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Annual Report 2016–2017

Chester F. Carlson Center for Imaging Science

contents

FOREWORD

By David W. Messinger, Ph.D.

On behalf of the faculty, staff, and students in the Chester F. Carlson Center for Imaging Science at RIT I am pleased to present the 2016–17 Academic Year CIS Annual Report. I hope you enjoy reading about all the accomplishments we have made in the past year.

We continue to be a leader in small Unmanned Aerial Systems (sUAS) Imaging for precision agriculture and infrastructure monitoring. This past year members of the Digital Imaging and Remote Sensing lab built a new multi-modal payload to fly on our sUAS. The payload is one of a kind and includes a VNIR hyperspectral sensor, a LIDAR, a thermal camera, and a high resolution color camera, all with a common data recorder and inertial measurement unit. Also in the UAS world, we hosted the first IEEE STRATUS workshop focused on sUAS imaging, with over 60 attendees.

Joel Kastner, was on sabbatical but was named the recipient of several fellowships to support his time away from the Center. Joel was the Study Abroad International Faculty Fellow for the month of November at the Arcetri Observatory in Florence, Italy. He was also awarded two additional fellowships for 2017—the prestigious Merle A. Tuve Fellowship from the Carnegie Institution for Science Department of Terrestrial Magnetism in Washington, D.C., for his six-week residency there, starting in January 2017; and a Smithsonian Institution Short Term Visitor fellowship for his residency at the Smithsonian Astrophysical Observatory in Cambridge, Mass., in March and April 2017. Zoran Ninkov was also on a very successful sabbatical working on a Multi-Object Spectrometer at the University of Toronto.

Multispectral and hyperspectral imaging technology continues to recover new insights from historical artifacts. Experts in this application of imaging technology from the Center and the University of Rochester have formed a group, R-CHIVE (Rochester Cultural Heritage Imaging, Visualization, and Education), which continues to image artifacts from around the world and held its first conference last summer with over 50 attendees.

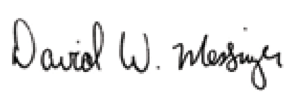
Software developed by Aaron Gerace and Matt Montanaro, senior scientists in the Center, was used to improve the accuracy of NASA's Landsat 8 Earth-sensing satellite, which was giving inaccurate readings due to defective optics in the thermal infrared sensor. Also in space, imaging technology advanced by researchers in the Center in collaboration with scientists from the Florida Institute of Technology was tested on the International Space Station and could someday be used on future space telescopes. Zoran Ninkov and Daniel Batcheldor, head of Physics and Space Sciences at FIT, designed the charge injection device camera to capture contrasts between light emitted by astronomical objects.

Kevin Moser, an imaging science student, and alumnus Peter A. Blacksberg '75 (photography) worked with Don Figer (RIT Center for Detectors) to develop an algorithm to remove the effects of damaged pixels in photographs by astronauts on the International Space Station. The work formed the basis of Kevin's senior capstone thesis and was presented at NASA's Johnson Space Center in Houston in May. Also, on of our graduating masters students, Tania Kleynhans, was selected as the College of Science Graduate Delegate for this year's Commencement Ceremony where she gave a wonderful speech about her journey to RIT.

As you can see, it was another exciting year for the Center and the upcoming year promises to be even more so. This coming year we will welcome two new faculty to the Center. Dr. Emmett Ientilucci continues his long career in the Center but now in a faculty role. Additionally, we will be joined by Dr. Guoyu Lu, an expert in computer vision systems for autonomous vehicles. Our reach into novel imaging systems and applications continues to grow!

I hope you enjoy reading this annual report to catch up on all the exciting developments in the Center this past year. We look forward to another exciting year coming up, and please do keep in touch or stop by the Center to see all the excitement in Imaging Science!

Thanks,



David W. Messinger, Ph.D.
Professor, Xerox Chair, and Director
Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology
http://www.cis.rit.edu/
http://www.cis.rit.edu/faculty-and-staff/profile/dwmpci

phone: (585) 475-4538
office: bldg 76, rm 2264

IMAGING SCIENCE GRADUATE PROGRAM

Program Coordinator's Comments By Dr. Charles Bachmann

The Imaging Science graduate program is the only degree program of its kind in the US, touching on all aspects of the science and application of imaging technology across multiple disciplines.

Overview

The Imaging Science graduate program is the only degree program of its kind in the US, touching on all aspects of the science and application of imaging technology across multiple disciplines. Graduates from our program are highly sought after by government and industrial laboratories, academic institutions, and not-for-profit organizations, and our alumni continue to advance the state of the art in both science as well as defense and civilian applications.

As in past years, this year began with an Immersion event for incoming graduate students. This program is designed to acclimate students to CIS while providing a condensed overview of the key subject areas that they will be studying in the core curriculum of the department. The Immersion also serves as a focal point for outlining the broader program of study including the research programs within CIS. To that end, this year the Immersion included an open house of all of the laboratories within CIS to allow new students the chance to get a first-hand introduction to the types of research opportunities that they might be able to explore during their thesis research.

Below are some highlights of this year's developments within the CIS faculty, curriculum, and student body, as well as some of their outstanding achievements. We continue to take pride in the outstanding accomplishments of our students.

Graduate Program Faculty

As of the end of the 2016–17 academic year there were a total of 57 members of the CIS Graduate Program Faculty. 17 are tenured, or tenure-track, with the Center as their primary appointment. Another 25 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 10 Research Faculty. There are five Program Allied Faculty who hold positions at other organizations outside of RIT.

This year, the department undertook two successful faculty searches for two new tenure track faculty, one in the area of remote sensing, and the other in computer vision and computational imaging. In the fall of 2017, we are delighted to be welcoming two new tenure track faculty to the Center, Dr. Emmett Ientilucci and Dr. Guoyu Lu. Dr. Ientilucci, whose area of expertise is remote sensing, especially radiometry and calibration, was previously a CIS research faculty member. Dr. Lu joins us from Ford Research and Advanced Engineering and is an expert in the area of computer vision in autonomous driving vehicles. We are looking forward to the many important contributions that Dr. Ientilucci and Dr. Lu will make to CIS in the future.

Curriculum Development

Our core curriculum continues to be extended by a wide range of elective courses, which include Special Topics courses offered within areas of faculty specialization. This year courses were offered in a broad range of areas such as Interactive Virtual Environments (Diaz), Optical System Design (Qiao), Introduction to Radiative Transfer (Bachmann), and a Vision Science Seminar (Ferwerda). A number of these courses have continued to draw students each year and are now being considered for conversion to permanent course offerings. In some instances, where appropriate this will include cross-listed courses which can be taken by either graduate students or senior undergraduate students, such as Dr. Qiao's Optical System Design course and Professor Ferwerda's Vision Science Seminar. With the arrival of Dr. Ientilluci and Dr. Lu to our tenure-track faculty, we look forward to expanding the curriculum to include their areas of specialization in our course offerings.

Graduate Student Body

At the beginning of the 2016-17 academic year, there were a total of 118 graduate students pursuing degrees in Imaging Science. Our graduate student body consisted of 25 resident M.S. students, 4 online M.S. students, and 89 Ph.D. students, including one who is pursuing the Ph.D. degree online.

The incoming class that started in the fall of 2016 included 8 MS. and 18 Ph.D. students. In this group of students, there are 3 US Air Force officers (1 M.S. and 2 Ph.D.) With the exception of our new Air Force officer in the Ph.D. program, all Ph.D. students received an assistantship covering full tuition and a stipend, while 3 of the M.S. students also received an assistantship covering tuition and stipend. 17 of the new students were from the United States, with the balance being international students, including 4 from India, 3 from Nepal, and 2 from Iran.

Student Awards

This year we highlight two student awards that represent the broad range of topics addressed in our student research. Below we provide some background on the award, and the student author names are underlined in the associated citation.

In recent years, Professor Tony Vodacek, who has been serving as the Paul and Francena Miller Chair in International Education, has been advising students in a number of African universities. Professor Vodacek's connections to Africa grew out of research that he originally undertook through a MacArthur Foundation grant which examined the Dynamics of the Lake Kivu System. Since then, Professor Vodacek has developed a number of interesting new projects focused on natural resource management and mapping, involving local communities in the effort. One of these projects was funded by a program known as Innovation for Education (MINEDUC and UKAID) and resulted in an award at a conference held this year in Uganda:

Donath Uwanyirigira, Anthony Vodacek, Best Presentation Award, 2016. African Association of Remote Sensing of Environment Conference in Kampala, Uganda, October 2016 for paper "Assessment of the Rwanda Rural Road Network Development Using Pan-sharpened Landsat 8 Data."

Having recently graduated, Donath Uwanyirigira is now an Assistant Lecturer in Physics at the University of Rwanda.

Another student paper award highlights the confluence of two different research thrusts within CIS: machine learning and the generation of radiometrically accurate scenes through DIRSIG. Sanghui Han was lead author for a paper which received the Lockheed Martin Best Paper award at SPIE Defense and Security 2017, Anaheim, CA:

Sanghui Han, Alex Fafard, John Kerekes, Michael Gartley, Emmett Ientilucci, Andreas Savakis, Charles Law, Jason Parhan, Matt Turek, Keith Fieldhouse, Todd Rovito, 2017. "Efficient generation of image chips for training deep learning algorithms", Proc. SPIE 10202, Automatic Target Recognition XXVII, 1020203 (2017/05/01); doi: 10.1117/12.2261702; http://dx.doi.org/10.1117/12.2261702.

Student Publications and Presentations

Presentation and publication of scholarly research remains a cornerstone of the CIS graduate curriculum, and this year was no exception. Students are widely represented in the scholarly output of CIS overall, and for almost all publications that emanate from CIS, a student is either the lead author or a co-author of the publication. Below we highlight some of these accomplishments by providing a list of articles published in refereed journals as well as in proceedings of professional conferences and symposia.

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

Concha, J.A., Schott, J.R., "Retrieval of Color Producing Agents in Case 2 Waters Using Landsat 8", *Remote Sensing of Environment,* http://dx.doi.org/10.1016/j.rse.2016.03.018, April 13, 2016.

Garma, J.D., Schott, J.R., Fiete, R.D., McKeown, "Image Quality Modeling and Characterization of Nyquist-Sampled Framing Sensors with Operational Considerations for Remote Sensing", *Optical Engineering 56(1), 013102*, Jan. 2, 2017.

Kemker, R., Kanan, C. (2017) Self-Taught Feature Learning for Hyperspectral Image Classification. *IEEE Transactions on Geoscience and Remote Sensing (TGRS)*, 55(5): 2693–2705.

Salvaggio, P.S., Schott, J.R., McKeown, D.M, "Validation of Modeled Sparse Aperture Post-Processing Artifacts", *Applied Optics 56,* 761-770", April, 2017.

Salvaggio, P.S., Schott, J.R., McKeown, D.M., "Genetic Apertures:an Improved Sparse Aperture Design Framework," *Applied Optics*, 55,12, pp. 3182-3191, Dec. 2016.

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

B. Ambeau, C. M. Bachmann, C. Griffo, J. Harms, E. Myers, G. Badura, to 2016. "The opposition effect and its relationship to sediment density in BRDF measurements from the Algodones Sand Dunes System," Proc. SPIE 9972, Earth Observing Systems XXI, 99720L-1 - 99720L-9, August 2016, http://dx.doi.org/10.1117/12.2236959.

C. M. Bachmann, B. Ambeau, C. Griffo, J. Harms, E. Myers, G. Badura, 2016. "Modeling geophysical properties of the Algodones

Dunes from field and laboratory hyperspectral goniometer measurements using GRIT and comparison with G-LiHT imagery," Proc. SPIE 9972, Earth Observing Systems XXI, 99720K-1 -99720K-13, August 2016,

http://dx.doi.org/10.1117/12.2238270.

C. M. Bachmann, R. Eon, B. Ambeau, J. Harms, G. Badura, C. Griffo, E. Myers, 2017. "Inverting A Radiative Transfer Model for Sediment Density Retrieval from hyperspectral BRDF data," Proc. IGARSS 2017, July 2017.

C. Jin, C. M. Bachmann, 2016. "Miigating noise in global manifold coordinates for hyperspectral image classification, Proc. of SPIE 9976, Imaging Spectrometry XXI, Detection and Data Characterization, 99760J-1 - 99760J-17, August 2016, http://dx.doi.org/10.1117/12.2239207.

Kafle, K., Kanan, C. (2017) An Analysis of Visual Question AnsweringAlgorithms. In: *International*

Conference on Computer Vision (ICCV-2017). [29% accept rate]

Kafle, K., Kanan, C. (2017) Visual Question Answering: Datasets, *Algorithms, and Future Challenges. J. Computer Vision and Image Understanding (CVIU).* doi:10.1016/j.cviu.2017.06.005

Kafle, K., Yousefhussien, M., Kanan, C. (2017) Data Augmentation for Visual Question Answering. In: *International Conference on Natural Language Generation (INLG-2017).*

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

Wang, Yue and Ientilucci, E. (2017). Landsat 8 TIRS Calibration with External Sensors. In: Proc. SPIE Earth Observing Systems XXII. SPIE. San Diego, CA:

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

Zhao, Runchen. and Ientilucci, E. (2017). Invited Paper: Improvements to an Earth Observing Statistical Performance Model. In: Proc. SPIE Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXIII. Vol. 10198. SPIE. Anaheim, CA:

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

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

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, 74, 1-6.

Eric Lifshin, Matthew Zotta, David Frey, Sarah Lifshin, Mandy Nevins, and Jeffrey Moskin (2016). "A Software Approach to Improving SEM Resolution, Image Quality, and Productivity." *Microscopy Today* 25, 18-24

Najat A. Alharbi, Richard K. Hai stone, and Benjamin Varela (2017). "A Microscopic Characterization of Alkali-Activated Slag." Non-Traditional Cement & Concrete, Brno, Czech Republic, June.

Graduates

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

- Brittany Lynn Ambeau, Using the Opposition Effect in Remotely Sensed Data to Assist in the Retrieval of Sediment Density Adviser: Charles Bachmann, Ph.D.
- Alexandra B. Artusio-Glimpse, The Realization and Study of Optical Wings Adviser: Grover Swartzlander, Ph.D.
- Colin Murphy Axel, Towards Automated Analysis of Urban Infrastructure after Natural Disasters Using Remote Sensing Adviser: Jan van Aardt, Ph.D.
- Yehuda Kfir Ben-Zikri, Medical Image Computing Tools in Support of Computer-aided Diagnosis: Respiratory, Cardiac and Orthopedic Applications Adviser: Cristian Linte, Ph.D.
- Lei Fan, Graph-based Data Modeling and Analysis for Data Fusion in Remote Sensing Adviser: David Messinger, Ph.D.
- Justin Harms, The Design and Implementation of GRIT-T: RIT's Next-generation Field-Portable Goniometer System Adviser: Charles Bachmann, Ph.D.
- Can Jin, Characterization and Reduction of Noise in Manifold Representations of Hyperspectral Imagery Adviser: Charles Bachmann, Ph.D.
- Gajendra Jung Katuwal, Machine Learning Based Autism Detection Using Brain MRI Advisers: Stefi Baum, Ph.D., and Andrew Michael, Ph.D.
- Kelly Grace Laraby, Landsat Land Surface Temperature Product: Global Validation and Uncertainty Estimation Adviser: John Schott, Ph.D.
- Douglas MacDonald, Modeling the Radar Return of Powerlines Using an Incremental Length Diffraction Coefficient Approach Adviser: Michael Gartley, Ph.D.
- Troy McKay, Detection of Anomalous Vehicle Loading Adviser: Carl Salvaggio, Ph.D.
- Leidy P. Dorado-Munoz, Spectral Target Detection using Schroedinger Eigenmaps Adviser: David Messinger, Ph.D.
- Rajagopalan Rengarajan, Evaluation of Sensor, Environment and Operational Factors Impacting the Use of Multiple Sensor Constellations for Long Term Resource Monitoring Adviser: John Schott, Ph.D.
- Philip Salvaggio, Image Quality Modeling and Optimization for Non-Conventional Aperture Imaging Systems Adviser: John Schott, Ph.D.
- Burak Uzkent, AERIAL VEHICLE TRACKING USING A MULTI-MODAL SENSOR Adviser: Matthew Hoffman, Ph.D.
- Fan Wang, Understanding high resolution aerial imagery using computer Vision Adviser: John Kerekes, Ph.D.
- McKay D. Williams, Generation, Validation, and Application of Abundance Map Reference Data for Imaging Spectroscopy Unmixing Adviser: Jan van Aardt, Ph.D.
- Wei Yao, Investigating the Impact of Spatially-explicit Sub-pixel Structural Variation on the Assessment of Vegetation Structure

from Imaging Spectroscopy Data Adviser: Jan van Aardt, Ph.D.

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

- Grant Anderson, *An evaluation of the silicon spectral range for determination of nutrient content of grape vines Advisers:* Jan van Aardt, Ph.D, Peter Bajorski, Ph.D
- Ritu Basnet, *Automated Quality Assessment of Printed Objects Using Subjective and Objective Methods Based on Imaging and Machine Learning Techniques* Adviser: Jeff B. Pelz, Ph.D.
- Emily Elizabeth Berkson, *A proposed multispectral imaging system to monitor unburned hydrocarbons emitted in aircraft jet engine exhaust* Adviser: David Messinger, Ph.D.
- Jack David Horowitz, *Characterization of Optimized Si-MOSFETs for Terahertz Detection* Adviser: Zoran Ninkov, Ph.D.
- Nirmalan Jeganathan, *HYPERSPECTRAL AND HYPERTEMPORAL LONG-WAVE INFRARED DATA CHARACTERIZATION* Adviser: John Kerekes, Ph.D.
- Tania Kleynhans, *Estimating top-of-atmosphere thermal infrared radiance using MERRA-2 atmospheric data* Adviser: Christopher Kanan, Ph.D.
- David Brian Rhodes, *Radiometrically Correct Synthetic Video Development of Thermal Vehicle Targets* Adviser: Zoran Ninkov, Ph. D.
- Paul Sponagle, *Automated flight planning for rooftop inspection using a facet-based approach* Adviser: Carl Salvaggio, Ph.D.
- Joseph Svejkosky, *Hyperspectral Vehicle BRDF Learning: Seeking Illuminant Invariant Signatures For Vehicle Reacquisition and Tracking* Adviser: Emmett Ientilucci, Ph.D.
- Jared Dale Van Cor, *Characterizing Resident Space Object Earthshine Signature Variability* Adviser: Michael Gartley, Ph.D.
- Zhenlin Xu, *3D Subject-Atlas Image Registration for Micro-Computed Tomography Based Characterization of Drug Delivery in the Murine Cochlea* Adviser: Nathan Cahill, Ph.D.

The following are post-graduate plans for some of the students who graduated during 2016-2017.

Can Jin—Display Color Imaging Engineer, Apple, San Francisco, CA

Kelly Laraby—Research Software Engineer, Eagleview, Henrietta, NY

Gajendra Katuwal—Machine Learning Scientist, Philips Research, Cambridge, MA.

Colin Axel—Geospatial Scientist, PrecisionHawk.

Ritu Basnet—Research Scientist, Conduent,Webster,NY

A freshman-designed motion capture system for use in virtual cinematography was a huge hit at this year's ImagineRIT Innovation and Creativity Festival.

IMAGING SCIENCE UNDERGRADUATE PROGRAM

Comments by Joe Pow, CIS Associate Director

The hallmark of the undergraduate program has always been the experiential education that our students receive.

The Center offers an unmatched number of opportunities for students to engage in experiential learning locally, regionally, and nationally through co-op experience in private or government labs, research experiences in academic institutions and labs, internship opportunities at public and private institutions, professional development activities, and through specific program coursework. These experiences all emphasize learning through doing or performing actions that promote the skills of critical thinking in iterative cycles of both reflection and active experimentation.

That exposure to experiential learning begins on the first day of the freshman year with the Freshman Imaging Project class. The 2016–2017 academic year marked the seventh time that the Center has offered this innovative course. This year a total of 16 students from Imaging Science and Motion Picture Science worked as a single, integrated design team to develop a "virtual cinematography" studio—a system which would use imaging to capture the motion of an actor, a light, and a camera in a "real world" set, and to have those motions mirrored in an animated "virtual world." The goal of the project was to reduce the cost to produce realistic computer generated videos while giving directors more of the creative control that has been typically been the responsibility of animators in these kinds of productions. Like all previous freshman projects, the system was put on display for the 30,000 attendees at the annual ImagineRIT Innovation and Creativity Festival.

Freshmen Ari Porkos and Lenny Wilkinson make adjustments to light emitting diodes on a student-developed motion capture suit being worn by Peter Jarvis.

CIS undergraduates also end their academic careers with a hands-on learning experience through their capstone senior project. The senior projects for the 2016–2017 academic year were as follows:

Timothy Bauch

"Low-cost and effective Structure-from-Motion 3-dimensional geometric reconstructions of targets at macroscopic scale"

Advisor: Carl Salvaggio

When an artist creates a painting there are always concerns over being able to properly protect the authenticity of their work. Counterfeiters may try to replicate the artwork and claim it as genuine. If an artist can accurately ascertain the surface topography of their artwork, they will be able to win any legal dispute of the authenticity of such work. There are currently many methods with which they may be able to properly image and protect their artwork. High-resolution, topographic detailing usually carries a high cost and may not be economically feasible for the average artist. This paper proposes a low cost, portable, and easy to use system that an artist, or other practitioner, may be able to use in order to measure surface structure on their paintings, currency, or other documents in order to protect its authenticity.

Through the combination of a computerized numerical controlled (CNC) machine with a common DSLR camera we have been able to put together a low-cost system that will give us all the data necessary for 3D surface reconstruction. This data can then be sent into any structure-from-motion photogrammetry software program on the market and produce an accurate model of the surface at a fraction of the cost of many other high-end surface-topography systems. This device has shown promise as a prototype off the shelf imaging system with a high degree of accuracy for the relatively low price point of the system.

Kelly Patterson

"Validation of Reference Data Using Hyperspectral Imagery from SHARE 2012"

Advisor: Jan VanAardt

This project validates a novel method for producing high spatial resolution reference data, commonly known as "ground truth" data. Hyperspectral imagery from the SHARE 2012 campaign is used for a test site in Avon, NY. Common forms of reference data have limited spatial resolution. Multiple versions of abundance map reference data (AMRD) are produced for the test site. An abundance map identifies the material (e.g., vegetation, pavement, water, etc.) associated with image elements. Nine independent sets of AMRD are produced for 10 pseudo-randomly chosen 10x10 meter plots in the scene. The nine independent sets include the following production methods: non-negative least squares (NNLS) unmixing algorithm (1), spectral angle mapper (SAM) classification algorithm (1), Euclidean distance (ED) classification algorithm (1), imagery analysis by three observers (3), and field surveying by the same three observers (3). The mean of all of the abundance maps presumably represents the true abundance data. Each version of AMRD is compared to the mean for accuracy assessment of each production method. The unmixing algorithm reference data has the smallest average MAE, meaning for all plots and classes it is the closest to the mean abundance data.

Seth Baker

"On Mapping Corn Yield Using Structure-From-Motion Data From Unmanned Aerial Systems"

Advisor: Jan VanAardt

- Sufficient crop yield demands the application of fertilizers and pesticides.
- Existing application approaches have multiple drawbacks:
    - o Chemical distribution is not efficient;
    - o Potential negative impacts on environment; and
    - o Not cost-optimized
- Crop yield and biomass estimation, derived from 3D structural metrics, has undergone little or no testing.
- This project assesses the accuracy of 3D corn crop models (plant height, canopy metrics, DEM) at different stages during the growing season.

Use 3D structural metrics as independent variables to develop corn yield and biomass (carbon) models.

Leah Bartnik

"Multispectral Detection of Subterranean Features"

Advisor: David Messinger

In archaeology, remote imaging can be invaluable in the field because some dig sites are either difficult or impossible to access on foot. In the past, archaeologists have managed to use government-issued satellite imagery to aid in field survey. However, satellite imagery typically only has single to several meter resolution at best, rendering the images almost useless except for general site mapping. In addition to satellite and small airplane visible imaging, LIDAR imaging from systems attached to low-flying planes has been used to make topological maps of sites; however, LIDAR images require several fly-bys to achieve usable resolution and are therefore similarly expensive, data- and power-intensive. Our proposed project solves the problems of resolution, excessive fuel consumption, and inaccessibility of remote imaging technology by using a UAV mounted with several imaging sensors that not only create a stitched image of a site but also reveal possible locations of subterranean features such as toms or stairwells. For more information, see the news item later in this section.

In addition to an RGB reference image of a site, two important spectral regions also need to be considered in order to extract the data required to make a map of subterranean features; the near-infrared and the far or thermal-infrared regions. Near-infrared data is used with RBG to create an NDVI map of the site. Furthermore, areas that designate a thermal anomaly correlated with a stressed region in an NDVI map may e an indicator to an archaeology that an object of interest is at that particular location. Ultimately, the end product is a three-dimensional model of the site created using structure from motion algorithms that includes RGB, three NIR bands, the NDVI map and thermal data to serve as a tool for the archaeologist.

Kevin Moser

"Cosmic Ray Damaged Image Repair"

Advisor: Don Figer

High velocity particles in space known as cosmic rays can strike the electronics, such as in an imaging sensor, and create permanent damage. This cosmic ray damage can lead to slightly structured random high value impulse noise throughout the scene which visually and analytically alters the image and which can be repaired for future use. We proposed an algorithm to process the raw data NASA captures from Nikon cameras on the International Space Station in order to remove the effects of cosmic ray damage in a way that is compatible with NASA workflow. A statistical z-score method and a structural convolution method were evaluated against marked images to calculate false positives and negatives results. The convolution method produced very low false positive and false negative rates and preserved important image details, such as in images of stars and the edges of the space station. The algorithm saves the restored raw data format for use later in Adobe Suites. For more information, see the news item later in this section.

Bijia Chen

"Active Vision for Visual Question Answering"

Advisor: Chris Kanan

Recently, great attention has been placed on the interaction between computer vision and natural language processing. One of these tasks is Visual Question Answering (VQA) where a system needs to be able to answer natural language based questions for a given image. In this paper we propose a new model which simulates the human visual system to solve VQA problems.

Adam Casson

"VUE-QA: Video Question Answering Using Deep Neural Networks"

Advisor: Chris Kanan

- Visual Question Answering (VQA) systems combine visual and language understanding to answer questions about static images.
- There is very limited work for adapting VQA to videos.
- We propose a new video QA dataset called VUE-QA (Video Understanding Experimentation with Question Answering).
- VUE-QA has 261,595 QA pairs for 11,970 videos
- We use a novel question generation scheme to convert video descriptions into AQ pairs.
- We establish baseline results to evaluate performance on VUE-QA.
- We present a full video question answering model with a novel video feature embedding pipeline.

Sadie Wolters

"Early Detection of White Mold in Snap Beans"

Advisors: Jan VanAardt, Carl Salvaggio

Snap beans are the fifth most grown vegetable crop in the United States by acreage. In 2015, 158,920 acres of snap beans were harvested for processing and 71,170 acres were harvested for fresh market in the United States, worth a combined value of $416 million. New York state ranks second in the nation for snap beans planted for processing and fresh market. White mold caused by the fungus Sclerotinia sclerotiorum devastates these crops across the United States. White mold is one of the most debilitating plant diseases in the world, and affects vegetable and field crop yields. The use of precision agriculture to combat this fungus and others like it is a growing area of research, and the first and most important step in doing this is the earlhy and accurate detection of white mold, before its symptoms are visible to the human eye, allowing agriculturalists to monitor plant health and eradicate the fungus before it has destroyed their crop. The wealth of data and information inherent to hyperspectral reflection data makes it an excellent resource for this research. To address this, hyperspectral data were collected by hand in a semi-controlled environment, for several days after the plants were infected with the mold. The data were analyzed using stepwise regression and linear discriminant analysis, to investigate possible differences the reflectance spectra of treated and untreated plants, as well as possible differences between fungicides. The treated and untreated spectra were more easily classified (72% overall accuracy) than the different fungicides (44% overall accuracy).

Lindsay Martinescu

"Differentiating crop treatments using UAS multispectral imagery: Fertilization in corn"

Advisors: Jan VanAardt, Carl Salvaggio

Recent growth in the field of remote sensing, utilizing unmanned aerial systems (UAS), has led to new applications in precision agriculture, and has allowed for new developments in classification of crop fields, especially with regard to detecting treatment and fertilization differences of corn. Over the course of the 2016 growing season, in a controlled field maintained by Advanced Biological Marketing (ABM), data was collected by a Tetracam Mini-MCA flown via UAS. The field consisted of 384 plots, we focused on 32 plots containing a control, ABM's current product SabrEx, and two pipeline products Omega, and K5AS2. Spectral analysis via established methods like linear discriminate analyses, canonical discriminate analysis, and various vegetation indices, was used to assess our ability to differentiate between crop treatments; both ABM type and fertilization level. From the data gathered, July or the middle of corn's growing cycle, is the best time to fly to determine the effects of fertilization levels. Differentiating by ABM type was not as significant as differentiating by fertilization level. This information can aid ABM in assessing which product performed best and allow for more informed decisions on how their products perform over a growing season.

Nick Ng

"Calibrating Polarization Imaging Camera by Observing Birefringence in Transparent Media"

Advisor: Zoran Ninkov and Dmitry Vorobiev

Birefringence is observed in many materials such as crystals, fibers, and polymers. These materials are composed of long molecules that primarily align in a preferred direction. Stress to these materials will induce birefringence. This molecular alignment causes linearly polarized light that is parallel to the molecules to experience a different index of refraction than polarized light perpendicular to the molecules. This project aimed to observe and measure birefringence in very anisotropic materials (polymers), somewhat anisotropic materials (quartz), and isotropic materials (glass) using the KAI 04070 housed in the Microline camera. To measure birefringence, typically a large setup such as an optical interferometer is used and requires alignment of the images. This compact design and micropolarizer array eliminates these problems. Preliminary results show that this system can detect the retardation in polymers and quartz plates, but cannot detect retardation in thin glass samples

NEWS

NASA astronaut photography gets big boost from RIT students and faculty

May 11, 2017

by Lauren Peace

An informal collaboration among RIT students, alumni and professors culminated in a meeting last week at NASA's Johnson Space Center in Houston.

Kevin Moser, an imaging science student from Rochester, Minn., and RIT alumnus Peter A. Blacksberg '75 (photography) made the trip south to meet with the heads of various NASA departments and present an algorithm that Moser spent the last year developing under the Center for Detectors at RIT.

Moser's work represents the culmination of research and development done by several student predecessors on the Cosmic Radiation Damage Image Repair (CRIDR) project. The algorithm he developed will remove the effects of bad pixels damaged by cosmic rays that penetrate detectors in the commercial cameras used to take photographs by astronauts on the International Space Station. It replaces values in the bad pixels with a statistical representative of values in surrounding pixels.

"This project was initially just summer work for me, but I had the opportunity to turn it into my senior project and continue to work on it throughout the year," said Moser, who became involved after responding to an online job posting in 2016. "Seeing it all come together and having the opportunity to visit the Johnson Space Center was really rewarding."

Moser will present his work during the Center for Imaging Science senior project presentations on Friday, May 12.

Blacksberg, who has a passion for both photography and space, bought a ticket to hear astronaut Don Pettit speak in New York City in 2014. During the lecture, Pettit pointed out spurious pixel values in certain images that he said were the result of damage caused by high-energy particles that cause detectors in cameras to deteriorate when exposed to the harsh radiation environment in space.

Photo by—Peter A. Blacksberg Kevin Moser, an imaging science student from Rochester, Minn., presented an algorithm on May 3 to NASA officials at Johnson Space Center.

Blacksberg recognized this as a problem that needed a solution and knew that RIT was the place to find it.

"I approached Dr. Pettit after the lecture and introduced myself," said Blacksberg. "I asked him if he was familiar with RIT and gave him a business card. Little did I know that a friendship would form."

In April 2015, Blacksberg arranged for Pettit to visit campus to present his work to the RIT community. It was during this visit that Pettit met with a handful of RIT professors and student researchers to discuss ways to reduce the damage to photographs caused by cosmic rays in space.

Don Figer, director of the Center for Detectors, was part of the meeting.

"Peter and Don came to us with this problem a few years ago, looking for a way to 'fix' damaged images," Figer said. "This project is very different than any other project I've worked on because ours tend to have a standard project management flow, and this one does not. It's more collaborative, and we've had several students work on it, Kevin being the current one."

When Pettit was pointing out the damaged pixels in his images, he was referring to regions of his photographs that contained pixels with values of stark contrast to their neighbors. Visually, these appeared as very bright spots in an otherwise dark scene and vice versa. A similar effect can be seen in a flat-screen TV that has pixels that are permanently "on."

"When a photograph is taken in space, some of the pixels are altered in a way that causes them to produce their own signal," said Figer. "Detectors normally produce a little bit of signal anyway, but cosmic rays are damaging the detectors in a way that is causing the pixels to produce bigger signals than they typically would. We use the word 'damage' to describe it."

While damaged images could be opened in Photoshop and touched up individually, this process is unfeasible for NASA, where images come in at a rate of 10,000 to 50,000 per week.

The algorithm developed by Moser and others at RIT provides a post-processing fix to the problem.

"Kevin's algorithm isn't finding the real information and putting it back in the pixel, rather it's finding the bad pixel and then replacing the signal in that pixel with an average of the surrounding pixels," Figer said.

Photo by—Peter A. Blacksberg Student Kevin Moser and astronaut Don Pettit talk at Johnson Space Center.

Although the algorithm does produce some false positives and false negatives, it marks a big step forward in the efforts to find a long-term solution. Pettit said that he is excited to see the results of the continued efforts in the future.

"I can see many applications for the process both for my photographs and those of Earth-bound astrophotographers," Pettit said. "I am especially pleased to have RIT involved with our NASA photography and photo science folks—many of them are RIT alumni. What really matters is inspiring the next generation to be involved in science and discovery, and I think RIT is doing just that."

Indiana Drones: Unmanned aerial vehicle gives archeologist a cool tool

Imaging science and engineering students showcase their senior design project at Imagine RIT

April 24, 2017

by Susan Gawlowicz

An off-the-shelf drone customized for archeological surveys by Rochester Institute of Technology students will be on exhibit at the 10th annual Imagine RIT: Innovation and Creativity Festival on May 6.

The Multispectral Imaging Drone will be located all day in The Think Tank zone in the Mobius Quad on the RIT campus. Members of the senior design team from the Kate Gleason College of Engineering and the College of Science developed the drone as an archeological survey tool to locate potential artifacts prior to a dig. Data taken off the drone could be used to locate objects on the ground or buried a few meters below the surface.

The idea began with project manager Leah Bartnik, a senior in RIT's Chester F. Carlson Center for Imaging Science, who grew up in West Seneca, N.Y., near the Penn-Dixie Fossil Park and Nature Reserve. While in high school, Bartnik worked at Penn-Dixie during the summers and fell in love with paleontology.

She wanted her senior capstone project to combine her interests in imaging science and paleontology, and to give her experience on an engineering team. Because RIT doesn't have a resident paleontologist, Bartnik used her senior capstone project in imaging science to customize an imaging system for archeologist William Middleton, associate professor in RIT's College of Liberal Arts. The team designed their drone to accommodate Middleton's search for Mayan ruins at an excavation site in Oaxaca, Mexico.

Bartnik designed the imaging system that clips on to the drone and measures chlorophyll, or the green pigment in vegetation. Her system combines a regular camera and near infrared sensors to measure the green pigment reflected in different wavelengths of light. Low levels of chlorophyll are a clue that an object of interest might be obstructing the roots. The thermal camera in the imaging system provides additional information to support or disprove the hunch.

"If there is a feature that emits heat at a different rate than the ground, and its position correlates with a feature that is stressing out the vegetation, there is probably something right at the surface or a few meters below," Bartnik said.

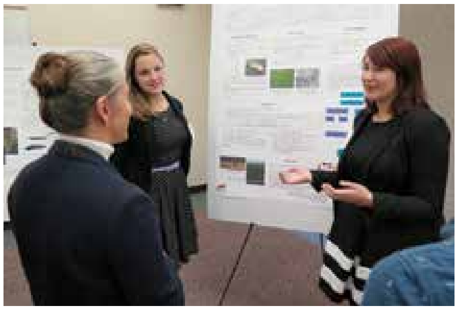
The imaging system is about the size of a tissue box and attaches to the custom-made gimbal built by mechanical engineers Ben McFadden from Fairport, N.Y., and Gavin Bailey, from Remson, N.Y. The carbon-fiber gimbal is the pivotal support mounted to the drone.

The imaging system and the gimbal had to be integrated with drone. The four electrical engineers on the team—Ryan Moore from New Hartford, N.Y.; Jeremy Sardella from Buffalo, N.Y.; Stephen Depot from Utica, N.Y.; and Arthur Svec from Fairfax, Va.—tied together the various software and control systems, including a flight planning system.

Imaging scientists, mechanical engineers and electrical engineers approach problems from the perspective of their own disciplines, and the project's success depended on the students' ability to interrelate. The yearlong project gave them insight into what makes a successful team work.

"We all communicated very well together, and we kept up to date with what everyone was doing," Sardella said. "There isn't a single person in the group who didn't pull their weight."

Campus Spotlight



Nov. 8, 2016   Photo by—Jacob Kaucher

Sadie Wolters, center, from Hilton, and Lindsay Martinescu, from Webster, fourth-year students in RIT's Chester F. Carlson Center for Imaging Science, presented their research on detecting white mold in snap beans using spectral remote sensing and drones at the "Systems and Technologies for Remote Sensing Applications Through Unmanned Aerial Systems," or STRATUS 2016, Workshop at RIT on Oct. 28. The workshop—sponsored by RIT's Center for Imaging Science, IEEE Geoscience and Remote Sensing Society, Pictometry and Headwall Photonics—brought together academics, industry representatives and domain specialists to share perspectives on UAS imaging. The UAS Center is an RIT signature research area.

Honeoye Falls Drone. Image of the Matrice-100 flying near Honeoye Falls, NY [Image provided by Martin LaChance].

DIGITAL IMAGING AND REMOTE SENSING LAB

Laboratory Director's Comments By Dr. John Kerekes

The DIRS Lab continued to be an active research and education hub during the 2016–2017 academic year contributing toward remote sensing science and engineering, as well as producing graduates poised to make immediate contributions to their organizations.

New research awards received during this past year totaled over $4M from fifteen different sponsoring organizations including industry, non-profit organizations and government agencies. More than fifteen students (BS, MS, PhD) received their imaging science degrees with a concentration in remote sensing. In addition, our faculty, staff, and students continued to be active professionally by publishing and serving their professions, with their contributions being recognized through awards and recognition.

New research grant highlights of the year included:

- Associate Professor Charles Bachmann received a research grant from the National Geospatial Intelligence Agency to develop and demonstrate with hyperspectral imaging the acquisition of geotechnical parameters in littoral regions to map trafficability;
- Assistant Research Professor Emmett Ientilucci received a grant from Oak Ridge National Laboratory to conduct fundamental research into the end-to-end performance evaluation of remote sensing imaging sensors carried by unmanned aerial systems;
- Senior Research Scientist Aaron Gerace received a research grant from the United States Geological Survey to continue his efforts to improve the calibration of Landsat thermal infrared sensors;
- Professor John Kerekes received a grant from the National Aeronautics and Space Agency in collaboration tih DRS Technologies to model and perform field validation studies for a prototype multispectral thermal imaging airborne sensor using a microbolometer array; and
- Professor Carl Salvaggio received a research grant from the Northeast Gas Association to conduct fundamental investigations into the use of small unmanned aerial systems to inspect gas transmission infrastructure.

Example graduate dissertations included:

- Kelly Laraby, Ph.D., "Landsat Surface Temperature Product: Global Validation and Uncertainty Estimation";
- Emily Berkson, M.S., "A Proposed Imaging System to Spatially and Temporally Monitor Unburned hydrocarbons in Jet Engine Exhaust";
- Lei Fan, Ph.D., "Graph-based Data Modeling and Analysis for Data Fusion in Remote Sensing."

Award, recognition, and professional activity highlights included:

- The DIRSIG Development Team including Principal Scientist Scott Brown, Senior Scientist Adam Goodenough, and Research Scientist Rolando Raqueno were recognized by receiving the United States Geospatial Intelligence

Forum's Academic Achievement Award presented at the 2017 GEOINT Symposium;

- Senior Scientists Aaron Gerace and Matthew Montanaro received recognition for development of an operational algorithm to correct a calibration problem on the Thermal Infrared Sensor on Landsat 8;
- Founding DIRS Director Professor John Schott was honored as the Faculty Award Recipient at the 2017 RITirees Dinner & Award Ceremony;
- M.S. Graduate Tania Kleynans was selected as the Graduate Student Commencement Speaker during the May 2017 graduation ceremonies;
- Assistant Research Professor Emmett Ientilucci chaired an inaugural one-day workshop on Systems and Technologies for Remote Sensing Applications Through Unmanned Aerial Systems (STRATUS) held at RIT in October 2016 which attracted over 80 participants. DIRS doctoral student Ryan Ford received an award for best oral presentation at the workshop.

While there was much to celebrate over the past year we are saddened to report the passing of Cindy Schultz, our longtime Staff Assistant, as she succumbed to cancer in August 2016. Cindy will be remembered fondly, and in celebration of her life current and past members of DIRS contributed toward a memorial plaque placed on a seat in the Gene Polisseni Center.

The DIRS Laboratory staff grew over this past year as recent RIT CIS alum Timothy Bauch was hired as a Lab Engineer to oversee our growing UAS hardware activity and assist in our field collections. Another recent RIT CIS alum, Jared Van Cor, was hired as an Assistant Research Scientist to join the DIRSIG team and contribute to our growing modeling and simulation research. Additionally, Colleen McMahon was hired as a Senior Staff Assistant to support our ever-expanding work. We now have 10 full-time faculty, 12 full-time research and administrative staff, and over 35 graduate students engaged in DIRS activities.

The following research summaries present a few examples of our 40+ ongoing research projects.

Unmanned Aerial Systems

Established in 2016 as one of RIT's signature research initiatives under the leadership of Dr. David Messinger and Dr. Carl Salvaggio, our UAS (drone) imaging systems research area grew significantly over the past year with the acquisition of several hardware sensors and platforms and new research activities underway.

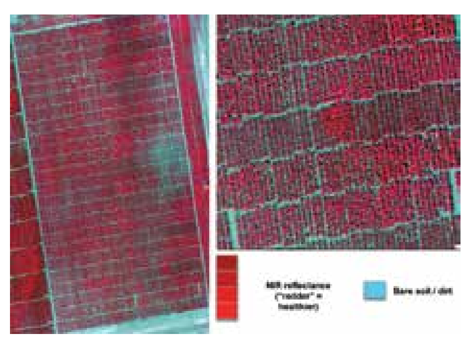
In collaboration with Headwall Photonics, a multi-modal payload has been developed and integrated with a six-rotor copter platform. Fig. MX1 shows the system undergoing initial tests with a VNIR hyperspectral, a lidar, a thermal infrared imaging microbolometer and a color camera all mounted together.

MX1. Multimodal acquisition UAS being prepared for initial tests.

Dr. Salvaggio has been leading many of the UAS activities and in one particular project has been working with MS student Paul Sponagle on the development of flight planning software to acquire imagery from drones using unique flight plans designed to acquire imagery for the purpose of 3D point cloud extraction. Another recently initiated project led by Dr. Salvaggio is an investigation of remote sensing methods to detect areas of stressed vegetation near natural gas pipelines as a potential indicator of a leak in the pipeline. Hyperspectral imagery are being acquired from our drone platforms to test the feasibility of these methods.

In collaboration with scientists from Cornell University and with funding from the United States Department of Agriculture (USDA), Dr. Jan van Aardt and Dr. Salvaggio have been working with MS student Mike McClelland and PhD student Ethan Hughes on developing a risk model for white mold in snap beans. This project has as its primary goal to develop maps that a farmer can use to judiciously apply fungicide only when and where needed. Drs. van Aardt and Salvaggio are working with plant pathologists Dr. Sarah Pethybridge and Dr. Julie Kikkert from Cornell University to apply lidar and imaging spectroscopy data to this problem.

Dr. van Aardt and his team have also begun a project in collaboration with Dr. Thomas Trabold of RIT's Golisano Institute of Sustainability (GIS) with support from Staples, Inc., using UAS-based lidar and imagery data to assess whether growers are subscribing to sustainable forest harvesting practices. Dr. Trabold is investigating the development of UAS fuel cells for increased flight duration. This is but one example of the cross-disciplinary collaborations ongoing in DIRS.

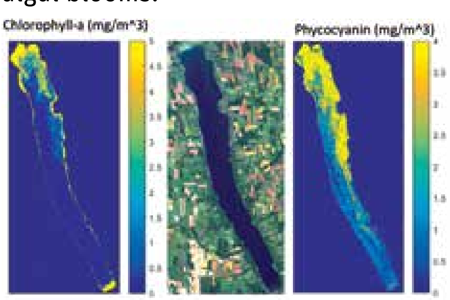


Cornfield. An example of UAS-based Tetracam imagery of a cornfield in Lyons, NY. In this case the display shows near-infrared = Red, red = Green, and green = Blue. Vegetation reflects

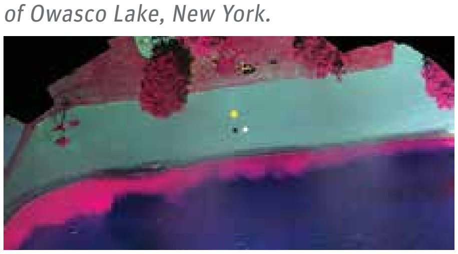
NIR heavily, but in varying degrees, depending on a plant's physiological condition. The variation in NIR (Red display) indicates plants under varying levels of physiological stress.

Remote Sensing of Water Quality

As Prof. John Schott transitions to retirement, Prof. Anthony Vodacek has continued research together with PhD student Ryan Ford on algorithm development for Landsat 8 and future Landsat sensors as applied to inland and coastal water quality monitoring. The approach, begun under the direction of Prof. Schott and being continued by Dr. Vodacek, is the Look-Up-Table and spectrum-matching method. In this method radiative transfer modeling is used to predict a wide variety of remote sensing reflectance scenarios from inland waters and real data are matched to the modeled data to find a best prediction of material concentrations. Preliminary application of this technique to identify a harmful algal bloom in Owasco Lake, New York, is shown in Figure Owasco. To complement the satellite algorithm development the team is also imaging from a drone platform to broaden the potential application of the technique to smaller water bodies. An example drone image mosaic showing a harmful algal bloom at a beach in Honeoye Lake is provided in Figure Honeoye. These types of drone images can be used to better understand the distribution of these very localized harmful algal blooms.



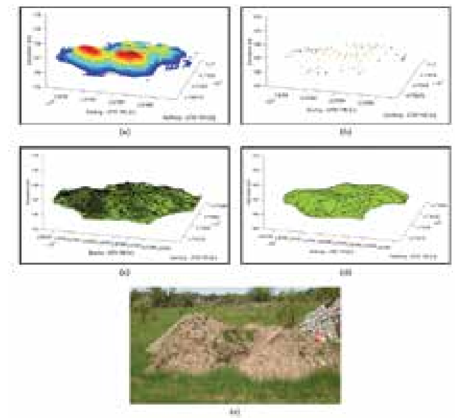
Owasco. Preliminary results of applying algorithms for extracting chlorophyll (left) and phycocyanin (right) concentrations from a Landsat 8 image (center, true color image) of Owasco Lake, New York.



Honeoye. A false color infrared image of the beach at the north end of Honeoye Lake, New York. The image data was collected with a multispectral camera on an RIT drone platform. The magenta colored band of water adjacent to the beach indicates the presence of a surface scum of cyanobacteria.

Assessing Road Network Condition Following a Disaster

Imaging Science PhD student Colin Axel recently completed his thesis on the use of remote sensing during disaster recovery situations under the direction of Prof. van Aardt, and in collaboration with researchers from the Rensselaer Polytechnic Institute, with funding from the Department of Transportation (DOT). The overall project goal was to develop tools for improved access restoration to critical resources and infrastructure, during the aftermath of a disaster. To this end, airborne and satellite remote sensing platforms have been used extensively to collect overhead imagery of disaster environments. In order to overcome the time and resource limitations of manual image interpretation, Axel investigated the feasibility of performing fully automated post-disaster analysis of roadways and buildings using airborne remote sensing data. Novel workflows were developed to automate three critical tasks: detection and volume estimation of roadway debris, building damage assessment, and flood inundation mapping and depth estimation. The debris detection and damage assessment algorithms leveraged local surface features calculated from airborne light detection and ranging (lidar) data to analyze the structure of objects in the disaster environment. Inundation mapping was performed using a target detection approach with 4-band, aerial imagery. Remotely sensed data collected during natural disasters between 2010 and 2016 were used to test the three methods. Results indicated that automated methods are successful and efficient at infrastructure analysis. This research is an important contribution, since any reduction in the latency between the disaster event and the delivery of damage maps to emergency responders, can reduce the impact of such disasters.



Debris. A comparison of high and low point density debris points and alpha shapes using a pile from a construction site in Rochester, NY. These data were used to assess the impact of lidar point density on detection and quantification of roadway debris. (a) A terrestrial lidar scan of the pile contains 41,179 points; (b) the airborne lidar scan of the pile, down-sampled to the density of the Haiti earthquake data, contains 128 points; (c) the alpha shape constructed from the high density data; (d) the alpha shape constructed from the low density data; and (e) an image of the debris pile.

Hyperspectral Imaging System

A new mast-mounted hyperspectral imaging system has come online this year. Acquired through a grant awarded in 2015 to Drs. Bachmann, Vodacek, and Hoffman (School of Mathematical Sciences) from the Defense University Research Instrumentation Program (DURIP), the system incorporates a Headwall micro Hyperspec high-efficiency imaging spectrometer operating in the visible and near infrared (VNIR) hosted on a General Dynamics Maritime pan-tilt mount. The system is being deployed in field settings on a telescopic mast that can raise the system from 2 meters to more than 15 meters above the ground. At these heights, the Headwall Hyperspec produces very high-resolution hyperspectral imagery. The high-speed pan-tilt mount enables a low-rate video mode in which a series of small hyperspectral images can be recorded. In addition to supporting a number of DoD sponsored research projects, the new system is also being used in a collaborative initiative funded internally through a Dean's Research Innovation Grant (DRIG) awarded to Dr. Bachmann and Dr. Christy Tyler (Environmental Sciences) to address carbon cycle science in coastal wetlands.

Hyperspec and Hyperspec_closeup. (Left) New hyperspectral imaging system during a test on the RIT campus in June 2017. The system incorporates a Headwall micro Hyperspec high-efficiency mounted on a General Dynamics Maritime pan-tilt and deployed on a telescopic mast. (Right) Close-up of the integrated Headwall Hyperspec and General Dynamics pan-tilt mount in Dr. Bachmann's GRIT Laboratory.

Combined 3D Processing of Electro-optical Data

Dr. Emmett Ientilucci has been supporting efforts by Ball Aerospace and Invertex, Inc. to develop methods to improve the atmospheric compensation of hyperspectral imagery acquired under a range of illumination using 3D information for lidar imagery or other data sources. Figure RIT_Campus shows some example airborne hyperspectral imagery acquired under this effort along with the retrieved image where the new method has recovered the true spectral nature of objects imaged in a shadow of the buildings.

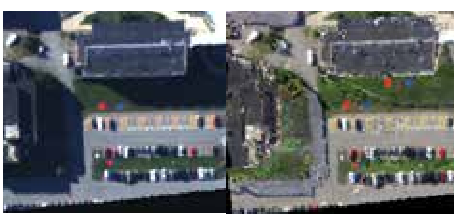


Figure RIT_Campus a and b: Hyperspectral (HS) image of the RIT campus showing colored targets (red, blue, green, brown) in (a) heavy shadow. (b) Shows the atmospherically compensated image where illumination differences between all pixels have been accounted for, thus colored targets in the shade look like their counterparts in the open.

Paul and Francena Miller Chair in International Education

Dr. Anthony Vodacek continued his second year of his two-year appointment as the Miller Chair with a focus on deepening the relationship between the University of Rwanda and RIT. In Rwanda, the African Centers of Excellence in Data Science, STEM Education, and the Internet of Things will be taking in their first M.S. student in September and first Ph.D. students in January 2018. The primary link for RIT faculty to the Centers will be through joint supervision of students, teaching of modules and short courses, and joint research proposal development. Prof. Vodacek led a January 2017 visit to the University of Rwanda to introduce Prof. Scott Franklin (School of Physics and Astronomy) and Prof. Ernest Fokoué (School of Mathematical Sciences) to the Centers.

Professional Engagement

DIRS Faculty and Staff continue to be active in their field beyond their direct roles in education and research. In addition to serving as reviewers, editors, and members of technical program committees, here are a few specific examples of this activity.

- Dr. Emmett Ientilucci co-chaired the SPIE Imaging Spectrometry XXI conference held in San Diego, California in August, 2016.
- Prof. Jan van Aardt served as an external PhD thesis examiner for a doctoral candidate at the University of Witwatersrand, South Africa in September 2016.
- Dr. Anthony Vodacek gave a keynote presentation at the Hyperspectral Imaging and Applications conference in Coventry, England, in October 2016.
- Dr. John Kerekes was appointed Chief Financial Officer of the IEEE Geoscience and Remote Sensing Society in January 2017.
- Dr. David Messinger co-chaired the SPIE Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXIV conference held in Anaheim, California in April 2017.

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Maitra, S.; Gartley, M. G.; Kerekes, J. P., "A Low-Cost Laboratory-Based Polarimetric Synthetic Aperture Radar System for Scattering Analysis," *IEEE Antennas & Propagation Magazine, 59, 2, pp. 130-141* (April 2017)

McKay, T. R.; Salvaggio, C.; Faulring, J. W.; Sweeney, G., "Remotely detected vehicle mass from engine torque-induced frame twisting," *Optical Engineering, 56, 6, pp. 063101-1-063101-8* (June 2017).

Salvaggio, P. S.; Schott, J. R.; McKeown, D., "Genetic apertures: an improved sparse aperture design framework," Applied Optics, 55, 12, pp. 3182-3191 (December 2016)

Schott, J. R.; Gerace, A. D.; Woodcock, C. E; Wang, S.; Zhu, Z.; Wynne, R. H.; Blinn, C. E.; "The impact of improved signal-to-noise ratios on algorithm performance: Case studies for Landsat class instruments," *Remote Sensing of Environment, 185, pp. 37-45* (November 2016)

Williams, M.; Parody, R.; Fafard, A.; Kerekes, J. P.; van Aardt, J. A., "Validation of Abundance Map Reference Data for Spectral Unmixing," *Remote Sensing, 9, 5, pp. 1-20* (May 2017).

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Han, S.; Fafard, A.; Kerekes, J. P.; Ientilucci, E.; Gartley, M.; Savakis, A., "Efficient Generation of Image Chips for Training Deep Learning Networks," *Proceedings of Automatic Target Recognition XXVII, SPIE Vol. 10202, 1020203, pp. 1-9, Anaheim, California, United*

States (April 2017).

Ientilucci, E. J., "New SHARE 2010 HSI-LiDAR Dataset: Re-Calibration, Detection Assessment and Delivery," *Proceedings of Imaging Spectrometry XXI, SPIE Vol. 9976, 99760I, pp. 1-9, San Diego, California, United States* (September 2016)

Jeganathan, N.; Kerekes, J. P.; Rosario, D., "Characterizing the temporal and spatial variability of longwave infrared spectral images of targets and backgrounds," *Proceedings of Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXIII, SPIE Vol. 10198, 101980K, pp. 1-11, Anaheim, California, United States* (April 2017)

Rengarajan, R.; Schott, J. R., "Modeling forest defoliation using simulated BRDF and assessing its effect on reflectance and sensor reaching radiance," *Proceedings of Remote Sensing and Modeling of Ecosystems for Sustainability XIII, SPIE Vol. 9975, 997503, pp. 1-11, San Diego, California, United States* (September 2016)

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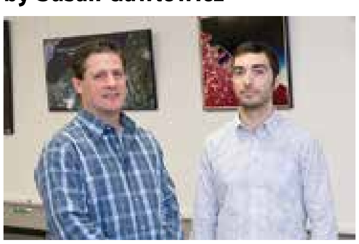
NEWS

RIT researchers fix Landsat 8 imagery, measurements with 'innovative' algorithm

Aaron Gerace and Matt Montanaro identified problem, developed correction

Nov. 16, 2016

by Susan Gawlowicz



RIT alumni Aaron Gerace '10 (imaging science), left, and Matt Montanaro '05, '09 (physics, imaging science) developed a data processing algorithm that mitigates the impact of stray light in the Landsat 8 thermal infrared sensor.

Rochester Institute of Technology researchers have solved a problem nagging NASA's Landsat 8 Earth-sensing satellite.

Stray light in the thermal infrared sensor, or TIRS, reduces accurate temperature measurements of the Earth's surface.

Software developed by Aaron Gerace and Matt Montanaro, senior scientists at RIT's Chester F. Carlson Center for Imaging Science, improves the accuracy of the Landsat 8 data. NASA funded their research with an $86,000 grant.

NASA and the U.S. Geological Survey have approved the algorithm that will automatically process and correct Landsat 8 images and refine reprocessed data.

NASA's Landsat program of Earth-orbiting satellites has monitored global changes to the landscape since 1972. Landsat satellites orbit the Earth's poles and pass over the same spot every 16 days to study how the Earth changes over time.

"Matt and Aaron were the developers, tuners and testers of the algorithm and its parameters," said Brian Markham, Landsat Calibration Scientist at NASA Goddard Space Flight Center. "The algorithm provides clear improvement in the image quality of the TIRS data and the ability to get accurate temperature measurements of Earth targets, such as lakes, particularly those surrounded by areas of different temperatures. This is important when you are trying to determine if targets are warming or cooling over time."

The effects of stray light on Landsat 8's thermal band measurements were detected shortly after the mission launched in February 2013. Defective optics in the thermal infrared sensor allow unwanted light to enter the optical system and disrupt accurate measurements. According to Gerace and Montanaro, errors have reached as high as 10 degrees Celsius in areas with extreme temperatures like Antarctic or desert regions. Mid-range surface temperatures more typical of the United States are less affected by these wide margins of error, they said.

"Everything you look at with Landsat 8 in the thermal infrared bands appears warmer than it should," Gerace said. "By implementing this fix, people can do accurate science because the temperatures coming from whatever they're looking at is correct now."

A new method to remove the effects of the stray light in the data became a high priority when standard calibration techniques failed to accurately adjust the imagery.

Montanaro had worked for NASA Goddard on the Landsat 8 calibration and TIRS instrument teams. The malfunction was traced to a hardware defect in the telescope, he said. "You would have to replace the telescope to fix this problem."

Gerace and Montanaro went beyond the quick fix of subtracting out the average error from the Landsat 8 imagery and developed a data processing algorithm to estimate the precise amount of extra light in each scene.

"The idea was that if you could determine from where the stray light is coming from and how much we're seeing, then you can use that information as a satellite flies over the scene to determine the stray light," Gerace said. "Our algorithm—adaptively per scene—figures out how much it should subtract to make the temperature accurate," Gerace said.

Jim Irons, deputy director of the Earth Sciences Division and Landsat 8 project scientist at NASA Goddard, called Gerace and Montanaro's solution "innovative."

"They performed a great deal of data analysis to convince the Landsat Science Team, a tough crowd, that their algorithm significantly and consistently improved the accuracy of TIRS data products," Irons said.

The U.S. Geological Survey Earth Resources Observation and Science Center in Sioux Falls, S.D., will begin using the software correction in its operational processing of Landsat 8 data in late 2016, Irons said.

The software correction anticipates a concern surrounding the future Landsat 9, slated to launch in 2020.

Montanaro will support the Thermal Infrared Sensor 2 for Landsat 9. "From headquarters to technical people, the No. 1 thing is, how do we prevent stray light from Landsat 9?"

NASA is implementing a hardware fix to the telescope for TIRS-2 before the launch, he noted.

A scientific paper validating Gerace and Montanaro's stray light correction for the Landsat 8 Thermal Infrared Sensor is currently under review.

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 2016–17:

Dmitry Vorobiev (AST - graduated)

Kevan Donlan (CIS)

Katie Seery (AST)

Ross Robinson (CIS)

Bryan Fodness (CIS)

Kyle Ryan (CIS)

Jack Horowitz (CIS - graduated)

Anton Travinsky (CIS)

David Rhodes (CIS –graduated)

Tiffany Cable (Manufacturing and Mechanical Systems Integration)

Undergraduate Students 2016–17:

Robert Ichiyama (Chemistry)

Alexander Knowles (Chemistry)

REU student Lee Bernard, Santa Rosa Junior College in Santa Rosa, CA.

Summer high school interns:

Ashley Cummings, Our Lady of Mercy High School

Peter Letendre, Webster Schroeder High School

Tristan Bachmann, Pittsford Mendon High School

1. Studies of the optical properties of TI DMDs an d 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 RIT-MOS 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)

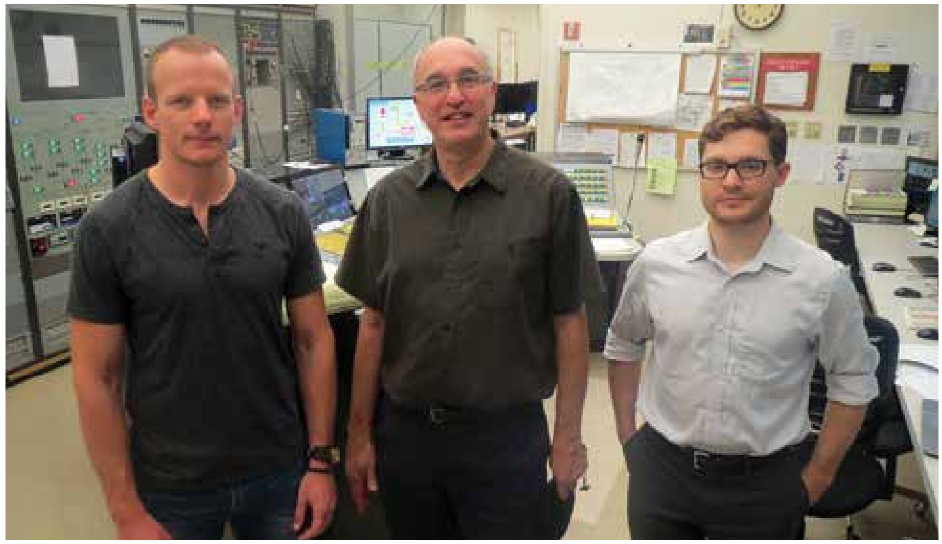


Figure 1: Travinsky, Ninkov and Vorobiev in the control room at the TAMU Cyclotron.

(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.

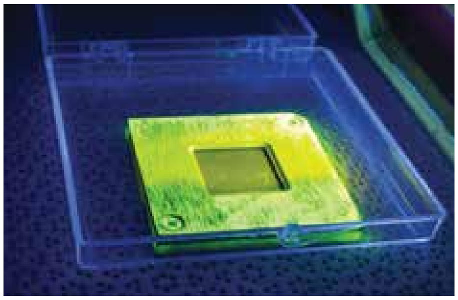


Figure 3: Quantum Dot coated detector in aluminum mask under UV illumination. The active area is 15mmx15mm

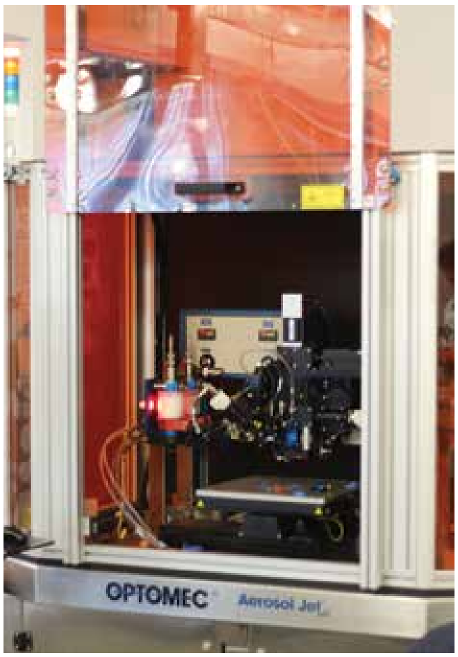


Figure 4: The Optomec Aerosol Jet sprayer used for these experiments at RIT.

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.

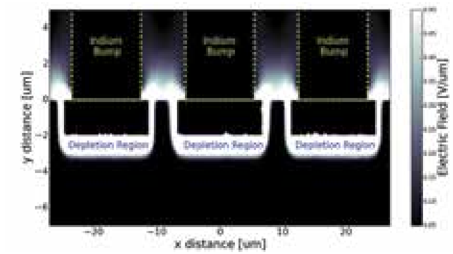


Figure 5: The strength and location of electric filed within pixels of a hybridized array.

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.

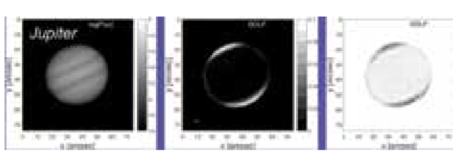


Figure 6: Images of Jupiter in integrated light (left), degree of linear polarization (center) and vector image of polarization (right).

(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.

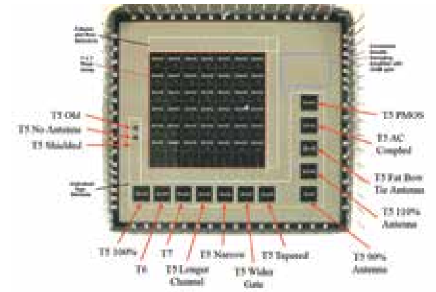


Figure 8 : Generation II MOSIS THz devices. Fifteen test structures are seen along the edges.

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. **Evaluation of digital micromirror devices for use in space-based multiobject spectrometer application**

Travinsky,A, Vorobiev,D., Ninkov,Z., Raisanen A., Quijada,M., Smee,S., Pellish J., Schwarz,T., Robberto M., Heap S,, Conley,D., Benavides, C.,Garcia N., Bredl,Z.,and Yllanes S.

Journal of Astronomical Telescopes, Instruments, and Systems (2017) accepted

2. **Using quantum-dots to enable deep-UV sensitivity with standard silicon-based imaging detectors**

Ichiyama, R. (Sch. of Chem. & Mater. Sci., Rochester Inst. of Technol., Rochester, NY, United States); Ninkov, Z.; Williams, S.; Robinson, R.; Bhaskaran, S. Source: Proceedings of the SPIE, v 10110, p 1011011 (9 pp.), 2017

3. **Modeling of hybridized infrared arrays for characterization of interpixel capacitive coupling**

Donlon, K. (Chester F. Carlson Center for Imaging Sci., Rochester Inst. of Technol., Rochester, NY, United States); Ninkov, Z.; Baum, S.; Linpeng Cheng Source: Optical Engineering, v 56, n 2, p 024103 (11 pp.), Feb. 2017

4. **Shock and vibration testing of digital micromirror devices (DMDs) for space-based applications**

Vorobiev, D. (Center for Imaging Sci., Rochester Inst. of Technol., Rochester, NY, United States); Travinsky, A.; Raisanen, A.D.; Ninkov, Z.; Schwartz, T.A.; Robberto, M.; Heap, S. Source: Proceedings of the SPIE, v 9912, p 99125M (13 pp.), 2016

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

Quijada, M.A. (NASA Goddard Space Flight Center, Greenbelt, MD, United States); Travinsky, A.; Vorobiev, D.; Ninkov, Z.; Raisanen, A.; Robberto, M.; Heap, S. Source: Proceedings of the SPIE, v 9912, p 99125V (10 pp.), 2016

6. **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

7. **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

8. **Terahertz detection in Si MOSFET 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

9. **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

10. **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

11. **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

12. **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

13. **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

14.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

15. 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

16. 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

17. 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

Laboratory for Advanced Instrumentation Research (LAIR) Research Group Picture July 2017

Left to Right: Lee Bernard, Kevan Donolan, Tristan Bachmann, Dmitry Vorobiev, Ashley Cummings, Zoran Ninkov, Katie Seery, Anton Travinsky, Peter Letendre

NEWS

RIT helps advance space camera being tested on ISS

Imaging technology could improve search for distant planets

March 6, 2017

by Susan Gawlowicz

Imaging technology advanced by researchers at Rochester Institute of Technology and Florida Institute of Technology is being tested on the International Space Station and could someday be used on future space telescopes.

Imaging technology advanced by researchers at Rochester Institute of Technology and Florida Institute of Technology is being tested on the International Space Station and could someday be used on future space telescopes.

A new twist on the charge injection device camera, originally developed in 1972 by General Electric Co., fine tunes the array of pixels for improved exposure control in low light conditions. The enhanced technology could give scientists a new method for imaging planets around other stars and improve the search for habitable Earth-like planets.

Zoran Ninkov, professor in RIT's Chester F. Carlson Center for Imaging Science, and Daniel Batcheldor, head of physics and Space Sciences at FIT, designed the charge injection device camera to capture contrasts between light emitted by astronomical objects.

"CID arrays offer considerable promise in many applications due to the focal plane architecture that allows random pixel access and non-destructive readout," said Ninkov, a member of RIT's Center for Detectors and Future Photon Initiative. "In addition to improving presently available devices, the development of next-generation imaging arrays promise considerable flexibility in read-out and on-chip processing for the future."

A SpaceX Falcon 9 rocket, on Feb. 19, carried the charge injection device to the International Space Station in the cargo of supplies and science experiments. Astronauts have installed the camera on a platform outside the space station. They will test the camera for six months.

"We expect to start seeing results by the end of April," said Batcheldor, lead scientist on the project. "A complex test pattern will be sent from a successfully operated camera through the ISS systems and down to the ground. A successful demonstration of CIDs on the International Space Station will put this technology at the NASA Technology Readiness Level 8, which means it's ready to fly as a primary instrument on a future space telescope."

Batcheldor is a former post-doctoral research associate in RIT's School of Physics and Astronomy and a former associate research scientist in RIT's Center for Imaging Science. He and Ninkov have worked together on this experiment for years. They previously have tested charge injection devices from ground-based observatories. Limitations created by the Earth's atmosphere prevent the sensor from capturing images sharp enough to detect planets in other solar systems, Batcheldor noted.

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.

kLab
Machine and Neuromorphic Perception Laboratory

Christopher Kanan's lab focuses on advancing the state-of-the-art in computer vision using machine learning and brain-inspired algorithms. 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 challenging problem that combines many aspects of computer vision: object segmentation, object detection, object recognition, activity detection, object counting, and more. Answering questions about images often requires reasoning and common sense, making this problem an important next step in creating flexible multi-task computer vision algorithms. With third year CIS Ph.D. student Kushal Kafle, Dr. Kanan published a paper in IEEE Computer Vision and Pattern Recognition (CVPR-2016) on VQA, 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. The lab has several new papers on VQA in review, which will likely appear soon. These papers examine the weaknesses in current VQA algorithms and provide a roadmap to overcoming them through better datasets.

Question: What is the man doing? **GT:** cutting **Prediction:** cutting

Question: What color is the shirt? **GT:** blue **Prediction:** blue

Question: Who is playing the music? **GT:** person **Prediction:** boy

The lab has been getting involved in remote sensing data analysis. With second 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) and stacked convolutional autoencoders. This approach enabled them to achieve state-of-the-art results on multiple datasets, even though the amount of data available was small compared to typical machine learning problems. Their work appeared in IEEE Transactions on Geoscience and Remote Sensing (TGRS). The lab is now using a variety of approaches to enable deep learning algorithms to work effectively for labeling pixels in multispectral and hyperspectral imagery.

Dr. Kanan published a paper at the 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.

Other ongoing projects in Dr. Kanan's lab involve automatically detecting the presence of invasive species, enabling neural networks to learn multiple tasks effectively, and building a deep learning model that incorporates constraints from the human visual system.

Three students graduated from Dr. Kanan's lab this year. Tania Kleynhans, M.S., worked on using deep learning to infer top-of-the-atmosphere thermal radiance data data from data assimilation products. Adam Casson, B.S., completed his senior project on creating a new algorithm and dataset for video question answering. Bijia "Cicy" Chen, B.S., completed her senior project on using active vision for VQA.

Graduating students from Kanan's Lab

Tania Kleynhans, M.S.

Adam Casson, B.S.

Bijia Chen, B.S.

PerForM Lab

Gabriel Diaz' Performance For Motion (PerForM) laboratory received a Google Research Award for the development of "Event detection in Real and Virtual Environments." The award will be used to support graduate and undergraduate student research in the PerForM lab aimed at extending existing algorithms for detecting different types of eye movements in static environments.

Dr. Diaz also taught a workshop in "Eye tracking in Mixed or Virtual Realities" at the 19th European Conference on Eye Movements (ECEM 2017) in Wuppertal, Germany in August of 2017. Over 30 people attended the hands-on workshop.

Visual estimation of surface BRDF

Dr. James Ferwerda recently presented a method he developed for visually estimating surface reflectance properties using a smartphone at the Vision Sciences Society Annual Meeting. The method estimates diffuse reflectance by scaling and linearizing the RGB values extracted from an image of the surface. Specular reflectance is estimated by applying the Fresnel equation. To complete the process surface roughness is estimated by displaying a square wave grating on the smartphone screen, reflecting the grating in the surface under consideration, and adjusting the spatial frequency of the grating until it is just visible. An algorithm that incorporates display characteristics, human contrast sensitivity, and viewing geometry estimates roughness from the grating spatial frequency at threshold. The method has been validated by measuring real surfaces, simulating the surfaces using parameters estimated through the method, and comparing images of the real and simulated surfaces.

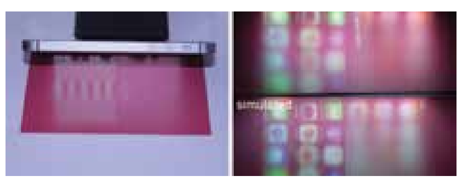


Figure 1: (left) Grating image on smartphone reflected in sample surface to estimate surface roughness. (right) Smartphone image reflected in real surface (top) and simulated surface (bottom) estimated using the method.

Dr. Preethi Vaidyanathan graduated this year, and accepted full-time employment at LC Technologies, where she continues her work in the development of eye-tracking algorithms and systems development.

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

MVRL Publications: 2016-2017

Bennett, J., Sridharan, S., John, B., and Bailey, R., Looking at Faces: Autonomous Perspective Invariant Facial Gaze Analysis, in *Proceedings of the 13th ACM Symposium on Applied Perception* (SAP 2016), pp. 105-112.

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.

Farnand, S. P., Jang, Y., Choi, L. K., and Han, C. A methodology for perceptual image quality assessment of smartphone cameras—color quality, *Proceedings of IS&T's Electronic Imaging Symp: IQSP conference*, February, 2017, pp. 95-99(5).

Farnand, S., Vaidyanathan, P., & Pelz, J. B. (2016). Recurrence Metrics for Assessing Eye Movements in Perceptual Experiments. *Journal of Eye Movement Research*, 9(4).

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MAGNETIC RESONANCE LABORATORY

Laboratory Director's Comments by Dr. Joseph Hornak

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 specific focus this past year has been to develop an analytical technique for studying paramagnetic complexes and stable free radicals in dried linseed coil suspensions on canvas. We have successfully been able to detect and identify the sulfur radical in ultramarine blue; the copper (II) metal ion in Han blue, Egyptian blue, and copper sulfate; the manganese ion in rhodochrosite; the iron (III) metal ion in terracotta red; and the carbon radicals in charcoal and coal in 600 μm thick paint. This result is significant because it indicates the LFEPR spectroscopy could be used to non-destructively and non-invasively identify some pigments in painted works of art.

In this year's report, I have decided to focus the report on a service function of the laboratory, specifically nuclear magnetic resonance (NMR) spectroscopy for structural and dynamical determinations.

NMR Spectroscopy

The Magnetic Resonance Laboratory in the Chester F. Carlson Center for Imaging Science houses a Bruker Avance III 500 MHz NMR spectrometer with an 11.7 Tesla narrow bore superconducting magnet. Scientists determine structural and dynamical properties of molecules using NMR spectrometers. Structures can be determined for molecules ranging in size from small five atom molecules to proteins. The utility of NMR spectroscopy to scientists is best demonstrated by their willingness to spend $500k for such an instrument. Our NMR spectrometer is used for a variety of applications by trained faculty, staff, students at RIT; and scientists in the local community. A few of the research groups and projects utilizing the NMR are listed next.

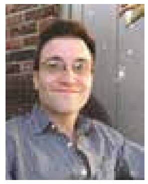
- Dr. Hans Schmitthenner (Chemistry) is studying novel contrast agents for detecting cancer. His research group uses the NMR spectrometer to confirm the structure of dyes used for confocal microscopy.
- Dr. Thomas Smith, Professor of Chemistry, used the 1H, 19F, 31P, and 13C NMR to study block copolymers and ionic liquids and polymers derived from both.
- Drs. George Thurston (Physics), Lea Michel (Chemistry), and Jeff Mills (Chemistry) are studying crystallins, a protein found in the lens of the eye. They are trying to characterize the protein's movement in solution and how they interact with other protein using 1H spectroscopy and diffusion NMR.
- Dr. Anju Gupta (Chemical Engineering), Dr. Jeff Mills (Chemistry) and Tom Allston (Chemistry) are studying drug delivery mechanisms by NMR.

- Dr. Massoud Miri's research group in Chemistry is using 1H and 13C NMR to study polymers. These 13C studies are particularly difficult as they often require the signal averaging of thousands of spectra recorded over a twelve hour period.
- NOHMs is a Rochester company which provides materials to the global lithium battery industry that result in significantly longer lasting, lighter, safer, and more sustainable batteries. They use 13C, 1H, 19F, and 31P NMR spectra to help characterize small molecule additives for use in Lithium ion batteries.
- The versatility of NMR is demonstrated by some of the projects Drs. Sandi Connelly (Biology) and Jeff Mills have undertaken recently. They have used the NMR to study: 1.) the substances leaching out of crumb rubber, ground up tires used as a substrate under artificial soccer fields. 2.) lipids in algae for biofuel production, and 3.) ethanol content in Blue Toad Cider sludge.

There is an educational component associated with the spectrometer. The spectrometer is the focus of a course titled Practical NMR (CHMA-740) taught by Dr. Jeff Mills in the RIT chemistry graduate program. Students learn the operation of the pulsed Fourier transform NMR spectroscopy with hands-on exercises and a final practical exam on the instrument. The goal of the course is to make the students independent users by the end of a semester so they can become the operators of the spectrometer when they join a research group in the College of Science.

Staff News

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



Baron Black is a participant in the CIS Research Experience for Undergraduates (REU) program. He joined the lab for the summer of 2017 and is working on the EPR mobile universal surface explorer.

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.

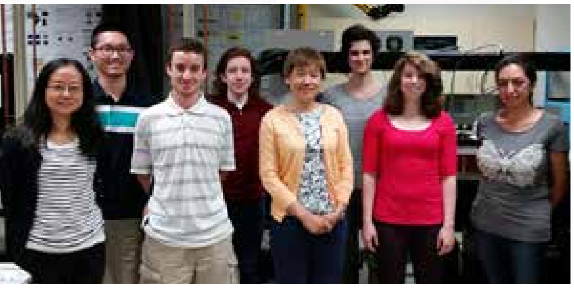
Dr. Hans Schmitthenner, a Research Scientist in the Center for Imaging Science and Lecturer in the Department of Chemistry, is working on targeted contrast agents for magnetic resonance imaging.

Stephany Javier-Santana is a Graduate Student working on her MS in Chemistry. She joined the lab in September and is working on using LFEPR to study the spectral signature of paramagnetic pigments in paint on canvas.

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.

Director: Dr. Jie Qiao qiao@cis.rit.edu http://www.rit.edu/science/people/jie-qiao

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



Research Overview

Dr. Qiao, Associate Professor, leads 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.

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. Dr. Qiao's group is conducting research in the areas of novel wavefront sensing and numerical and experimental investigations of the mechanism and performance of ultrafast lasers based photonics / optics fabrication and packaging. Two PhD students, one Master student, one undergraduate, two visiting scientist, and one post-graduate researcher have been conducting their research projects at the AOFIM lab during the past academic year.

Dr. Qiao has won external funding from NSF/EPMD, NSF/IUCRC/CeFO, DoD-ONR through OptiPro Systems LLC, NYSTAR CEIS, Jeff Lawrence NY Manufacturing Innovation fund and the OSA Foundation

Research Projects

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

High-resolution wavefront sensors are of great interest for laser engineering, astronomy, visual correction, and phase detection of the biological cells. This project will innovate a high-performance optical differentiation wavefront sensor (ODWS), with a potential path to achieve unprecedented, simultaneous high accuracy and high dynamic range.

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. Figure 1 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.

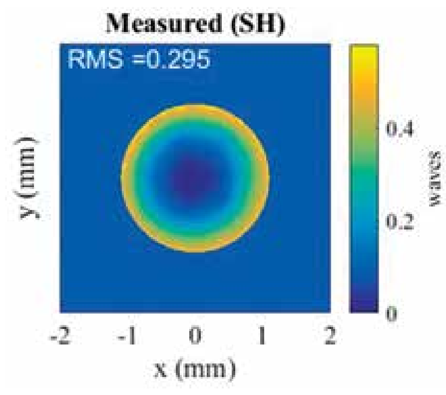


Fig.1. Wavefront measured with ODWS

The ODWS research was recently published in Optics Express (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 Congress, 2015 (invited talk), 2016 (post deadline paper), and 2017 (invited talk).

2. 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. AOFIM team investigates the phenomena, mechanism, systems, and metrology of 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.

Ultrafast Laser-Based Welding for Photonic Packaging: This project will provide a quantum leap inadvancing photonics packaging through investigating ultrafast laser welding (UFLW) to eliminate the current sub-optimal epoxy-bonding approach. Ultrafast laser pulses will be used as a flexible, fast welding tool to bond photonic materials (silicon and glass). The fundamental interaction mechanism and effectiveness between ultrafast laser pulses and glass/silicon will be modeled and tested. The UFLW viability for bonding glass fibers/silicon V-grooves will be demonstrated.

Ultrafast-laser-based polishing for freeform optics and additive manufacturing: This project develops ultrafast-laser-based polishing methods, systems, and processes for freeform optics and additively manufacturing to eliminate polishing waste, mid-spatial-frequency ripples, long-lead time, and high-cost factors. Ultrafast laser pulses having tightly controlled spatial and temporal localization will be used as a small, flexible, and fast polishing tool to polish optics through melting and/or ablation. The fundamental mechanism of ultrafast laser-material interaction will be modeled to determine the optimized processing conditions. The processes and effectiveness will be validated by material removal rate and surface quality evaluations.

Dr. Qiao's group has built a state-of-the-art ultrafast laser processing system, consisting of a femtosecond laser, 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. 2. Femtosecond laser processing system at RIT/AOFIM lab

A paper titled, "Optimization of Femtosecond Laser Processing of Silicon via Numerical Modeling", has been published in Optical Materials Express (Sept., 2016, rated as one of the most downloaded papers of OME in 2016). The progress of this research was presented at the following conferences in the past two years: SPIE Photonics West 2016 (Feb. 2016), the 2nd Conference on Laser Polishing (LaP 2016, April 2016), CLEO 2016 (June 2016), Frontiers in Optics 2016, OSA Optical Fabrication and Testing 2017, and SPIE OptiFab 2017.

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

Outreach: Leading WiSTEE connect to make global impact

As the Founder and Chair of WiSTEE Connect, Prof. Qiao successfully organized the 2nd International Global Women of Light Symposium on 17 September 2017 at the OSA Headquarters in Washington DC. This event was attended by over 70 women and men from more than 14 nations and 43 institutions. Attendees spanned career ranks, including students of levels, academic faculty, scientists, engineers, entrepreneurs and government program directors. The symposium's theme was "Collectively Advancing Women across Academia, Industry, Government and Intersecting Science and Entrepreneurship." The introductory speech given by Dr. Jie Qiao, and the featured panels and speakers of women leaders from science, government, and industry provided insights on and strategies for adopting entrepreneurial spirit and approach, overcoming hidden barriers, building strong networks among women, fixing the leaky pipeline. Panelists included Aleksandra Boskovic, director, Corning Corp.; Dominique Dagenais, director, U.S. National Science Foundation; Frederica Darema, director, Air Force Office of Scientific Research; Susan O'Keefe, vice president, Edmund Optics; and Ursula Keller, professor, ETH Zürich. These panel and round-table discussions all centered on the goal of establishing more women role models by advancing women through the identified mid-career barriers to leadership positions, in all sectors.

WiSTEE awarded 14 travel grants to international students and faculty members to attend the symposium, including four faculty members, five graduate students and five undergraduate students. Ten RIT faculty (3), graduate student (2) and undergraduate (5) attended this program [Faculty members: Jeyhan Karaltepe (Physics), dt Ogilvie (Business), Jie Qiao (CIS); Graduate Students: Cayla Fromm(CIS), Jie Yang (CIS); Undergraduate Students: Grace Annese, Sophia Kourian

(CIS), David Lewis (CIS), Madeline Wolters (CIS), and Emily Vicedomine (Mechanical Engineering)].

WiSTEE has received requests from a few universities, companies and national labs expressing an interest in becoming part of the WiSTEE network. Many female faculty/scientist, students and postdocs expressed a desire to participate and/or lead WiSTEE efforts at their own institutions

Please enjoy the OPN article featuring WiSTEE's Global Women of Light Symposium, published by OSA, The Optical.

WiSTEE will host the 2018 Global Women of Light Symposium on 16 September 2018 in Washington DC. Please mark your calendar for another thought provoking, forward-looking symposium.

Selective Funding Awards

1. NSF, Electronics, Photonics and Magnetic Devices Program (EPMD), Optical Differentiation Wavefront Sensing for High-Dynamic-Range High-Sensitivity Freeform Metrology ($358,962, PI), 6/15/2017 - 5/30/2020, awarded on June 8, 2017
2. NY State Jeff Lawrence Manufacturing Innovation Fund Passing through FuzeHub, Femtosecond-laser Polishing for Advanced Optical / Photonic Manufacturing ($75,000, PI), 3/15/2017 - 3/15/2019, awarded
3. NSF, Industry–University Cooperative Research Centers Program (IUCRC), Center for Freeform Optics, Ultrafast-laser-based polishing for freeform optics and additive manufacturing ($100,735/yr1&2, PI/co-PI), January 01, 2017 – December 31, 2018 (anticipated three-year funding for a total of $143,199), year 1&2 awarded

Selected Publications

(* denotes student co-author)

Refereed Journal Publications

1. R. Garma*, J. Schott, R. Fiete, J. Qiao, D. McKeown, "Image Quality Modeling and Characterization of Nyquist Sampled Framing Systems with Operational Considerations for Remote Sensing,", Optical Engineering, 56 (1), 013102 (2017)

http://dx.doi.org/10.1117/1.OE.56.1.013102

2 L. Taylor*, Jun Qiao, and Jie Qiao, "Optimization of femtosecond laser processing of silicon via numerical modeling," Optics Materials Express, 6 (9), 2745-2758 (2016)

https://doi.org/10.1364/OME.6.002745

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

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

Conference Proceedings/Presentations (2014 – 2017, selective)

1. (Invited) J. Qiao and C. Dorrer, "Measuring wavefront by optical differentiation with binary pixelated filters," in Imaging and Applied Optics 2017 (3D, AIO, COSI, IS, MATH, pcAOP), OSA Technical Digest (online) (Optical Society of America, 2017), paper ITu4E.3. OSA Imaging and Applied Optics Congress 2017, San Francisco, 26–29 June 2017
2. (Invited) J. Qiao, Z. Mulhollan* and C. Dorrer, " Optical Differentiation Wavefront Sensing using binary pixelated filters for Freeform Metrology and Phase Imaging," 9th International Conference on Information Optics and Photonics (CIOP 2017, abstract), Harbin, 17–20 July 2017
3. (Invited) J. Qiao and L.L. Taylor*, "Predicting Optimal Femtosecond Laser Processing of Silicon via Integration of the Thermal and Two-Temperature Models," 9th International Conference on Information Optics and Photonics (CIOP 2017, abstract), Harbin, 17-20 July 2017
4. L. Taylor*. J. Frechem*, H. Han, J. Xu, T, Thomas, M. Pomerantz, J. Lambropoulos, J. Qiao, Controlling material removal rate and surface quality in femtosecond laser processing of optical materials, SPIE, OPTIFAB 2017, 2, Rochester, New York, 16 October 2017
5. L. L. Taylor,* J. C. Frechem*, H. Han, J. Xu, T. R. Smith*, M. Pomerantz, J. C. Lambropoulos, and J. Qiao, "Material Removal and Thermal Impact of Femtosecond-Laser Polishing for Germanium-Based Freeform Optics," in Optical Design and Fabrication 2017 (Freeform, IODC, OFT), OSA Technical Digest (online) (Optical Society of America, 2017), paper OTu3B.4, Denver, CO, 09–13 July 2017

https://doi.org/10.1364/OFT.2017.OTu3B.4

6. J. C. Lambropoulos, S. Salzman*, T. R. Smith*, J. Jing Xu*, M. Pomerantz, P. Shanmugam*, M. A. Davies, L. L. Taylor*, and J. Qiao, "Subsurface Damage (SSD) Assessment in Ground Silicon Carbide (SiC)," in Optical Design and Fabrication 2017 (Freeform, IODC, OFT), OSA Technical Digest (online) (Optical Society of America, 2017), paper OM3B.5, Denver, CO, 09–13 July 2017
7. R. Scott, L. L. Taylor*, and J. Qiao, "Comparison of Two-Temperature and Thermal Models for Prediction of the Optimal Femtosecond Laser-Material Processing of Silicon," in Conference on Lasers and Electro-Optics (CLEO), OSA Technical Digest (online) (Optical Society of America, 2017), paper ATu4C.5, San Jose, CA, 15–19 May 2017

https://doi.org/10.1364/CLEO_AT.2017.ATu4C.5

8. J. Qiao, L.L. Taylor*, and R. Scott*, "Determining Optimal Femtosecond Laser-Material Processing via Integrating Two-Temperature and Thermal Models," The 18th International Symposium on Laser Precision Microfabrication (LPM), Toyama, Japan, 5–8 June 2017
9. (Post-deadline) 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

10. 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

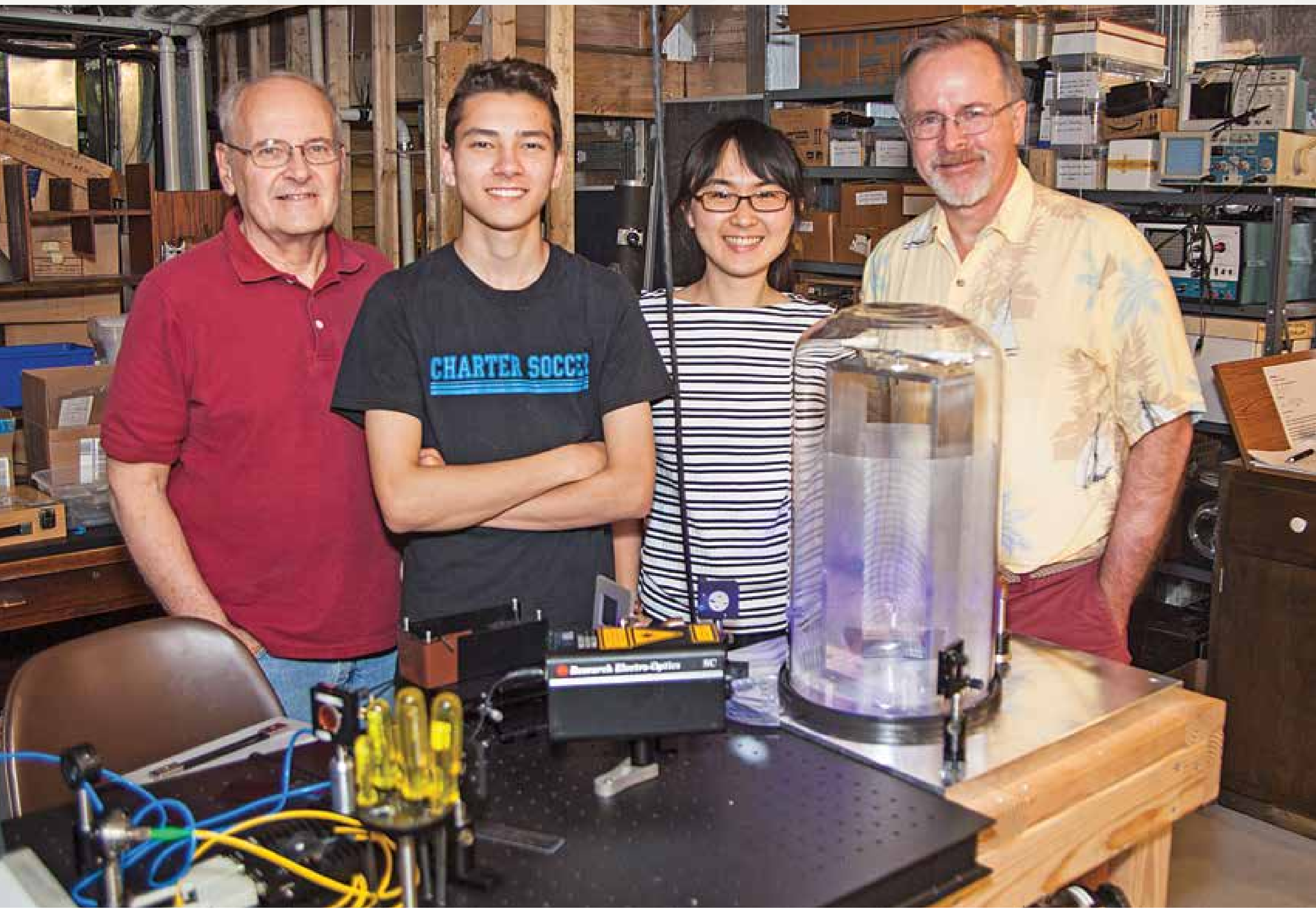
11. J. Qiao, L. Taylor*, and J. Qiao,

"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

12. 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


CHARTER SOCC
Research Electro-Optics

Laboratory Director's Comments By: Dr. Grover Swartzlander

Grover Swartzlander is exploring radiation pressure, advanced imaging concepts, and laser counter-measures to protect sensors from damage. He is a Fellow of the Optical Society of America, a NASA NIAC Fellow, a Cottrell Scholar, and an NSF Young Investigator.

Dr. Swartzlander is the Editor-in-Chief of the Journal of the Optical Society of America—B, and has been a past associate editor for Optics Letters. He has pioneered a number of topics in the field of optics, with his garnering roughly 5000 citations.

Sensor Protection from Laser Dazzle

This ONR funded project, a joint collaboration between RIT and the US Naval Research Laboratory, seeks to use "point spread function" engineering, combined with computation imaging techniques to reduce the peak intensity of a laser beam at the focal plane by blurring with a pupil plane phase mask. Image reconstruction may then be achieved in post processing by means of deconvolution techniques. Designing a phase mask that provides both high suppression an image fidelity is no easy task. Experimental, theoretical, and numerical techniques are applied to seek out masks which, in addition, may be easy to fabricate without undue complexity. A state-of-the-art spatial light modulator was purchased test various holographic phase elements. The figure below illustrates an example whereby the image of a toy car was reconstructed with a mask providing a 100 times reduction of the peak laser irradiance. This work was conducted by RIT graduate student Jacob Wirth (president of the OSA local chapter), in collaboration with Prof. Swartzlander (RIT), and Dr. Abbie Watnik (NRL scientist).

Radiation Pressure on a Diffraction Grating

This pioneering NSF funded research predicted that radiation pressure could be used in place of a reflective material for applications such as solar sailing. Together with CIS PhD student Ying-Ju (Lucy) Chu, Prof. Swartzlander constructed various systems to test this theory, including magnetic and acoustic levitation devices. With little time left to complete the project he decided to build a highly sensitive torsion oscillator to make measure the radiation pressure for on a laser-driven grating. This turned into a widely collaborative effort, including MFA student Kyriani Hinkleman (RIT Metals and Jewelry Design program), REU student Christian Cammarota (RIT School of Physics and Astronomy), engineers from Sydor Optics, and Eric Jannson (along with his father, Peter) from the Charter High School of Delaware. By the end of summer we had succeeding is demonstrating radiation pressure on a 190 μm thick Littrow diffraction grating. The figure below (left) shows the torsion angle of the oscillator when the grating was illuminated with 1.5 W of laser power (the laser shutter was opened at t=400 s). The graph includes a theoretical step function response curve, which matches the experimental data. The photo below (right) shows from left to right Peter Jannson, Eric Jannson, Ying-Ju (Lucy) Chu, and Grover Swartzlander, along with the laser-illuminated torsion oscillator mounted inside a vacuum bell jar.

Glitter Telescope

A continuation of a NASA funded collaboration with CIS PhD Student Xiopeng Peng, Prof. Swartzlander, and JPL scientist, Marco Quadrelli, this work completed a multiyear investigation that explored whether a randomly varying granular aperture comprised of randomly distributed subapertures could be used to form a resolvable image. Ms. Peng constructed a set of random apertures by puncturing 150 small holes through 100 foil sheets with a fine sewing needle. A sheet of cellophane provided a random phase across the foil. Post-processing of the 100 images included both lucky imaging and blind deconvolution customized algorithms. As shown in the figure below, the reconstructed images of a binary light source were better resolved that a perfect diffraction limited aperture. These results provide a proof-of-concept that a large ill-figured random aperture space telescope could be designed to achieve extraordinary resolution.

Advanced Diffractive MetaFilm Sailcraft

The abundant untapped momentum of solar photons is becoming increasingly attractive as a means to propel spacecraft with an attached solar sail. Like the early days of the Wright brothers, this is the dawn of the Age of Sailcraft for navigating the heavens. Today's sails are primitive structures, comprised of inefficient reflective constructions that required complex attitude adjustments for orbital maneuvers like orbit raising. Today's reflective sails are akin to ancient Egyptian spinnakers rather than optimized vessels seen in the America's Cup. However, the triple coincident of the emergences of fledgling solar sailcraft demonstration missions, the national urgency to develop CubeSat technology, and the development of broadband high efficiency electro-optically controlled diffractive thin films, provides an opportunity to replace reflective sails with potentially superior performing diffractive sails. This new project is seeking funding to show that diffractive sails may be as effective as (or superior to) reflective sails. As shown in this orbit-raising study, diffractive sails may reach the target in shorter times than reflective sails. What is more, diffractive sails absorb little light and therefore do not suffer the re-radiation problems attributed to reflective materials. Furthermore, transmissive diffractive sails provide opportunities to recycle photons – either for multiple sail layers or for converting light into electricity. These advantages will inspire future work to explore optimized sailcraft missions (e.g., using electro-optic control of diffractive meta-films), the development of broadband space-qualified diffractive films, and fabrication techniques to produce large area diffractive layers of micrometer-scale thickness. The figure below illustrates how a diffractive sailcraft could be used to minimize the atmospheric drag in low Earth orbit, compared to the buffeting experienced by a reflective sail.

Optical Vortex Coronagraph Scatterometer

This work was conducted with Dr. Lingyu Wan who was a visiting scholar, Garreth Ruane (recent PhD graduate), and Prof. Swartzlander. The important but difficult-to-measure zero and low-angle scattering spectrum, as well as the broader angular spectrum was measured by use of an optical vortex coronagraphic scatterometer, invented by Prof. Swartzlander. Experimental measurements agreed well with predictions from Mie scattering theory. High constrast discrimination allowed us to remove the unscattered coherent illumination, revealing a low angle superimposed scattered signal. A patent for this device is pending. The figure below shows that experimental and theoretical measurements are in good agreement for 9 μm diameter polystyrene spheres suspected in water. Whereas traditional scatterometers do not provide data below the illuminating beam size $\theta\beta$ (5 milliradians in this case), our device provided measurements at all angles.

Special News

Recent PhD graduate, Alexandra Artusio-Glimpse, received the RIT Outstanding PhD Dissertation award for her work on radiation pressure "The Realization and Study of Optical Wings." She also received a prestigious NRC Postdoctoral Fellowship. Dr. Artusio-Glimpse continues work on radiation pressure at the National Institute of Standards and Technology, Boulder, Colorado.

Another PhD student from Dr. Swartzlander's group was awarded a competitive NSF Postdoctoral Fellowship, and continues his research on advanced coronagraphs for exoplanet imaging and detection at the California Institute of Technology, Pasadena, California.

Peer Reviewed Publications (2016-17)

Randomized apertures: high resolution imaging in far field, X Peng, GJ Ruane, MB Quadrelli, GA Swartzlander, Optics Express 25 (15), 18296-18313 (2017).

Radiation pressure on a diffractive sailcraft, GA Swartzlander, JOSA B 34 (6), C25-C30 (2017).

Incoherent imaging in the presence of unwanted laser radiation: vortex and axicon wavefront coding, AT Watnik, GJ Ruane, GA Swartzlander, Optical Engineering 55 (12), 123102-123102 (2016).

Incoherent imaging in the presence of unwanted laser radiation: vortex and axicon wavefront coding, AT Watnik, GJ Ruane, GA Swartzlander, Optical Engineering 55 (12), 123102-123102 (2016).

Low-angle optical vortex coronagraphic scatterometer, L Wan, GJ Ruane, GA Swartzlander, Optics Letters 41 (21), 4915-4918 (2016).

Simulating Phase-Only Pupil Plane Masks for Laser Suppression, JH Wirth, A Watnik, G Ruane, GA Swartzlander, Laser Science, JW4A. 1 (2016).

Digital control of spatial coherence in vortex beams, B Perez-Garcia, A Yepiz, RI Hernandez-Aranda, A Forbes, GA Swartzlander, SPIE Optical Engineering+ Applications, 99500Y-99500Y-6 (2016).

Optical gradient force assist maneuver, AB Artusio-Glimpse, JH Wirth, GA Swartzlander. Optics Letters 41 (17), 4142-4145 (2016).

Digital generation of partially coherent vortex beams, B Perez-Garcia, A Yepiz, RI Hernandez-Aranda, A Forbes, GA Swartzlander, Optics Letters 41 (15), 3471-3474 (2016).

J. Optical Society of America Editorials from the Editor-in-Chief

JOSA B celebrates a publishing Centennial, GA Swartzlander, JOSA B 34 (4), ED1-ED2 (2017)

JOSA B celebrates OSA's Centennial II, GA Swartzlander, JOSA B 33 (8), ED3-ED5 (2016).

JOSA B celebrates OSA's Centennial, GA Swartzlander, JOSA B 33 (1), ED1-ED2 (2016)

Patents and Technical Reports

NIAC Phase II Orbiting Rainbows: Future Space Imaging with Granular Systems, MB Quadrelli, S Basinger, D Arumugam, G Swartzlander, NASA Technical Report (2017), https://ntrs.nasa.gov/search.jsp?R=20170004834

Optical Vortex Coronagraph Scatterometer, GA Swartzlander inventor, non-provisional, RIT ID 2017-007.

Used scanning electron microscope installed April 2017.

NANOIMAGING RESEARCH LABORATORY

Laboratory Director's Comments By Professor Rich Hailstone

The major news this year is the installation of another scanning electron microscope (SEM) in April (see image opposite page). This is a 2005-vintage SEM with a field-emission electron gun, similar to the new SEM installed in December 2015.

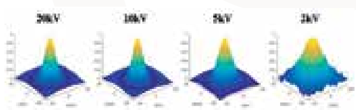


Figure 1. Beam Shape over a Range of Beam Voltages. These beam shapes were determined using the TEM grid sample. In general, as the beam energy decreases, the beam shape diameter increases. The PSFs show lowest to highest elevations as dark blue to light yellow, respectively.

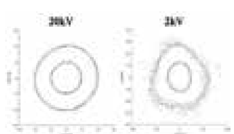
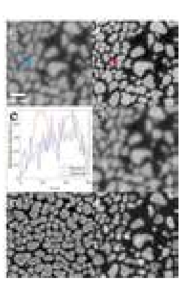


Figure 2. Comparison of Beam Shapes between Different Regions of the Same Sample. For each beam voltage, six non-overlapping regions in a TEM grid square are imaged. A contour plot representing the beam shape for each region is shown for 20kV on the left and 2kV on the right. The inner contour level represents the approximate FWHM (containing ~40% of probe current) and the outer contour level presents the approximate FWTM (containing ~75% of probe current). Scale is different between 20kV and 2kV.



The operator interface is all digital, making it easier to use. But unlike the new SEM it has variable pressure capabilities, which allows one to look at nonconductive samples without applying a gold or carbon coating to the sample to make it conductive. In addition, it has in-lens capabilities which means it will actually have somewhat higher resolution than our new SEM. Thus the two SEMs complement each other and extend our sample capabilities.

Viability of Point Spread Function Deconvolution for SEM (PhD student Mandy Nevins). In this study, we investigate beam shape variation at different beam voltages 1) across multiple regions of the same sample and 2) between different samples. For these experiments, we capture backscattered electron images with a TESCAN MIRA3 field emission SEM (FESEM). In addition, we quantify the restoration provided by PSF deconvolution for comparison to image enhancement capabilities in commonly used software such as ImageJ, Adobe Photoshop, and RawTherapee. Our image quality metrics include ISO/TS 24597 on image sharpness in the SEM.

To study beam shape invariance, we image 19nm gold nanoparticles on a carbon film transmission electron microscope (TEM) grid and on a substrate such as Kapton. To test for spatial invariance, we image at least six non-overlapping, same-sized regions the area of within one grid square. We start with a region of best focus and then keep the same beam shape for the following regions. To test for sample invariance, we image one region of best focus on either the TEM grid or the substrate and then, using the same beam shape, image a same-sized region on the other sample. Analyzing this data involves obtaining a PSF of each region using Aura and fitting a 2D Gaussian to each using MATLAB's curve fitting tool. The standard deviations of a beam, σ_x and σ_y, can be used for comparison to other beams.

Beam shape variation at different voltages reflects our general understanding, being that beam diameter increases as beam voltage decreases (Figure 1). Noise becomes more prominent at low voltage as well, as seen by comparing the smooth surfaces of the higher kV beams to the rough surface of the 2kV beam. In the case of the TEM grid, our preliminary findings suggest the PSF is approximately spatially invariant regardless of beam voltage (Figure 2). Absolute percent differences between the beam shape standard deviations are shown in Table 1 for voltages depicted in Figure 2. We are currently undergoing study of spatial invariance for the substrate and beam shape invariance between the carbon TEM grid and the substrate. We are examining the image quality of Aura's restorations in comparison to enhancements done with ImageJ, Photoshop, and RawTherapee and other reference data imaged with the FESEM (Figure 3).

Figure 3. Visual Comparison of Low Voltage Gold on Carbon. a) observed at 2kV, b) restoration of (a) with Aura, c) intensity profile of arrow in (a) and (b) where the blue line is the observed intensity and the red line is the restored intensity, d) enhancement of (a) with RawTherapee, e) similar field as (a) using beam deceleration at 2kV, f) same field as (a) at 20kV. Scale bar in (a) applies to all images.

Beam Voltage	σ_x median	σ_x range	σ_y median	σ_y range
20 kV	2.0	0.6-5.5	3.6	0.5-8.5
2 kV	5.3	0.0-13.6	3.8	0.4-9.9

Table 1. Absolute Percent differences between Beam Shapes for Different Regions of the Same Sample.

SEM Characterization of Cement (MS student Najat Alharbi). This project is a continuation of the project described in last year's report. The purpose of this joint project with Professor Varela in Mechanical Engineering 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.

The alkali activation of slag is a complex reaction that can yield different microstructures depending on the type of alkali used, concentration, curing conditions, time, etc. but it has been proved and accepted that one of the main phases is a calcium silicate hydrate similar to the one obtained in the hydration of Portland Cement but with Aluminum tetrahedrons replacing some of the silicon tetrahedrons in its structure, what is now called the C-A-S-H gel.

Two techniques were used to determine the nanostructure of the materials: (1) scanning electron microscopy to acquire back scattered electron (BSE) images and (2) energy-dispersive x-ray spectroscopy (EDS) mapping of element distribution. In this work, a TESCAN MIRA3 SEM and a Bruker XFlash 6|30 system were used. The advantage of using BSE images is to display contrast due to the chemical composition of the sample. The images were taken at 2kX magnification. EDS maps were acquired for 90 min in order to have enough x-ray counts for good phase mapping. Standards-based elemental quantification was measured for six points in each phase to study the concentration of the elements.

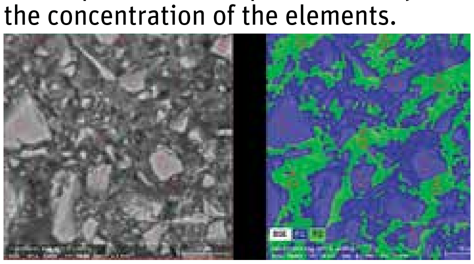


Figure 4. BSE image of raw slag showing two distinct regains (left) corresponding to two distinct phases (right). The circles indicate regions where elemental quantification was performed.

Figure 4 presents BSE image of the unactivated slag (left) and the spatial distribution of the phases with similar chemical composition (right). The unactivated slag shows two distinct features, irregular particles with sharp edges and an amorphous background region. As seen in Figure 4 (right) these regions correspond to two major phases with distinct chemical composition. The blue-colored phase, mostly corresponding to the particles covers 51.3 % of the area, whereas the green-colored phase in the background covers 36.6 %. The average chemical composition for each phase is shown in Table 2.

Phase/Element (Atom %)	O	Si	Ca	Al	Mg
Particle (dark blue)	60.44	13.90	16.40	3.50	5.76
Background (green)	43.15	20.97	28.85	3.55	3.48

Table 2. Average elemental composition for the phases observed in unactivated slag

It can be seen from Table 2, that there are significant differences between the phases. The particle is much richer in O and Mg, while the background is richer in Si and Ca. The Al is homogenously distributed in both phases.

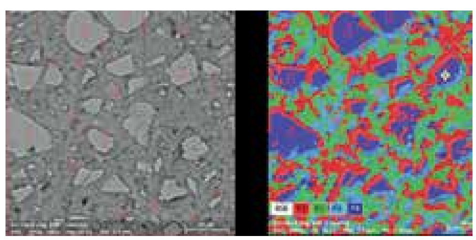


Figure 5. *BSE image of the alkali activated slag. The image to the right shows the splitting of the background into 3 distinct phases. The circles indicate the regions where elemental quantification was performed.*

Figure 5 presents the BSE image of the slag after alkali activation. The morphology of the sample shows irregular particles and an amorphous background similar to the unactivated slag, but significant changes were observed in the chemical composition and spatial distribution of the phases, particularly in the background phase. Table 3 presents the average chemical composition for each of the observed phases.

Phase/Element (Atom %)	O	Si	Ca	Al	Mg	K
Particle (dark blue)	52.82	16.29	20.79	3.71	6.24	0.19
Phase 1 (red)	65.43	12.96	9.66	3.64	6.82	1.49
Phase 2 (green)	67.89	11.41	16.01	1.66	1.76	1.20
Phase 3 (light blue)	59.97	11.94	22.54	1.88	2.02	1.66

Table 3. Average elemental composition for the phases observed in the alkali activated slag

The dark-blue-colored phase corresponding to the particles covers 17.8% of the area and it shows a significant decrease in O and an increase in Si and Ca, compared to the unactivated slag, whereas Mg and Al remained relatively constant. The K concentration was very low in this phase (0.19 %). The phases in the background colored red, green and light blue cover 31.6%, 29.2% and 21.3% of the area, respectively, and these are the phases where the most significant changes in the chemical composition were observed.

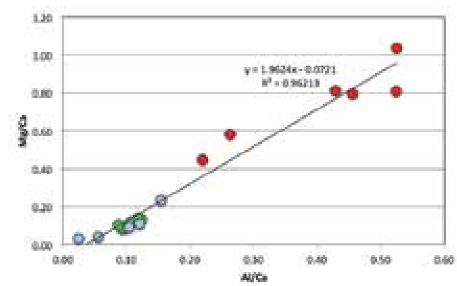


Figure 6. Mg/Ca atomic ratio versus Al/Ca atomic ratio for 6 points in the background phases.

Figure 6 shows a plot of Mg/Ca versus Al/Ca for 6 points in each one of the phases observed in the background. The points lie on a straight line and the differences among the three phases can be observed. If we extend the line to the intersection with the abscissa the obtained Al/Ca ratio is 0.04 which can be assigned to a pure C-A-S-H gel.

Phase identification of alkali activated slag is not an easy task to be done by one single technique. Instead, a combination of techniques needs to be used. The paste obtained after alkali activation of blast furnace slag with a KOH base solution is mostly amorphous but some phases such as hydrotalcite, calcite and stishovite were detected by x-ray diffraction. This work shows that both particles and background in the alkaline activated slag react in a different manner, with changes in chemical composition more noticeable in the background.

Outer Membrane Vesicles. This is a collaborative project with Lea Michel (Chemistry) and Ravinder Kaur (Rochester Regional Health) with the intent to provide images of these vesicles so as to understand their size and shape. Bacteria communicate among themselves and with other living organisms via the release of nanoscale membrane vesicles from their outer membranes. These vesicles are involved in transporting signaling biochemicals, which may include DNA, RNA, proteins and endotoxins. A sample for imaging in the transmission electron microscope was prepared by depositing 3 μliters on a TEM grid and then staining with uranyl acetate to improve the image contrast.

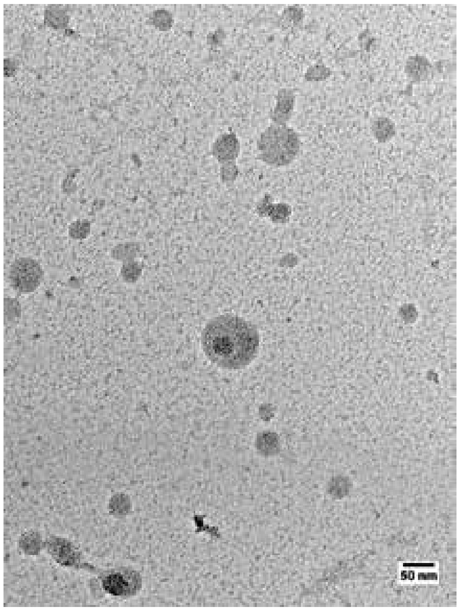


Figure 7. Image of outer membrane vesicles (darker approximately circular regions).

Figure 7 gives an example image. The vesicles are approximately circular with a mean diameter of about 35 nm.

Analysis of 3D Printed Plastic. This is work with an external client specializing in 3D printing of materials. Information about the internal structure of the printed material is desired. After mechanically fracturing the material it was treated with osmium tetroxide, which reacts with carbon-carbon double bonds in the plastic. Secondary electron (SE) and backscattered electron (BSE) images were acquired simultaneously from the same area of the sample. The former displays mainly topographic information, whereas the latter displays mainly compositional information.

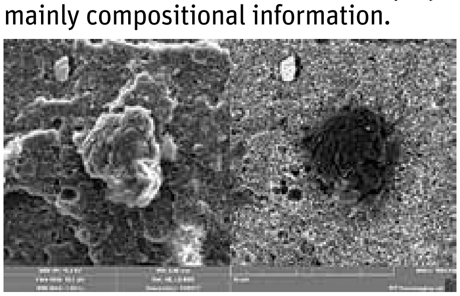


Figure 8. SEM images of 3D-printed plastic mechanically fractured. Left, secondary electron image displaying mainly topographic information. Right, backscattered electron image displaying mainly compositional information.

An example image is shown in Fig. 8 where the left-hand side shows the SE image and the right-hand side shows the BSE image. The pixel brightness in the BSE image is related to the atomic number of the elements in that pixel to the second power. Thus, the bright spots in the BSE image indicate where the osmium is located and therefore the uniformity of the material with the carbon-carbon double bonds. This is important information for the client, as nonuniformities can lead to poor mechanical performance of the printed material.

Publications, Patent Applications, Patents Issued, and Conference Presentations 2016-2017

1. Kathleen Ellis, Rachel Silvestrini, Benjamin Varela, Najat Alharbi, Richard Hailstone (2016). Model ing Setting Time and Compressive Strength in Sodium Carbonate Activated Blast Furnace Slag Mortars Using Statistical Mixture Design. Cement and Concrete Composites, 74, 1 - 6.
2. Eric Lifshin, Matthew Zotta, David Frey, Sarah Lifshin, Mandy Nevins, and Jeffrey Moskin (2016). "A Software Approach to Improving SEM Resolution, Image Quality, and Productivity." Microscopy Today 25, 18-24.
3. Najat A. Alharbi, Richard K. Hailstone, and Benjamin Varela (2017). "A Microscopic Characterization of Alkali-Activated Slag." Non-Traditional Cement & Concrete, Brno, Czech Republic, June.
4. Mandy C. Nevins, Matthew D. Zotta, and Richard K. Hailstone (2017). "Viability of Point Spread Function Deconvolution for SEM." Microscopy & Microanalysis 2017, St. Louis, MO, August
5. Najat A. Alharbi, Richard K. Hailstone, and Benjamin Varela (2017). "EDS-Based Phase Analysis of Alkali Activated Slag." Microscopy & Microanalysis 2017, St. Louis, MO, August.
6. A. G. DiFrancesco, R.K. Hailstone, A. Langner, K.J. Reed (2016). Method of Preparing Cerium Dioxide Nanoparticles, Japanese Pat. No. 5864627.
7. A. G. DiFrancesco, T. D. Allston, R. K. Hailstone, A. Langner, K. J. Reed (2016). Fuel Additive Containing Lattice Engineered Cerium Dioxide Nanoparticles, Japanese Pat. No. 5870081.
8. A. G. DiFrancesco, R. K. Hailstone, K. J. Reed, and G. R. Prok (2016). Method of Making Cerium Oxide Nanoparticles, U. S. Pat. No. 9,303,223.
9. A. G. DiFrancesco, R. K. Hailstone, K. J. Reed, and G. R. Prok (2016). Method of Making Cerium Oxide Nanoparticles, U. S. Pat. No. 9,340,738.
10. A. G. DiFrancesco, R. K. Hailstone, A. Langner, and K. J. Reed (2016). Method of Preparing Cerium Dioxide Nanoparticles, European Pat. No. 2064153.
11. K.J. Reed, A. G. DiFrancesco, R.K. Hailstone, G.R. Prok, T.D. Allston (2016). Structured Catalytic Nanoparticles and Method of Preparation, U. S. Patent 9,415,373.

Grants and Contracts 2016-2017

Cerion Advanced Materials, $28k

Other Income 2016-2017

Microscopy Facility User Fees, $70k

A manuscript being imaged in Milan, Italy.

HISTORICAL MANUSCRIPT IMAGING

Laboratory Director's Comments By Dr. Roger Easton

The Laboratory for Historical Manuscript Imaging had another eventful year. The lab is now involved in a very exciting new collaboration with the University of Rochester.

Faculty, students, and research staff from both institutions have formed the group "Rochester Cultural Heritage Imaging, Visualization, and Education" (www.r-chive.net), which has the goal of extending the corpus of mankind's cultural heritage. Though membership obviously is concentrated in the Rochester area, it also includes colleagues in Washington DC, Colorado, North Carolina, Texas, and Hawaii. Because of the expertise in humanities and technology concentrated in Rochester, we are hopeful that this organization will help make the region become a world-wide focus for this vitally important and urgent work. To accomplish this end, R-CHIVE will hold a small conference on June 19-20, 2017, spending one day at each institution. Attendees of the conference will include colleagues from as far away as Italy and Hawaii.

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, Dr. Adrian Wisnicki of the University of Nebraska and Dr. Megan Ward of Oregon State University (David Livingstone Diaries project) and Dr. Daniel Stökl Ben Ezra of the École Pratique des Hautes Études (Cairo Genizah Palimpsests project). Graduate students participating in this work include Di Bai and Anna Starynska.

Leidy Dorado-Munoz is a post-doctoral fellow focusing on the use of spatial-spectral analysis tools from the remote sensing literature to identify faded / erased / damaged text on the Gough Map, a Late Medieval map of the island of Great Britain at the Bodleian Library of the University of Oxford. Dr. Dorado-Munoz is working with two colleagues at the University of London: Dr. Catherine Delano-Smith, Senior Research Fellow at the Institute of Historical Research (and Editor of IMAGO MUNDI The International Journal for the History of Cartography) and Mr. Damien Bove.

Among the objects imaged and/or processed during the past year were:

- Gough Map at the Bodleian Library of Oxford University, which is the first object in what is hoped to be a continuing collaboration with colleagues in the U.K.
- Jagiellonian Globe in Kraków, imaged in July 2016 in collaboration with Chet Van Duzer
- Dexippus Palimpsest in Vienna, reimaged in August 2016, in collaboration with Dr. Jana Grusková of the Austrian Academy of Sciences, Dr. Ira Rabin of Bundesanstalt für Materialforschung und –prüfung in Berlin and the Centre for the Study of Manuscript Cultures at the University of Hamburg, and the Early Manuscripts Electronic Library (EMEL);
- Enoch Palimpsest at the Berlin State Library in October 2016, in collaboration with EMEL

- Jubilees Palimpsest at the Ambrosiana Library in Milan in January 2017, a collaboration with EMEL and Dr. Todd Hanneken of St. Mary's University of San Antonio TX;
  - several manuscripts at the Museum of the Bible in March 2017, with further imaging planned for July 2017, in collaboration with the Museum and EMEL.

Several students from other institutions participated in the work of the lab this past year, and others are expected to participate in the coming year. Allyse Toporek and Madeline Loui, CIS high school interns, worked with us in summer 2016. Nicole Polglaze from Grinnell College was accepted into the "Research Experience for Undergraduates" program in Imaging Science in the summer of 2017, Ivan Shemchuk from University of Hamburg will be here in July 2017.

The work of the lab also was acknowledged in articles in the Rochester Review (Spring 2017)

Presentations by Lab participants:

1. "Spectral Image Processing Methods," Roger L. Easton, Jr. and David Messinger, to the SEAHA (Centre for Doctoral Training in Science and Engineering in Arts Heritage and Archaeology) Seminar on Hyperspectral and Multispectral Imaging, Oxford UK, 30 June 2016.
2. "Image Processing Techniques for Spectral Images of Historical Objects," Roger L. Easton, Jr., Digital Humanities 2016, in Kraków, Poland, 13 July 2016.
3. Modern Imaging Technologies in Historical Studies," Roger L. Easton, Jr., Gregory Heyworth, Keith Knox, Ken Boydston, and Brent Seales, Invited presentation at SciX (The Great Scientific Exchange) National Meeting of the Society for Applied Spectroscopy (SAS) and North American Society for Laser-Induced Breakdown Spectroscopy (NASLIBS), Minneapolis MN, 21 September 2016.
4. "Modern Imaging Technologies to Recover History," Roger L. Easton, Jr. and Gregory Heyworth, RIT Brick-city Weekend, 15 October 2016.
5. "Innovative Deciphering of Ancient Historical Documents," Roger L. Easton, Jr., Pflaudler Lecture at RIT OSHER Lifelong Learning Institute, 20 October 2016.
6. "Spectral Image Processing in the David Livingstone Diaries Project," with Adrian Wisnicki, Megan Ward, and Keith Knox, at the University of Edinburgh on 14 November 2016, at Oxford University on 16 November 2016, and at Queen's College (Belfast, N.I.), 18 November 2016.
7. "Spectral Imaging and the Future of the Past," Invited presentation to the Presidential Plenary Session of the Archaeological Institute of America, Toronto, 6 January 2017
8. "A pigment analysis tool for hyperspectral images of cultural heritage artifacts," D. Bai, D.W. Messinger, and D. Howell, at Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXIII, May 2017, Proceedings of SPIE vol. 10198
9. "Imaging a Future for the Past," R-CHIVE Exhibit at Imagine RIT, 6 May 2017.

Publications by Lab participants:

"Hyperspectral Analysis of Cultural Heritage Artifacts: Pigment Material Diversity in the Gough Map of Britain," Di Bai, David W. Messinger, and David Howell, Opt.Eng. 56(8), 081805, 2017, doi: 10.1117/1.OE.56.8.081805

The lab hosted researchers from other institutions for visits to CIS during the year, including two speakers in the CIS Seminar program, Dr. David Howell of the Bodleian Library at the University of Oxford, and Dr. John Delaney of the National Gallery of Art. In addition, Dr. Brent Seales of the University of Kentucky gave the John Wiley Jones Distinguished Lecture "Digital Unwrapping, Homer, Herculaneum, and the Scroll from En-Gedi."

Planned imaging trips and presentations:

1. R-CHIVE Conference, RIT and UR, June 2017
2. Imaging at the Museum of the Bible, July 2017
3. Work on the Selden Map of China, beginning in summer 2017, including a visit to Oxford / Univ. of London in July 2017
4. ManuSciences '17 at the Villa Clythia near Fréjus, France, 10-15 September 2017

The lab is also collaborating with other institutions in other projects, including imaging of the Erdapfel globe by Martin Behaim, c. 1491, and the Gaius palimpsest in Verona.

NEWS

RIT professor images David Livingstone diaries, gives talks in UK

Roger Easton contributes to Livingstone Spectral Imaging team

Nov. 9, 2016

Multispectral imaging technology continues to recover new insights from the field diaries of 19th-century explorer David Livingstone. A team of scholars and scientists who worked on the Livingstone Spectral Imaging project will present their research in public talks in the United Kingdom in November.

While stranded in Central Africa, Livingstone composed letters, diaries, maps and sketches on scraps of paper using inks made from local berries. His writings and drawings document the Central African slave trade, social dynamics among local populations and geographical information.

"Because of the poor quality of the ink, the works probably had only been read by Livingstone himself," said Roger Easton, professor in the Chester F. Carlson Center for Imaging Science at Rochester Institute of Technology, who imaged the Livingstone documents.

Easton is a member of a team of scholars and scientists, led by Adrian Wisnicki, assistant professor of

English at the University of Nebraska–Lincoln, and Megan Ward, assistant professor at Oregon State University, that has assembled a digitally processed archived dedicated to the explorer. Livingstone Online: Illuminating Imperial Exploration archives more than 7,500 digital documents of original material.

To make Livingstone's writings readable, advanced spectral imaging and analysis was conducted by a team that included Easton and Keith Knox, retired scientist from the U.S. Air Force Research Labs.

The team of four scholars and scientists will present the results of the David Livingstone Spectral Imaging project—including both the technical aspects of the imaging and the results of the scholarly studies—in talks at the University of Edinburgh on Nov. 14, the University of Oxford on Nov. 16 and Queen's University in Belfast on Nov. 18.

For more information, contact Roger Easton at easton@cis.rit.edu.

LABORATORY FOR MULTIWAVELENGTH ASTROPHYSICS

Laboratory Director's Comments By Prof. Michael Richmond

The Laboratory for Multiwavelength Astrophysics (LAMA) exists to foster the use 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.

Contents

1. Summary

The Laboratory for Multiwavelength Astrophysics (LAMA) exists to foster the use 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 2016 was a good 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 17 refereed papers and 21 conference presentations and other non-refereed publications. A significant fraction of these publications resulted from projects in which LAMA personnel play leading roles within national and international teams of astrophysics researchers. Six new grants, totaling nearly $471 K in funding allocations, were initiated by LAMA PIs during CY 2016. In 2016, 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 and Objectives

LAMA's Mission. The mission of LAMA is to foster the use 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 spacebased astronomical observing facilities/missions;
- exploitation and mining of the present and forthcoming generations of multiwavelength data archives;
- development of scientific requirements for future astronomical observingfacilities/missions and future data archival and mining methods;

- analysis and modeling of multiwavelength astronomical and astrophysical data.

Goals and 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 2016, LAMA-affiliated faculty, postdocs and students made the following progress toward these goals and objectives:

- LAMA continued to disseminate research results at a high rate. Specifically, LAMA faculty, postdocs, and students were lead or co-authors of 17 refereed papers and 21 conference presentations and other non-refereed publications appearing in CY 2016 (see Sec. 6), and led the editing of the Proceedings of International Astronomical Union Symposium 314 (see Sec 5). A significant fraction of these publications resulted from projects in which LAMA personnel play leading roles within national and international teams of astrophysics researchers.
- Six new grants, totaling nearly $471 K in new funding allocations, were initiated during CY 2016. (see Sec. 3)
- In summer 2016, 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 and 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), Michael Richmond (SoPA, Professor), Andrew Robinson (SoPA, Professor)

Research Staff: Ben Sargent (CIS, Research Scientist), Krystal Tyler (SoPA, Research Scientist)

Graduate Students: Triana Almeyda, Jesse Bublitz, Kevin Cooke, Dorothy Dickson-Vandervelde, Yashashree Jadhav, Kristina Punzi, Trent Seelig, Ekteban Shah, Meaghann Stoelting, Sravani Vaddi, Brittany Vanderhoof, Billy Vazquez (all AST Ph.D. or M.S. students)

Undergraduate Students: Kaitlin Schmidt, Dale Mercado, Noah Reuter, Jake Mekker, Brennan Dell, Sam Zimmerman, Isabella Cox (all Physics majors)

Administrative Assistant: Cheryl Merrell

Finances: Six grants, totalling roughly $471K in new funding allocations, were successfully initiated in CY 2016 (see Table 1). A total of $27,998 in overhead return was credited to the LAMA discretionary fund in CY 2016. The largest single expense was student stipends ($9K) . A detailed breakdown of LAMA grants, grant expenditures, and lab account income and expenses for CY 2016 is available upon request.

Table 1: Funded LAMA Proposals, CY 2016

PI	Sponsor	Title	Total Funding
Kartaltepe	NASA/JPLy	The Role of Galaxy Mergers and Interactions over Cosmic Time/Probing the Environment of Distant Star-Forming Galaxies	$18,000
Dube	NSF	REU Imaging in the Physical Science (2017-2020)	$267,467
Sargent	NASA/USRA	An EXES Medium Resolution Search for Formaldehyde Gas in the Class 1/11 Young Stellar Object IRAS 04278+2253	$13,000
Sargent	NASA/USRA	An EXES Low-Resolution Search for Formaldehyde Gas in the Protoplanetary Disk of DL Tau	$20,000
Kastner	NASA/STScI	Universe in Transition: Powerful Activity in the Bright Ages	$17,912
Kastner	NASA/SAO	X-rays from Young Low-Mass Stars: Inhospitable Habitable Zones?	$135,015

4. Student Support, Community Building, Outreach

Immersive Summer Undergraduate Student Research Program. In summer 2016, 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. Participating students included Lydia Gingrich of Haverford College and Tori Knapp of Ithaca College (working with Kastner), who combined optical and X-ray data to study stars in the field of the puzzling infrared-luminous star RZ Piscium; RIT undergraduates Shaun Foster and Bryanne McDonough, who used reverberation mapping to study the structure of active galactic nuclei with Robinson's research group; and RIT undergraduates Dale Mercado, Noah Reuter, and Jake Mekker, who investigated galaxy evolution with Kartaltepe and her team. As in previous summers, our LAMA-supported students 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 2016 RIT Summer Undergraduate Research Symposium, as well as a poster at the 2017 January meeting of the American Astronomical Society (Gingerich et al., Bulletin of the AAS, 229, 154.22, 2017).

RIT Astrophysics Community Building. Via hospitality support in 2016, 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 2016, 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:

Figure 1: Members of the AST program at their exhibit for the 2016 Imagine RIT event.

- ImagineRIT. Kristina Punzi (LAMA) and Chi Nguyen (Center for Detectors) led the development and organization of the AST graduate program's exhibit at the May 2016 edition of ImagineRIT, "Cosmic Companions: From Planets to Black Holes" (see Fig. 1). The festival brought over 25,000 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, eclipse demonstrations, telescope models, and interactive displays. All of our LAMA-sponsored AST graduate students played essential roles in this effort.
- 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 five 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. The March 12, 2016, edition featured presentations by LAMA's Richmond and three other faculty from RIT. 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.

Figure 2: Local amateur astronomer Leo Kellett (at left) at the RIT Observatory during the transit of Mercury. Kellett's telescope, with its special H-alpha filter, provided some of the best views of the event.

- RIT Observatory: The RIT Observatory runs a number of events for members of the local community: school groups, Girl Scout troops, families, students at RIT and other colleges. In 2016, our largest event took place on May 9, when the planet Mercury passed in front of the Sun. Transits of Mercury are uncommon, occurring only 13 or 14 times per century. Observatory Director Richmond and Connelly, together with several other faculty and a number of AST grad students, showed the tiny black dot of Mercury to about 60 visitors and a local TV news team.

5. Research Highlights

Jeyhan Kartaltepe and the Galaxy Evolution research group: One of the important processes for transforming the properties of galaxies over cosmic time is the merger of two galaxies into a single galaxy. These mergers can enhance star formation, fuel a central black hole, and transform the shapes of galaxies. Jeyhan Kartaltepe's Galaxy Evolution research group explores the various ways that galaxies change over time as a result of this process using data from a number of facilities, both on the ground and in space, across the entire electromagnetic spectrum. A number of RIT undergraduate and graduate students have been active participants in this research. During Spring 2016, computer science major Brennan Dell worked on a project looking at the evolution of the galaxy pair fraction over time. He was only able to devote a few weeks to the project before starting a co-op program, but he made excellent progress in that time. Over the summer, Physics major Dale Mercado worked on a project to ascertain the best way to separate black hole activity from star formation in high redshift galaxies, Noah Reuter worked on identifying galaxies in close pairs, and Jake Mekker worked on a public outreach project to develop a mobile game illustrating various aspects of galaxy evolution in a way that is accessible and entertaining to the general public. CIS high school intern Niels Rasmussen also worked on this project. Finally, FastForward student Bradley Hamel spent four weeks working on a project with Jeyhan Kartaltepe and Jennifer Connelly. He conducted a morphological analysis of a sample of massive galaxies at moderate redshift in order to look for trends with environment. Starting in Fall 2016, senior capstone student Sam Zimmerman began a project testing various algorithms for measuring galaxy morphology in a quantitative and automated way. Also in the fall, first year physics major Isabella Cox joined the group and has begun to work on the reduction of data from a Gemini GMOS spectroscopic survey.

Jeyhan Kartaltepe went on two different observing runs to major observatories in 2016. The first was to use the NIRSPEC instrument on the Keck telescope in Hawaii (see status of this data in next paragraph) and the second was to use the FMOS instrument on the Subaru telescope to complete a multi-year near-infrared spectroscopic survey. Those data are currently being analyzed and the final results should be published soon. Kartaltepe was awarded time on ALMA, with observations scheduled for next October, and with Keck, scheduled for next February.

Postdoc Krystal Tyler started at RIT in September 2016 and her research focuses on the effect of large scale environment on galaxy properties. With Jeyhan Kartaltepe, she is working on improving measurements from archival observations from the Herschel Space Observatory. She has also been active in mentoring graduate and undergraduate students. Krystal presented her research at the ASNY meeting at Siena College in November 2016.

Kevin Cooke is a graduate student in his fifth year, measuring the star formation rates in the most massive galaxies in galaxy clusters. His paper "Star Formation in Intermediate Redshift $0.2 < Z < 0.7$ Brightest Cluster Galaxies" recently appeared in Astrophysical Journal (see Figure 3 below). He has also written a pipeline which re-reduces archival Hubble Space Telescope images taken with the Wide-Field Camera 3 to improve their spatial resolution; the improved images are being used to study the morphology of high-redshift galaxies by the COSMOS collaboration. In April, 2016, he became the first representative of the American Astronomical Society to attend the Catalyzing Advocacy in Science and Engineering Workshop in Washington, DC.

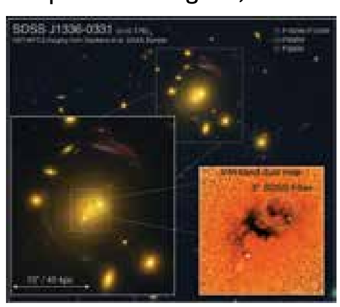


Figure 3: Graduate student Kevin Cooke was first author on a paper describing star formation in the giant elliptical galaxies at the center of rich clusters.

Graduate student Ekta Shah has begun a research project investigating the properties of galaxies in pairs in order to determine how their properties relate to pair separation and thus the role that the interaction has on these properties. She has reduced observations from the DEIMOS instrument on Keck, combined them with all publicly available spectroscopic observations for the five CANDELS survey fields, and constructed a large sample of spectroscopically confirmed galaxy pairs. Kartaltepe was awarded one additional night of Keck observations for this project scheduled for Jan 2017.

Brittany Vanderhoof joined the group in August as a first year PhD student. Her research thus far focuses on near-infrared spectroscopic observations of $z\sim1.5$ galaxies taken with MOSFIRE on Keck to determine the role of mergers in galaxy evolution using kinematic measurements. Likewise, Meaghann Stoetling joined the group in August, 2016, as a first-year master's student. She is working on the resolved spectral energy distributions of galaxies using observations from the Hubble Space Telescope.

Trent Seelig: A graduate student working with Andy Robinson, Seelig studies the growth process of supermassive black holes (SMBH) in the centers of galaxies, and how it may influence the stellar evolution of the host galaxy. At distances of tens of parsecs from the nucleus, how does the inward flow of material fueling the SMBH relate to the luminosity and the kinematic power of the Active Galactic Nucleus (AGN) and its associated outflows? Observations of the galaxies MCG-06-30-015 and NGC 4180 with the Multi Object Spectrograph Integral Field Units on the GEMINI telescopes in Hawaii and Chile allow Seelig and colleagues to map gas flows and disentangle radial motions from circular rotation patterns to determine the rates of mass inflow and outflow. The results of this study will eventually help us to understand the relationships of properties of host galaxies to the properties of their AGN (see Figure 4).

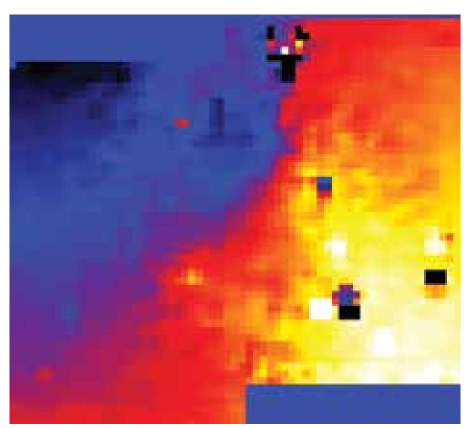


Figure 4: The unique capabilities of IFU observations allow us to map the line-of-sight velocity of gas at many locations within a small field. In this example, near the center of NGC 4180, blue regions represent gas moving toward the observer and red regions gas moving away from the observer.

Joel Kastner: Working with his present AST PhD student Kristina Punzi, recently minted AST PhD Dave Principe, and an international team of young-star researchers, Kastner investigated whether X-rays from young, low-mass stars can affect the likelihood that planets might form around such stars. Kastner's team studied several dozen M-type members of a loose group of roughly 10-million-year-old stars (dubbed the "TW Hydrae Association" by Kastner in the late 1990's). These M-type stars range in mass from less than one-tenth to roughly half the Sun's mass. It is actually a bit misleading to call the objects at the lowest end of this mass range "stars" since, in fact, they will never have sufficient mass to fuse hydrogen to helium in their cores, and are hence destined to "fail" (i.e., to become so-called "brown dwarfs"). The team assembled all available X-ray and infrared data for the TW Hydrae Association M stars. From their analysis of these data, Kastner's team established that those TW Hydrae Association stars that have masses of one-third to one-half that of the Sun are exceedingly bright in X-rays, and none of them retain planet-forming disks of gas and dust. In contrast, about half of the lowest-mass young stars and future brown dwarf are orbited by dusty disks from which the stars are themselves still accreting (gaining mass), and these ultra-low-mass objects have systematically weaker X-ray output. The team concluded that the strong X-rays from higher-mass M stars rapidly disperse (photoevaporate) their surrounding planet-forming disks, whereas the tepid X-ray emission from the lowest-mass objects allows their disks to survive longer -- in many cases, up to and perhaps exceeding the 10-million-year age of the TW Hydrae Association.

Kastner's paper on X-rays and disks associated with M stars in the TW Hydrae Association appeared in the Astronomical Journal, and the results were featured on the Chandra X-ray Science Center's EPO website: http://chandra.harvard.edu/photo/2016/twhya/ On the basis of the AJ paper, Kastner proposed for, and was awarded, a Chandra X-ray Observatory Large Program in 2017 to observe another 10 very low-mass stars and brown dwarf candidates in the TW Hydrae Association.

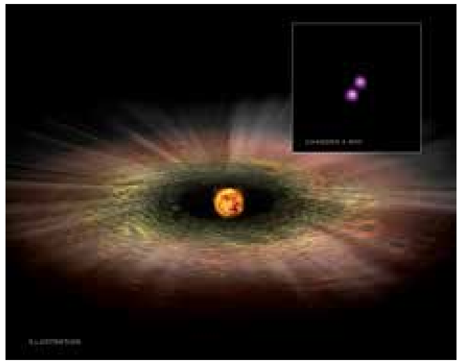


Figure 5: Artist's impression of the disk around a young star, like those in the TW Hya association. X-ray emission from the young star can greatly affect the evolution of material in the disk, some of which may eventually form planets. The inset shows a Chandra X-ray image of TW Hya itself. (Credit: X-ray: NASA/CXC/RIT/J. Kastner et al.; Illustration: NASA/CXC/M. Weiss)

During the last four months of 2016, Kastner benefitted from sabbatical residencies at the Institut de Planetologie et Astronomie de Grenoble (France) and Arcetri Observatory (Florence, Italy). The former residency was facilitated by an IPAG visitor's stipend obtained by Kastner's IPAG colleagues Pierre Hily-Blant and Thierry Forveille. The Arcetri residency was the result of Kastner's being awarded Study Abroad International's 2016 Faculty Fellowship (https://www.saiprograms.com/faculty-advisors/faculty-fellows/). During his time at IPAG, Kastner worked with Hily-Blant, Forveille, and their Grenoble students and colleagues on studies of the nearest-known planet-forming disks using the Atacama Large Millimeter Array, the world's most powerful radio telescope. Kastner's time at Arcetri was spent working with his former RIT postdoc Germano Sacco, who is now on the permanent science staff of the Observatory and is a member of the new Gaia space telescope astrometry mission science team. While at Arcetri, Kastner and Sacco initiated a program to exploit the extreme precision of the Gaia distances and proper motion that are newly available for millions of stars to identify previously unrecognized examples of young stars within a few hundred light years of our solar system. AST PhD student Punzi joined Kastner and Sacco for a week of Kastner's month-long Arcetri residency.

In 2016, the Proceedings of International Astronomical Union Symposium (IAUS) #314, "Young Stars & Planets Near the Sun," were published by Cambridge University Press. Kastner, who served as co-chair of the meeting's Scientific Organizing Committee, was lead editor of the IAUS 314 Proceedings. The meeting 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. The IAUS 314 Proceedings book includes 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.

In 2016, Marcus Freeman, an AST student who defended his PhD in 2015, and his erstwhile supervisor (Kastner) jointly published Freeman's detailed 3-D model of the planetary nebula BD +30 3639. Planetary nebulae, so named because they vaguely resembled planets when first observed through telescopes a couple centuries ago, are actually the ejected outer layers of Sun-like stars that have exhausted their core supplies of hydrogen. The intense UV radiation from the newly exposed stellar core ionizes and illuminates the ejected gas. The planetary nebula end-stage of a Sun-like star's life is short-lived, so the processes that generate the beautiful and complex structures that characterize these objects are poorly understood. In their study of BD +30 3639, Freeman and Kastner compiled a library of all available images of the object, spanning wavelengths from the X-ray through the radio regimes. Freeman modeled this comprehensive image suite using the software Shape, which facilitates detailed 3-D volumetric renderings that can be tranformed into radiometrically accurate 2-D synthetic images. The 3-D model that best accounts for the available imagery consists of a concentric set of expanding ellipsoids that has been "punctured" by faster, highly collimated flows more recently ejected by the present-day central star. The fast outflows may point to the influence of an unseen (perhaps cannibalized) binary companion to the star. Alternative views of the same basic 3-D model that well describes BD +30 3639 can explain the observed shapes of other well-studied planetary nebulae, like the famous Ring Nebula (M 57). The Freeman & Kastner study of BD +30 3639 appeared in Astrophysical Journal Supplement Series.

Figure 6: Composite HST (optical light, shown in orange) and Chandra (X-ray light, shown in blue) image of BD+30 3639. (Credit: X-ray: NASA/CXC/RIT/J. Kastner et al.; Optical: NASA/STScI/Univ. MD/J.P. Harrington)

Michael Richmond: At the beginning of January, Richmond led a team to Kitt Peak National Observatory in Arizona for a week-long observing run at the WIYN 0.9-meter Telescope. Composed of Visiting Assistant Professor Jen Connelly, AST graduate students Kristina Punzi and Ekta Shah and undergraduate Physics major Kaitlin Schmidt, the group collected images for a range of projects, including planetary nebulae, ionized gas in star-forming galaxies, and the eclipsing binary star HH UMa. On the night of 2016 Jan 22, they noticed an electronic alert describing a bright optical flare in the direction of the Pleiades and quickly started taking a series of images of the object. Unfortunately, it turned out to be nothing more than the ordinary asteroid (4801) Ohre (see http://spiff.rit.edu/richmond/asras/master/master.html for the whole story).

Richmond and Connelly acted as co-advisors for Kaitlin Schmidt's capstone project, a study of the multicolor light curve of HH UMa. Schmidt combined measurements from Kitt Peak with others taken at the RIT Observatory to create nearly complete phase coverage in the BVRI passbands. Using her light curves, Schmidt was able to determine that the period of the system is lengthening very gradually.

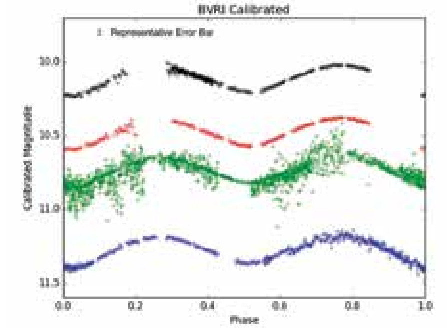


Figure 7: Light curves of the eclipsing binary system HH UMa, in passbands (from bottom to top) BVRI. Credit: Kaitlin Schmidt.

Richmond spent much of the summer of 2016 monitoring the nearby supernova 2016coj, which was discovered in late May and remained bright enough to yield good measurements with the RIT Observatory's 12-inch telescope through August. In addition, he tested an addition to the Observatory's equipment, a new ATIK 11000 CCD camera with a large sensor and wide field of view.

RIT granted a professional leave to Richmond for the 2016-2017 academic year. During the fall semester, he travelled to Japan in order to teach and work at the University of Tokyo. The Research Center for the Early Universe (RESCEU), based at the Hongo campus in Tokyo, hired Richmond to teach a course to its graduate students on exoplanets. He built upon materials used to teach a course at RIT (together with Joel Kastner) the previous year, which will come in handy the next time the exoplanets course enters the rotation in Rochester. In addition, Richmond joined a team of astronomers in Tokyo who are building a high-speed camera designed to carry out large-area surveys of the sky, searching for transient optical sources. The Tomoe Gozen project (http://www.ioa.s.u-tokyo.ac.jp/tomoe/about.html) will make use of the 105-cm Kiso Schmidt Telescope in the central mountains of Japan, not far from the ski-slopes of Nagano.

6. Publications

(1) Schnorr-Müller, Allan; Storchi-Bergmann, Thaisa; Robinson, Andrew; Lena, Davide; Nagar, Neil M., 2016. Feeding and feedback in NGC 3081. Monthly Notices of the Royal Astronomical Society, 457, 972

(2) Couto, Guilherme S., et al., 2016. Integral field spectroscopy of the circum-nuclear region of the radio Galaxy Pictor A. Monthly Notices of the Royal Astronomical Society, 458, 855

(3) Baldi, Ranieri D.; Capetti, Alessandro; Robinson, Andrew; Laor, Ari; Behar, Ehud, 2016. Radio-loud Narrow Line Seyfert 1 under a different perspective: a revised black hole mass estimate from optical spectropolarimetry. Monthly Notices of the Royal Astronomical Society: Letters, 458, L69

(4) Lena, Davide, et al., 2016. Ionized gas kinematics within the inner kiloparsec of the Seyfert galaxy NGC 1365. Monthly Notices of the Royal Astronomical Society, 459, 4485

(5) Principe, David A.; Sacco, G.; Kastner, J. H.; Stelzer, B.; Alcalá, J. M., 2016. Evidence for variable, correlated X-ray and optical/IR extinction towards the nearby, pre-main-sequence binary TWA 30. Monthly Notices of the Royal Astronomical Society, 459, 2097

(6) Kastner, Joel H., et al., 2016. M Stars in the TW Hya Association: Stellar X-Rays and Disk Dissipation. Astronomical Journal, 152, 3

(7) Freeman, M. J.; Kastner, Joel H., 2016. A Multi-wavelength 3D Model of BD+30°3639. Astrophysical Journal Supplement Series, 226, 15

(8) Civano, F., et al., 2016. The Chandra Cosmos Legacy Survey: Overview and Point Source Catalog. Astrophysical Journal, 819, 62

(9) Peth, Michael A., et al., 2016. Beyond spheroids and discs: classifications of CANDELS galaxy structure at $1.4 < z < 2$ via principal component analysis. Monthly Notices of the Royal Astronomical Society, 458, 963

(10) Laigle, C., et al., 2016. The COSMOS2015 Catalog: Exploring the $1 < z < 6$ Universe with Half a Million Galaxies. Astrophysical Journal Supplement Series, 224, 24

(11) Huertas-Company, M., et al., 2016. Mass assembly and morphological transformations since z ˜ 3 from CANDELS. Monthly Notices of the Royal Astronomical Society, 462, 4495

(12) Kimura, Mariko, et al., 2016. Repetitive patterns in rapid optical variations in the nearby black-hole binary V404 Cygni. Nature, 529, 54

(13) Wolf, Rachel C., et al., 2016. SDSS-II Supernova Survey: An Analysis of the Largest Sample of Type Ia Supernovae and Correla-

tions with Host-galaxy Spectral Properties. Astrophysical Journal, 821, 115

(14) de Miguel, E., et al., 2016. Accretion-disc precession in UX Ursae Majoris. Monthly Notices of the Royal Astronomical Society, 457, 1447

(15) Kato, Taichi, et al., 2016. Survey of period variations of superhumps in SU UMa-type dwarf novae. VIII. The eighth year (2015-2016). Publications of the Astronomical Society of Japan, 68, 65

(16) Srinivasan, S., et al., 2016. The evolved-star dust budget of the Small Magellanic Cloud: the critical role of a few key players. Monthly Notices of the Royal Astronomical Society, 457, 2814

(17) Sloan, G. C., et al., 2016. The Infrared Spectral Properties of Magellanic Carbon Stars. Astrophysical Journal, 826, 44

Other (Non-refereed) Publications

(1) Richmond, M.; Shah, E.; Connelly, J.; Schmidt, K.; Punzi, K, 2016. Master flare may be asteroid (4801) Ohre. Astronomer's Telegram, No. 8573

(2) Simmons, Brooke, et al., 2016. Galaxy Zoo CANDELS Data Release I: Morphologies of ~50,000 Galaxies With $z \leq 3$ in Deep Hubble Legacy Fields. American Astronomical Society, AAS Meeting 227, 342.42

(3) Portman, Matthew, et al., 2016. AGB Stars in the Large and Small Magellanic Clouds. American Astronomical Society, AAS Meeting 227, 144.24

(4) Sargent, Benjamin A.; Srinivasan, Sundar; Meixner, Margaret; Kastner, Joel, 2016. Mass Loss from Dusty AGB and Red Supergiant Stars in the Magellanic Clouds and in the Galaxy. American Astronomical Society, AAS Meeting 227, 228.06

(5) Montez, Rodolfo, et al., 2016. Out on a Limb: Updates on the Search for X-ray Emission from AGB Stars. American Astronomical Society, AAS Meeting 227, 239.02

(6) Audard, Marc, et al., 2016. Swift and SMARTS observations of the 2015 outburst of V1118 Ori. Astronomer's Telegram, No. 8548

(7) Kastner, J. H.; Stelzer, B.; Metchev, S. A., 2016. Young Stars & Planets Near the Sun. Proceedings of the International Astronomical Union, IAU Symposium, Volume 314

(8) Kastner, Joel H., 2016. A Brief History of the Study of Nearby Young Moving Groups and Their Members. Proceedings of the International Astronomical Union, IAU Symposium, Volume 314, 16

(9) Principe, David; Kastner, Joel. H.; Rodriguez, David, 2016. Magnetic Activity of Pre-main Sequence Stars near the Stellar-Substellar Boundary. Proceedings of the International Astronomical Union, IAU Symposium, Volume 314, 126

(10) Kastner, J. H., et al., 2016. Rings of C2H in the Molecular Disks Orbiting TW Hya and V4046 Sgr. Proceedings of the International Astronomical Union, IAU Symposium, Volume 314, 193

(11) Punzi, Kristina M., et al., 2016. Constraining X-ray-Induced Photoevaporation of Protoplanetary Disks Orbiting Low-Mass Stars. Proceedings of the International Astronomical Union, IAU Symposium, Volume 314, 203

(12) Rodriguez, David R., et al., 2016. A Molecular Disk Survey of Low-Mass Stars in the TW Hya Association. Proceedings of the International Astronomical Union, IAU Symposium, Volume 314, 207

(13) Bodman, Eva H. L., et al., 2016. Dippers and Dusty Disks Edges: A Unified Model. arXiv:1605.03985

(14) Principe, David A.; Kastner, Joel H.; Rapson, Valerie, 2016. Imaging the Circumstellar Disk of a Solar Nebula Analog: Polarimetric Observations of MP Mus. Resolving planet formation in the era of ALMA and extreme AO, 8

(15) Montez, Rodolfo; Ramstedt, Sofia; Kastner, Joel H.; Vlemmings, Wouter, 2016. A Catalog of GALEX Ultraviolet Emission from Asymptotic Giant Branch Stars. American Astronomical Society, AAS Meeting 228, 317.07

(16 Sargent, Benjamin A.; Srinivasan, Sundar; Meixner, Margaret; Kastner, Joel H., 2016. Dusty Mass Loss from Galactic Asymptotic Giant Branch Stars. American Astronomical Society, AAS Meeting 228, 405.07

(17) Kastner, Joel, 2016. Making The Best Of Great Things: Gpi & Alma Imaging Of The Nearest Known Protoplanetary Disks. Resolving planet formation in the era of ALMA and extreme AO

(18) Matsuura, Mikako, et al., 2016. Detection of rotational CO emission from the red-supergiants in the Large Magellanic Cloud. Proceedings of the IAU, Volume 29B, 459

(19) Sargent, B. A., et al., 2016. Comparative Studies of the Dust around Red Supergiant and Oxygen-Rich Asymptotic Giant Branch Stars in the Local Universe. Proceedings of the IAU, Volume 29B, 470

(20) Connelly, Jennifer L.; Parker, Laura C., 2016. Most Massive Group Galaxies at Intermediate Redshifts. American Astronomical Society, AAS Meeting 227, 440.11

(21) Rice, Emily L., et al., 2016. Expanding the Universe of "Astronomy on Tap" Public Outreach Events. American Astronomical Society, AAS Meeting 227, 248.02

NEWS

RIT professor wins Smithsonian, Carnegie and SAI fellowships

Joel Kastner studies young stars and planets

Nov. 4, 2016

by Susan Gawlowicz

RIT professor Joel Kastner is the Study Abroad International Faculty Fellow at the Arcetri Observatory in Florence, Italy.

Rochester Institute of Technology professor Joel Kastner is broadening and deepening his research program on the origins of our solar system and planetary systems orbiting other stars while on four consecutive fellowships and visiting positions during his sabbatical this academic year.

Kastner, professor in RIT's Chester F.

Carlson Center for Imaging Science and the School of Physics and Astronomy, is the Study Abroad International Faculty Fellow for the month of November at the Arcetri Observatory in Florence, Italy. He is collaborating with former RIT postdoctoral fellow Germano Sacco and other Arcetri scientists to identify and study young stars within a few hundred light years of the sun using newly available data from the European Space Agency's Gaia space telescope.

He was also awarded two additional fellowships for 2017—the prestigious Merle A. Tuve Fellowship from the Carnegie Institution for Science Department of Terrestrial Magnetism in Washington, D.C., for his six-week residency there, starting in January 2017; and a Smithsonian Institution Short Term Visitor fellowship for his residency at the Smithsonian Astrophysical Observatory in Cambridge, Mass., in March and April 2017.

Prior to his residency in Florence, Kastner spent two months as a visiting astronomer at the Institut de Planetologie et Astronomie de Grenoble, or IPAG, in France, studying the compositions of planet-forming disks around young stars in a collaboration with scientists there who work in the areas of interstellar and solar system chemistry.

"The astrophysicists at IPAG, Arcetri, Carnegie and the Smithsonian Astrophysical Observatory are combining observations with the world's most powerful astronomical facilities with sophisticated computer modeling to attack the complex problem of how planetary systems, including our own solar system, have come into being," Kastner said. "I feel very fortunate to be able to work so closely with so many 'black belt' astrophysicists during one sabbatical year."

CIS alumnus Kyle Foster (second from right) and his crewmates for NASA's HERA XI mission.

Comments By Joe Pow, CIS Associate Director

Intern Program

The summer of 2017 marked the 18th year of the CIS high school intern program. This year a total of 14 students from 10 different schools worked on projects in six different research labs as shown in the table below.

Tristan Bachmann	Pittsford Mendon	Sensors/Advanced Instrumentation
Nate Brunacini	McQuaid	Visual Perception/Machine Vision
Gerry Chen	Pittsford Sutherland	Visual Perception/Machine Vision
Ronny Chen	Pittsford Sutherland	Optics/Laser-Based Manufacturing
Ashley Cummings	Mercy	Sensors/Advanced Instrumentation
Henry Edmondson	Webster Schroeder	Optics/Laser-Based Manufacturing
Emma Hornak	Harley	Drone-Based Remote Sensing
Peter Letendre	Webster Schroeder	Sensors/Advanced Instrumentation
Titus Mickley	Athens (PA)	Visual Perception/Machine Vision
Paige Phillips	Victor	Document Restoration
Emily Polo Rankin	Tioga	Document Restoration
Aditi Seshadri	Allendale Columbia	Visual Perception/Machine Vision
Anjana Sethadri	Allendale Columbia	Magnetic Resonance Imaging
Ryan Luu	Victor	Visual Perception/Machine Vision

Research Experience for Undergraduates

The NSF-funded REU grant "Imaging in the Physical Sciences" was renewed in December 2016 for an additional 3 years. This program provides funding at RIT for undergraduate research and supports students from around the US. As a result of this renewal, the REU will be able to continue to support REU research for 8 students as it has in the past. These students are matched with suitable mentors from the CIS faculty as dictated by common interests. The program this year included 2 STEM lectures per week, covering skills such as entrepreneurship, grant writing, and presentations, as well as lectures by guest faculty on various areas of research within CIS. This year's the mentors include Roger Easton, Joe Hornak, Chris Kanan, Zoran Ninkov/Dimitri Vorobiev, Jeff Pelz, Aaron Gerace, Jeyhan Kartaltepe and Joel Kastner.

K-12 Outreach

Although the number of K-12 engagements has declined since the departure of our outreach program coordinator, Bethany Choate, CIS faculty and staff members still are still promoting the Center to prospective students of all ages whenever opportunities arise.

For example, Dr. Jeff Pelz, the Frederick Wiedman Professor, participated in the Stoneham (MA) Central Middle School's first annual STEM Fair on June 2, 2017. Professor Pelz was among a number of professionals from various STEM fields who spoke with 8th graders about STEM careers, highlighting research and development. The purpose of the fair was to introduce students to opportunities in science, technology, engineering and math that await them in the future. Dr. Pelz was invited to participate by Ms. Nancy Dapkiewicz, on the faculty at Stoneham Central Middle School, and alumna of RIT's School of Photography.

In addition, CIS Associate Director Joe Pow also made a school visit this year, spending the day with about 75 8th graders at Canandaigua Middle School in January. Joe introduced the students to the imaging chain, and showed them examples of how imaging plays a vital role in many fields such as medicine, manufacturing, defense, and environmental protection. As always, the thermal camera demonstration was the high point of the day.

Alumni

During the 2016-2017 academic year CIS Director Dave Messinger teamed with the RIT Office of Alumni Relations to significantly strengthen the Center's connection with our alumni across the country and around the world. The more popular annual events, such as our DC Alumni Reception, have been retained, and several new events have been added.

One of these new events was the first annual Air Force Alumni Reunion. This hugely successful event, held at RIT in conjunction with the ImagineRIT festival, brought in former Air Force students representing 40 years of the program's history. Shown below are the participants at this inaugural event.

Throughout the year we were also fortunate to have several alumni come back to the Center to give presentations at the weekly meetings of the Imaging Science Club. One of the most popular of these presentations took place in October when Kyle Foster, Imaging Science class of 2007, gave a talk on his experiences as a crew member of NASA's HERA (Human Exploration Research Analog) Mission XI. The HERA Mission XI crew began their 30-day "flight" on July 11. HERA is one of several analogs used by the Human Research Program to research ways to help NASA astronauts move from lower-Earth orbit to deep space exploration. A spaceflight analog is a situation on Earth that produces physical and mental effects on the body similar to those experienced in space. During the 11th HERA mission, crew members went through all the motions of a real deep space mission without ever actually leaving the Johnson Space Center's Building 220. To learn more about this mission, and Kyle's role in it, visit http://www.nasa.gov/ and search for HERA 11.

Kyle Foster, Imaging Science Class of 2007

Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology
54 Lomb Memorial Drive
Rochester New York 14623
(585) 475–5944

http://www.cis.rit.edu/