovinin [2016] Source: Proceedings of SPIE—The International Society for Optical Engineering, v 9908, 330

10. The effects of heavy ion radiation on digital micromirror device performance
Anton Travinsky, Dmitry Vorobiev , Zoran Ninkov , Alan D. Raisanen, Jonathan A. Pellish,

Massimo Robberto, Sara Heap [2016] Source: Proceedings of SPIE—The International Society for Optical Engineering, v 9912, 270

11. Signal Dependence of Inter-pixel Capacitance in Hybridized HgCdTe H2RG Arrays for use in James Webb Space Telescope's NIRcam

Kevan Donlon, Zoran Ninkov,Stefi_ Baum [2016] Source: Proceedings of SPIE—The International Society for Optical Engineering, v 9915, 93

12. Radiation Testing of CID Arrays

Bryan Fodness, Zoran Ninkov, Suraj Bhaskaran, Carey Beam [2016]] Source: Proceedings of SPIE—The International Society for Optical Engineering, v 9915, 97

13. Optical evaluation of digital micromirror devices (DMDs) with UV-grade fused silica, sapphire, and magnesium windows and long term reflectance of bare devices

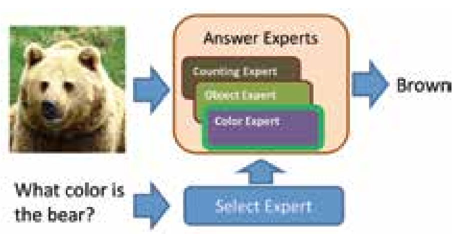
Manuel A. Quijada, Anton Travinsky, Dmitry Vorobiev, Zoran Ninkov, Alan Raisanen, Massimo Robberto, and Sara Heap [2016] Source: Proceedings of SPIE— The International Society for Optical Engineering, v 9912, 269

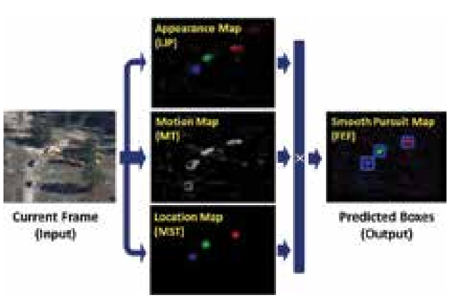
MULTIDISCIPLINARY VISION RESEARCH LABORATORY

Laboratory Director's Comments By Dr. Jeff Pelz

The overarching goals of the Multidisciplinary Vision Research Laboratory (MVRL), to further the understanding of high-level visual perception, is supported by work across a number of disciplines, focus areas, and research topics within the Center.

Dr. Christopher Kanan joined the MVRL this year, establishing the Machine and Neuromorphic Perception Laboratory. The "kLab" focuses on advancing the state-of-the-art in computer vision, and also does work on human cognition, especially studying human eye movements. Much of the lab's research has focused on Visual Question Answering (VQA), which is a new problem in computer vision. In VQA, an algorithm is given a text-based question and an image, and it must produce a text-based answer to the query. This is a very challenging problem that combines many aspects of computer vision: object segmentation, object detection, object recognition, activity detection, object counting, and more. Moreover, many questions also require reasoning and common sense, making this problem an important next step in creating flexible multi-task computer vision algorithms. With second year CIS Ph.D. student Kushal Kafle, Dr. Kanan published a paper on VQA in IEEE Computer Vision and Pattern Recognition (CVPR-2016), which is widely regarded as the best computer vision publication venue. At the time of submission, their paper significantly advanced the state-of-the-art.



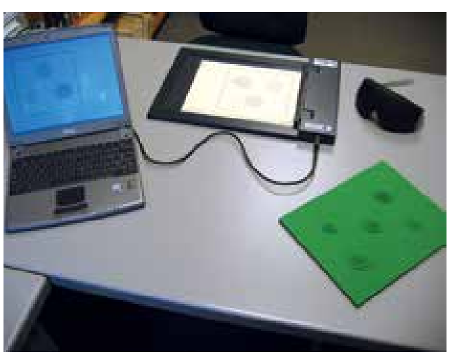


They built a system that combined deep learning with a Bayesian model that was able to predict the type of answer to be generated. An online demo of a simplified version of their system can be found at: http://askimage.org. The lab is currently working on more sophisticated algorithms that can reason about images, and they recently submitted a paper on generating questions for images. Beyond VQA, Dr. Kanan published a paper with CIS Ph.D. student Mohammed Yousefhussien at IEEE Winter Applications of Computer Vision Conference (WACV-2016) on tracking small objects using deep learning and gnostic fields, an algorithm created by Dr. Kanan during his Ph.D. The method significantly surpassed all widely used state-of-the-art trackers. Their method was inspired by the primate smooth-pursuit system.

The lab has also been getting involved in remote sensing data analysis. With first year Ph.D. student Ronald Kemker, Dr. Kanan created a new algorithm for classifying hyperspectral pixels by using self-taught learning with Independent Component Analysis (ICA). ICA has been widely used in computational neuroscience to model the neural responses of the primary visual cortex, and they found that the spatial-spectral filters it learned from hyperspectral imagery worked very well for the classification task. They are currently revising a journal paper on the new system.

Another important aspect of high-level visual perception under study within the MVRL is how vision is used to guide action in everyday life. Dr. Gabriel Diaz leads the PerForM (Perception For Movement) Laboratory, dedicated to bettering our understanding of the mechanisms that allow humans to perform everyday actions that are guided by vision like driving a car, walking over uneven terrain, or catching a ball. Although these are natural actions, the natural environment does not afford the experimental control required for the rigorous testing of hypotheses about how vision is used to guide action. In contrast, traditional laboratory-based study has a tendency to validate hypothesis that are unique to the laboratory environment, and unrepresentative of more complex, real-world behaviors. To resolve this conflict, Dr. Diaz and his students in the PerForM lab leverage advances in virtual reality and motion capture technologies that afford both freedom of movement, and a naturalistic visual experience to conduct controlled, naturalistic studies on the human visual and motor systems. Two graduate students from the PerForM lab recently brought their expertise from the PerForM Lab and the Carlson Center for Imaging Science to Magic Leap, in Florida working on 'mixed,' or 'augmented-reality' systems. Kamran Binaee and Rakshit Kothari spent the summer at the headquarters of the startup that WIRED magazine described as the world's hottest and most secretive startup.

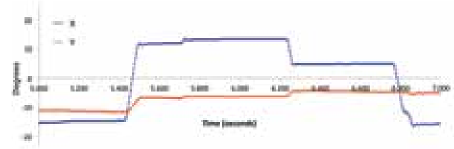
Dr. James Ferwerda recently published research he performed with ViewPlus Technologies, focused on providing graphical information to all those who seek it, without regard to visual ability. Dr. Ferwerda worked with ViewPlus, a provider of Braille printers, to evaluate accessible graphics systems that make complex, multidimensional graphical information available to the visually impaired.

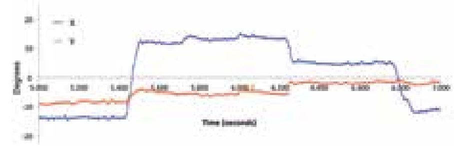


Other projects in Dr. Ferwerda's lab included work with sistine solar, the startup out of MIT that is designing color and texture-matched solar panels for residential and commercial buildings, and the Dole Food Company.

Dr. Ferwerda also released the "FechDeck" (http://fechdeck.com). The FechDeck is a deck of playing cards modified to support exploration of psychophysical methods; experimental methods used to quantify the relationship between physical stimuli and perception. The backs of one suit of cards in the FechDeck are printed with visual noise textures of varying density; face cards have line segments arranged in "L" patterns; and the jokers are printed with ruled faces and with backs that serve as noise standards. The FechDeck allows users to conduct a range of experiments using psychophysical methods including threshold, ranking, paired comparison, categorical rating, and magnitude estimation methods. The cards are useful for classroom projects, demonstrations, and self-study on a broad range of techniques important in evaluating vision and imaging systems.

Dr. Jeff Pelz was on sabbatical leave, visiting at the IT-Universitetet København (IT University of Copenhagen) in Denmark during the last academic year. His work focused on the development of an advanced eyetracking method that works outdoors and has increased accuracy and precision compared with currently available systems. The new algorithm can extract data from the same input video that with dramatically improved data quality, as illustrated in the accompanying figures; the first figure shows horizontal and vertical eye position from a two-second video extracted using the traditional "pupil – corneal reflection" method that is used in most commercial systems. The second figure shows the same two-second video processed with the new method, clearly revealing the fixations (the periods where the eye is stationary) and saccades (the rapid eye movements separating the fixations) with sufficient clarity to allow determination of saccadic velocity even for the smallest eye movements.





Preethi Vaidyanathan, a graduate student working with Dr. Pelz and Drs. Cecelia Ovesdotter Alm and Emily Prud'hommeaux of RIT's College of Liberal Arts, is interning at LC Technologies in Virginia, an award-winning provider of eye-tracking instrumentation and software to the international research and assistive-technology communities.

The work of all the members of the Multidisciplinary Vision Research Laboratory was again well represented in peer-reviewed publications:

MVRL Publications: 2015-2016

Alm, C. O. (2016). Language as Sensor in Human-Centered Computing: Clinical Contexts as Use Cases. Language and Linguistics Compass, 10(3), 105-119.

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Bethamcherla, V., Paul, W., Alm, C. O., Bailey, R., Geigel, J., & Wang, L. (2015, September).

Face-speech sensor fusion for non-invasive stress detection. In Proceedings of the 1st Joint Conference on Facial Analysis, Animation, and Auditory-Visual Speech Processing (pp. 196-201).

Binaee, K., Diaz, G., Pelz, J., & Phillips, F. (2016, July). Binocular eye tracking calibration during a virtual ball catching task using head mounted display. In Proceedings of the ACM Symposium on Applied Perception (pp. 15-18). ACM.

Diaz, G., Smith, A., Binaee, K., & Gopinathan, R. (2015). Evaluation of a Phantogram groundplane for the Study of Visually Guided Walking Behavior. Journal of Vision , 15 (12), 1327-1327.

Farnand, S., Vaidyanathan, P., & Pelz, J. B. (2016). Recurrence Metrics for

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Ferwerda, J. A., Bulatov, V., & Gardner, J. (2016). Evaluating the Effectiveness of Auditory and Tactile Surface Graphs for the Visually Impaired. Electronic Imaging, 2016(16), 1-6.

Guo, X., Yu, Q., Li, R., Alm, C. O., Calvelli, C., Shi, P., & Haake, A. (2016, April). An Expert-in-the-loop Paradigm for Learning Medical Image Grouping. In Pacific-Asia Conference on Knowledge Discovery and Data Mining (pp. 477-488). Springer International Publishing.

Humphries, T., Kushalnagar, P., Mathur, G., Napoli, DJ, Padden, C., Pollard, RQ, Rathmann, C., & Smith, SR (2016). Advice for Parents of Deaf Children. Clinical Pediatrics, 1-5.

Kafle, K., Kanan, C. (2016) Answer-Type Prediction for Visual Question Answering. In: Proc. IEEE Conference on Computer Vision and Pattern Recognition (CVPR-2016).

Kanan, C., Bseiso, D. N., Ray, N. A., Hsiao, J. H., & Cottrell, G. W. (2015). Humans have idiosyncratic and task-specific scanpaths for judging faces. Vision research, 108, 67-76.

Kothari, R., Binaee, K., Matthis, J. S., Bailey, R., & Diaz, G. J. (2016, March). Novel apparatus for investigation of eye movements when walking in the presence of 3D projected obstacles. In Proceedings of the Ninth Biennial ACM Symposium on Eye Tracking Research & Applications (pp. 261-266). ACM.

Kushalnagar, P., Bruce, S.*, Sutton, T., & Leigh, I. (2017). Retrospective Parent-Child Communication Difficulties and Risk for Depression in Deaf Adults. Journal of Physical and Developmental Disabilities.

Kushalnagar, P., Smith, S., Hopper, M., Ryan, C.*, Rinkevich, M.*, & Kushalnagar, R. (2016). Making Cancer Health Text on the Internet Easier to Read for Deaf People who use American Sign Language. Journal of Cancer Education.

Kushalnagar, P., Naturale, J., Paludneviciene, R., Smith, SR, Werfel, E.*, Doolittle, R., Jacobs, S., DeCaro, J. (2015). Health Websites: Accessibility and Usability for American Sign Language Users. Journal of Health Communication, 30, 8,830-837.

Morice, A. H., Diaz, G. J., Fajen, B. R., Basilio, N., & Montagne, G. (2015). An affordance-based approach to visually guided overtaking. Ecological Psychology, 27(1), 1-25.

Pieszala, J., Diaz, G., Pelz, J., Speir, J., & Bailey, R. (2016, March). 3D gaze point localization and visualization using LiDAR-based 3D reconstructions. In Proceedings of the Ninth Biennial ACM Symposium on Eye Tracking Research & Applications (pp. 201-204). ACM.

Simon, D., Sridharan, S., Sah, S., Ptucha, R., Kanan, C., & Bailey, R. (2016, July). Automatic scanpath generation with deep recurrent neural networks. InProceedings of the ACM Symposium on Applied Perception (pp. 130-130). ACM.

Sridharan, S., & Bailey, R. (2016, July). Saliency and optical flow for gaze guidance in videos. In Proceedings of the ACM Symposium on Applied Perception (pp. 140-140). ACM.

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Sridharan, S., Pieszala, J., & Bailey, R. (2015, September). Depth-based subtle gaze guidance in virtual reality environments. In Proceedings of the ACM SIGGRAPH Symposium on Applied Perception (pp. 132-132). ACM.

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Yousefhussien, M., Browning, N.A., Kanan, C. (2016) Online Tracking using Saliency. In: Proc. IEEE Winter Applications of Computer Vision Conference (WACV-2016).

Zhang, M.M., Choi, J., Daniilidis, K., Wolf, M.T., Kanan, C. (2015) VAIS: A Dataset for Recognizing Maritime Imagery in the Visible and Infrared Spectrums. In: Proc of the 11th IEEE Workshop on Perception Beyond the Visible Spectrum (PBVS-2015).

Laboratory Director's Comment by Dr. Navalgund Rao

Marching Towards a Low Cost Photoacoustic Imaging Device for Cancer Diagnosis

Our vision is to apply physics and engineering concepts in to building a low cost, portable handheld photoacoustic imaging device that can be used by physicians to screen patients for prostate, thyroid, breast and skin cancer diagnosis. Photoacoustic (PA) imaging is a promising new modality that is making a transition from bench to bedside. We have been active in incorporating innovative ideas into the design, fabrication and ex-vivo testing of a home grown PA camera. This year has seen some exciting developments, funded by NIH and Summers foundation grants. This work was done in collaboration with Dr. V. Dogra, MD, professor of Radiology and Dr. W. Knox, professor, institute of Optics at University of Rochester and Dr. H. Schmitthnner and Dr. I. Evans of RIT. Other team players have been B. Chinni, Z. Han, K. Jnawali, A. Patra and A. Rajanna, all either alumni or current graduate students at RIT.

Quality Metric Evaluation of an Acoustic Lens Based PA Camera System

Zichao Han, Ph.D. student, CIS, RIT

We developed our own patented idea of using an acoustic lens in conjunction with a linear array of ultrasound sensors to acquire b-scan, C-scan and 3D photoacoustic images in real time. In the past, the lens was designed using optical lens design software. This year we developed from scratch, a simulation model of our camera system using an open source MATLAB toolbox that can generate and propagate PA waves in 2D and 3D, through our in-house designed acoustic lens. Fig.1 is a 2D version of our camera system in 2f geometry, where f is the focal length of the lens.

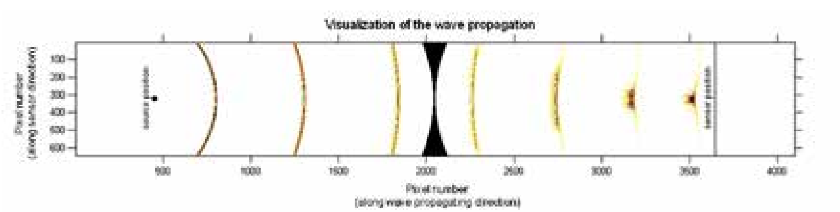


Fig.1 Simulation setup to evaluate quality metric of PA camera

The lens is located in the center. PA waves generated at a point source can be seen on the left and the resulting wave-front propagating to the right towards the lens. After crossing the lens, the wave front can be seen converging at 2f distance, where a linear ultrasound sensor array captures the A-line time signals. We have generated several quality metrics [Point spread function (PSF), MTF, depth of field, etc.]. Fig. 2 shows PSF at 10 different depths around the best focal plane which is at 2f. With this camera, 1 mm resolution in the C-scan plane and 0.3 mm resolution between different depth planes is possible with a depth of field of 1.5 cm.

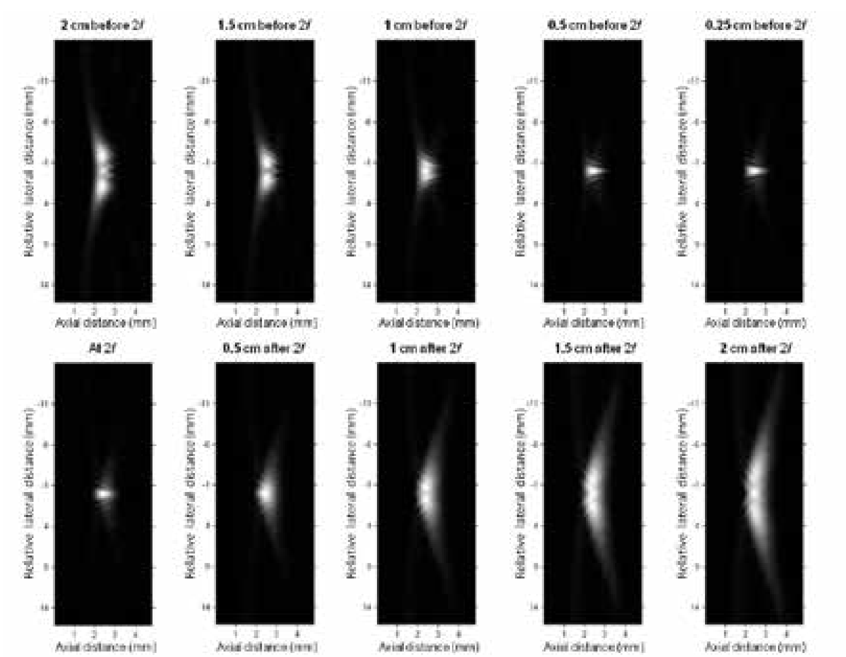


Fig.2 camera PSF at different depth planes

Incorporate Ultrasound Imaging into the PA Imaging camera

Zichao Han, Ph.D. student, CIS, RIT

According to our own ex-vivo work with the PA imaging camera, we have found that it is very efficient in visualizing cancer regions and differentiating benign from malignant cancer. But PA images alone do not provide internal body organ boundaries and land marks that are often needed by physicians for biopsy guidance. Ultrasound image guided biopsy is usually the preferred choice. By making our camera a dual modality device, we increase its value proposition because both differential diagnosis and biopsy guidance can be achieved with one camera and two co-registered (PA and ultrasound) images. An innovative idea of using a plane wave ultrasound generator and focusing the backscattered signal with the same lens and same sensor array is being implemented. Frequency modulated input signals followed by cross-correlation technique to enhance signal-to-noise ratio (SNR) has been implemented. Fig. 3 shows the simulation results on speckle generating phantom that has strong reflecting targets that mimic biopsy needle. Left panel is phantom and the middle is the lens focused B-scan image. Note that this image is distorted due to travel time effects for off-axis points. This is easily corrected for as shown in the right most panel image.

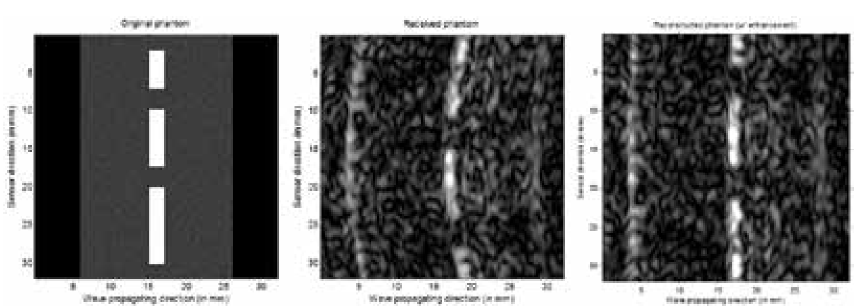


Fig.3 Ultrasound imaging with the PA camera - simulation results.

Prototype PA Imaging Camera Design and Fabrication

B. Chinni, Research Associate, University of Rochester

In order to make the PA camera suitable for in-vivo imaging, the laser delivery had to be optimized. A team of biomedical Optics seniors at University of Rochester worked on the problem and came up with best possible solution that was implemented in a 3D CAD design and then 3D printed, including the lens. Fig. 4 shows the final fabricated camera body that is less than a foot in height. The laser beam is delivered from the side and is reflected by 45 degree angle and beam shaped before exposing the tissue. The PA signals propagate through water filled cylinder to the lens and are detected by a 32 element linear array transducer. A home built 32 channel data acquisition system digitized the signals and sends it to a computer for display.

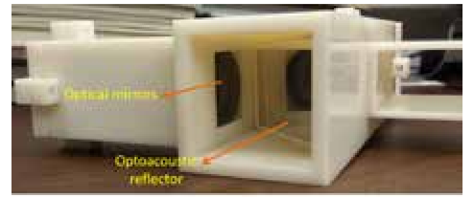


Fig.4 fabricated PA camera with lens

Development of Low Cost Laser Technology

K. Jnawali, Ph.D. student, RIT

Nanosecond (ns) pulsed lasers used in current PA imaging systems are expensive, bulky and they often waste energy. We have evaluated through simulations, the use of continuous wave laser whose amplitude is linear frequency modulated (chirp) for PA imaging. The k-wave Matlab tool box was used to simulate photoacoustic signals in three dimensions for absorbers ranging in size from 0.1 mm to 0.6 mm, in response to laser excitation amplitude that is linearly swept from 0.5 MHz to 4 MHz.The chirp signal provides significant SNR improvement potential and full control over PA signal frequencies excited in the tissue. From Fig. 5 we see that the response from different size absorber varies with the size of the absorber and correspondingly the PA signal spectrum also varies as shown in Fig. 6. A mismatch between input chirp spectrum and the output PA signal spectrum can affect the compressed pulse that is recovered from cross-correlating the two, as shown in Fig. 7 for all the 6 different absorber sizes used in the simulation. We have quantitatively characterized this effect. For the chirp methodology, the compressed pulse peak amplitude, pulse width and side lobe structure parameters were extracted for different size absorbers. While the SNR increased 6 fold with absorber size, the pulse width decreased by 25%.

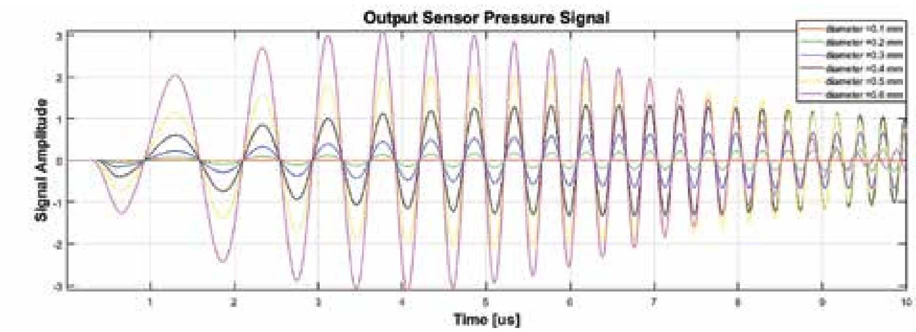


Fig.5 chirp PA response for different size absorbers

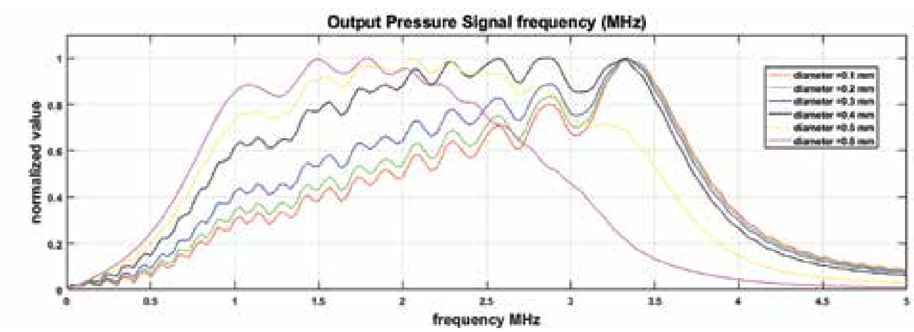


Fig.6 chirp spectrum for different size

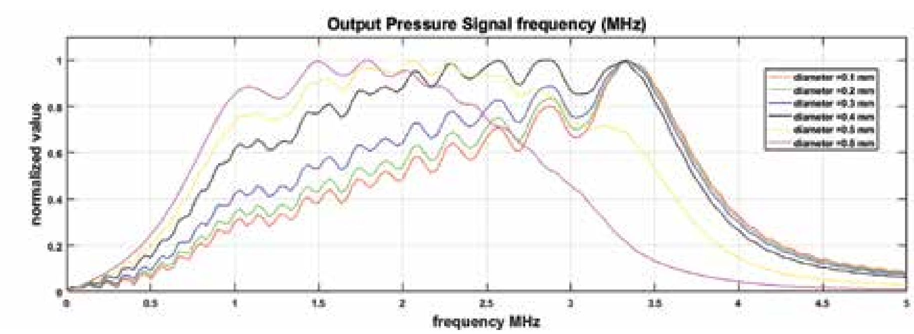


Fig.7 compressed pulse for different size absorbers

RESEAR

MAGNETIC RESONANCE LABORATORY

Laboratory Director's Comments by Dr. Joseph Hornak

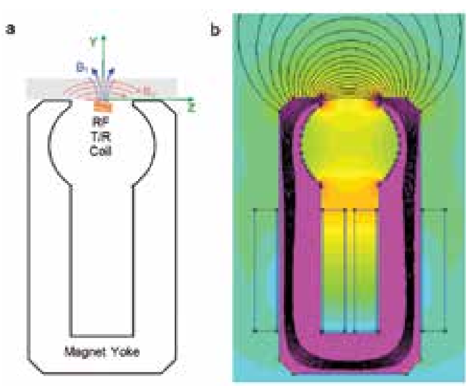
Overview

The RIT Magnetic Resonance Laboratory (MRL) is a research and development laboratory devoted to solving real world problems with magnetic resonance.

This past year we continued our work on the development of low frequency electron paramagnetic resonance (LFEPR) spectroscopy for studying ceramic, painted, and marble objects with cultural heritage significance. Our focus has been the design and construction of an electron paramagnetic resonance (EPR) mobile universal surface explorer (MOUSE), which is highlighted in this report.

EPR MOUSE

Many laboratories have demonstrated the utility of conventional high frequency EPR (HFEPR) spectroscopy for studying ceramic, painted, and marble objects with cultural heritage significance. Although HFEPR has wonderful spectral resolution and sensitivity, it is invasive and destructive, requiring approximately one cubic mm of sample. The MRL has been developing LFEPR as a solution to this problem. LFEPR is less sensitive and has poorer resolution than HFEPR, but it is non-destructive and non-invasive. Our current system can examine objects as large as 15 cm in diameter and meters long. Investigating larger objects becomes impractical with our current configuration as it becomes costly to increase the size of the electromagnet. An alternative approach to studying larger objects is to scale down the size of the electromagnet and utilize a unilateral system design where the magnet and radio frequency (RF) coil are on one side of the object being examined. This is the idea behind the EPR MOUSE.



This approach has not been applied to LFEPR of cultural heritage objects where wide-line, broad magnetic field scan EPR is required. The MOUSE requires a sweepable magnetic field (Bo) produced by a unilateral electromagnet and a micro RF transmit and receive (T/R) coil or antenna producing an RF magnetic field (B1) also adjacent to the surface of the object studied. We have chosen a design which produces Bo parallel and B1 perpendicular to the surface of the studied object. Figure 1 presents a schematic presentation of the MOUSE configuration.

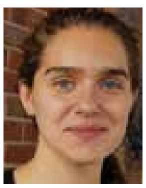
We are currently optimizing the design of the magnet and RF coil depicted in Figure 1 and designing the spectrometer's RF bridge to send the RF energy into the sample and detect the EPR signal from the paramagnetic metals in the sample.

Staff News

Dr. Joseph Hornak, Professor of Chemistry, Materials Science and Engineering, & Imaging Science finished his third 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 continued her work on low frequency EPR and developing an EPR MOUSE after graduated from RIT Magna Cum Laude with a BS in Chemistry. She left in January 2016 to accept a position at Machaon Diagnostics in Oakland, CA.

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. W.J. Ryan, L.E. Switala, J.P. Hornak, Low-Frequency EPR Imaging of Planar Objects with a Surface Coil. Rocky Mountain Conference on Magnetic Resonance, Snowbird, UT, July 2015.
2. W.J. Ryan, L.E. Switala, M. Hoffman, W. Brown, N. Zumbulyadis, J.P. Hornak, A Modular Low Frequency EPR Spectrometer for Studying Objects with Cultural Heritage Significance. Rocky Mountain Conference on Magnetic Resonance, Snowbird, UT, July 2015.
3. L.E. Switala, M. Hoffman, W. Brown, W.J. Ryan, E.I. Hornak, N. Zumbulyadis, J.P. Hornak, Low Frequency EPR of Ceramic and Marble Objects with Cultural Heritage Significance. Rocky Mountain Conference on Magnetic Resonance, Snowbird, UT, July 2015.
4. L.E. Switala, W. J. Ryan, M. Hoffman, W. E. Brown, N. Zumbulyadis, J. P. Hornak, A Modular Low Frequency EPR Spectrometer for Studying Objects with Cultural Heritage Significance. Eastern Analytical Symposium, Somerset, NJ, November 2015.
5. N. Zumbulyadis, F. Perras, T. Kobayashi, A. Murphy, Y. Yao, J. Catalano, M. Pruski, S. Centeno, C.R. Dybowski, L. Switala, J.P. Hornak, Exploring the Potential of Advanced Magnetic Resonance Techniques for the Characterization of Cultural Heritage Materials. American Chemical Society National Meeting. San Diego, CA, March 2016.

Publications

1. L.E. Switala, W.J. Ryan, M. Hoffman, W. Brown, J.P. Hornak, Low Frequency EPR and EMR Point Spectroscopy and Imaging of a Surface. Mag. Reson. Imag. 34:469-472 (2016).

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

Dr. Qiao, Associate Professor, leads the the laboratory for Advanced Optical Fabrication, Instrumentation and Metrology (AOFIM) at the Chester F. Carlson Center for Imaging Science.

Her research group conduct 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 characterizing 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 field of wavefront sensing and the use of femtosecond lasers for photonics / optics fabrication require significant investment in equipment. Through building collaborations with a number of industrial partners, Dr. Qiao has built up a state-of-the-art femtosecond laser facility and metrology lab hosting over $650k worth of equipment infrastructure. Working with her graduate, undergraduate students, and research associates, Dr. Qiao's group is conducting the development of a novel wavefront sensing technique and numerical and experimental investigations of the mechanism and performance of ultrafast lasers based photonics / optics fabrication and packaging.

One PhD student, two undergraduate students, one visiting scholar, and one post-graduate researcher have been conducting their research projects at the AOFIM lab during the past academic year.

Between July 2015 and July 2016, Dr. Qiao's grouppublished three refereed journal articles, two in Optics Express and one in Optics Materials Express, covering all three aforementioned research thrusts. Dr. Qiao's group also published / presented six conference proceedings papers and three additional conference abstracts/summaries over the past year. Dr. Qiao has won external funding from DoD-ONR through OptiPro Systems LLC, NYSTAR CEIS, and the OSA Foundation.

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, micro-optics, and optoelectronic packaging.

AOFIM Lab conducts fundamental and applied research on the theoretical modeling and experimental demonstration of ultrafast laser-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.

Dr. Qiao's group has built a state-of-the-art ultrafast laser processing system through collaborating with six industrial partners, consisting of a femtosecond laser (from Amplitude Systèmes) and a beam control module and a high speed, three-axis optical scanner to extend processing capability. This laser processing system, housed in the AOFIM Lab, is pictured, below:

Fig. 1. Femtosecond laser processing system at RIT/AOFIM lab: (A) Femtosecond laser (Amplitude), (B) beam modification device (LASEA), (C) 3-axis optical beam scanner, (D) 3-axis sample positioning stage.

Qiao's group has performed sensitivity testing of heat accumulation to laser processing parameter variations, and verified the optimized processing conditions predicted in the modeling work.

The ultrafast laser processing team is also working on ultrafast-laser-based welding of glass and silicon for photonics packaging. Ultrafast lasers can be used to spot-weld materials at specific locations or to perform welding over a specified region by scanning prepared substrates under the focused laser beam. By controlling nonlinear absorption at the material interface, the welding process is able to be tuned for different bonding scenarios and, by optimizing the process, bonds as strong as the glasses themselves can be obtained.

Building on the UFLW hardware and software capability in the AOFIM lab, Dr. Qiao, as the principal, has led the preparation and submission of an academy, industry, and government collaborative proposal to the AIM Photonics, titled "Ultrafast-laser-based welding for advanced photonics packaging." Through the AOFIIM Lab partnering with eight industrial enterprises and one national lab, this project will provide unprecedented opportunity for collaboration of top-level experts and implementation of multi-disciplinary resources and capabilities working towards single, industrial goal of high importance and high manufacturing impact. AIM Photonics allows establishing the unique ecosystem for this project as no single player in this project can achieve this goal alone.

Within the period of July 2015–July 2016, modeling work was conducted to gain a first approximation of heating within femtosecond laser processing of silicon to describe oxidation and melting phenomena seen in experimental surface processing experiments. The numerical model was used to predict optimized processing conditions which can potentially mitigate thermal effects in processing. A manuscript titled, "Optimization of Femtosecond Laser Processing of Silicon via Numerical Modeling", has been published in Optical Materials Express (Sept., 2016). The progress of this work was presented at five conferences within the past year: Ultrafast Optics X (Aug. 2015), SPIE OptiFab 2015 (Oct. 2015), SPIE Photonics West 2016 (Feb. 2016), the 2nd Conference on Laser Polishing (LaP 2016, April 2016), and CLEO 2016 (June 2016).

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 ODWS showed excellent self-consistency using two sets of orthogonal filters. A comparison experiment with a Shack-Hartmann sensor was performed. Figure 2 shows the expected wavefront and the reconstructed wavefronts obtained from the ODWS and SHWS. These preliminary results indicate that ODWS can be a reliable instrument for use in broadband light adaptive optics systems.

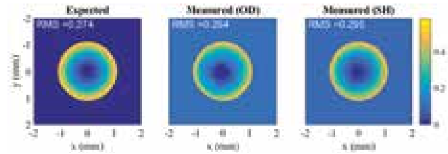


Fig.2. Wavefront of lens with 2-m focal length (a) calculated, (b) measured with ODWS [pixel size = 10 μm], and (c) measured with SHWS. All the wavefronts are measured with a broadband tungsten light and expressed in waves (λ ~ 550nm)

The ODWS research was recently published in Optics Express (April, 2016), titled "Optical differentiation wavefront sensing with binary pixelated transmission filters." The progress of this work has also been presented at SPIE Photonics West 2016 (Feb. 2016), and OSA CLEO 2016 (June 2016), SPIE Astronomical Telescope and Instrumentation (July, 2016), and OSA Imaging and Applied Optics 2016 (July, 2016, as a post deadline paper).

3. Adaptive Optics and 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 published a refereed journal paper in Optics Express, "Spatio-temporal modeling and optimization of a deformable-grating compressor for short high-energy laser pulses," (Aug., 2015).

Dr. Qiao Research Group and AOFIM Lab Facility

Third-year CIS PhD student Lauren Taylor presented "Femtosecond laser polishing of optical materials" to over 120 attendees at the 2015 SPIE OptiFab conference in Rochester, NY, Oct. 2015. She has won a SPIE travel grant and presented "Advanced optic fabrication using ultrafast laser radiation" at the 2016 Photonics West conference in San Francisco, CA, Feb. 2016.

Dr. Jun Qiao, Professor of College of Materials Science and Metallurgy at the University of Science and Technology Liaoning, China, was a visiting scholar at the AOFIM lab from May 2015 to May 2016. He brought in materials science expertise and contributed to the experiments, the understanding of the laser material interactions and a number of publications of the ultrafast lasers for photonics fabrication research.

RIT undergraduate Ryan Scott (Physics Department) building the non-linear absorption model to investigate the interaction process between femtosecond laser and photonics materials.

Test bed of the optical differentiation wavefront sensing system, using deformable mirror to create desired freeform surfaces and a shack-hartmann wavefront sensor for performance comparison tests.

Zachary Mulhollan, a recent graduate of the RIT Chester F. Carlson Center for Imaging Science has contributed to the ODWS research project via summer work and his senior project “Optical Differentiation Wavefront Sensing” at the AOFIM lab. He most recently presented his work at the Senior Project Symposium at the RIT Center for Imaging Science.

Publications (July 2015–July 2016, * denotes student co-author)

Refereed Journal Publications

1. L. L. Taylor*, J. Qiao, and J. Qiao, “Optimization of femtosecond laser processing of silicon via numerical modeling,” Optical Materials Express 6 (9), 2745-2758 (Sept, 2016).

http://dx.doi.org/10.1364/OME.6.002745

2. J. Qiao, Z. Mulhollan*, and C. Dorrer, “Optical differentiation wavefront sensing with binary pixelated transmission filters,” Optics Express, 24 (9), pp. 9266-9279 (April, 2016)

http://dx.doi.org/10.1364/OE.24.009266

3. J. Qiao, J. Papa*, and X. Liu*, “ Spatio-temporal modeling and optimization of a deformable-grating compressor for short high-energy laser pulses,” Opt. Express 23 (20), 25923-25934 (Aug., 2015)

http://dx.doi.org/10.1364/OE.23.025923

Conference Proceedings (2014–2015)

1. J. Qiao, Z. Mulhollan*, and C. Dorrer, "Optical Differentiation Wavefront Sensing for Astronomy and Vision Applications," in Imaging and Applied Optics 2016, OSA Technical Digest (online) (Optical Society of America, 2016), paper AOTh2C.4 (July, 2016).

http://dx.doi.org/10.1364/AOMS.2016.AOTh2C.4

2. J. Qiao, Z. J. Mulhollan*, A. Schweinsberg, and C. Dorrer, “Development of an optical differential wavefront sensor based on binary pixelated transmission filters,” Proc. SPIE 9909, Adaptive Optics Systems V, 99096R (July, 2016)

http://dx.doi.org/10.1117/12.2232813

3. J. Qiao, L. Taylor*, and J. Qiao, "Thermal Modeling and Heat Mitigation for Femtosecond-Laser-Based Silicon Processing," in Conference on Lasers and Electro-Optics, OSA Technical Digest (online) (Optical Society of America, June, 2016), paper ATu3K.4.

http://dx.doi.org/10.1364/CLEO_AT.2016.ATu3K.4

4. J. Qiao, Z. Mulhollan*, A. Schweinsberg, and C. Dorrer, "Performance of an Optical Differentiation Wavefront Sensor based on Binary Pixelated Transmission Filters," in Conference on Lasers and Electro-Optics, OSA Technical Digest (Feb., 2016) (Optical Society of America, June 2016), paper SM2M.5.

http://dx.doi.org/10.1364/CLEO_SI.2016.SM2M.5

5. L. Taylor*, J. Qiao, J. Qiao, “Advanced optic fabrication using ultrafast laser radiation,” in SPIE Photonics West 2016, Proc. SPIE. 9740, 97400L (February, 2016)

http://dx.doi.org/10.1117/12.2211850

6. L. Taylor*, J. Qiao, J. Qiao, “Femtosecond laser polishing of optical materials,” in OptiFab 2015, Proc. SPIE. 9633, , 96330M (October, 2015).

http://dx.doi.org/10.1117/12.2195840

Conference Abstracts / Summaries (* denotes student co-author)

7. J. Qiao, L. Taylor*, and J.Qiao,

"Optics polishing using ultrafast laser radiation," the 2nd Conference on Laser Polishing - LaP 2016, Aachen, Germany, 26-27 April 2016

8. J. Qiao, Z. Mulhollan*, A. Schweinsberg, M. Chalifour*, C. Dorrer, "Demonstrations of an optical differentiation wavefront sensor," Proc. SPIE. 9741-22, SPIE Photonics West, San Francisco, CA, 14–18 February 2016.

http://dx.doi.org/10.1117/12.2079846

9. L. Taylor* and J. Qiao, "Ultrafast laser polishing of silicon-based materials," the 10th International Conference on Ultrafast Optics (UFO X), Beijing, China, 16-21 August 2015

http://www.ultrafastoptics2015.org/UserFiles/File/Conference%20Book-final%281%29.pdf

GRANTS

(1) PI, NYSTAR CEIS, Ultrafast Lasers for Advanced Optic/Photonics Fabrication, July 01, 2016–June 30, 2016, $7,500, June 01, 2016–June 1, 2017, awarded

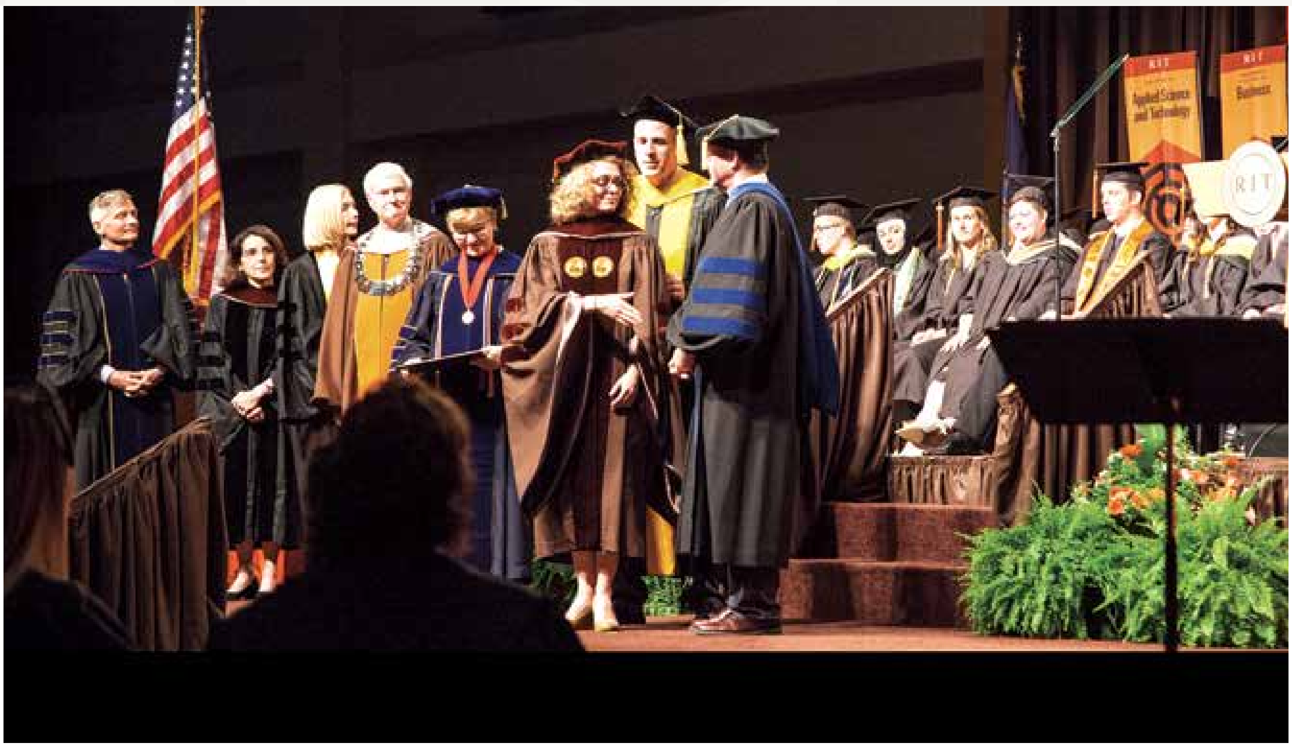
(2) PI, DoD-ONR through OptiPro Systems LLC, Ultrafast Lasers for Advanced Optic / Photonics Fabrication, $30,000, June 01, 2016–June 1, 2017, awarded

(3) PI, Optical Society of America Foundation: WiSTEE (Women in Science, Technology, Engineering and Entrepreneurship) Connect, $15,000, 2016, awarded

(4) PI, AIM Photonics, Ultrafast Lasers for Advanced Optic/Photonics Fabrication, January 01, 2017–Dec. 30, 2017, $525,207, pending

STUDENT AWARD

Lauren Taylor has received a travel grant award ($250) from SPIE for presenting a paper at the 2016 SPIE Photonics West conference in San Francisco, CA.



Alexandra Artusio-Glimpse receives her PhD hood at the 2016 Academic Convocation ceremony

Laboratory Director's comments by Dr. Grover Swartzlander

Physical optics and imaging activities included experimental, numerical, and theoretical research on diverse topics such as radiation pressure, advanced imaging, and protection of sensors from laser damage.

Dr. Lingyu Wan from Guangxi University worked with the optics group as a visiting scholar.

The research was supported by the National Science Foundation (NSF), Office of Naval Research (ONR), and NASA/Jet Propulsion Laboratory. Strong student participation was involved. Two of these students prepared to complete their PhD thesis work: Alexandra Artusio-Glimpse and Garreth Ruane. Both students successfully competed for highly competitive national postdoctoral fellowship programs. Ms. Artusio-Glimpse was awarded a National Research Council fellowship that will secure for her three years of funding at the National Institute of Science and Technology (NIST) in Boulder, Colorado. Mr. Ruane was awarded a National Science Foundation fellowship that will be used to support continued research on advanced exoplanet coronagraphs at the California Institute of Technology in Pasadena, California. These are two of the top rated research institutions in the world. Two other mid-level PhD students have been awarded summer research internships. Xiaopeng Peng will travel to Silicon Valley for a stint at Samsung, and Jacob Wirth will work in Washington, DC, to conduct research with our collaborator, Dr. Abbie Watnik, at the Naval Research Laboratory. A fifth PhD student, Ying-Ju (Lucy) Chu, started working in the optics group this year. Another member of the group is Lingyu Wan, a visiting scholar from the Center for Astrophysics and Space Science, Guangxi University, Nanning, China. The group leader, Prof. Grover Swartzlander, gave invited seminar talks at three universities in China last summer, and another one at Lehigh University. This summer he will present an invited talk at an international imaging conference in Heidelberg, Germany. As editor-in-chief of the Journal of the Optical Society of America, B (JOSA B), he continued to support high quality international publications in exciting new areas of physical optics. This leadership position brings him in contact with other international leaders in optics. This year the OSA, which started in Rochester during WWI in response to a shortage of German optics, is celebrating it's 100th anniversary. Prof. Swartzlander is publishing periodic scholarly editorials in JOSA B that reflect on this 100 year history.

Research Themes

- **Applications of Optical Vortex Phase Masks**
  - Exoplanet detection device. Advanced aperture and pupil plane masks are being explored to achieve high contrast imaging on segmented telescopes. These future systems will be used to image exoplanets, zodiacal dust, and other relatively dim structures nearby bright sources.
  - Scatterometer. Industry uses measurements of scattered light to determine particles sizes, but small angle scattering cannot conventionally be measured. We have demonstrated that the full angular scattering spectrum can be achieve with the aid of a vortex phase mask.
  - Sensor Protection from Laser Threats. A well characterized phase mask may be used to spread damaging laser radiation out of the focal spot,

thereby lessening the chance of damage. Deconvolution schemes are required to restore the quality of the image.

- **Imaging**
  - — Glitter telescope and Iterative Blind Deconvolution. Experiments and numerical processing are being explored to determine the potential use of an ill-figured segmented telescope. This may allow a means to form an extremely large, low cost space telescope.
  - — Saturated video image processing. Bright regions in a scene may saturate camera pixels. Predictions of the scene from prior video frames may allow the saturated region to be reconstructed.
- **Radiation Pressure**
  - — Laser induced torque on an optical wing. Microfabricated glass torsion oscillators are being designed and made in the RIT SMFL. They will be used to measure the small torque from a beam of light.
  - — Laser driven small satellite mission to Mars. We previously proposed to NASA to develop a laser driven cubesat to achieve a rapid delivery system between Earth and Mars.
  - — Laser analog to a gravitational assist maneuver. The so-called slingshot maneuver provides free propulsion of a satellite during a flyby of a moon or planet. We propose to replace the massive body with a moving laser beam to achieve the speeding or slowing of micro particles.
  - — Enhanced optical lift from an optical metamaterial. Radiation pressure on a solar sail is inefficient for raising or lowering the orbit. We have proposed how metamaterials to increase this efficiency and reach the limit imposed by the law of conservation of momentum.
  - — Acoustic levitation. Radiation pressure is very difficult to measure on Earth, owing to the competing gravitational force and so-called stiction forces. We are exploring a means to overcome this difficulty by levitating particles with sound waves.

Publications in 2015 and 2016

Lyot-plane phase masks for improved high-contrast imaging with a vortex coronagraph

GJ Ruane, E Huby, O Absil, D Mawet, C Delacroix, B Carlomagno, GA Swartzlander Astronomy & Astrophysics 583, A81 (2015)

Optics of a granular imaging system (ie “orbiting rainbows”)

SA Basinger, D Palacios, MB Quadrelli, GA Swartzlander

SPIE Optical Engineering+ Applications, 96020E-96020E-15 (2015)

Optimized focal and pupil plane masks for vortex coronagraphs on telescopes with obstructed apertures

GJ Ruane, E Huby, O Absil, D Mawet, C Delacroix, B Carlomagno, GA Swartzlander SPIE Optical Engineering+ Applications, 96051I-96051I-19 (2015)

Nonlinear response and stability of a 2D rolling semi-cylinder during optical lift

DG Schuster Jr, MW Gomes, AB Artusio-Glimpse, GA Swartzlander Jr

Nonlinear Dynamics 81 (1-2), 561-575 (2015)

Image restoration from a sequence of random masks

X Peng, GJ Ruane, AB Artusio-Glimpse, GA Swartzlander

SPIE/IS&T Electronic Imaging, 94010D-94010D-13 (2015)

Nodal areas in coherent beams

GJ Ruane, GA Swartzlander, S Slussarenko, L Marrucci, MR Dennis

Optica 2 (2), 147-150 (2015)

Reducing the risk of laser damage in a focal plane array using linear pupil-plane phase elements

GJ Ruane, AT Watnik, GA Swartzlander

Applied optics 54 (2), 210-218 (2015)

Dynamics and Control Of Granular Imaging Systems

MB Quadrelli, S Basinger, G Swartzlander, D Arumugam

AIAA SPACE 2015 Conference and Exposition, 4484 (2015)

JOSA B celebrates OSA’s Centennial: editorial

GA Swartzlander

JOSA B 33 (1), ED1-ED2 (2016)

Randomized Aperture Imaging

X Peng, GJ Ruane, GA Swartzlander Jr

arXiv preprint arXiv:1601.00033 (2016)

Collaborations

Jet Propulsion Laboratory: Marco Quadrelli, Scott Basinger, David Palacios, Darmindra Arumugam

NASA Marshall Space Flight Center: Charles (Les) Johnson

Univ. Liege, Belgium: Elsa Huby, Olivier Absil, Christian Delacroix, Brunella Carlomagno, Pierre Piron

California Institute of Technology: Dimitri Mawet

Naval Research Laboratory: Abbie Watnik

Univ. Naples, Italy: Lorenzo Marrucci, Sergei Slussarenko

Bristol Univ, UK: Mark Dennis

Rochester Institute of Technology: Alan Raisanen, Michelle Chabot, Daniel Schuster, Mario Gomes

PhD Students

Alexandra Artusio-Glimpse

Garreth Ruane

Xiaopeng Peng

Jacob Wirth

Ying-Ju (Lucy) Chu

Visiting Scholar

Lingyu Wan, Center for Astrophysics and Space Science, Guangxi University, China

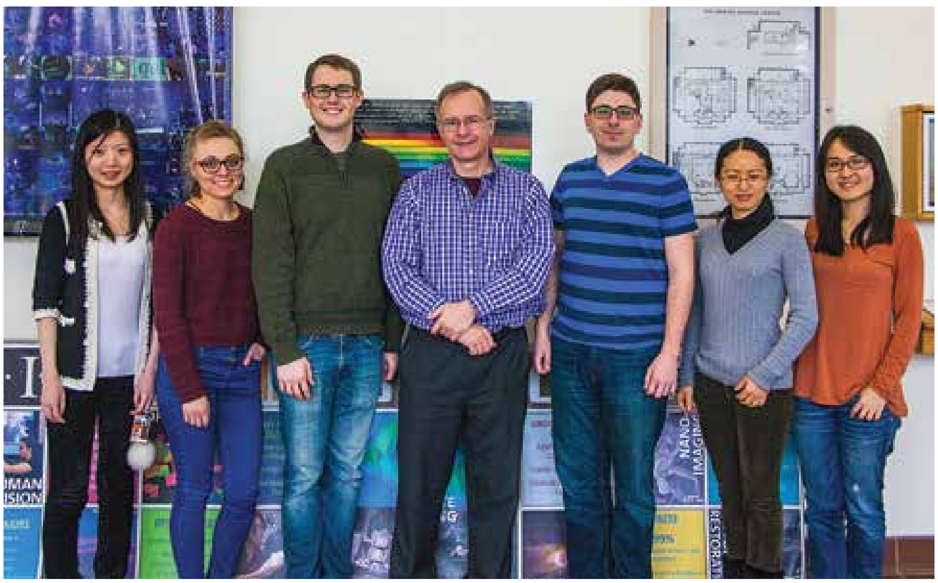
Funding Sources

National Science Foundation (NSF)

National Aeronautics and Space Administration (NASA)

Office of Naval Research (ONR)

Prof. Swartzlander visits the laser optics laboratory of Prof. Qingqing Liang (to his left) at the Liaoning Normal University in Dalian, China. Also in the photo are four of Prof. Liang's graduate students.



Group photo with member's of Prof. Swartzlander's optics laboratory. Left to right: Xiaopeng Peng (PhD candidate), Alexandra Artusio-Glimpse (recently awarded a PhD and now a National Research Council Fellowship Recipient at the National Institutes of Science and Technology, Boulder, CO), Garreth Ruane, (recently awarded a PhD and now a National Science Foundation Fellowship Recipient at the California Institute of Technology, Pasadena, CA), Prof. Swartzlander, Jacob Wirth (PhD candidate), Prof. Lingyu Wan (Visiting Scholar from Guangxi University, Key Laboratory for Relativistic Astrophysics), and Ying-Ju Chu (PhD candidate).

Prof. Swartzlander is hosted by the Liaoning Science and Technology University, Anshan, China where he delivers an RIT Memorandum of Understanding. The MOU was prepared by Dr. James Myers, RIT Assoc. Provost, International Education and Global Programs, and Prof. Jie Qiao, CIS faculty member (not shown).

New scanning electron microscope installed December 2015.

NANOIMAGING RESEARCH LABORATORY

Laboratory Director's Comments By Professor Rich Hailstone

The major news this year is the installation of a new scanning electron microscope (SEM) in December (see image opposite page). This SEM has a more advanced electron gun, providing much higher resolution than our old SEM. The noperator interface is all digital, making it easier to use.

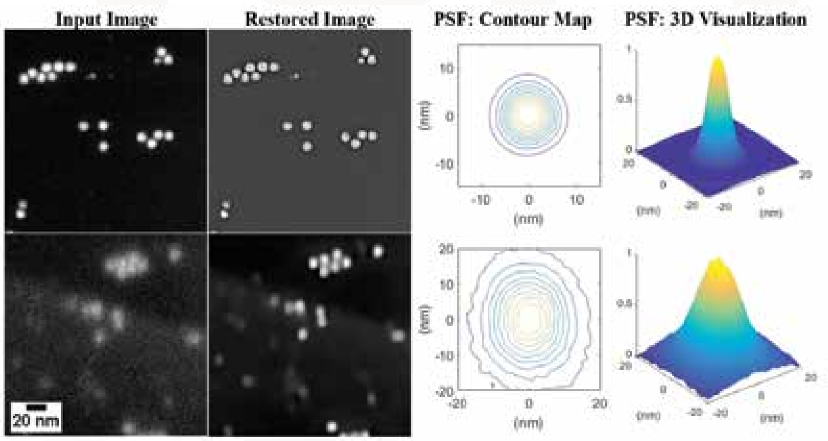


Figure.1: Comparison of Aura Processing at Different Beam Energies. The top row of images corresponds to a 20kV beam, while the bottom row corresponds to a 3kV beam. The input image and restored image columns use the same scale bar as shown in the bottom leftmost image. The PSFs show lowest to highest elevations as dark blue to light yellow, respectively.

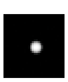


Figure 2: Generated Reference Particle. This 19nm particle was theoretically calculated by Nanojehm.

In addition we have installed on the microscope a new x-ray detector that enables the mapping of elemental composition using energy-dispersive spectroscopy (EDS). The new SEM is already supporting 15 research groups on campus, as well as four industrial partners. The usage is likely to grow in the coming year. In addition, it is supporting four graduate-level courses.

Image Restoration. This is a new project in collaboration with Nanojehm (Albany, NY) in which image deconvolution is used to improve the resolution of an SEM. Image deconvolution relies on having detailed knowledge of the PSF, which Nanojehm's Aura software is able to determine. Mandy Nevins (PhD student) is using a beta unit on loan from Nanajehm to evaluate the Aura software.

We have studied the effect of different electron energies on the ability of the software to enhance image resolution. By comparing an average particle to a reference of a perfect particle (see Figure 2), the PSF is determined. With this PSF, we can restore the input nanoparticle image (see Figure 1), or any other image recorded with the same microscope settings (see Figure 3), to its "perfect" form through deconvolution of the PSF and the image.

We captured backscattered electron images of a 19 nm gold nanoparticle sample at multiple beam energies, ranging from 3kV to 20kV. At higher voltages, Aura identified many particles in a calibration image, which created a good representation of the average particle. This gave us a better approximation of the PSF's shape. Even when microscope settings were almost ideal, Aura was able to produce a PSF which characterized remaining factors hindering resolution. The original image may already have had good resolution, but Aura provided an extra degree of clarity. At lower voltages, particles were more difficult to distinguish in the calibration image, which led to a less descriptive and noisier average particle. Despite that, Aura's restoration for low beam energy images provided sharper edges and improved resolution. Visualizations from this discussion are shown in Figure 1. As expected, the 20kV electrons form a sharper conical shape than that of the lower energy, 3kV electrons. The blurriness in the 3kV observed image is described by the broader and noisier shape of its PSF.

In terms of image quality, in both the 3kV and 20kV cases, Aura improved image clarity, which provided more distinct boundaries for measurements. The restored boundaries are blurrier at low beam energies, but the particles are easier to distinguish. Some artifacts were introduced during deconvolution, including dark halos around bright objects, but these become less visible with optimizing the choice of smoothing parameters.

SEM Characterization of Cement. This project is a continuation of the project described in last year's report, but now using the new SEM. 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 in ordinary cement. The slag material is predominately composed of the oxides of calcium and silicon, with minor constituents of the oxides of aluminum and magnesium.

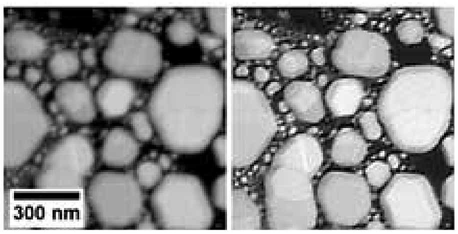


Figure 3: 617 Gold Standard. The image on the left was taken with the same operating conditions as the 3kV nanoparticles shown in Figure 1, bottom leftmost image. The image on the right is the restored image, which used the PSF determined for 3kV in Figure 1, bottom rightmost image. Both images shown here have the same scale.

Characterization of two specimens; slag activated with KOH, and G5, which is slag with amorphous hydrophobic silica. Specimens were sputter coated with gold-palladium under a vacuum of 10 Pa, and then taken to the SEM for examination. Backscattered electron images were acquired at approximately 2.5kX magnification using a 15kV beam voltage. In addition, elemental mapping and analysis were obtained by using energy dispersive X-ray spectroscopy on the specimens.

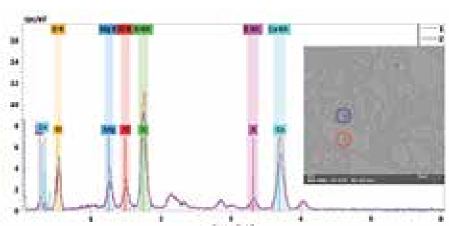


Figure 4: Slag activated with KOH SE images with EDS spectrum, curve 1 is the particle and curve 2 is the background.

The image of the slag activated with KOH shows homogenous bright particles in a darker background. The elemental mapping indicates a high concentration of Ca, Si and Mg in the white particles and a low concentration in O, Al and K. On the other hand, the background had a low concentration of Ca, Si and Mg, while O, Al and K are higher in the background, as shown in Figure 4. The spectrum of the bright particle and the background is shown in Figure 5 where Ca, Si and Mg peaks are higher in the particle as compared with the background. However, the Ca/Si ratios for both the particle and the background are relatively similar: 1.66 and 1.69, respectively. In contrast, G5 image shows homogenous dark gray particles in a lighter background. The elemental mapping of dark particles

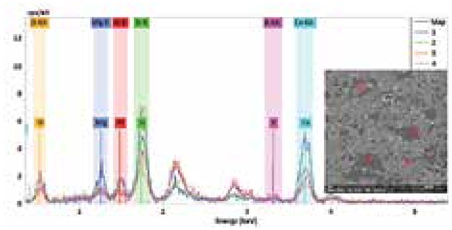


Figure 5: G5 SE images with EDS spectrum, curves 1,2 are the particles, and 3, 4 are the background.

is similar to the bright particles in the slag specimen. It shows a high density of Ca, Si and Mg and a lower density of O, Al and K. The Ca/Si ratios are high (1.45 and 1.57) in the particles, while they are 1 and 1.27 in the background.

Organic Films for Photovoltaics. Prof Chris Collison (Chemistry) and MS student Chenyu Zheng are studying organic films being used in solar cells and how solvent annealing affects their structure. The transmission electron microscope (TEM) was used to image the structure of these films and Fig. 6 shows the results. As can be seen the grayscale image of the film is impacted

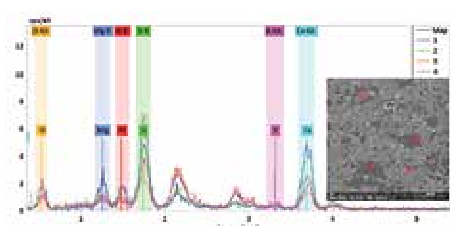


Figure 6: Illustration of the effect of annealing temperature on film microstructure as revealed by TEM.

by the annealing process, suggesting the structure of the film has changed and that the electron-hole transport thru the film will likely be affected.

Characterization of Multijunction Solar Cells. Prof Seth Hubbard (Physics) and PhD student Elisabeth McClure (Microsystems) are studying high-efficiency multijunction solar cells. These cells depend upon crystalline semiconductor substrates such as germanium (Ge), which has a low bandgap and similar lattice constant to gallium arsenide (GaAs), making it a strong candidate for a bottom cell and substrate. Inexpensive techniques to obtain polycrystalline substrates with large grains on inexpensive platforms would be advantageous in realizing low-cost III-V solar cells. Techniques to relieve stress during recrystallization must be investigated if III-Vs on arbitrary, compliant substrates are to be achieved.

Aluminum-induced crystallization (AIC) has been investigated as one

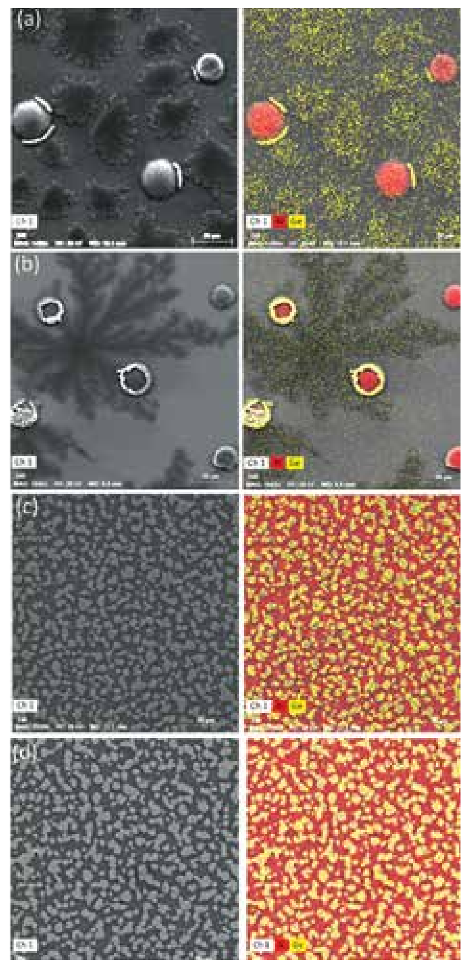


Figure 7: Plan-view SEM images with corresponding EDS mapping of samples with 300 nm of Al and 200 nm of Ge after a 500 °C setpoint anneal for 10 hours. The corresponding ramp conditions for the anneal were: (a) 1 °C/s ramp-up rate, 1 °C/s ramp-down rate. (b) 1 °C/s ramp-up rate, 0.1 °C/s ramp-down rate. (c) 0.1 °C/s ramp-up rate, 1 °C/s ramp-down rate. (d) 0.1 °C/s ramp-up rate, 0.1 °C/s ramp-down rate.

method to achieve polycrystalline substrates with lower stress. By depositing the Al layer between the substrate and Ge layer, stress can be released during annealing as aluminum diffuses to the surface and layer transfer occurs. This study evaluates the role that anneal ramp-up and ramp-down rates have on stress, taking into consideration films with different thicknesses of Al and Ge. SEM and EDS are being used to characterize the films after annealing and an example of the results are shown in Fig. 7.

Antimicrobial Activity of Black Silicon. Professors Hudson and Savaka are investigating black silicon as an antmicrobial and antifungal surface. Black silicon (b-Si) refers to silicon that has been chemically treated so as to form silicon spikes on the surface. As bacteria and fungi adsorbed to the surface the silicon spikes puncture the biomaterial, leading to its demise. The SEM is being used to image the biomaterial-b-Si interecation and Fig. 8 is representative of this interaction.

Surface-Enhanced Raman Spectroscopy

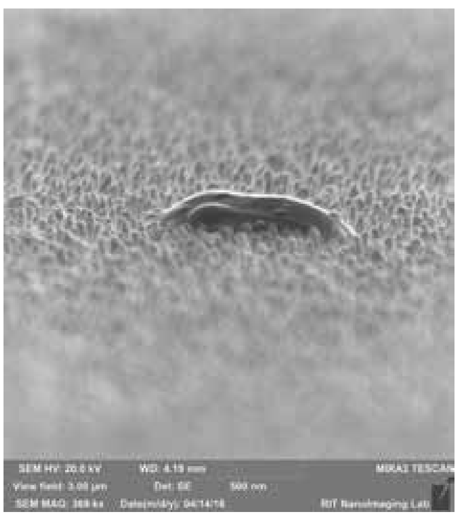


Figure 8: Bacteria adsorbed to black silicon surface.

(SERS). Availability of reproducible substrates for SERS measurements that enables detection of molecules in diluted samples remains a challenge. This project seeks to address this challenge by studying the characteristics of using electrolessly deposited gold clusters as a function of particle size and cluster density on silicon wafers and correlating the results to the SERS spectra obtained for a dye which is adsorbed on gold clusters at varying concentrations. This project is sponsored by the Dean's Research Initiation Grant and is done in collaboration with Professor Anju Gupta (Dept of Chemical Engineering) who prepared the materials for SERS.

Characterization of the developed substrates is being done using the SEM and elemental analysis by EDS. Figure 9 (left) shows an image of the SERS substrate consisting of a layer of gold nanoparticles with adsorbed rhodamine dye. The latter is a classic molecule with which to study the enhancement of signal by the gold substrate. Figure 9 is

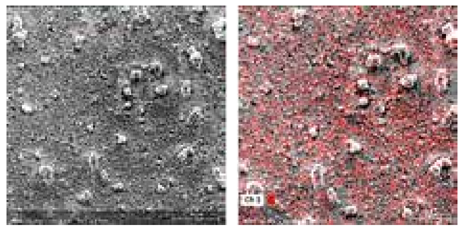


Figure 9: (left) SEM image of gold nanoparticles on silicon substrate. (right) EDS map showing carbon detected as red.

a map of carbon, as determined by the x-ray detector, showing that the dye is adsorbed to the gold nanoparticles. The next step is to determine the enhancement of the spectroscopic signal from the dye by being adsorbed on the gold nanoparticles.

Publications, Patent Applications, Patents Issued, and Conference Presentations 2015-2016

1. Kathleen Ellis, Rachel Silvestrini, Benjamin Varela, Najat Alharbi, Richard Hailstone (2016). Modeling Setting Time and Compressive Strength in Sodium Carbonate Activated Blast Furnace Slag Mortars Using Statistical Mixture Design. Cement and Concrete Composites, accepted.

1. A. G. DiFrancesco, T.D.Allston, R.K. Hailstone, A. Langner, K.J. Reed (2015). Fuel Additive Containing Lattice Engineered Cerium Dioxide Nanoparticles, Australian Patent No. 2008365234, August.

2. Elisabeth L. McClure, Michael A. Slocum, Richard K. Hailstone, Patrick T. Furrey, Zachary S. Bittner, Sergey Maximenko, Christopher G. Bailey, Seth M. Hubbard (2016). "In-Situ Stress Analysis for Aluminum-Induced Crystallization of Germanium as a Function of Anneal Ramp Time." Photovoltaic Specialists Conference, Portland, Oregon, June.

2. F. Piazza, C. Ozoria1, G. Paredes1, M. Monthioux, R. Hailstone (2016). "Hydrogenation of Graphene from a New and Scalable Route." XII Internacional Interdisplinary Scientific Research Congress, Santo Domingo, Dominican Republic, June.

3. Mandy C. Nevins, Matthew D. Zotta, and Richard K. Hailstone (2016). "Image Restoration using Point Spread Function Deconvolution." Microscopy & Microanalysis 2016, Columbus, Ohio, July.

4. Najat A. Alharbi, Richard K. Hailstone, and Benjamin Varela (2016). "SEM Characterization of Alkali Activated Slag." Microscopy & Microanalysis 2016, Columbus, Ohio, July.

Grants and Contracts 2015-2016

Cerion Advanced Materials, $28k

Dean's Research Initiation Grant, $15k

Other Income 2015–2016

Microscopy Facility $45k

Laboratory Director's Comments By Dr. Roger Dube

In 2015, the Spaceweather project focused its work on planetary interactions, in particular the concept that life may have originated on another planet (such as Mars) and then "seeded" life here on earth.

Aviriana Follett, a research student from the Onondaga Nation of the Iroquois Confederacy, carefully analyzed 7 meteorites that had been ejected from Mars by an ancient meteoric impact and launched into space, eventually coming to rest on the white sands of northern Africa. This work included various microscopic techniques, including spectrofluoresence, scanning electron microscopy, and atomic force microscopy to search for traces of life at the cellular and molecular scales. Although the key components were found in these carbonaceous chondrites, no irrefutable evidence was discovered. This research also included work by Bruce Jones on filter-based hyperspectral imaging using an automated filter wheel. The latter has become the basis for a PhD thesis by Jie Yang on Crime Scene Investigation.

Roger Easton, Keti Margiani, and Gregory Heyworth walking toward Orthodox Monastery in Usguli, Republic of Georgia, with the high Caucasus Mountains beyond.

HISTORICAL MANUSCRIPT IMAGING

Laboratory Director's Comments By Dr. Roger Easton

The past year was exciting for the Laboratory for Historical Manuscript Imaging, including the beginning of a number of new research efforts and strengthening of some existing collaborations.

The single most important development was a substantial donation from the Carlson Foundation as an endowment to support the work of the Laboratory. When the proceeds from this donation become fully available, the Laboratory will have guaranteed funds for student support and travel.

Dr. David Messinger has brought his expertise about high-level spectral imaging and image processing to the projects of the laboratory. His new tools will bring new dimensions to the processing capability of the laboratory.

Imaging team at St. Catherine's Monastery, Sinai, in July 2015. Fr. Justin, Librarian of the Monastery, is fourth from right.

In another exciting development, Dr. Gregory Heyworth from the University of Mississippi, the longtime collaborator of the Laboratory, has accepted a faculty position at the University of Rochester beginning in the fall of 2016. This will facilitate interaction with the laboratory and further promote the Lazarus Project, which has a goal to image important manuscripts, particularly those housed at smaller institutions, which have neither the imaging equipment nor have the processing expertise to recover their unique texts.

Dr. Roger Easton heads the lab, which collaborates with faculty and staff at other institutions and other imaging scientists, including Dr. Heyworth, Michael Phelps of the Early Manuscripts Electronic Library (St. Catherine's Palimpsests project) , Adrian Wisnicki of the University of Nebraska (David Livingstone Diaries project) and Dr. Daniel Stoekl Ben Ezra of the École Pratique des Hautes Études (Cairo Genizah Palimpsests project). The students participating in this work include David Kelbe, Kevin Sacca. and Anna Starynska.

The work of the laboratory was acknowledged in several venues during the year. The imaging effort of the c. 1491 world map by Henricus Martellus Germanus, a major effort by the lab in 2014 and 2015, was acknowledged as "Shedding Light on Ancient Maps, #74 on the list of the 100 top science news stories in the January/February 2016 issue of Discover Magazine. The work of the lab also was acknowledged in articles in the Rochester Democrat and Chronicle (10 January 2016), the City Newspaper (16 March 2016), and the RIT University Magazine (Spring 2016). It also was featured on the "Motherboard" online blog in a posting The Scientists Who Are Deciphering 'Unreadable' Ancient Texts on 10 February 2016.

Among the imaging projects which laboratory undertook or participated in during the past year were the following:

1. Proposal to the Shri Madhwa Vadiraja Institute Of Technology and Management (SMVITM) Bantakal, India, to establish the Center for the Preservation of Manuscripts. The proposal was accepted during a visit to SMVITM in June, 2015.
2. Imaging/processing trip to St. Catherine's Monastery (July 2015)

3. Imaging/processing trip to the National Center for Manuscripts, Tbilisi, Republic of Georgia (July 2015)
4. Imaging/processing trip to the Georgia National Archives, Tbilisi, Republic of Georgia (August 2015)
5. Exploratory trip to the Svaneti Museum in Mestia, Republic of Georgia to discuss possible imaging of manuscripts housed there. (August 2015).
6. Imaging/processing trip to the University Library, Cambridge University to image palimpsested manuscripts from the Cairo Genizah and other documents from the collection chosen by the Library staff (September 2015)
7. Discussion with the photographic staff of the Vatican Library about the value of imaging of certain items in the collection (November 2015)
8. Imaging of bomb-damaged manuscripts from the Chartres Cathedral at L'Apostrophe Library, Chartres, France (January 2016)

Among the presentations by the Lab:

1. Dr. Easton participated as faculty at the French-German Summer School Manusciences '15 at Frauenchiemsee, Germany (September 2015)
2. Rediscovering text in the Yale Martellus Map, poster presentation by Roger Easton, Kevin Sacca, Gregory Heyworth, Chet Van Duzer, Kenneth Boydston and Michael Phelps to 7th IEEE International Workshop on Information Forensics and Security (WIFS) 2015 in Rome
3. Invited plenary talk at the Digital Archiving meeting, National Archives, Washington DC (April 2016)
4. Invited plenary talk at the Conference on the Syriac-Galen Palimpsest, University of Pennsylvania (April 2016)
5. Imaging and presentations at the International Medieval Congress, Kalamazoo MI (May 2016)

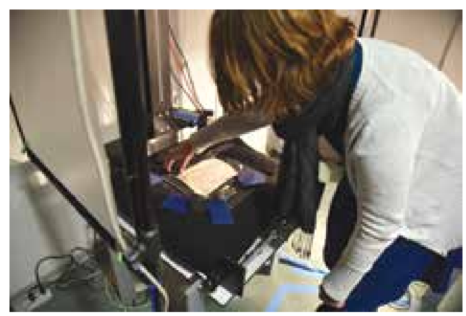
Imaging team at Mestia, Republic of Georgia, in August 2016.

The lab also has much on its plate for the upcoming year, and expects to be collaborating with Dr. Heyworth at the University of Rochester to host a conference on imaging of historical artifacts in 2017 or early 2018.

Planned imaging trips and presentations:

1. SEAHA (Centre for Doctoral Training in Science and Engineering in Arts Heritage and Archaeology) Seminar on Hyperspectral and Multispectral Imaging, Oxford UK, July 2016
2. Presentation and imaging workshop at Digital Humanities 2016, in Kraków, Poland, July 2016
3. imaging/processing of the Dexippus Palimpsest in Vienna, supervised by Jana Grusková of the Austrian Academy of Sciences, July 2016
4. SciX meeting, Minneapolis MN, September 2016
5. Presidential Plenary Session of the Archaeological Institute of America, Toronto, January 2017

Roger Easton addresses faculty at Shri Madhwa Vadiraja Institute of Technology and management, Udupi, India, on June 15, 2015.



Imaging at National Centre for Manuscripts, Tblisi, Republic of Georgia, July 2015.

Dr. Easton receives acknowledgement from Swamiji Sri Vishwavallabha Theertha, Udupi, India, June 2015.

Imaging at the Georgia State Archives, Tblisi, Republic of Georgia, August 2015.

Orthodox Monastery at Ushguli, Republic of Georgia, repository of Georgian manuscripts.

LABORATORY FOR MULTIWAVELENGTH ASTROPHYSICS

Laboratory Director's Comments By Dr. Joel Kastner

1. Summary

The Laboratory for Multiwavelength Astrophysics (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 2015 represented another banner year for LAMA in terms of both its very high rate of dissemination of research results and new funding awards. Specifically, LAMA faculty, postdocs, and students were lead or co-authors of over 30 refereed papers and 30 conference presentations and other non-refereed publications. A significant fraction of these (62) publications resulted from projects in which LAMA personnel play leading roles within national and international teams of astrophysics researchers. A dozen new grants, totaling nearly $700K in funding allocations, were initiated by LAMA PIs during CY 2015, and LAMA PIs generated over $650K in additional new funding via proposals submitted in CY 2015. In 2015, LAMA continued its highly successful summer student research programs, again played a lead role in astrophysics outreach activities within and beyond RIT, and continued its investments in RIT's astrophysics research infrastructure.

2. Mission; Goals & Objectives

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 2015, LAMA-affiliated faculty, postdocs and students made the following progress toward these goals and objectives:

- LAMA continued the very high rate of dissemination of research results established by the Lab in CY 2014. Specifically, LAMA faculty, postdocs, and students were lead or co-authors of over 30 refereed papers and 30 conference presentations and other non-refereed publications appearing in CY 2015 (see Sec. 6). A significant fraction of these (62) publications resulted from projects in which LAMA personnel play leading roles within national and international teams of astrophysics researchers.
- A dozen new grants, totaling nearly $700K in new funding allocations, were initiated during CY 2015. LAMA PIs furthermore generated another $650K in new funding via successful proposals submitted in CY 2015 (see Sec. 3).
- 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 (see Sec. 4).
- LAMA contributed to RIT's investment in the WIYN 0.9 m telescope consortium via partial 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 (see Sec. 4).

3. Personnel & Finances

Faculty: Jennifer Connelly (SoPA, Visiting Assistant Professor), Roger Dube (CIS, Research Professor), Jeyhan Kartaltepe (SoPA, Assistant Professor), Joel Kastner (CIS/SoPA, Professor; LAMA Director), Rupal Mittal (SMS, Adjunct Instructor); Michael Richmond (SoPA, Professor), Andrew Robinson (SoPA, Professor)

Research Staff: Benjamin Sargent (CIS, Research Scientist)

Table 1: LAMA Funding Awards Initiated During CY 2015

PI	SPONSOR	TITLE	ALLOCATION
Robinson	NASA (Astrophys. Data Analysis)	Reverberation mapping the dusty tori in AGN	$53,154
Kastner	NASA/STScI (Hubble Space Telescope)	Mysterious Ionization in Cooling Flow Filaments	$17,391
Kartaltepe	NASA/JPL (Spitzer Space Telescope)	The Role of Obscured AGN at the Epoch of Peak Galaxy Growth	$18,000
Kastner	NASA/USRA (SOFIA)	Mid-IR Imaging of X-ray Sources in L1630 and NGC 2264	$15,000
Kastner	NASA/USRA (SOFIA)	Investigating Dusty Disks in Low-Mass Stars: the TWA 30 System	$3,000
Sargent	NASA/JPL (Spitzer Space Telescope)	Light Curves of the Dustiest AGB Stars in the SMC	$10,000
Robinson	NASA/Cornell (NY Space Grant)	RIT Space Grant 2015-2018	$17,000
Sargent	NASA/JPL (Spitzer Space Telescope)	Following Up on Light Curves of the Dustiest AGB Stars in the LMC & SMC	$5,000
Sargent	NASA/USRA (SOFIA)	An EXES Search for Formaldehyde in Protoplanetary Disks	$2,000
Dube	NY State Education	RIT Collegiate Science Technology Entry Program	$244,800
Sargent	NASA (Astrophys. Data Analysis)	Mass Loss at Higher Metallicity: Mass Return from Stars in the Galactic Bulge	$216,726
Robinson	NASA/STScI (Hubble Space Telescope)	Do Supermassive BHs Really Reside at the Centers of Their Host Galaxies?	$77,092

Table 2: Funded LAMA Proposals, CY 2015

PI	SPONSOR	TITLE	TOTAL FUNDING
Kastner	NASA/USRA (SOFIA)	Mid-IR Imaging of X-ray Sources in L1630 and NGC 2264	$15,000
Kastner	NASA/USRA (SOFIA)	Investigating Dusty Disks in Low-Mass Stars: the TWA 30 System	$3,000
Sargent	NASA/JPL (Spitzer Space Telescope)	Following Up on Light Curves of the Dustiest AGB Stars in the LMC & SMC	$5,000
Robinson	NASA (Astrophys. Data Analysis)	Reverberation mapping the dusty tori in AGN	$93,997
Kastner	NASA (Astrophys. Data Analysis)	Hazardous Early Days In and Beyond the Habitable Zones Around the Lowest- Mass Stars	$266,413
Kastner	NASA (Exoplanets)	Multiwavelength Studies of the Nearest Known Protoplanetary Disks	$320,000
Robinson	NASA/Cornell (NY Space Grant)	RIT Space Grant 2015-2018	$24,000
Kastner	NASA/SAO (Chandra X-ray Observatory)	High-resolution X-ray Spectroscopy of the Young Cluster IC 348	$8,000
Kartaltepe	NASA/JPL (Spitzer Space Telescope)	The Role of Obscured AGN at the Epoch of Peak Galaxy Growth	$18,000

Graduate Students: Triana Almeyda, Kevin Cooke, Marcus Freeman, Yashashree Jadhav, Davide Lena, Kristina Punzi, Valerie Rapson, Trent Seelig, Sravani Vaddi, Billy Vazquez (all AST Ph.D. or M.S. students)

Undergraduate Students: Alex Jermyn (Imaging Science), John Reuter (Physics), Makayla Roof (Imaging Science), Kaitlin Schmidt (Physics), Lindsey Schwartz (Imaging Science), Luke Shadler (Physics), Sadie Wolters (Physics)

Administrative Assistant: Cheryl Merrell

Finances. A dozen grants, totaling nearly $700K in new funding allocations, were initiated during the last CY (see Table 1). In addition, LAMA PIs generated over $650K in new funding via successful proposals submitted in CY 2015, where this total does not include funding already allocated toward a few of these projects in 2015 (see Table 2). Expenditures in CY 2015 totaled approximately $XXXK, and overhead return to LAMA in CY 2015 totaled $YYYYY. Expenses in CY 2015 totaled $ZZZZZ. A detailed breakdown of LAMA grants, grant expenditures, and lab account income and expenses for CY 2015 is available upon request.

4. Student Support, Community Building, and Outreach

Immersive Summer Undergraduate Student Research Program. In summer 2015, 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 students (Makayla Roof, Kaitlin Schmidt, and Sadie Wolters) were 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. Monthly group science lunches 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 2015 RIT Summer Undergraduate Research Symposium. Summer REU student Matthew Portman, who worked under the supervision of LAMA's Ben Sargent, also presented at the Jan. 2016 American Astronomical Society meeting, and a few projects are developing into papers for refereed journals.

RIT Astrophysics Community Building. Via hospitality support in 2015, 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).

Outreach within and beyond Rochester. In 2015, LAMA-supported AST graduate students and LAMA faculty continued to play leadership roles in astronomy public outreach on campus as well as within and beyond the Rochester community. Highlights included:

- ImagineRIT. Kristina Punzi led the development and organization of the AST graduate program's exhibit at the May 2015 edition of ImagineRIT, "Marvels of the Universe" (see Fig. 1). The festival brought over 30,000 adults and families to RIT, many of whom attended the AST exhibit. The exhibit showcased AST graduate student research, engaging the public through an astronomy trivia game, telescope models, solar observing, and interactive displays. All of our LAMA-sponsored AST graduate students played essential roles in this effort.

Figure 1: AST graduate students, led by LAMA's Punzi, developed and presented the "Marvels of the Universe" exhibit at the 2015 ImagineRIT festival.

- RIT Astronomy Club: A group of AST students led by Sravanni Vaddi founded the RIT Astronomy Club (RAC) in 2015 (see Fig. 2). The RAC is devoted to promoting astronomy to the public, including opportunities for night sky observing and presentations of up-to-date discoveries in astronomy, we well as providing presenting career options to students interested in astronomy and offering astronomy research experiences to students in other fields.

Figure 2: AST graduate students, led by LAMA's Vaddi, founded the RIT Astronomy Club in 2015.

- The CANDELS blog (http://candels-collaboration.blogspot.com/), developed and maintain by LAMA's Kartaltepe, presents science snapshots, paper summaries, and insight into the lives of astronomers and has reached a vast audience (over 200,000 hits from all over the world). Both CANDELS and COSMOS maintain active social media accounts on Twitter and Facebook and these have been steadily increasing in followers.
- Astronomy on Tap (AoT): AoT events are audience-centric evenings that feature a few professional scientists, mostly professors, postdocs, and graduate students from RIT and nearby institutions, giving down-to-earth presentations of their research, an astronomy topic in the news, or of pop science that are approximately 15 minutes in length each. These talks are interspersed with music and trivia. So far four AoT events have been held in Rochester, organized and emceed by LAMA's Connelly, with nearly full house attendance of ~50 people at each event. Advertising is done utilizing Facebook and other online tools. A sign language interpreter is available upon request and the venue is accessible to those using mobility aids. Accessibility for these communities is a primary concern of the organizer and an area we feel is often neglected at traditional astronomy outreach/education events.

5. Research Highlights

Valerie Rapson

Rapson completed her AST Ph.D. thesis in summer, 2015. As the capstone to her thesis work, Valerie led a team composed of world-reknowned astrophysicists from Harvard-Smithsonian, Space Telescope Science Institute, Stanford, and the National Astronomical Observatory of Japan in winning "Early Science" observing time with the brand-new Gemini Planet Imager (GPI) instrument on the 8-meter Gemini South telescope in Chile. These GPI observations yielded the first-ever direct images of the planet-forming regions of a dusty circumstellar disk orbiting a young double star (named V4046 Sagittarii). The GPI images provide strong evidence for the presence of one or more young, massive planets in circumbinary orbits around V4046 Sagittarii. In addition to publishing two refereed papers based on her thesis research—the aforementioned GPI imaging of V4046 Sagittarii, and a second, infrared spectroscopic study, using the Spitzer and Herschel space telescopes, that revealed the detailed chemical composition of V4046 Sagittarii's circumbinary disk—Valerie leveraged her thesis work so as to win a new award of GPI observing time in spring of 2015. This time, she and her team obtained images of the planet-forming disk orbiting the iconic nearby, young star TW Hydrae (see Fig. 3).

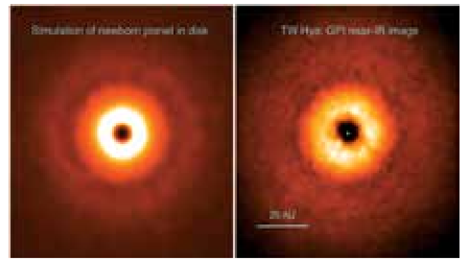


Figure 3: Simulated near-infrared coronagraphic image of a planet forming in a dusty circumstellar disk orbiting a young star (left), and GPI near-infrared coronagraphic image of starlight scattering off the TW Hya disk (right, adapted from Rapson et al. 2015). The comparison serves as evidence that a sub-Jupiter-mass planet is forming in the TW Hya disk, at the approximate position of Uranus in our solar system.

As in the case of V4046 Sgr, Valerie's GPI images of TW Hya also showed evidence for a newly formed giant planet; these results were published in her third first-author refereed paper of 2015. Like her V4046 Sgr GPI work, Valerie's TW Hya GPI results made quite a splash in the online science media:

http://cosmicdiary.org/geminiplanetimager/

http://www.gemini.edu/node/12469

Valerie has moved on from her Ph.D. work at RIT to take on the position of Outreach Astronomer at Schenectedy's historic Dudley Observatory:

http://dudleyobservatory.org/staff/

Davide Lena

In 2015 Davide Lena successfully defended his PhD dissertation, entitled "Aspects of supermassive black hole growth in nearby active galactic nuclei. A search for recoiling supermassive black holes, and gas kinematics in the circumnuclear region of two Seyfert galaxies". Supervised by Prof. Andrew Robinson, Davide used images obtained with the Hubble Space Telescope, and spectra obtained with the integral field unit on the Gemini Multi Object Spectrograph to study the nuclear regions of nearby active galaxies. Using the Hubble data, Davide tested the prediction of long living oscillations between the nuclear SBH and the galactic core. The oscillations being the result of anisotropic emission of gravitational waves during the merger of an SBH-binary. This work was published in the Astrophysical Journal (Lena et al., 2014, ApJ, 795, 146). The GEMINI data allowed to probe the kinematics of the ionized gas in the inner kiloparsec of two Seyfert galaxies (NGC 1386 and NGC 1365), raising new questions on our understanding of the interplay between galaxies and the supermassive black holes dwelling their centers. The study of NGC 1386 was published in the Astrophysical Journal (Lena et al., 2015, ApJ, 806, 84), while the work on NGC 1365 was submitted to the journal Monthly Notices of the Royal Astronomical Society. Davide also provided one of the first and most complete tutorials on the complex process of integral field data reduction (ArXiv ID: 1409.8264).

Marcus Freeman

Freeman was the third LAMA-sponsored AST graduate student to receive a Ph.D. in 2015. His thesis was entitled "Multiwavelength Imaging of Planetary Nebulae: Resolving and Disentangling Structure." Planetary nebulae (PNe) represent the late stages of low-mass stellar evolution. The formation of the myriad of PNe morphologies involves processes that are present in many other astrophysical systems such as the wind-blown bubbles of massive stars. In his dissertation, Marcus presented the results of an X-ray study of PNe, and two modeling projects that incorporate the resulting data with the goal of furthering our understanding of their X-ray properties and morphologies, and the 3D multiwavelength structure of PNe. This work expands the Chandra Planetary Nebula Survey (ChanPlaNS), which was designed to investigate X-ray emission from PNe, from 35 to 59 objects. Marcus presented analysis of Cycle 14 Chandra observations of the 24 additional PNe that brought the overall ChanPlaNS diffuse X-ray detection rate to ~27% and the point source detection rate to ~36%. The detection of diffuse X-ray emission is unmistakably associated with young, compact PNe that exhibit closed elliptical structures and high electron densities. These results were previously published in the Astrophysical Journal (in Freeman et al. 2014). Utilizing the ChanPlaNS data for 14 PNe that exhibit diffuse X-ray emission, Marcus constructed simple, spherically symmetric two-phase models using the astrophysical modeling tool, SHAPE. His models consisted of a hot bubble and swept-up shell with the intent of investigating the X-ray morphology of these objects and the extinction caused by the swept-up shell. Marcus compared simulated and observed radial profiles and concluded that while most (~79%) PNe present a limb-darkened X-ray morphology, this is due to nebular extinction of an intrinsic limb-brightened hot bubble structure. Expanding upon the two-phase model, Marcus then used SHAPE to generate a 3D model of the brightest diffuse X-ray PN, BD+30º3639, with the model constrained by previously published multiwavelength data extending from the radio to the X-ray regimes. This study resulted in a more comprehensive picture of the multiwavelength 3D structure of this well-studied nebula, allowing evolutionary connections to various PNe at different viewing geometries. A manuscript derived from Marcus's thesis study of the structure of BD+30º3639 was submitted to the Astrophysical Journal in early 2016.

Kevin Cooke

AST Ph.D. student Cooke, working with advisors O'Dea and Baum, examined the star formation properties of brightest cluster galaxies (BCGs) in clusters at intermediate redshift (0.2 < z < 0.7). The specific star formation rates (sSFR, star formation rate per unit stellar mass) are too low to result in significant mass growth of the BCGs. The mean sSFR among BCGs we studied is 1.83 x 10-11 /yr (Fig. 4), which corresponds to a mass doubling time of 55 billion years. This is consistent with hierarchical models for formation and evolution of massive galaxies which suggest that for z< 1, BCGs are growing mainly through mergers with gas-poor galaxies rather than by accreting cold gas and actively forming new stars.

Kristina Punzi

AST Ph.D. student Punzi's paper entitled "An Unbiased 1.3 mm Emission

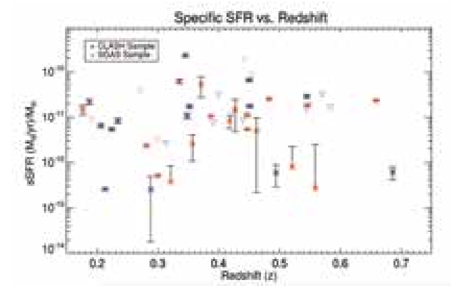


Figure 4: Specific star formation rate (sSFR) versus redshift for galaxy samples studied by Cooke et al. Asterisks denote averages of detected star formation rates. Downward facing triangles denote the lowest specific star formation rate upper limit.

Line Survey of the Protoplanetary Disk Orbiting LkCa 15" appeared in The Astrophysical Journal in 2015. This work, an extension of Kristina's masters-level research, characterized the gaseous molecular content of the circumstellar disk of LkCa 15. She also began working on a new project intended to constrain the X-ray spectral properties and temporal behavior of young (~10-100 Myr), nearby, low-mass (M type) stars. This work will give us an improved understanding of X-ray emission and its relationship with stellar age and mass, and insight into the radiation environment of low-mass pre-main sequence stars, which will help develop more physically accurate irradiated disk models. She presented preliminary results from this work at International Astronomical Symposium 314, "Young Stars and Planets Near the Sun," in May in Atlanta, GA. In addition to the X-ray study of low-mass stars, she has also been studying the enigmatic star RZ Psc, whose evolutionary status is unknown. She aims to determine the evolutionary status of RZ Psc using X-ray observations obtained with XMM-Newton by measuring RZ Psc's X-ray luminosity relative to its bolometric luminosity and modeling its spectrum. Kristina was awarded the AST Graduate Student Fellowship for 2015–2016 in recognition of her academic performance, research achievements, and service contributions.

Rupal Mittal

Brightest cluster galaxies (BCGs) are unique not only in their special location but also in that they occupy the most massive end of the galaxy luminosity function. Due to the early formation of the stellar component, ellipticals are considered as being "red and dead'' since they are not expected to show any recent star formation. However, BCGs in cool-core galaxy clusters, additionally, are surrounded by a large reservoir of cold gas and are forming stars, albeit not at the expected level. The last decade has witnessed tremendous progress in the field of cooling flows in galaxy clusters, both theoretically and observationally. However, the star formation rates in BCGs in cooling-flow galaxy clusters ("cool-core BCGs") are still very poorly constrained, with an unacceptably wide discrepancy between different estimates, and are an impediment preventing development of a coherent narrative. R. Mittal with collaborators, J. T. Whelan and F. Combes, recently finished an Bayesian-based SED (spectral energy distribution) analysis of a sample of 10 cool-core BCGs (Mittal et al., 2015) in order to obtain robust ranges of plausible SFRs. They calculated marginalized posterior probability distributions for various model parameters and obtained 68 % plausible intervals from them. The 68 % plausible interval on the SFRs is broad, owing to a wide range of models that are capable of fitting the data, which also explains the wide dispersion in the star formation rates available in the literature. The ranges of possible SFRs are robust and highlight the strength in such a Bayesian analysis. The SFRs are correlated with the X-ray mass deposition rates (the former are factors of 4 to 50 lower than the latter), implying a picture where the cooling of the ICM is a contributing factor to star formation in cool-core BCGs. They also find that 9 out of 10 BCGs have been experiencing starbursts since 6 Gyr ago. While four out of 9 BCGs seem to require continuous SFRs, 5 out of 9 seem to require periodic star formation on intervals ranging from 20 Myr to 200 Myr. This time scale is similar to the cooling-time of the ICM in the central (< 5 kpc) regions.

Ben Sargent

A star of low to intermediate mass (i.e., below about 8 times the Sun's mass) loses a significant fraction of its mass in the final stages of its life. This mass is returned to the host galaxy to which the star belongs, available to become incorporated in a new generation of stars. The outflows from these stars are mostly composed of gas but also include small amounts of dust that form in the outflows. Therefore, learning how evolved stars lose mass is an important part of understanding the life cycle of matter in galaxies, and, consequently, how galaxies evolve over time. Ben Sargent has been modeling mass loss from evolved stars called asymptotic giant branch (AGB) stars in our Galaxy by fitting radiative transfer models of the dust shells around AGB stars to their spectral energy distributions (SEDs; plots of flux versus wavelength). This radiative transfer modeling determines various properties of these mass-losing evolved stars, such as mass-loss rate, stellar luminosity, etc. By comparing mass-loss rates from evolved stars in the Galaxy to those in the lower metallicity Large Magellanic Cloud (LMC) and Small Magellanic Cloud (SMC), Ben and collaborators are determining how mass loss from evolved stars depends upon metallicity, and, therefore, how the life cycle of matter in galaxies is affected by metallicity. Ben presented initial findings for this work at the Astronomical Society of New York (ASNY) meeting at Skidmore College on November 7, 2015.

Ben also uses infrared spectroscopy to study the composition of the dust around evolved stars. Spitzer-IRS spectra of red supergiant (RSG) and oxygen-rich AGB stars in the LMC and SMC 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. Ben is investigating the properties of the dust grains around AGB and RSG stars by constructing detailed models that make use of optical properties of astrophysical dust grain analogs published in the literature. Ben reported on this work at the 225th American Astronomical Society meeting in Seattle, WA on January 6, 2015; at the National Optical Astronomy Observatory in Tucson, AZ on March 25, 2015; and at the focus meeting "Stellar Behemoths—Red Supergiants across the Local Universe" at the XXIX International Astronomical Union meeting in Honolulu, HI on August 4, 2015.

Michael Richmond

In June, 2015, astronomers around the world focused their telescopes on a binary star system lying in the constellation Cygnus, known as V404 Cygni. We had known for years that two objects orbited around each other in this system: an ordinary star not unlike our Sun, and a black hole with a mass about 10 times greater. The orbit is so small that it completes one revolution in about 6 days—and the gravitational pull is so strong that gas from the ordinary star is pulled out and captured by the black hole. As the gas spirals inward toward its doom, it heats up and emits radiation of all wavelengths: optical, infrared, and X-rays (see Fig. 5).

On rare occasions, the flow of gas toward the black hole surges, creating a sudden flare and increasing the system's brightness. An X-ray telescope detected one of these flares on June 15, 2015, and followed it for several weeks. Astronomers on the ground pointed their optical telescopes at the system, too, to watch the action at visible wavelengths. We used the 12-inch telescope at the RIT Observatory to monitor V404 Cygni for many hours on three nights, sending our measurements to VSNet, a central repository for astronomical data. Fig. 6 shows our measurements from June 23.

Figure 5: Schematic view of detection of radiation from a "cataclysmic variabl"e binary star system.

Scientists at the University of Kyoto compared these optical measurements to those from X-ray telescopes, and noticed a surprising result: the

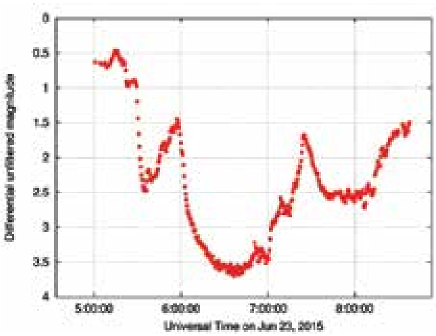


Figure 6: The light curve of V404 Cyg, as measured by the RIT Observatory on June 23, 2015.

quick variations in X-rays caused by irregularities in the flowing gas—just a few minutes long—appeared in the optical measurements! The standard theories suggested that only X-rays could penetrate through the inner regions close to a black hole, but somehow, optical photons were also escaping. A large collaboration described this unexpected phenomenon in a paper published in Nature in 2016 (Kimura et al., Nature, 2016, vol. 529, p 54). You can find a simplified explanation on the RIT Observatory's website at

http://spiff.rit.edu/richmond/ritobs/v404cyg/v404cyg.html

Joel Kastner

Kastner spent a large chunk of 2015 serving in his capacity as lead co-Chair of the Scientific Organizing Committee (SOC) of International Astronomical Union Symposium #314, "Young Stars & Planets Near the Sun." IAUS 314 was held on the campus of Georgia State University in downtown Atlanta, GA in May 2015 and was attended by more than 130 astronomers from five continents. In addition to leading the development and management of the scientific program and coordinating between the SOC and the Local Organizing Committee in Atlanta, Kastner also served as lead editor of the IAUS 314 conference proceedings. The IAUS 314 Proceedings, which were published in early 2016 by Cambridge University Press (see Fig. 7), include 70 contributed papers, ranging from comprehensive reviews by the leading astrophysicists in the field of young star and planet research to summaries of recent, groundbreaking work by a few dozen students who attended the meeting.

Figure 7: The cover of the proceedings of International Astronomical Union Symposium 314, "Young Stars & Planets Near the Sun."

The following is an excerpt from Kastner's Preface to the IAUS 314 Proceedings.

The motivation for a 2015 IAU Symposium dedicated to the study of young stars and planets near the Sun is captured perfectly in the following summary from our original meeting proposal, written by SOC member Ben Zuckerman: The region surrounding the Sun out to a distance of roughly 100 pc is often described as the "local bubble" due to the relatively low density of the interstellar medium and an accompanying lack of regions of star formation. In the past two decades, research by many astronomers has revealed an abundance of post T Tauri stars and early type stars of comparable age inside of the bubble. Many of these stars have been classified as members of kinematic moving groups, whose ages range from roughly 8 Myr up to 200 Myr. Because these stellar groups are so close to Earth, they provide some of the best samples available to astronomy to investigate the early evolution of low- to intermediate-mass stars. While these nearby, youthful stars are themselves of great interest to stellar astronomy, they also represent the most readily accessible targets for direct imaging (and other measurements) of dusty circumstellar debris disks and young, substellar objects—i.e., newly formed brown dwarfs and, especially, planets. Indeed, <200 Myr-old stars within about 100 pc represent the best laboratories to study the conditions and timescales associated with protoplanetary disk evolution and the formation and early physical and dynamical evolution of planetary systems.

Our Symposium was intended to highlight the major advances in our understanding of the early evolution of stars and planetary systems, and the potential for further progress, flowing from investigations of nearby young stars. Our aim was to gather scientists approaching such studies from a wide variety of directions: the identification, ages, and origins of local young moving groups; early stellar evolution from theoretical and observational perspectives; the signatures of nascent or recently formed exoplanet systems, including the dispersal of protoplanetary disks, the nature of debris disks, and star-disk, planet-disk, and planet-planet interactions; and the properties of newborn planets.

To draw out the latest results in (and connections between) these diverse topics, he meeting was organized into five, interrelated themes, which also represent the basis for the presentation of the papers in these Proceedings:

1) the identification, ages, and origins of nearby young stars and moving groups;
2) the early evolution of low- to intermediate-mass stars;
3) the dispersal of protoplanetary disks and the origins of debris disks;
4) the early evolution of planetary systems; and
5) the prospects for advances in the study of nearby young stars and planets resulting from new and future observing facilities.

6. Publications

Refereed Journal Articles

(1) Kato, T., and 91 colleagues 2015. Survey of period variations of superhumps in SU UMa-type dwarf novae. VII. The seventh year (2014-2015). Publications of the Astronomical Society of Japan 67, 105.

(2)) Rapson, V. A., Kastner, J. H., Millar-Blanchaer, M. A., Dong, R. 2015. Peering into the Giant-planet-forming Region of the TW Hydrae Disk with the Gemini Planet Imager. The Astrophysical Journal 815, L26.

(3) Kocevski, D. D., and 14 colleagues 2015. Are Compton-thick AGNs the Missing Link between Mergers and Black Hole Growth?. The Astrophysical Journal 814, 104.

(4) Kartaltepe, J. S., and 46 colleagues 2015. CANDELS Visual Classifications: Scheme, Data Release, and First Results. The Astrophysical Journal Supplement Series 221, 11.

(5) Huertas-Company, M., and 14 colleagues 2015. A Catalog of Visual-like Morphologies in the 5 CANDELS Fields Using Deep Learning. The Astrophysical Journal Supplement Series 221, 8.

(6) Silverman, J. D., and 20 colleagues 2015. A Higher Efficiency of Converting Gas to Stars Pushes Galaxies at z ~1.6 Well Above the Star-forming Main Sequence. The Astrophysical Journal 812, L23.

(7) Jones, O. C., Meixner, M., Sargent, B. A., Boyer, M. L., Sewilo, M., Hony, S., Roman-Duval, J. 2015. The Dustiest Post-Main Sequence Stars in the Magellanic Clouds. The Astrophysical Journal 811, 145.

(8) Rodriguez, D. R., van der Plas, G., Kastner, J. H., Schneider, A. C., Faherty, J. K., Mardones, D., Mohanty, S., Principe, D. 2015. An ALMA survey for disks orbiting low-mass stars in the TW Hya Association. Astronomy and Astrophysics 582, L5.

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Comments By Joe Pow, CIS Associate Director

The most significant change in the Center's outreach program over the past year has been the departure of our Senior Associate for Outreach and Communication, Bethany Choate.

In the five years Bethany was with us, she was responsible for transmitting the CIS story to a whole new generation of tech-savvy prospects. She was the vision behind the overhaul of the Center's web site. She gave the Center a presence on social media. She created an enormous portfolio of vibrant new promotional publications. And she personally took the CIS message to thousands of students through classroom visits, career fairs, and laboratory demos. Her parting gift to the Center was a comprehensive recruiting plan which she created as her MS capstone project. We owe Bethany a debt of gratitude for her tireless efforts to increase enrollments in the Center's degree programs.

With Bethany's departure the Center's outreach efforts are moving away from a centralized recruiting model toward one in which our outreach is distributed among the entire faculty and staff. So for example, over the past year Dr. Matt Montanaro gave a series of talks to students at Webster Thomas High School about his work on the processing of imagery from the New Horizons probe that flew by Pluto. And Dr. Mike Gartley did a demonstration of thermal imaging at a career fair in the Victor Central School District.

In spite of the move toward a new recruiting model, the Center is still maintaining some tried-and-true elements of the old recruiting program.

For example, the summer of 2016 marks the 17th year of the CIS high school intern program. Although the program has undergone a number of changes over the years it continues to be the Center's most effective recruiting tool. Between 2000 and 2015 a total of 185 students participated in the intern program. Of those, 27 (15%) applied for admission to the imaging science undergraduate program. Not all of those enrolled as CIS students, but since the program's inception 12 former interns (6%) have earned their BS degrees, and of those, one went on to earn an Imaging Science MS and two earned their PhD's. There are currently seven former interns

Student Name	High School	CIS Research Lab
Nathan Baker	Victor	Visual Perception
Emily Lang	Rush-Henrietta	Astronomical Imaging
Alice Li	Rush-Henrietta	Visual Perception
Madeline Loui	Fairport	Historical Manuscript Imaging
Maria Morcos	Rush-Henrietta	Visual Perception
Zihao Qi	Brighton	Magnetic Resonance Imaging
Niels Rasmussen	Pittsford-Mendon	Astronomical Imaging
Allyse Toporek	Brighton	Historical Manuscript Imaging
Cecilia Weber	Hilton	Magnetic Resonance Imaging

enrolled as undergraduates. Assuming each of those seven successfully completes their degree program, more than 10% of all of the interns to that date would have earned their BS in Imaging Science. The 2016 interns include the following high school students:
In the summer of 2016 the Center also continued to offer our National Science Foundation-funded Research Experience for Undergraduates (REU) in Imaging in the Physical Sciences. This year the following REU student have joined us:

Student Name	Home University	CIS Research Group
Malaka De Vass Gunawardena	Syracuse University	PerForm Lab
Johnathan Germick	Iowa State University	Remote Sensing
Lydia Gingerich	Haverford College	Astronomy
Chris Giottonini	Trinity College	Spectral Analysis Lab
Tori Knapp	Ithaca College	Astronomy
Natasha Manygoats	University of Arizona	Spectral Analysis Lab
Stacy Mendez	Fairfield University	Biomedical
Lauren Randaccio	Hobart and William Smith Colleges	Visual Perception

For further information about outreach and recruiting opportunities, please refer to the CIS web site at cis.rit.edu/outreach/k-12-programs or contact Associate Director Joe Pow at pow@cis.rit.edu.

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