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Annual Report 2017–2018

Chester F. Carlson CENTER for IMAGING SCIENCE

COVER PHOTO: Members of the Digital Imaging and Remote Sensing (DIRS) Laboratory pose outside the Carlson Building with some of the calibration targets, sensors, and aerial platforms they use in their research. (Photo courtesy of Professor Frank Cost)

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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 2017-18 Academic Year Annual Report of the Center. It has been another exciting year and I hope you enjoy reading about all of our recent activities and accomplishments!

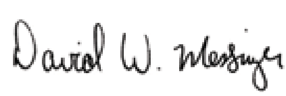
Our students, at both the undergraduate and graduate level continue to excel and lead their fields. Sanghui Han, an imaging science Ph.D. student, received the inaugural K. Stuart Shea Endowed Scholarship from the United States Geospatial Intelligence Foundation during the GEOINT 2018 Symposium. Mandy Nevins, another of our Ph.D. students, was awarded a Microscopy & Microanalysis 2018 Student Scholar award for her conference paper on visualizing astigmatism in the scanning electron microscope beam. And Sara Leary who graduated with a BS this past spring, along with her adviser, Michael Murdoch (Color Science), won the Best Poster Award at the ACM Symposium on Applied Perception. Sara's poster, "Manipulating Object Lightness in Augmented Reality," summarized her senior capstone project research on the optical and perceptual effects of augmented reality overlays on real objects. Dr. Aly Artusio-Glimpse won the RIT Outstanding Ph.D. Dissertation award, and Dr. Ron Kemker was selected as the College of Science outstanding Graduate Delegate this year and was invited to speak at the College Commencement ceremony. As you can see by these few examples, our students continue to be at the cutting edge of research in Imaging Science.

We hosted several alumni events this past year, engaging with alumni in both the Rochester community, the Washington DC area, and Silicon Valley. Next year will be very exciting as in October 2019 we will be celebrating the 30th anniversary of the opening of the Chester F. Carlson Center building! We hope you can join us for this occasion.

Our faculty continue to be recognized for their leadership in their fields. Professor John Kerekes received the 2017 IEEE Geoscience and Remote Sensing Society (GRSS) Outstanding Service Award (OSA), recognizing his long term commitment to the international remote sensing community. We are also increasing our international footprint in other ways. Dr. Tony Vodacek is an external collaborator and advisor to an Academic Center of Excellence at the University of Rwanda and the University of Kibungo, promoting that nation's development by helping to build graduate programs and a culture of scholarship in a country healing from civil war and genocide. Additionally, Dr. Emmett Ientilucci, who after years as a research professor in the Center joined our tenure track faculty as an assistant professor, was an invited speaker for the Remotely Sensed Big Data Analysis and Mining conference in Kolkata, India, at the Indian Statistical Institute. We were also joined by Dr. Guoyu Lu as a new faculty member in the Center who is working on novel approaches to computer vision.

We hosted an exciting event merging photography and science, hosting a visit and exhibition by Dr. Don Pettit, NASA Astronaut in the spring. Dr. Pettit is world renown for his photography from the International Space Station, and the Center worked closely with alumnus Peter Blacksberg to exhibit some of Dr. Pettit's photography in the University Gallery, as well as hosting him for a public lecture about conducting science in space. It was an exciting event with over 200 attendees at the exhibit opening, with many more seeing the exhibit that was on display through the Imagine RIT festival.

It was another exciting year in the Center, and we are looking forward to another one! I hope you enjoy reading through this annual report to learn about all that is going on in the Center. 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!



David W. Messinger, PhD
Director

CIS Staff Assistants Cheryl Merrell (left) and Melanie Warren (right) represented the Center at this year's Presidential Awards for Outstanding Staff ceremony. Cheryl was a nominee for an individual excellence award for the support she provides to four of our research labs, and Mel was a recipient of a team excellence award as the co-chair of the College of Science Staff Advisory Council. Congratulations Cheryl and Mel!

IMAGING SCIENCE GRADUATE PROGRAM

Program Coordinator's Comments By Dr. Charles Bachmann

Our Imaging Science graduate program remains a unique degree program in the US.

Its interdisciplinary nature draws a remarkable cross-section of students from a wide variety of disciplines, and it is this interdisciplinary demographic which helps to foster the unique research atmosphere and diverse range of research undertaken within the Center for Imaging Science. As students graduate from our program, they depart with both a solid foundation in core sub-disciplines and a set of research experiences that prepare them well for the types of interdisciplinary research environments they are likely to encounter in the workforce. Our graduates continue to be a source of great pride and are highly prized by recruiters from government and industrial laboratories, academic institutions, and not-for-profit organizations.

Below are details of the many developments within the graduate program this past year. This includes highlights such as the arrival of new tenure-track faculty, new course offerings, and a wide variety of outstanding student achievements.

Graduate Program Faculty

As of the end of the 2017–18 academic year there were a total of 57 members of the CIS Graduate Program Faculty, including two new tenure track faculty. This year, CIS welcomed Dr. Guoyu Lu and Dr. Emmett Ientilluci as new tenure-track faculty members. With the addition of Dr. Lu and Dr. Ientilluci, CIS now has a total of 19 tenured or tenure-track faculty with the Center as their primary appointment. Another 25 CIS faculty 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.

Curriculum Development

This year, new CIS faculty member Dr. Guoyu Lu, who is an expert in autonomous vehicles and imaging systems, offered a new Special Topics course entitled Robot Vision. In addition, five courses, that had previously been offered as Special Topics courses, became permanent new offerings in our graduate curriculum. These courses reflect the broad diversity of research interests within CIS. New permanent courses include: Vision Sciences Seminar (IMGS-622, taught by Dr. James Ferwerda); Interactive Virtual Environments (IMGS-624, taught by Dr. Gabriel Diaz); Optical Component, Systems Design and Performance Evaluation (IMGS-635, taught by Dr. Jie Qiao), and Radiative Transfer I and II (IMGS-719 and IMGS-721, bouth taught by Dr. Charles Bachmann. Finally, this year the CIS Faculty decided to revise the structure of our Graduate Laboratory course. In recent years, this course has been a two-semester project-based course offered in the first year. The newly revised Graduate Laboratory course (IMGS-609) will be offered now as a single semester course in the first semester and is designed to provide a foundation for the core graduate curriculum by covering critical subjects and skills such as experimental design and analysis, advanced mathematics and numerical optimization, and scientific programming.

Graduate Student Body

At the beginning of the 2017-18 academic year, there were a total of 116 graduate students pursuing graduate degrees in Imaging Science. Our CIS graduate student population included 88 upper-level graduate students and 28 incoming students, of which 18 were new Ph.D. students and 10 were new MS students. Among the incoming class, half were from the US, while the other half were international students: 6 from India, 2 from Nepal, 2 from Iran, 2 from Bangladesh, and 2 from China.

Student Awards

This year a number of graduate students received awards and recognition in a wide variety of professional venues. The awards listed below reflect 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.

Han, Sanghui.:USGIF Announces First K. Stuart Shea Endowed Scholarship Recipient student award PhD (GEOINT 2017)

Margot Accetura received the Conference Best Paper Award in the Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping III Conference oat SPIE Commercial + Scientific Sensing and Imaging, Orlando, Florida, April 2018.

Connal, Ryan, Behrens Scholarship, ASPRS Scholars (January 21, 2018)

Ford, Ryan T.; Vodacek, Anthony; Schott, John R., RIT Graduate Showcase Oral Presentation Award, RIT (November 03, 2017)

Murphy, Cara, USGIF Scholarship, United States Geospatial Intelligence Foundation (September 01, 2017)

Han, Sanghui, Lockheed Martin Best Paper Award, SPIE (May 03, 2017).

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)

Alharbi, N; Hailstone, Richard K.; Varela, B, Multiple Phase Identification in Alkali-Activated Slag by SEM-EDS, *Key Engineering Materials*, pp.—(July 2018)

Alharbi, N; Hailstone, Richard K.; Varela, B, Multiple Phase Identification in Alkali-Activated Slag by SEM-EDS, *Key Engineering Materials*, pp.—(2017)

Bachmann, Charles M.; Eon, Rehman; Ambeau, Brittany; Harms, Justin; Badura, Gregory; Griffo, Carrie, Modeling and Intercomparison of Field and Laboratory Hyperspectral Goniometer Measurements with G-LiHT Imagery of the Algodones Dunes, *Journal of Applied Remote Sensing*, 12, 1, pp. 012005-1-012005-20 (September 27, 2017)

Badura, Gregory P.; Bachmann, Charles M.; Tyler, Anna C.; Goldsmith, Sarah; Eon, Rehman S.; Lapszynski, Christopher S., A Novel Approach for Deriving LAI of Salt Marsh Vegetation Using Structure from Motion and Multi-Angular Spectra, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, submitted, pp.—(March 28, 2018)

Badura, Gregory; Bachmann, Charles M.; Harms, Justin; Abelev, Andrei, Modeling the Impact of Surface Roughness on BRDF of Clay Sediments, *IEEE Transactions on Geoscience and Remote Sensing*, submitted, pp.—(December 01, 2017)

Bai, Di; Messinger, David; Howell, David, Apigmentanalysistoolforhyperspectralimagesofculturalheritageartifacts, *Algorithms and Technologies for Multispectral, Hyper- spectral, and Ultraspectral Imagery XXIII, Defense and Commercial Sensing, Defense and Commercial Sensing, 10198, pp. -, Anaheim, California, United States* (May 2017)

Binaee, K., Starynska, A., Pelz, J., Kanan, C., Diaz, G. (2018) Characterizing the Temporal Dynamics of Information in Visually Guided Predictive Control Using LSTM Recurrent Neural Networks. In: *Proc. 40th Annual Conference of the Cognitive Science Society* (CogSci-2018).

Donlon, Kevan; Ninkov, Zoran; Baum, Stefi A.; Cheng, Linpeng, Modeling of hybridized infrared arrays for characterization of interpixel capacitive coupling, *Optical Engineering, 56, 2, pp.* —(February 07, 2017)

Dorado-Munoz, Leidy; Messinger, David, Spatial-Spectral Schroedinger Embedding for Target Detection, *Optical Engineering, 56, 9, pp.*—(2017)

Dorado-Munoz, Leidy; Messinger, David; Bove, Damien, Integrating Spatial and Spectral Information for Enhancing Spatial Features in the Gough Map of Great Britain, *Journal of Cultural Heritage, pp.*—(April 2018)

Eon, Rehman S.; Bachmann, Charles M.; Gerace, Aaron, Retrieval of geophysical properties of Earth sediments by inversion of a modified Hapke model of airborne and satellite imagery BRDF, *Remote Sensing of Environment, submitted, pp.*—(May 26, 2018)

Fan, Lei; Messinger, David, Joint Spatial-Spectral Hyperspectral Image Clustering Using Block-Diagonal Amplified Affinity Matrix, *Optical Engineering, 57, 3, pp.*—(2018)

Garma, Rey Jan D.; Schott, John R.; Fiete, Robert D.; Qiao, Jie; McKeown, Donald, Image quality modeling and characterization of Nyquist-sampled framing sensors with operational considerations for remote sensing , Optical Engineering, 56, 1, pp. - (January 02, 2017)

Gibbs, Timothy; Messinger, David, Remotely Sensed Physical Property Estimation from Powder Contaminated Surfaces, *Journal of Applied Remote Sensing, 11, 4, pp.*—(2017)

Han, Sanghui; Kerekes, John P., Overview of Passive Optical Multispectral and Hyperspectral Image Simulation Techniques, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10, 11, pp. 4794-4804* (September 2017)

Harms, Justin; Bachmann, Charles M.; Ambeau, Brittany; Faulring, Jason; Ruiz Torres, Andres; Badura, Gregory; Myers, Emily, A fully-automated laboratory and field-portable goniometer used for performing accurate and precise multi-angular reflectance measurements, *Journal of Applied Remote Sensing, 11, 4, pp. 046014-1046014-1-046014-15* (November 24, 2017)

Kafle, K., Cohen, S., Price, B., Kanan, C. (2018) DVQA: Understanding Data Visualizations via Question Answering. In: Proc. *IEEE Conference on Computer Vision and Pattern Recognition (CVPR-2018).*

Kemker, R., Luu, R., Kanan, C. (2018) Low-Shot Learning for the Semantic Segmentation of Remote Sensing Imagery. *IEEE Transactions on Geoscience and Remote Sensing (TGRS).*

Kemker, R., McClure, M., Abitino, A., Hayes, T., Kanan, C. (2018) Measuring Catastrophic Forgetting in Neural Networks. In: AAAI-2018.

Kemker, R., Kanan, C. (2018) FearNet: Brain-Inspired Model for Incremental Learning. In: *International Conference on Learning Representations* (ICLR-2018).

Kemker, Ronald; Salvaggio, Carl; Kanan, Christopher, Algorithms for semantic segmentation of multispectral remote sensing imagery using deep learning, *ISPRS Journal of Photogrammetry and Remote Sensing, pp. 1-18* (April 20, 2018)

Mahdavi, Mahshad; Kanan, Christopher; Salvaggio, Carl, Roof damage assessment using deep learning methods, *IEEE Xplore (Proceedings of the 46th Annual Applied Imagery Pattern Recognition Workshop), pp. 1-8* (October 10, 2017)

Paris, Claudia; Kelbe, David; van Aardt, Jan A.; Bruzzone, Lorenzo, A novel automatic method for the fusion of ALS and TLS LiDAR data for robust assessment of tree crown structure, *IEEE Transactions on Geoscience and Remote Sensing, 55, 7, pp. 3679-3693* (July 2017)

Ruane, Garreth J.; Mawet, Dimitri; Kastner, Joel H.; Meshkat, T; Bottom, M; CastellÃ¡, B. Fem., Deep Imaging Search for Planets Forming in the TW Hya Protoplanetary Disk with the Keck/NIRC2 Vortex Coronagraph, *The Astronomical Journal, 154, 2, pp.—* (July 27, 2017)

Spivey, Alvin J.; Vodacek, Anthony, Fourier landscape pattern indices for predicting South Carolina watershed fecol coliform, *Journal of Landscape Ecology, 10, 1, pp. 20-34* (July 2017)

Spivey, Alvin J.; Vodacek, Anthony, Multiscale Fourier Landscape Pattern Indices for Landscape Ecology, *Journal of Landscape Ecology, Submitted, pp.—*(2017)

Taylor, Lauren; Scott, Ryan; Qiao, Jie, Integrating Two-Temperature and Classical Heat Accumulation Models to Predict Femtosecond Laser Processing of Silicon, *Optics Materials Express, 8, pp. 648-658* (January 16, 2018)

Travinsky, Anton; Vorobiev, Dmitry; Ninkov, Zoran; Raisanen, Alan D.; Quijada, Manuel; Smee, Stephen A.; Pellish, Jonathan A.; Schwartz, Tim; Robberto, Massimo; Heap, Sara; Conley, Devin; Benavides, Carlos; Garcia, Nicholas; Bredl, Zach; Yllanes, Sebastian, Evaluation of digital micromirror devices for use in space-based multiobject spectrometer application, *Journal of Astronomical Telescopes, Instruments, and Systems, 3, 3, pp.*—(July 01, 2017)

van Aardt, Jan A.; Axel, Colin, Building Damage Assessment Using Airborne Lidar , *J. of Applied Remote Sensing, 11, 4, pp. 1-17* (December 18, 2017)

Vorobiev, Dmitry; Ninkov, Zoran, High-resolution two-dimensional and three-dimensional modeling of wire grid polarizers and micropolarizer arrays, *Optical Engineering, 56, 11, pp.* —(November 29, 2017)

Wang, Fan; Kerekes, John P.; Xu, Zhuoyi; Wang, Yangdong, Residential roof condition assessment system using deep learning, *SPIE Journal of Applied Remote Sensing, 12, 1, pp. 1-20* (March 2018)

McKay, Troy R.; Salvaggio, Carl; Faulring, Jason W.; Sweeney, Glenn, Remotely detected vehicle mass from engine torque-induced frame twisting, O*ptical Engineering, 56, 6, pp. 063101-1-063101-8* (June 2017)

Williams, McKay; Kerekes, John P.; van Aardt, Jan A., Application of Abundance Map Reference Data for Spectral Unmixing, *Remote Sensing, 9, 8, pp. 1-22* (August 2017)

Williams, McKay; Parody, Robert; Fafard, Alex; Kerekes, John P.; van Aardt, Jan A., Validation of Abundance Map Reference Data for Spectral Unmixing, *Remote Sensing, 9, 5, pp. 1-20* (May 2017)

Yang, Jie; Messinger, David; Dube, Roger, Bloodstain Detection and Discrimination Impacted by Spectral Shift Using an Interference Filter based VNIR Multispectral Crime Scene Imaging System, *Optical Engineering, 57, 3, pp.*—(2018)

Yang, Jie; Messinger, David; Dube, Roger, Fixed pattern noise pixel-wise linear correction for crime scene imaging CMOS sensor, *Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXIII, Algorithms and Technolo- gies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXIII, Defense and Commercial Sensing, 10198, pp. -, Anaheim, California, United States* (May 2017)

YousefHussien, Mohammed; Kelbe, David J.; Ientilucci, Emmett J.; Salvaggio, Carl, A multi-scale fully convolutional network for semantic labeling of 3D point clouds, *ISPRS Journal of Photogrammetry and Remote Sensing, pp. 1-13* (March 16, 2018)

Zhao, Runchen; Ientilucci, Emmett, Improvements to an Earth Observing Statistical Performance Model, *Defense and Security, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXIII, pp.—, Anaheim, California, United States* (April 23, 2017)

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

Accettura, Margot S.; Bauch, Timothy D.; Raqueno, Nina G.; Mallia, Joseph; Salvaggio, Carl, Hyperspectral detection of methane stressed vegetation, *Proceedings of the SPIE, Commercial + Scientific Sensing and Imaging, Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping III, Thermal and Hyperspectral Imaging from UAVs, 10664, pp. 106640I-1-106640I-13, Orlando, Florida, United States* (April 2018)

Alharbi, N; Hailstone, Richard K.; Varela, B, New Developments in the Characterization of Alkali-Activated Slag, *****, Third International Conference on Innovative Materials, Structures and Technologies, RIGA, ****, Latvia* (September 2017)

Alharbi, N; Hailstone, Richard K.; Varela, B, A Microscopic Characterization of Alkali-Activated Slag, ****, Non-Traditional Cement & Concrete, Brno, Czech Republic, Czech Republic* (June 2017)

Bachmann, Charles M.; Eon, Rehman; Ambeau, Brittany; Harms, Justin; Badura, Gregory; Griffo, Carrie; Myers, Emily, INVERTING A RADIATIVE TRANSFER MODEL FOR SEDIMENT DENSITY RETRIEVAL FROM HYPERSPECTRAL BRDF DATA, *Proc. of IGARSS, International Geoscience and Remote Sensing Symposium, IGARSS 2017, Optical Modeling in Remote Sensing, pp. 1477-1479, Fort Worth, Texas, United States* (January 10, 2017)

Binaee, Kamran; Starynska, Anna; *Kothari, Rakshi*; Kanan, Christopher; Pelz, Jeff B.; Diaz, Gabriel J., Modeling Hand-Eye Movements in a Virtual Ball Catching Setup using Deep Recurrent Neural Network, *Vision Science Society, Vision Science Society, Vision Science Society, St. Petersburg, Florida, United States* (2017)

Binaee, Kamran; Starynska, Anna; Pelz, Jeff; Kanan, Chris; Diaz, Gabriel, Characterizing the Temporal Dynamics of

Information in Visually Guided Predictive Control Using LSTM Recurrent Neural Networks, *Cognitive Science Society, pp.—, Madison, Wisconsin, United States* (February 01, 2018)

Cui, Zhaoyu; Kerekes, John P.; Schott, John R., Validation of Landsat-8 OLI Image Simulation, *Proceedings of IGARSS 2017, International Geoscience and Remote Sensing 2017, pp. 3186-3189, Fort Worth, Texas, United States* (July 2017)

Dorado-Munoz, Leidy; Messinger, David, Global and Adaptive K-Nearest Neighbor Graphs in a Spectral Target Detector Based on Schroedinger Eigenmaps, *017 IEEE International Geoscience and Re- mote Sensing Symposium (IGARSS), 017 IEEE International Geoscience and Re- mote Sensing Symposium (IGARSS), 017 IEEE International Geoscience and Re- mote Sensing Symposium (IGARSS), pp.—, Fort Worth, Texas, United States* (2017)

Ford, Ryan T.; Vodacek, Anthony, Quantifying Landsat's Ability to Monitor Cyanobacteria in the Great Lakes Region, *IAGLR, 2017 IAGLR Conference, Remote Sensing, Detroit, Michigan, United States* (May 15, 2017)

Han, Sanghui; Fafard, Alex; Kerekes, John P.; Ientilucci, Emmett; Gartley, Michael; Savakis, Andreas, Efficient Generation of Image Chips for Training Deep Learning Networks., *Defense and Security, Automatic Target Recognition XXVII, 10202, 1020203, pp.—, Anaheim, California, United States* (April 12, 2017)

Jeganathan, Nirmalan; Kerekes, John P.; Rosario, Dalton, Characterizing the temporal and spatial variability of longwave infrared spectral images of targets and backgrounds, P*roceedings of Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXIII, Defense and Commercial Sensing, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXIII, 10198, 101980K, pp.— Anaheim, California, United States* (April 2017)

Kothari, Rakshit; Binaee, Kamran; Bailey, Reynold R.; Kanan, Chris; Pelz, Jeff B.; Diaz, Gabriel J., Gaze-in-World movement Classification for Unconstrained Head Motion during Natural Tasks., *VSS, Vision Science Society, Vision Science Society, Saint Petersburg, Florida, United States* (2017)

Kucer, Michal; Cahill, Nathan; Loui, Alex; Messinger, David, Augmenting salient foreground detection using Fiedler vector for multi-object segmentation, *Computational Imaging XV, Electronic Imaging, Electronic Imaging, pp.—, Burlingame, California, United States* (January 2017)

Kucer, Michal; Messinger, David, Aesthetic Inference for Smart Mobile Devices, IEEE Western Applications in Computer Vision (WACV) 2018, *IEEE Western Applications in Computer Vision (WACV), pp.—, Lake Tahoe, California, United States* (March 2018)

Mamaghani, Baabak G.; Sasaki, Geoffrey V.; Connal, Ryan J.; Kha, Kevin; Knappen, Jackson S.; Hartzell, Ryan A.; Marcellus, Evan D.; Bauch, Timothy D.; Raqueno, Nina G.; Salvaggio, Carl, An initial exploration of vicarious and in-scene calibration techniques for small unmanned aircraft systems, *Proceeding of the SPIE, Commercial + Scientific Sensing and Imaging, Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping III, Collecting Reliable Image Data with UAVs, 10664, pp. 1066406-1-1066406-20, Orlando, Florida, United States* (April 2018)

Nevins, M; Hailstone, Richard K.; Zotta, M; Lifshin, E, Viability of Point Spread Function Deconvolution for SEM, *Microc. Microanal. Proceedings, Microscopy and Microanalysis 2017, 23 S1, pp. 126-127, Saint Louis, Missouri, United States* (August 2017)

Qiao, Jie; Mulhollan, Zachary; Dorrer, Christophe, (Invited talk) Optical Differentiation Wavefront Sensing using binary pixelated filters for Freeform Metrology and Phase Imaging, *CIOP, 9th International Conference on Information Optics and Phontics, 6, Harbin, Heilongjiang, China* (July 17, 2017)
Qiao, Jie; Taylor, Lauren, (Invited Talk) Predicting Optimal Femtosecond Laser Processing of Silicon via Integration of the Thermal and Two-Temperature Models, *CIOP, 9th International Conference on Information Optics and Photonics , 11, Harbin, Heilongjiang, China* (June 20, 2017)

Rangnekar, A; Mokashi, N; Ientilucci, Emmett J.; Kanan, Christopher, Aerial Spectral Super-Resolution using Conditional Adversarial Networks, *Computer Vision and Pattern Recognition (CVPR), Computer Vision and Pattern Recognition (CVPR), Computer Vision and Pattern Recognition (CVPR), pp.—, Salt Lake City, Utah, United States* (November 01, 2017)

Ichiyama, Robert; Ninkov, Zoran; Williams, Scott; Robinson, Ross; Bhaskaran, Suraj, Using quantum-dots to enable deep-UV sensitivity with standard silicon-based imaging detectors, *Photonic Instrumentation Engineering IV, Photonics West, SPIE OPTO, 10110, 1011011, pp. -, San Francisco, California, United States* (February 20, 2017)

Scott, Ryan E.; Taylor, Lauren L.; Qiao, Jie, Comparison of Two-Temperature and Thermal Models for Prediction of the Optimal Femtosecond Laser-Material Processing of Silico, *ATu4C - Laser Interaction with Semiconductrors, Glasses and Metals , CLEO: Applications and Technology 2017 , Laser Interaction with Semiconducttrors, Glasses and Metals (ATu4C), pp. ATu4C- , San Jose, California, United States* (May 14, 2017)

Sponagle, Paul; Salvaggio, Carl, Automatic mission planning algorithms for aerial collection of imaging-specific tasks, *Proceedings of the SPIE, Commercial and Scientific Sensing and Imaging, Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping II, Control Systems and Artificial Intelligence in Agricultural UAV Applications, 10218, pp. 1021807-1-1021807-13, Anaheim, California, United States* (April 10, 2017)

Starynska, Anna; Easton, Roger; Messinger, David, Methods of Data Augmentation for Palimpsest Character Recognition with Deep Neura lNetworks, *4th International Workshop on Historical Document Imaging and Processing, 4th International Workshop on Historical Document Imaging and Processing, 4th International Workshop on Historical Document Imaging and Processing, pp.—, Kyoto, Kyoto, Japan* (2017)
Scott, Ryan E.; Taylor, Lauren L.; Qiao, Jie, Comparison of Two-Temperature and Thermal Models for Prediction of the Optimal Femtosecond Laser-Material Processing of Silico, *ATu4C —Laser Interaction with Semiconductrors, Glasses and Metals , CLEO: Applications and Technology 2017 , Laser Interaction with Semiconducttrors, Glasses and Metals (ATu4C), pp. ATu4C- , San Jose, California, United States* (May 14, 2017)

Taylor, Lauren L.; Frechem, Joshua C.; Han, Hainian; Xu, Jing; Smith, Thomas R.; Pomerantz, Michael; Lambropoulos, John C.; Qiao, Jie, Material Removal and Thermal Impact of Femtosecond-Laser Polishing for Germanium-Based Freeform Optics ,

OTu3B—Lasers in Optical Fabrication , Optical Fabrication and Testing 2017 , Lasers in Optical Fabrication (OTu3B), pp. OTu3B- , Denver, Colorado, United States (July 09, 2017)

van Aardt, Jan A.; Fafard, Alex; Kelbe, David; Giardina, Christian; Selmants, Paul; Litton, Creighton; Asner, Greg P., A terrestrial lidar's assessment of climate change impacts on forest structure, *Silvilaser 2017, 2017, pp. 1-1, Blacksburg, Virginia, United States* (October 2017)

Williams, McKay; Patterson, Kelly; Kerekes, John P.; van Aardt, Jan A., An Introduction to Abundance Map Reference Data, with Applications in Spectral Unmixing, *Proceedings of IGARSS 2017, International Geoscience and Remote Sensing 2017, pp. 201-204, Fort Worth, Texas, United States* (July 2017)

Wang, Yue; Ientilucci, Emmett, Landsat 8 TIRS Calibration with External Sensors, *Optics and Photonics, Earth Observing Systems XXII, pp.—, San Diego, California, United States* (August 14, 2017)

Yang, Jie; Messinger David W.; Dube, Roger R.; Ientilucci, Emmett J., Fixed pattern noise pixel-wise linear correction for crime scene imaging CMOS sensor, *SPIE Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXIII, SPIE, SPIE, 10198, pp.—, Anaheim, California, United States* (May 05, 2017)

Zhang, Chi; Sah, Shagan; Nguyen, Thang; Peri, Dheeraj; Loui, Alexander; Salvaggio, Carl; Ptucha, Raymond, Semantic sentence embedding for paraphrasing and text summarization, *IEEE Global Conference on Signal and Information Processing (GlobalSIP), GlobalSIP 2017, Knowledge-based Multimedia Computing, 978-1-5090-5990-4, pp. 1-5, Montreal, Quebec, Canada* (November 14, 2017)

Zhang, Chi; Nguyen, Thang; Sah, Shagan; Ptucha, Raymond; Loui, Alexander; Salvaggio, Carl, Batch-normalized recurrent highway networks, *2017 IEEE International Conference on Image Processing (ICIP), 10.1109/ICIP.2017.8296359, pp. 640-644, Beijing, Chaoyang District, China* (September 2017)

Graduates

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

- Ronald Matthew Kemker, Low-Shot Learning for the Semantic Segmentation of Remote Sensing Imagery
  Adviser: Christopher Kanan, Ph.D.
- Preethi Vaidyanathan, Visual-Linguistic Semantic Alignment: Fusing Human Gaze and Spoken Narratives for Image Region Annotation
  Adviser: Jeff Pelz, Ph.D., Emily Prud'hommeaux, Ph.D., Cecilia O. Alm, Ph.D.
- Fan Wang, Understanding high resolution aerial imagery using computer vision techniques
  Adviser: John Kerekes, Ph.D.
- Chao Zhang, Functional Imaging Connectome of the Human Brain and its Associations with Biological and Behavioral Characteristics
  Advisers: Stefi Baum, Ph.D., and Andrew Michael, Ph.D.

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

Margot Sophia Accettura
Isaiah Ditmer
Anne Marie Giannandrea
Megan M. Iafrati
Fu Jiang
Sanjana Kapisthalam
Michael Patrick McClelland II
Nilay Vijay Mokashi
Ayushi Patra
Raghu Puppala
Nenad Vrucinic

The following are post-graduate plans for some of the students who graduated during 2017-2018.

Anne Marie Giannandrea, Interface Analyst, HeathVantics, Rochester, NY

Ayushi Patra, Excellus, Rochester, NY

Fan Wang, Image Quality Engineer at GoPro, California

Isaiah Ditmer, Lead Lidar Analyst, Kodiak Mapping Inc, Alaska

Megan Iafrati, Imaging Scientist at Harris Corporation, Rochester, NY

Nenad Vrucinic, Doctoral of Philosophy—Ph.D. Optical Science and Engineering Student, North Carolina

Nilay Mokashi, Imaging Scientist at ON Semiconductor, California

Preethi Vaidyanathan, Eyegaze Developer and Research Scientist, Eyegaze

Raghu Puppala, Software Engineer at KLA-Tencor, California

NEWS

2018 Imaging Science PhD graduate Captain Ronald Kemker was selected as this year's College of Science Graduate Commencement delegate. While working on his PhD, Ron took on many roles that allowed him to be a mentor to the next generation of STEM researchers including starting an outreach program that teaches optics and photonics to high school students.

CIS PhD Student Sanghui Han Named by USGIF As First K. Stuart Shea Endowed Scholarship Recipient

April 23, 2018

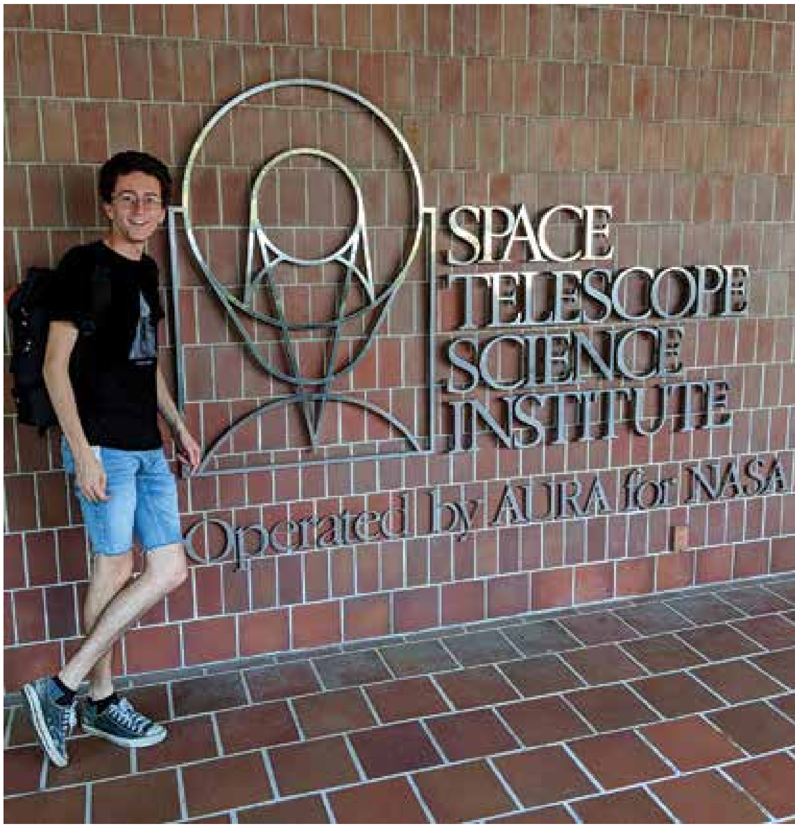
Monday morning at USGIF's GEOINT 2018 Symposium, Sanghui Han was awarded the first ever $15,000 K. Stuart Shea USGIF Endowed Scholarship. Han is pursuing a Ph.D. in imaging science at the Rochester Institute of Technology (RIT) in Rochester, N.Y. USGIFChairman of the Board The Honorable Jeffrey K. Harris presented the award to Han on stage.

The USGIF Board of Directors announced the creation of this new scholarship at the GEOINT 2017 Symposium in honor of K. Stuart Shea, one of the founders of USGIF and the first chief executive and chairman of the organization. The scholarship will be annually awarded to a Ph.D. student studying cartography, geography, or imaging science.

"Being a single mom and a student is challenging, especially financially," Han said. "What this scholarship means to me immediately is some breathing room in my finances, which enables me to better conduct my research. Another facet to this scholarship are the recognition and networking opportunities, which would expand opportunities after I graduate and throughout my career by opening up possibilities for collaboration between organizations that have congruent missions. I hope the connections I make will empower me to bring together my experiences in the military and research at RIT to contribute to the advancement of geospatial intelligence."

Han earned her bachelor's degree in mathematics from the University of Colorado, and upon completion was commissioned as a U.S. Army intelligence officer. She began pursing her master's degree in imaging science through RIT while deployed to Afghanistan and continued her studies throughout her Army tenure. She completed her master's degree toward the end of military career and then began pursing a Ph.D. in imaging science full-time. Han's research develops a framework for predicting utility of spectral images to facilitate the design of imaging systems. She hopes this research can help build simple, flexible systems optimized for various information requirements.

"Developing advanced tradecraft is a priority for the Foundation and the USGIF Board is very pleased to award the first K. Stuart Shea USGIF Endowed Scholarship to Sanghui," Harris said. "Her career trajectory has an important connection to the GEOINT mission having served with the U.S. Army as a Joint Reconnaissance Officer in South Korea. This hands-on experience provides an excellent opportunity to help ensure that her research in improved precision image modeling can translate directly into positive GEOINT mission impact. Recognizing the substantial contributions to USGIF by former chairman Stu Shea, this scholarship reaffirms his leadership principal to actively build the community."



Third year Imaging Science major Greg Nero was one of several undergraduates who took advantage of the summer break to get valuable hands-on experience through a co-op, internship, or other research opportunity.

IMAGING SCIENCE UNDERGRADUATE PROGRAM

Comments by Program Chair, Professor Jim Ferwerda

Over the past year, based on feedback from program students, the Undergraduate Curriculum Committee reviewed and revised our approach to teaching computing starting with graphical and script-based tools to provide an on-ramp to more traditional computer programming.

We now start in the freshman year by introducing spreadsheet-based computing in SOFA-103 Introduction to Imaging and Video Systems and Python-based scripting in IMGS-221 Vision and Psychophysics. In the sophomore year MATLAB is introduced in IMGS-351 Color Science prior to the deep dive into object-oriented coding in C++ taught in IMGS-180 Introduction to Computing and Control. We have made these changes to provide students with knowledge of the computing tools and methods that they need to work in the increasingly compute-enabled field of imaging science and to make them competitive in a marketplace that demands these skills.

This year the students in the Freshman Imaging Project class tackled one of the most challenging projects in the eight year history of this course. Inspired by the work of Professor Matt Hoffman in the School of Mathematical Sciences, they attempted to build a system that would automatically provide the coaching staff of the RIT Tigers Hockey Team with individual and team analytics based on the analysis of video captured during actual game play. The system they designed included two major subsystems:

1. The main rink system consisting of three fixed focal length digital single lens reflex (DSLR) cameras mounted in the stands at center ice on one side of the rink. These cameras were oriented so as to provide complete video coverage of the entire surface of the ice throughout the game. The data from these cameras was first processed through a neural network to isolate all objects in the field of view that were identified as a "person." After calibrating the images and extracting the coordinates of the bounding boxes surrounding each person, the system was able to determine the position of every player on the ice as a function of time. By comparing the color of each player's jersey with that of a fully-characterized RIT jersey, the system could tell which players were on the RIT team and which were on the opposing team. And lastly, by again using a neural network the system was supposed to identify the jersey number of each player and associate that number with the individual's name.
2. The goalie system consisting of two fixed focal length Mako scientific cameras, one outside the rink behind the goal, and one in the rafters directly above the goal, looking down at the ice. The overhead camera was used to determine exactly when a goal was scored. Given that, it was possible to process the video from the rear camera through a blob detection algorithm to determine where the puck was when it crossed the goal line.

While the overall system fell slightly short of delivering the level of performance the students were shooting for, each of the subsystems did successfully demonstrate some of the key functions that the coaching staff requested. The device was exhibited in the Gordon Field House during the annual Imagine RIT Innovation and Creativity Festival.

The senior projects for this academic year were as follows:

Monocular Visual Odometry Methodology for LWIR systems

Makayla Roof

Professor Guoyu Lu, Advisor

Abstract: Visual Odometry (VO) is the process of tracking distance between frames to obtain a camera position as well as the position change over time. This process is prominent in autonomous vehicle systems. Using thermal imagery to "see" in the dark for a VO autonomous vehicle system is an idea that requires extensive analysis. Due to the unique nature of thermal images, common VO procedures tend to fail. This research focused on analyzing methods of monocular VO for autonomous driving and specifically tailoring those methods to accommodate thermal images. The ambition of the project was to find a successful feature detection and matching method which estimated the camera position and pose.

Forward Modeling for Vicarious Calibration

Nathan Dileas

Dr. Matt Montanaro, Advisor

Abstract: Forward modeling, as in Padula (2008), entails taking ground temperature measurements and using atmospheric data and modelling to propagate that measurement to the top of atmosphere. Then, that modeled radiance can be compared with the measured radiance of the sensor in question. However, previous implementations of this process have severe drawbacks such as manual data retrieval and sparse spatial and temporal resolution of atmospheric data. This project will automate the data retrieval and switch the atmospheric data source to a reanalysis source. This in turn will make the process of thermal calibration faster, require less manual work, and improve the number of scenes that can be used. This data can then be used to validate the absolute calibration of any long wave infrared sensor, including Landsat 8 TIRS, Terra/MODIS, or GOES. As well, it can be used for related work, such as the development of a land surface temperature product.

Automatic Spatio-Temporal Registration of Disparate Video Feeds for 3D Reconstruction

Ryan Hartzell

Professor Carl Salvaggio, Advisor

Abstract: This paper outlines a workflow for spatio-temporal registration of videos of a common scene using a modified version of the cost matrix based approach proposed by Wang et. al. The resulting linearly registered playback product allows for high quality image mosaics or three dimensional reconstructions of the scene to be assembled without large errors due to temporal offsets affecting dynamic elements of the scene. Additionally, a non-linearly registered playback product is also available, and enables time to be treated agnostically when constraining video synchronization. This allows frames containing best matching visual information to be synced even if they did not occur at the same global time, providing easier spatial registration of frame pairs and the features they contain. To date, temporal registration, or syncing, has been achieved through the comparison of captured audio or specific, previously-inserted visual cues. However, many problems arise once neither audio nor artificial visual cues are available for correlation. Audio is not always available, especially in the case of lab work or even sUAS captures where no microphones are present or feasible, while artificially placed visual cues can interrupt data and are burdensome for researchers to place and record, thus are not ideal. The described workflow, hereby referred to as VidSync, effectively solves these issues solely by utilizing organic visual feature information within the frames. In doing so, extra preparation can be avoided during capture stages, making the process seamless from capture to data interpretation. VidSync allows users to quickly and easily sync multiple videos to one another and provides a few additional methods for extended applications of the workflow, and is expandable and open-source under the MIT License on Github.

Spectral Phenomenology of Historical Parchments and Inks to Aid Cultural Heritage Imaging System Development

Tyler Kuhns

Professor David Messinger, Advisor

Abstract: Cultural Heritage Imaging is a rapidly expanding area of research utilizing multi and hyperspectral imaging systems to study historical artifacts of significance. Current imaging systems are based on colored LED illumination and select filter wheels to produce imagery in reflective, transmissive, and fluorescent modalities. The advent of new, smaller, hyperspectral systems provides an opportunity to re-think the imaging system for this particular application. This project is to assist in the design and development of a new hyperspectral imaging system for imaging historical documents. Specifically, this project will conduct a band selection study for the imaging system to use for this application, which leads to decisions such as which illumination sources, sensors, and filters should be available on the new imaging system. This paper will present spectral measurements of representative parchments, inks, and reagents. Measurements will be made using a point spectrometer covering 0.4 - 2.4 um. Fluorescence will be measured using a UV illumination LED in a darkened room. Measurements will be made of both bare parchment as well as parchment with ink and reagent applied.

Deriving Thermal Inertia Maps from Thermal Satellite Imagery and Thermodynamic Modeling

Ryan Connal

Dr. Aaron Gerace, Advisor

Abstract: A workflow to produce thermal inertia maps of a location is presented, which involves the integration of thermal satellite imagery and thermodynamic modeling. An understanding about the diurnal activity of land surface temperature for materials found in-scene could provide insight into how significantly they will change between satellite overpasses. Thermal imagery is sampled from Landsat 8 TIRS, as well as GOES-16, over a 24-hour period, since high temporal resolution is more important with regards to defining diurnal cycles than obtaining high spatial resolution data. Each pixel in the temporal cube has its own diurnal cycle once imagery is converted to land surface temperature via split-window algorithm. A lookup-table of modeled diurnal cycles is generated in the THERM modeling software within DIRSIG, where the material-specific parameters for each curve are known. Thermal inertia at each pixel-location is calculated from the parameters used to generate the modeled curve of best-fit to the sampled diurnal cycle. A thermal inertia map relative to the Algodones Dunes in Southern California was derived, with results agreeing with predicted values for the materials found in-scene. GOES-16 imagery was resampled to 1km spatial resolution, which governed the sampled dataset, produc-

ing a quantized looking map. For future work, a study into utilizing TIRS imagery to sharpen the sampled data, as well as locating and eliminating pixels contaminated by clouds, will be carried out.

Manipulating Object Lightness in Augmented Reality

Sara Leary

Professor Michael Murdoch, Advisor

Abstract: An experiment was conducted to uncover how well the perceived lightness of a real object in a real scene can be manipulated using augmented reality (AR). An optical see-through AR setup was used to add displayed images as luminous overlays onto scene objects. In this experiment, real cubes differing in physical lightness (equivalently, reflectance) were used as objects, and AR overlays were created in several configurations. Large, rectangular overlays were used with the expectation that they behave as veiling luminance, easiest for an observer to ignore. Tightly-cropped overlays with edges aligned with the real cubes were used, both in single-color and faceted configurations, were expected to be more realistic and harder to interpret as veiling luminance. Small square overlays, completely within a single face of the real cube were included as well, in order to compare with prior experiments. For all overlay configurations, the observers' task was the same: adjust the luminance of the overlay to make the appearance of the cube match that of a lighter, reference cube with no overlay.

Multispectral Image Registration for Historical Writings Using Transmissive Imaging

Jackson Knappen

Professor Roger Easton, Advisor

Abstract: Multispectral imaging techniques have proven useful for the analysis of historical writings, particularly for recovering lost or faded text. By applying various image processing techniques to combinations of different spectral bands, certain features on these manuscripts can be revealed or enhanced. A transmissive imaging technique may be used in conjunction with reflective and fluorescent imaging of the two sides of a historical manuscript. The transmissive image features may be used to register the two sides, which would allow data from both sides to be combined and possibly improve the ability to segment faded text. This research describes the process in detecting matching features on both sides, followed by the subsequent warping of all bands, providing a complete method of multispectral image registration for historical writings. Results from the ENVI® software package demonstrate accurate global registration of multispectral image cubes, with potential for subpixel precision. However, questions remain about whether the combination of bands from both sides of the manuscript actually result in improved segmentation of faded text.

NEWS

Congratulations to the CIS undergrads who were honored at a reception for students on the fall semester Dean's List. Shown in this picture with CIS Director Dave Messinger are sophomore Greg Nero, junior Beth Bogart, freshman Jared Gregor, and Professor Roger Dube. Other CIS students on the Dean's List were Rachel Shadler, Madeline Wolters, Don Schultz, Makayla Roof, Ryan Connal, Jared Ingoglia, Jackson Knappen, Wade Pines, Sara Leary, Sophia Kourain, Kevin Kha, and Ambar DeSantiago. Congratulations to all!

CIS Director, Dr. David Messinger, and John Wiley Jones Distinguished speaker Dr. Sönke Johnsen from Duke University, present the annual John Wiley Jones Award for outstanding performance in science to CIS junior Kevin Kha. Kevin, who was one of six COS recipients of the award this year, will be spending his summer as an intern at Oak Ridge National Lab in Tennessee, where he will be investigating the use of multispectral drone imagery to predict crop yields.

Shown here is CIS senior Madeline Wolters at the Geography Institute at the University of Bonn in Germany where she is currently doing a research internship to develop a model for determining the preparedness of a community to use geographic information systems as a means to respond to a disaster. During her internship, Maddie also visited a UN building in Brussels, as well as a research site in the Netherlands for a research excursion with the United Nations University in Bonn.

NASA astronaut Don Pettit started a day-long visit to RIT by meeting informally with students in the Carlson Learning Center, where he was able to hear about their various research projects. His schedule also included a meeting with President Munson, a reception at University Gallery to formally open a showing of his photographs from space, and a presentation in Ingle Auditorium where he talked about the notion of "frontiers" and shared stories of the many of the scientific experiments he conducted while in orbit.

DIGITAL IMAGING AND REMOTE SENSING LAB

Laboratory Director's Comments By Dr. John Kerekes

During the 2017–18 academic year DIRS continued its role as a world-class academic research lab focused on the science and engineering of remote sensing systems, technologies, and applications.

New research funding received during this past year totaled over $2M from fifteen different sponsoring organizations including industry, non-profit organizations and government agencies. More than ten 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 honored through awards and recognition.

New research grant highlights of the year included:

- Research Professor Robert Kremens received several grants from the United States Department of Agriculture to continue his research into fire phenomenology;
- The Unmanned Aerial Systems (UAV) initiative received funds from New York State to purchase a shortwave hyperspectral imaging camera;
- Senior Research Scientist Aaron Gerace received a new research grant from the United States Geological Survey to continue his efforts to monitor and improve the calibration of Landsat thermal infrared sensors;
- Professor John Kerekes received a grant from the Air Force Research Laboratory through a small business innovative research award to Kitware, Inc., to assist with the development of an automated system to monitor for changes with commercial satellite imagery.

Example graduate dissertations included:

- Brittany Ambeau, PhD, "Using the Opposition Effect in Remotely Sensed Data to Assist in the Retrieval of Bulk Density."
- Timothy Gibbs, PhD, "Physical Property Extraction of Powder Contaminated Surfaces from Longwave Infrared Hyperspectral Imagery"
- Fan Wang, PhD, "Understanding High Resolution Aerial Imagery Using Computer Vision Techniques,"
- McKay Williams, PhD, "Generation, Validation, and Application of Abundance Map Reference Data for Spectral Unmixing,"
- Fu Jiang, MS, "Evaluation of Stray Light Correction for the Thermal Infrared Sensor (TIRS) from Landsat 8."
- Nirmalan Jeganathan, MS, " Hyperspectral and hypertemporal Longwave Infrared Data Characterization,"
- Nilay Mokashi, MS, " Empirical Satellite Characterization for Realistic Imagery Generation,"
- Paul Sponagle, MS, "Automated Flight Planning for Roof Inspection Using a Face-based Approach,"

Award, recognition, and professional activity highlights included:

- Ph.D. student Sanghui Han was selected as the first recipient of the K. Stuart Shea Endowed Scholarship from the United States Geospatial intelligence Foundation (USGIF);
- Ph.D. student Ronald Kemker was selected as the Graduate Student Commencement Speaker during the College of Science May 2018 graduation ceremonies;
- M.S. student Margot Accettura won the Best Paper Award for her paper and presentation entitled "Hyperspectral detection of methane stressed vegetation" at the SPIE Conference on Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping III held in April 2018;
- Assistant Professor Emmett Ientilucci chaired the 2017 workshop on Systems and Technologies for Remote Sensing Applications Through Unmanned Aerial Systems (STRATUS) held at RIT in October which attracted over 80 participants.
- Laboratory Director and Professor John Kerekes received the 2017 Outstanding Service Award from the IEEE Geoscience and Remote Sensing Society;
- Professor Anthony Vodacek was appointed College of Science Leader Faculty for Study Abroad and International Education;
- Senior Research Scientist Aaron Gerace edited a special issue of the Journal of Applied Remote Sensing on "Improved Intercalibration of Earth Observation Data."

We honored retiring Distinguished Researcher Michael Richardson during a lunchtime reception in December. Mike retired from RIT after 18 years of service leading efforts in managing our research activity. We will miss Mike but wish him well in his new pursuits. Founding Lab Director and Professor John Schott fully transitioned to retirement status during this past year, although we continue to enjoy his occasional presence as he works on writing up the history of the Center of Imaging Science. Also, in August of 2017, Dr. Emmett Ientilucci was appointed as a tenure-track Assistant Professor, transitioning from his previous position as research faculty. As of June 2018 we now have 9 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.

Fundamental Image Science Research

Professor Emmett Ientilucci is leading a team of faculty, staff, and students on a three-year project funded by the Oak Ridge National Laboratory to perform fundamental research into the end-to-end performance and evaluation of remote sensing imaging systems and the exploitation of image data from such systems. The overall objectives are to perform research on topics such as image quality, detection algorithms, information extraction and understanding of three-dimensional scenes, and unmanned aerial system data analysis and collection. Specifically, they are currently focused on the areas of LiDAR point data analysis, multi-modal image registration, synthetic aperture radar simulations, shadow detection and UAS data collections. As one example of the work, Figure SAR.png shows the results of recent simulations of a 0.4 x 0.4 km region of an industrial area as rendered by a panchromatic optical sensor and a synthetic aperture radar (SAR) sensor.

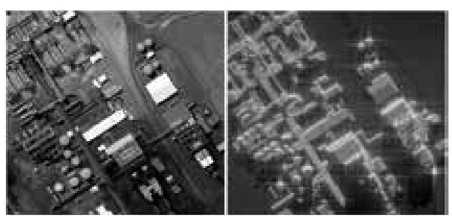


Figure SAR.png. DIRSIG simulated (left) nadir view panchromatic and (right) low incidence angle SAR imagery delivered to ORNL during the month of May.

Hyperspectral Imaging for Assessing "Blue Carbon"

Collaborative research between Dr. Bachmann's research group (GRIT Lab) and Dr. Christy Tyler's research group in Environmental Science focuses on carbon storage in coastal wetland systems. In 2017 they began a field research project at the Virginia Coast Reserve (VCR) Long Term Ecological Research Site (LTER). The VCR LTER, comprised of an extensive chain of barrier islands, shallow water lagoons, and coastal wetlands, is part of a network of sites established by the National Science Foundation and dedicated to ecological research. Their research is using a mast-mounted hyperspectral imaging system, a Headwall micro Hyperspec, to study a marsh chrono-sequence on one of the VCR barrier islands, where Dr. Bachmann, Dr. Tyler and their students are working to more accurately quantify carbon storage in wetland systems as a function of marsh age. Recently, Dr. Bachmann and Dr. Tyler have been awarded a new grant from the National Geographic Society to continue and expand this research.

Figure Blue_carbon.png. Research on "Blue Carbon" storage in coastal wetland systems from hyperspectral remote sensing by Dr. Bachmann's GRIT Lab and Dr. Tyler's lab in Environmental Science during a July 2017 field experiment at the VCR LTER. (Left) Headwall mast-mounted hyperspectral imaging system being deployed by graduate students Rehman Eon and Chris Lapszynski (background) with GRIT-T hyperspectral goniometer system during a calibration cycle (foreground); (top, center) field team at the VCR LTER: graduate student Chris Lapszynski, co-op student mark Foote, undergraduate Nelmy Robles-Serrano, Dr. Bachmann, and Dr. Tyler with the Headwall system. (Bottom, center) Coastal salt marsh scene of Hog Island, VA capture by the Headwall system on Hog Island, VA; (right) Headwall scene of salt panne and coastal salt marsh with example retrieval of leaf biomass, one of several biophysical properties retrieved from the hyperspectral imagery through inversion of a radiative transfer model.

Unmanned Aerial System Research

Our Unmanned Aerial System research has continued to grow and is now supporting several projects with sponsorship from the USDA, NASA, and NYSEARCH. Many of these projects use the new RIT-developed multi-modal MX1 payload system that allows for simultaneous collection of four different types of imaging modalities; RGB, LWIR, LiDAR and Hyperspectral. By collecting all modalities simultaneously, we can collect data under the same weather conditions and light levels. This also eliminates the need to change gimbals in the field and reduce the wear and tear on the equipment from multiple payload changes. This sensor payload was developed by DIRS staff in the beginning of 2017 and began collecting data in June 2017. Since then the DIRS staff have flown the MX1 over 300 times and have collected over 10 TB of data, while supporting 10 different research projects. Figure MX1 shows this payload mounted on a DJI Matrice 600 Pro.

Figure MX1. MX1 payload incorporating hyperspectral, lidar, thermal infrared, and color visible sensors onto a single platform.

Research Using Imaging Spectroscopy and Lidar from UAS

As an example of the research using the UAS payloads, the roles of imaging spectroscopy (hyperspectral) and light detection and ranging (lidar) in precision agriculture are being explored in the context of agricultural disease detection, structural quantification, moisture stress assessment, and nutrient mapping. Under the leadership of Prof. Jan van Aardt and together with collaborators at Cornell University, graduate students Ethan Hughes and Ronnie Izzo are working on the development of robust analytical approaches to these precision agriculture challenges. Specifically they are investigating the development of risk models for proactive management of white mold (Sclerotinia sclerotiorum) in snap beans (Figure snap-bean-nir) as well as the assessment of vineyard moisture stress. The study areas are located at the New York State Agricultural Experiment Station in Geneva, NY and at Fox Run Vineyards in Penn Yan, NY. This research is using advanced multi-modal payloads on the DJI Matrice-600 UAS platform including a high spatial resolution color camera, Headwall Photonics imaging spectrometers (400-1000 nm & 1000-2500 nm), and a Velodyne VLP-16 lidar system. Initial findings from these various projects have shown an ability of >90% classification accuracy for the detection of flowering (critical to white mold management), and have hinted at strong correlations between the spectral measurements and stem water potential (SWP) in vineyards. These efforts have also motivated the development of proper reflectance calibration of the imaging data and the benefit of fusing 3D lidar data with high fidelity spectral imagery.

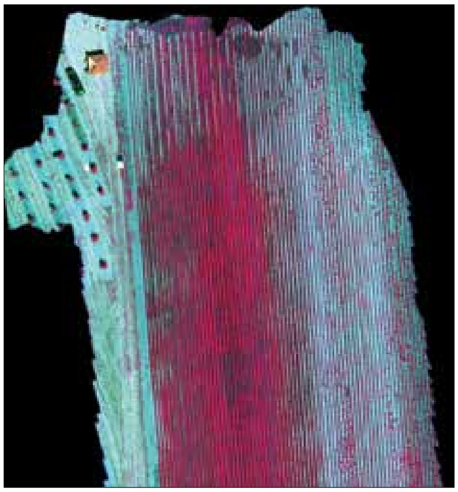


Figure Snap-bean-NIR.png. An example of UAS visible-near-infrared imagery for a snap bean field neat Geneva, NY. This kind of imagery can be used to assess plant health, detect flowering stage, etc., all toward development of a white mold risk model that farmers can use to direct fungicide application

Methane Detection Via Stressed Vegetation

Graduate student Margot Accettura together with Professor Carl Salvaggio are pursuing research to determine the optimal sensor design for underground methane leak detection from a small unmanned aerial system (sUAS) carrying a multispectral imaging sensor. This project used spectral reflectance data from two month-long simulated pipeline experiments. These experiments involved simulating a methane leak by leaking a consistent amount of methane below the surface of sod (Figure Methane). The experiments included other stressors as well as control vegetation in order to differentiate by their spectral reflectance methane stressed vegetation from that stressed by a variety of other sources. These data were used together with the MODTRAN atmospheric code to simulate radiance measurements from the stressors in various atmospheres. The data were analyzed depending on altitude of the sUAS, and the accuracy of detection per altitude was analyzed to determine the optimal sensor for future use.

Selected Journal Articles

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Paris, C., Kelbe, D., van Aardt, J., Bruzzone, L., "A novel automatic method for the fusion of ALS and TLS LiDAR data for robust assessment of tree crown structure," *IEEE Transactions on Geoscience and Remote Sensing*, 55(7), (July 2017)

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Dorado-Munoz, L., Messinger, D., "Spatial-spectral Schrödinger embedding for target detection in hyperspectral imagery," *Optical Engineering,* 56(9), (September 2017).

Gerace, A., Montanaro, M., Connal, R., "Leveraging intercalibration techniques to support stray-light removal from Landsat 8 Thermal Infrared Sensor data," *Journal of Applied Remote Sensing*, 12(1), (October 2017)

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multi-angular reflectance measurements," *Journal of Applied Remote Sensing,* 11(4), (November 2017)

Goodenough, A., Brown, S., "DIRSIG5: Next-generation remote sensing data and image simulation framework," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 10(11), (November 2017)

Han, S., Kerekes, J., "Overview of Passive Optical Multispectral and Hyperspectral Image Simulation Techniques," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 10(11), (November 2017)

Rengarajan, R., Schott, J., "Modeling and simulation of deciduous forest canopy and its anisotropic reflectance properties using the digital image and remote sensing image generation (DIRSIG) tool," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 10(11), (November 2017)

Axel, C., van Aardt, J., "Building damage assessment using airborne lidar," *Journal of Applied Remote Sensing*, 11(4), (December 2017).

Gibbs, T., Messinger, D., "Remotely sensed physical property estimation from powder contaminated surfaces," *Journal of Applied Remote Sensing*, 11(4), (December 2017).

Fan, L., Messinger, D., "Joint spatial-spectral hyperspectral image clustering using block-diagonal amplified affinity matrix," *Optical Engineering*, 57(3), (March 2018).

Wang, F., Kerekes, J., Xu, Z., Wang, Y., "Residential roof condition assessment system using deep learning," Journal of Applied Remote Sensing, 12(1), (March 2018).

Yousefhussien, M., Kelbe, D., Ientilucci, E., Salvaggio, C., "A multi-scale fully convolutional network for semantic labeling of 3D point clouds," *ISPRS Journal of Photogrammetry and Remote Sensing*, (March 2018).

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NEWS

Sean Lahman, @seanlahmanPublished 6:36 a.m. ET Sept. 15, 2017 | Updated 3:58 p.m. ET Sept. 15, 2017

CIS Professor and DIRS Lab Director John Kerekes receiving the 2017 IEE Geoscience and Remote Sensing Society Outstanding Service Award presented by Professor Adriano Camps, 2017 IEEE GRSS President.

The GRSS established the Outstanding Service Award to recognize an individual who has given outstanding service for the benefit and advancement of the Geoscience and Remote Sensing Society.

Henrietta company's aerial imaging technology helps hurricane victims

(Photo: Gerald Herbert, AP)

Hurricane Harvey hit the Texas coast with an unforgiving fury. Wind gusts of more than 130 mph battered buildings when the storm made landfall on Aug. 25, and in the days that followed, many areas around Houston received more than 50 inches of rain.

By the time the massive storm moved out of the area, roughly 450 square miles of Harris County were under water, and tens of thousands of people were displaced.

For many of those storm victims, the discomfort of having to evacuate their homes was compounded by the not-knowing. With flood waters making it impossible to return home, they were left wondering whether there was anything to return to at all. To help those victims, Henrietta-based EagleView Technologies launched a website to show aerial images depicting what Harvey left in its wake.

Users can enter a street address to see before and after images side-by-side. These images, in some cases just hours old, show areas that have been impacted by flooding and the extent of damage caused by high winds.

"We did something similar in 2008 for Hurricane Ike when that hit the greater Houston area," said Frank Giuffrida, vice president of engineering at EagleView. "Galveston Island was evacuated and basically shut off. FEMA didn't let folks back for several weeks."

EagleView, formerly known as Pictometry, provides aerial imagery and data analytics for local and federal government agencies, most of which is captured by its fleet of planes equipped with specialized cameras and backed by powerful software.

Over the years, the company has captured more than 350 million images, covering more than 90 percent of the most populated areas in the United States.

They're capturing these images for their clients: state and local governments or insurance companies. In this instance, that work can also benefit the general public in a real and immediate way.

"In this case, we have complete coverage of that whole Gulf Coast area," Guiffrida. That meant EagleView already had a library of "before" images, all captured within the last two years.

Aerial photo of Houston neighborhood shows damage to houses after Hurricane Harvey (Photo: Provided by EagleView)

For other major storms when they didn't have that coverage, like Hurricane Katrina in 2005, they could go out and capture it as the storm approached.

It's a huge challenge, of course, to do aerial photography in the days just before or just after a major storm.

The weather is only one of the challenges the pilots face. More difficult are the temporary flight restrictions that get put into place while the Coast Guard conducts search and rescue operations, or when Air Force One brings the president to town.

"Planning and staging are a huge part of this process," Guiffrida said. "As soon as it becomes safe to fly, we'll be opportunistic about where we can go."

EagleView deployed 22 planes to the Houston area in the days before Harvey hit, getting them pre-positioned based on where the impact was forecast to be most severe.

They deployed a similar number to Florida as Hurricane Irma approached a week after Harvey, and they'll be prepared to deploy for other storms that follow.

Once the worst of Harvey passed and conditions were safe, those planes in Texas took to the air and started capturing images.

Within a few days, they had logged more than 350 flight hours and covered roughly 5,600 square miles, capturing about a million images. They're still flying, continuing to record conditions on the ground as they evolve.

Local research

Pictometry was founded by John Ciampa, a former Rochester Institute of Technology professor, and Stephen Schultz, an RIT graduate.

The company and the school have had a long partnership, and RIT's research in the field of aerial imaging has continued to push forward the boundaries of what is possible.

Whether the images are captured by airplanes, remotely piloted drones, or satellites high above the earth, building a library of high-resolution images is just the first step.

"Nobody cares about the pictures anymore," says RIT professor Carl Salvaggio. "A person or even a team of people can't look at a million images. We have to teach computers to look at those batches and tell us what's interesting."

He and his colleagues at RIT's Digital Imaging and Remote Sensing Laboratory are doing just that. Whether it's evaluating the health of each plant in a cornfield or inspecting gas pipelines in remote areas, the images captured from above are just a means to an end.

"When you talk to a utility company like RG&E, they don't want 8,000 images of power lines," Salvaggio said. "They want to know which poles have broken conductors or wires in need of repair."

Computers use machine learning to do that, analyzing each of the images, understanding what each image shows, and kicking out a report for repair crews with the location of problem spots.

Over the last decade, drones have become cheaper and the quality of pictures they take keeps improving. The weakest link? The humans who pilot them.

"Pilots are not good at keeping the camera aimed straight down, at flying straight, at keeping a consistent altitude," Salvaggio said. "All of those things affect the quality of the images. That's why we're working on totally autonomous flight."

Technology is already pretty good for having a drone fly itself from point to point. The goal would be to have a human launch a drone, have it recognize its surroundings and plot its own course.

"To analyze storm damage, for example, we're teaching the camera to fly up to about 150 feet, begin to understand the geography of a rooftop, and build a 3-D model," Salvaggio explains. "Then it flies 10 feet above the building taking pictures."

And within RIT's drone program is a specialty lab called IPLER — the Information Products Lab for Emergency Response. Researchers there have worked on projects to monitor forest fires and to assess flood and earthquake damage.

Smarter drones

After a massive event like Hurricane Harvey, insurance companies are going to be overwhelmed with calls from policyholders. One of the things that EagleView can do is create a heat map to identify the areas that have been hit the hardest.

"They can't send claims adjustors to every home on day one," Giuffrida said.

While they're doing that, machine learning algorithms can start the process of assessing damage on individual homes. In some cases, that can be done from images captured by manned aircraft. In other cases, they use drones, which can get much closer to the damaged structure.

It's a service EagleView has been offering for several years, and they work with 18 of the top 20 property and casualty insurance carriers in the United States.

They can kick out a report that assesses how much damage a homeowner has endured, and in many cases the imagery is sufficient to allowing adjusters to close claims without physically visiting the property.

Machine-learning applied imagery from Hurricane Harvey. (Photo: EagleView Technologies)

"Machine learning is relatively new technology," Giuffrida said. "It's going to become better and better with time."

One of the other applications for this technology is property assessment.

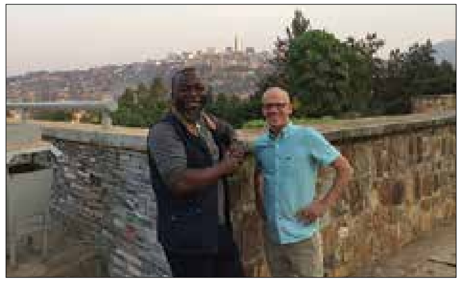
"An assessor doesn't have the bandwidth to visit every single home in a jurisdiction every year," Guiffrida said. Aerial imagery can capture 50,000 homes, compare it to images from a year earlier, detecting which ones have undergone significant changes.

Figure Methane. Experiment to investigate observable effects on healthy vegetation stressed by methane leaked into soil.

Collaboration strengthens Rwanda through education

Oct. 12, 2017

by Susan Gawlowicz



Associate Professor Ernest Fokoue, left, and Professor Anthony Vodacek on a recent trip to Rwanda where they are working to develop higher education.

Professors in RIT's College of Science are working with faculty at the University of Rwanda and the University of Kibungo, promoting that nation's development by helping to build graduate programs and a culture of scholarship in a country healing from civil war and genocide.

Higher education in Rwanda has been a priority during Anthony Vodacek's two-year tenure as RIT's Paul and Francena Miller Chair in International Education. Through strategic use of travel funding, Vodacek—whose tenure as chair ends in December—has created the potential for collaborative research opportunities and meaningful international experiences for students.

"In this last decade, I've seen enormous strides toward transforming Rwanda to a knowledge-based economy," Vodacek said.

Since 2008, Vodacek, a professor in RIT's Chester F. Carlson Center for Imaging Science, has visited Rwanda nearly 20 times. His work there focuses on remote sensing and environmental research and has led to many contacts in higher education.

Vodacek's colleagues at the URwanda public education system invited him to work on proposals to build graduate centers through a World Bank program. URwanda was awarded four African Centers of Excellence in Higher Education, three of which named RIT as their primary international partner. They are the Centers of Excellence in Data Science, the Internet of Things and for Teaching and Learning Mathematics and Science. RIT's role will be to provide teaching and research-supervision of MS and Ph.D. students and collaboration on joint proposals and journal articles.

The World Bank has established nearly 25 Centers of Excellence to promote graduate education in Africa. While graduate education is available on the continent, many students seek advanced degrees abroad in North America, Europe or Asia.

"The problem is that if they don't return, it's a significant brain drain," Vodacek said.

The total population in Africa is 1.2 billion, and more than 600 million are under the age of 20, Vodacek said.

Many students in this generation of African scientists, engineers and designers will be shaped by the World Bank's Centers of Excellence, and RIT's expertise will be part of their education, said James Myers, associate provost of International Education and Global Programs.

"RIT's global strategy focusses on being a leader engaged in the Centers of Excellence reflecting our strengths in science, engineering, technology and the arts," Myers said.

During the proposal process, Vodacek recruited Ernest Fokoué, an associate professor in the School of Mathematical Sciences, and Scott Franklin, director of RIT's Center for Advancing STEM Teaching, Learning & Evaluation.

With Miller chair funding, Vodacek, Fokoué and Franklin traveled to Rwanda to establish research collaborations and present at conferences. In July, RIT co-hosted a scientific conference at the University of Kibungo, a small private institution, and met with the leaders of the African Centers for Excellence at URwanda.

"My own feeling is that Africa is going to be the continent of this century in a similar way the development of Asia marked the end of the last century," Vodacek said. "My effort as Miller Chair is to position RIT to contribute to development in Rwanda and ultimately across Africa."

HISTORICAL MANUSCRIPT RESTORATION LAB

Laboratory Director's Comments By Dr. Roger Easton

The Laboratory for Historical Manuscript Imaging had another busy year, due in part to the collaboration with the University of Rochester in the group "Rochester Cultural Heritage Imaging, Visualization, and Education" (www.r-chive.com).

Figure 1: David Messinger explaining the principles of spectral imaging.

Figure 2: Exhibit at the March for Science

R-CHIVE leveraged the good result of its conference in Rochester on June 19-20, 2017, which had more than 50 attendees from as far away as Italy and Hawaii. The second conference, on June 7-8, 2018, had attendees from Vienna, Hamburg, Berlin, and the University of Durham. Speakers from a wide variety of disciplines presented their work.

One of the goals of the conference where to foster collaboration between the humanities and the sciences. Therefore, at the start of the conference, the attendees were divided into two groups (humanists and scientists) to each attend a crash course in the other discipline. Humanists attended a lecture on the basics of spectral imaging (Figure 1), while scientists were treated to a thorough walkthrough of the history of materials and inks used in ancient times.

In April 2018, R-CHIVE exhibited at the March for Science, Rochester, NY (Figure 2). Here they gave a live demonstration with a small multispectral system to show how spectral imaging could possibly recover lost or damaged text. Students from the University of Rochester also assisted to explain the significance of some examples of ancient text that was recovered successfully.

During Summer 2018, two Victor High School interns, Emerald Rafferty and Hudson Pavia, worked in the historical document imaging lab (Figure 3). They set up the Multispectral Imaging System for Historical Analysis (MISHA), the low cost system that a CIS senior built two years ago, to image two documents. The first document imaged was a 14th century palimpsest, with underwriting from the 13th century, from the Cary Collection at RIT. The other document was a 1969 corvette tank sticker that had degraded to a point where the part numbers were not visible at all. Great results were obtained with the palimpsest where the undertext were made clearly visible.

In July 2018, David Messinger and a group of students from the University of Rochester, went to the Bodleian Library at Oxford to image manuscript leafs with the hyperspectral system with David Howell. The goal of this project is to compare results from the hyperspectral imaging with those of previous multispectral imaging of the same manuscripts.

Dr. Roger Easton heads the lab, which collaborates with faculty and staff at other institutions and other imaging scientists, including Dr. David Messinger, Dr. Gregory Heyworth of the University of Rochester, Dr. Keith Knox and Michael Phelps of the Early Manuscripts Electronic Library, Dr. John Delaney of the National Gallery of Art, and Dr. Jana Grusková of the Austrian Academy of Sciences. Graduate students participating in this work include Di Bai and Anna Starynska. One of the significant additions to the personnel team is Tania Kleynans, 2017 M.S. graduate of the Carlson Center, who is now serving half-time in the role of administrator for grant writing and liaison with other institutions.

Figure 3: Tania Kleynhans explaining what a palimpsest is to the high school interns.

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

- *Zacynthius Bible* at the Cambridge University Library, July 2018
- 14th century palimpsested leaf of the Cary Collection at the Bodleian Library, Oxford, July 2018
- Calibration targets imaged at the Bodleian Library in Oxford to assist with registration issues.

Activities by Lab participants:

1. Roger L. Easton, Jr. was a faculty member at "*ManuSciences '17*," French-German Summer School held at "La Villa Clythia" in Fréjus, France, 11-15 September 2017.
2. Research Exhibit for the inauguration of Dr. David Munson as President of RIT, 28 September 2017.
3. "STEAM" Lecture at Honeoye Falls/Lima High School in Honeoye Falls, NY, by Roger L. Easton, Jr., 30 October 2017.
4. "Hyperspectral Analysis of the Gough Map of Britain," Di Bai, David W. Messinger and David Howell (Bodleian Library, Oxford University), at *Terra Digita 2017*, New Approaches to Medieval Mapping, Cornell University, 4 November 2017.
5. Workshop on Multispectral Imaging at Terra Digita 2017, New Approaches to Medieval Mapping, Cornell University, 5 November 2017 by Roger L. Easton, Jr. and Dr. Gregory Heyworth (University of Rochester).
6. "Spectral Image Processing Methods for Recovering Damaged Text," Roger L. Easton, Jr., presentation as part of *Multispectral Imaging and the recovery of "Lost" Texts from Palimpsests at Pseudepigrapha; Digtial Humanities in Biblical, Early Jewish, and Christian Studies*, Annual Meeting of the Society for Biblical Literature, Boston MA, 20 November 2017.
7. "Discerning Text in the Noise: Customized Statistical Processing of Spectral Imagery from St. Catherine's Monastery," Roger L. Easton, Jr., talk presented at *The Other Voice of the Desert: The palimpsest manuscripts of the Sinai Monastery*," Conference in Athens, 28 November 2017.
8. "Customized Processing of Multispectral Imagery of Palimpsests Based on Spectral Statistics," talk by Roger L. Easton, Jr. at *New Light on Old Manuscripts, Recent Advances in Palimpsest Studies*, Austrian Academy of Sciences, Vienna, Austria, 25 April 2018.
9. "Hyperspectral Imaging of Historical Artifacts: A Novel Imaging Approach for the Study of Materials and Methods" talk as keynote presented by Dr. David Messinger in Hamburg. This focused on our hypersepctral image analysis of the Gough and Selden Maps, and what algorithmic approaches worked best to distinguish within similar visual color pigments. The goal is to aid in understanding the history of the artifacts and how they may have been modified over time.
10. "Useful Metrics for Characterizing Multispectral Systems Used for Cultural Heritage Imaging," talk by Tyler Peery, Rolando Raqueño, and Roger L. Easton, Jr. at *3rd International Conference on Natural Sciences and Technology in Manuscript Analysis*, Centre for the Study of Manuscript Cultures, University of Hamburg, 14 June 2018.
11. "Convergence of Sciences and Humanities to "Image a Future for the Past," presentation by Roger L. Easton, Jr. in the panel Virtual, Mechanical, Invisible, and Radical: Rochester Convergences Across Town and Across Disciplines, Annual Meeting of the Rare Book and Manuscripts Section of the American Library Association, New Orleans, 21 June 2018.

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 2017-18:

Kevan Donlan (CIS)

Katie Seery (AST)

Ross Robinson (CIS)

Bryan Fodness (CIS)

Kyle Ryan (CIS)

Alexis Irwin (AST)

Kate Oram (CIS)

Anton Travinsky (CIS)

Lucas Black (Manufacturing and Mechanical Systems Integration)

Undergraduate Students 2017–18;

Robert Ichiyama (Chemistry)

Alexander Knowles (Chemistry)

REU student (2017–18)

Graham Wilcox (Cornell)

Post-Doctoral Fellow

Dmitry Vorobiev (AST-graduated)

Co-Op Student

Jonathon Hoover (Computer Science)

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

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

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

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

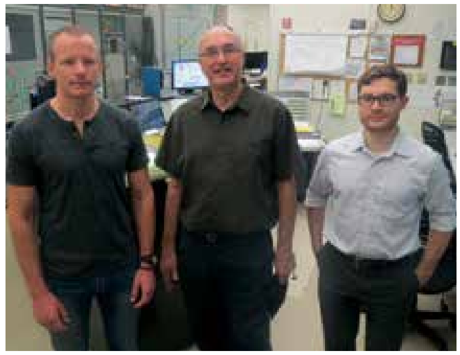


Figure 1 : Travinsky, Ninkov and Vorobiev in the control room at the TAMU Cyclotron.

(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 : Irwin, Oram, Vorobiev and Ninkov at Gamma Testing facility at NASA GSFC.

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.

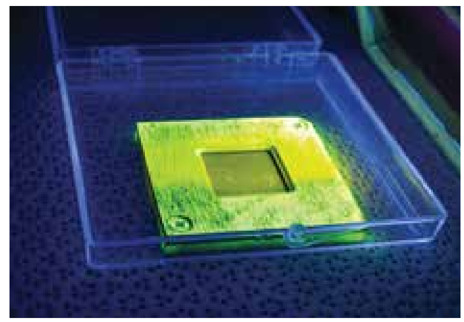


Figure 3 : Quantum Dot coated detector in aluminum mask under UV illumination. The active area is 15mmx15mm

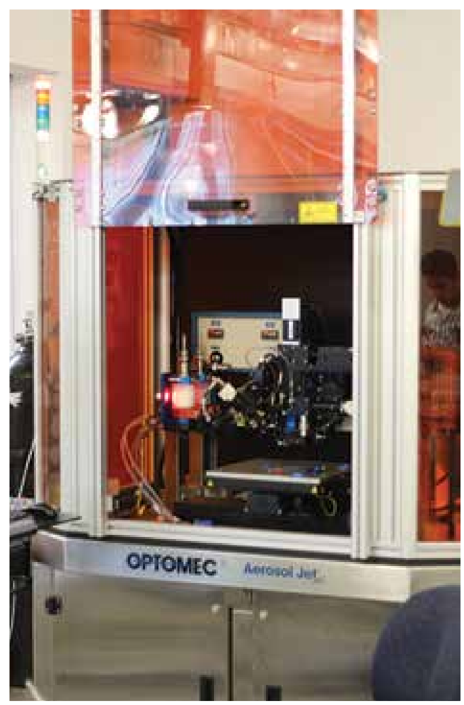


Figure 4 : The Optomec Aerosol Jet sprayer used for these experiments at RIT.

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.

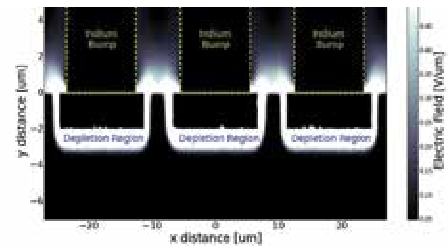


Figure 5: The strength and location of electric filed within pixels of a hybridized array.

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.

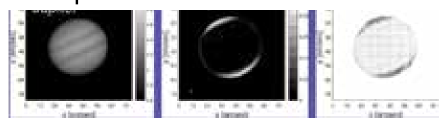


Figure 6: Images of Jupiter in integrated light (left), degree of linear polarization (center) and vector image of polarization (right).

(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.

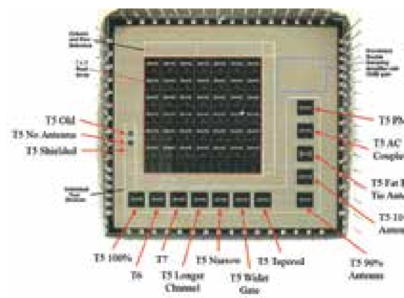


Figure 8 : Generation II MOSIS THz devices. Fifteen test structures are seen along the edges.

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

Sample Publications

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

Travinsky, A. (Chester F. Carlson Center for Imaging Sci., Rochester Inst. of Technol., Rochester, NY, United States); Vorobiev, D.; Ninkov, Z.; Raisanen, A.; Quijada, M.A.; Smee, S.A.; Pellish, J.A.; Schwartz, T.; Robberto, M.; Heap, S.; Conley, D.; Benavides, C.; Garcia, N.; Bredl, Z.; Yllanes, S. Source: *Journal of Astronomical Telescopes, Instruments, and Systems,* v 3, n 3, p 035003 (20 pp.), July 2017

Database: Inspec

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Data Provider: Engineering Village

2. 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

Database: Inspec

Data Provider: Engineering Village

3. High-resolution two-dimensional and three-dimensional modeling of wire grid polarizers and micropolarizer arrays

Vorobiev, D. (Sch. of Phys. & Astron., Rochester Inst. of Technol., Rochester, *NY, United States); Ninkov, Z. Source: Optical Engineering*, v 56, n 11, p 113113 (23 pp.), Nov. 2017

Database: Inspec

Data Provider: Engineering Village

4. 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

Database: Inspec

Data Provider: Engineering Village

5. Astronomical Polarimetry with the RIT Polarization Imaging Camera

Vorobiev, D.V. (Center for Imaging Sci. Rochester Inst. of Technol., Rochester, NY, United States); Ninkov, Z.; Brock, N. Source: *Publications of the Astronomical Society of the Pacific*, v 130, n 988, p 064501 (23 pp.), June 2018

Database: Inspec

Data Provider: Engineering Village

6. Characterization of Si-MOSFET CMOS devices for detection at 170 to 250 GHz

Seery, K.E. (Rochester Inst. of Technol., Rochester, NY, United States); Ninkov, Z.; Horowitz, J.; Newman, D.; Fourspring, K.; Sacco, A.; Lee, P.; McMurtry, C.; Pipher, J.; Ignjatovic, Z.; Hassanalieragh, M. Source: *Proceedings of the SPIE*, v 10531, p 105311R (7 pp.), 2018

Database: Inspec

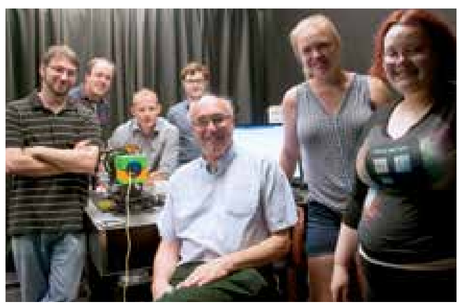
Data Provider: Engineering Village

7. Point-spread Function Ramifications and Deconvolution of a Signal Dependent Blur Kernel Due to Interpixel Capacitive Coupling

Donlon, K. (Chester F. Carlson Center for Imaging Sci., Rochester Inst. of Technol., Rochester, NY, United States); Ninkov, Z.; Baum, S. Source: *Publications of the Astronomical Society of the Pacific*, v 130, n 989, p 074503 (14 pp.), July 2018

Database: Inspec

Data Provider: Engineering Village



Laboratory for Advanced Instrumentation Research (LAIR) Research Group Picture

NEWS

RIT scientist modifies digital cinema technology for future space missions

NASA funds development of new astronomical imaging system

March 29, 2018 by Susan Gawlowicz

Rochester Institute of Technology researchers are developing and testing an astronomical imager inspired by an Oscar-award winning cinema projection system.

RIT scientist Zoran Ninkov modified Texas Instruments' Digital Micromirror Device—the micro-electro-mechanical systems, or MEMS, device found in Digital Light Processing projectors—to simultaneously capture light signatures from multiple objects in the same area of sky. The RIT astronomical imaging system is competing with other technologies for deployment on future NASA space missions for surveying star and galaxy clusters.

NASA is supporting Ninkov's ongoing research on the RIT multi-object spectrometer with a $550,000 grant to recoat the Digital Micromirror Device with aluminum to increase its reflectivity and performance at ultraviolet wavelengths.

"We've worked extensively on space qualification for the Texas Instruments Digital Micrormirror Device and have shown the current generation of these devices is well suited to space applications," said Ninkov, a professor in RIT's Chester F. Carlson Center for Imaging Science. "There's a need for a technology to allow for the rapid programmable selection of targets in a field of view that can be input to an imaging spectrometer for use in astronomy and remote sensing."

The Texas Instruments device consists of 2048-by-1080 individual mirrors that can switch between two positions at thousands of times per second. Ninkov recognized the programmable mirrors had applications in astronomical imaging and remote sensing.

During the last decade, Ninkov's team turned the commercial product into a scientific instrument to detect and capture astronomical data. The new technology selects targets from a two-dimensional sky field and deflects light down two distinct pathways—either to an imaging spectrometer or to an imaging array detector. The spectrometer records light at many contiguous spectral wavelengths and compresses information in the field of view into a data cube. The imaging detector array captures light signals from the objects with a charge-coupled device similar to technology found in digital cameras.

Ninkov's team includes Dmitry Vorobiev, a postdoctoral researcher at RIT; graduate students; and collaborators at NASA Goddard Flight Center.

Ninkov leads the Laboratory for Advanced Instrumentation Research in RIT's Center for Imaging Science. He is also a member of RIT's Center for Detectors and the Future Photon Initiative.

MULTIDISCIPLINARY VISION RESEARCH LABORATORY

Laboratory Director's Comments By Dr. Jeff Pelz

The Multidisciplinary Vision Research Laboratory (MVRL) seeks to further the understanding of high-level visual perception and support the work of researchers across a number of disciplines, focus areas, and research topics within the Center, College, and University.

[MVRL_fig_4.jpg] CIS Research Scientist Kate Walders (left) and Ph.D. student Anjali Jogeshwar (center) collect gaze and hand movement data from a subject performing a natural task in the MVRL.

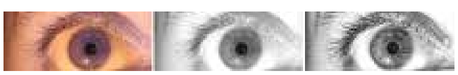
The Multidisciplinary Vision Research Laboratory (MVRL) seeks to further the understanding of high-level visual perception and support the work of researchers across a number of disciplines, focus areas, and research topics within the Center, College, and University.

Projects in the MVRL this year have included a project with the National Academies of Sciences, ongoing research on new eyetracking methodologies, and collaborations with Cecilia Ovesdotter Alm (Linguistics/English, College of Liberal Arts), Gabriel Diaz (Center for Imaging Science, College of Science), Susan Farnand (Program of Color Science, College of Science), Elena Fedorovskaya (Media Sciences, College of Art and Design), Michael Murdoch (Program of Color Science, College of Science), Martin Gordon (Manufacturing & Mechanical Engineering Technology, College of Engineering Technology), and Kate Walders (Center for Imaging Science and College of Liberal Arts).

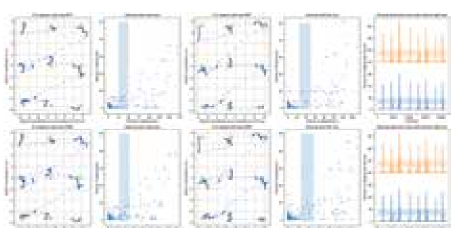
The National Academy of Sciences funded a study to collect data using wearable eyetracking to examine gaze behavior in natural environments. CIS Ph.D. student Anjali Jogeshwar worked with Jeff Pelz, Gabriel Diaz, Kate Walders, and CIS undergraduate Sheela Ahmed to collect data and analyze the gaze behavior and hand movements of observers as they performed natural tasks. Analyzing the large dataset required the development of new computer-vision based analysis tools, which are the focus of Ms. Jogeshwar's Ph.D. thesis.

CIS Ph.D. student Aayush Chaudhary and M.S. student Rujul Desai are working on developing a new methodology for tracking eye movements. The method, developed by Jeff Pelz and Dan Witzner Hansen of the IT University of Copenhagen (ITU) while Jeff was on sabbatical leave at ITU, is capable of providing much higher fidelity data from video-based input than currently available systems. Aayush Chaudhary's research is focused on applications of the new method to monitoring the miniature eye movements the eye makes during 'fixations,' when the eye is normally considered to be motionless. The eye actually makes a number of "microsaccades" during these periods; eye movements too small to be measured by most current video-based eyetrackers. Chaudhary is developing methods to extract records of these microsaccades from video records and quantify their number, direction, and size.

Rujul Desai's research is focused on moving the new method outside of the laboratory, examining the practicality of developing a wearable version of the system. Desai is developing 3D-printed models of novel illumination and image-capture schemes to overcome the challenges of daylight illumination.



Left: Frame from high-speed video captured with visible & near-infrared illumination Center: Red channel from frame Right: Frame processed to extract maximum texture from iris



Position and velocity data extracted from video data using new methodology

CIS Ph.D. student Mingming Wang, supervised by Program of Color Science (PoCS) faculty Susand Farnand, is working with Farnand, Jeff Pelz, Gabriel Diaz, and Martin Gordon (CET) to develop an immersive driving simulator in the PerForM lab in CIS. The goal of Wang's research is the development of a flexible VR platform for use in driving research. We hope that the new capability will have broad value within the Center to groups doing research in human and autonomous driving, attentional studies, and to others at RIT including in the Program of Color Science and the College of Engineering Technology.

Finally, this year saw a patent (finally) granted to Pelz and (then) graduate students Thomas Kinsman, Daniel Pontillo, and Susan Munn for "METHODS FOR ASSISTING WITH OBJECT RECOGNITION IN IMAGE SEQUENCES AND DEVICES THEREOF" (US Patent 9,785,835). The patent application process took five years, but in that time the patent was licensed for use by a prominent manufacturer of wearable eyetrackers, providing revenue to RIT, the MVRL, and the student and faculty inventors.


United States Patent
Pelz et al.
Patent No.: US 9,785,835 B2
Date of Patent: Oct. 10, 2017

US Patent 9,785,835, the most recent generated from research in the MVRL.

MVRL Publications: 2017-2018

Pelz, J. B., Kinsman, T. B., Pontillo, D. F., Munn, S. M., Harrington, N. R., & Hsieh, B. B. K. (2017). *U.S. Patent No. 9,785,835*. Washington, DC: U.S. Patent and Trademark Office.

Vaidyanathan, P., Prud'hommeaux, E. T., Pelz, J. B., & Alm, C. O. (2018). SNAG: Spoken Narratives and Gaze Dataset. In *Proceedings of the 56th Annual Meeting of the Association for Computational Linguistics (Volume 2: Short Papers)* (Vol. 2, pp. 132-137).

Wang, M., Walders, K., Gordon, M. E., Pelz, J. B., & Farnand, S. (2018). Auto-simulator Preparation for Research into Assessing the Correlation Between Human Driving Behaviors and Fixation Patterns. *Electronic Imaging*, 2018(17), 1-6.

Wang, D., Mulvey, F. B., Pelz, J. B., & Holmqvist, K. (2017). A study of artificial eyes for the measurement of precision in eye-trackers. *Behavior research methods*, 49(3), 947-959

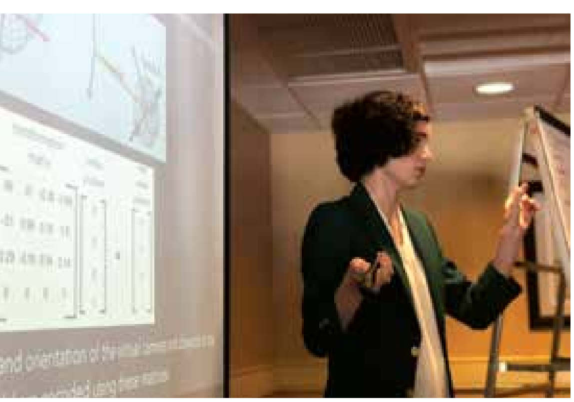
Watalingam, R. D., Richetelli, N., Pelz, J. B., & Speir, J. A. (2017). Eye tracking to evaluate evidence recognition in crime scene investigations. *Forensic science international*, 280, 64-80.

Rakshit Kothari (left) poses with Zhizhuo (George) Yang (right), who is wearing a custom-made system for the collection of eye + head pose when performing natural task. This involves record movements of the eyes with a Pupil Labs mobile eye tracker, and the head with an internal measurement unit, and the scene color and depth maps with stereo RBG cameras. This system is being used for the development of novel machine learning algorithms for understanding the gaze behavior of observers during navigation and task execution.

PERCEPTION FOR MOTION (PerForM) LAB

Laboratory Director's Comments By Dr. Gabriel Diaz

The PerForM Laboratory is five years old this August, and is now more productive than ever. Research in the Perform Lab is intended to improve understanding of the mechanisms that allow humans to perform everyday visually guided actions, like catching a ball, driving a car, or walking over uneven terrain.



Although these are natural actions, the natural environment does not afford the experimental control required for the rigorous testing of hypotheses. To overcome the limitations of real-world studies without sacrificing realism or freedom of movement, the PerForM Lab leverages and develops several next-generation technologies, including virtual reality, motion capture, and eye tracking. A review of projects currently ongoing at the PerForm Lab can be found on the laboratory website hosted on the CIS departmental webpage.

The laboratory, and RIT's Chester F. Carlson Center for Imaging Science, was very well represented this May at the Vision Science Society's annual meeting, an annual conference which draws approximately 3000 scientists from around the world to share their contributions to the understanding of the human visual system. Gabriel Diaz's research was highlighted by collaborator Mary Hayhoe in her invited seminar, "Predictive Eye movements in Natural Vision." Fifth year graduate student Kamran Binaee delivered an oral presentation, "Investigating the Differences in Predictive Oculomotor Strategies Using Long Short-Term Memory Recurrent Neural Network Models," fourth year student Rakshit Kothari delivered an oral presentation, "The Classification and Statistics of Gaze-In-World Events," and second year graduate student, and Cayla Fromm presented a poster, "Humans compensate for the tangential acceleration of an approaching ball-in-flight by coupling movement of the gaze vector to the ball's rate of optical expansion." In addition, all three graduate students assisted advisor Gabriel Diaz in delivering a half-day workshop on eye tracking in virtual reality, which was sponsored by the OSA, and attended by 30 participants.

Kamran Binaee (top), Rakshit Kothari (middle), and Cayla Fromm (bottom) facilitate a workshop on eyetracking in virtual reality to an international audience of vision scientists at the 2018 annual meeting of the Vision Science Society, in St. Pete's Beach, Florida.

Graduate students Rakshit Kothari and Zhizhuo "George" Yang have continued their development of machine learning methods for the classification of behavioral events embedded within the eye and head signal. These gaze-related events include prolonged fixation on an object in the environment, a sudden change in gaze position, or the visual pursuit of an object in motion. Although this work is funded by Google's Daydream Laboratories, the award would not have been possible without initial support from a Dean's Research Initiation Grant provided by RIT's College of Science.

Our newest PerForm lab member, Cayla Fromm has been actively involved in the development of a new collaborative project with Krystel Huxlin at the University of Rochester, funded by the Unyte Foundation. This work involves the development of perceptual training paradigms for at-home visual rehabilitation following cortical blindness due to stroke, which is an increasingly prevalent, debilitating cause of partial blindness, and afflicts about 1% of the population over age 50. Over the past 15 years, Dr. Huxlin has demonstrated that visual rehabilitation can recover a variety of visual detection and discrimination abilities following stroke. Our goal is to integrate the Huxlin visual assessment and rehabilitation paradigm into the HTC VIVE VR system with a customized built-in eye tracker for more affordable and convenient at-home rehabilitation.

A related component of this work involves the development of affordable hardware for eye tracking in head-mounted virtual reality displays the at-home setting. Our approach is to modify the open-source eye tracking platform developed by Pupil Labs for use during visual rehabilitation. Over the summer of 2018, development of this eye tracker has been spearheaded by visiting scholar Clara Richter from Mount Holyoke College, under the guidance of graduate student Cayla Fromm. Clara was able to visit RIT as a participant in the Research Experience for Undergraduates program made possible by the National Science Foundation. Her visit was a tremendous success, and Clara is expected to join up with the laboratory at the 2019 meeting of the Vision Science Society in St. Pete's Beach, Florida, where she will present her research to an international audience of vision scientists.

Visiting student Clara Richter (Mt. Holyoke College) shows CIS professor Jeff Pelz her progress in modifying the Pupil Labs Virtual Reality integration into the HTC Vive Virtual reality helmet. Clara's visit was funded by CIS's Research Experience for Undergraduates award, funded by the NSF.

The Perform Lab is happy to announce that graduate student Kamran Binaee has accepted a position at the Nvidia Corporation in Santa Clara, CA, where he will perform cutting edge work on eye tracking in head mounted displays. This excellent news follows a busy year for Kamran. In addition to his contributions at VSS, Kamran delivered oral presentations of his work, "Modelling Hand-Eye Coordination Methods Using Deep Learning Methods" at the annual meeting of the Cognitive Science Society in Madison, Wisconsin, and in November at the annual meeting of the Society for Neuroscience in Washington DC.

PerForM Lab director Gabriel Diaz has also been quite active as a representative of RIT's Center for Imaging Science. In August, 2017, Gabriel Diaz travelled to Wuppertal, Germany, where he delivered a 6 hour workshop on eye-tracking in virtual environments to room of approximately 40 participants, in addition to an invited oral presentation, "Virtual Reality for the Study of Visually Guided Action." In addition, March 2018, Gabriel Diaz travelled to SXSW in Austin Texas, where he was invited to participate by Lt. Colonel Eric Frahm to participate in a panel on Virtual Reality in Air and Space, and to tour the United States Air Force's new virtual reality pilot training program, Air Force Next, based in Austin TX. This program is exploring the potential to replace legacy training simulators with more affordable, higher fidelity virtual reality simulators with integrated biometrics.

Left: From left to right, CIS professor Gabriel Diaz, NASA Scientist Matthew Noyes, US Major Justin Chandler, and Lt. Colonel Eric Frahm participate in a SXSW panel on Virtual Reality in Air and Space. Right: The nearby Austin Bergstrom International Airport is a home to the Pilot Training Next project, which aims to use virtual reality with integrated biometrics to move pilot training and assessment into the future.

In other news, Dr. Diaz has been appointed as Events Officer for the Vision Technical Group of the Optical Society of America, and served as session chair of the section on Color and Vision in OSA's 2017 meeting, Frontiers in Optics. Gabriel Diaz was also invited to co-organize the Rochester symposium Frontiers in Virtual Reality

(2018), hosted by the University of Rochester and RIT at the Modern Art Gallery in downtown Rochester. It was attended by over 100 academics and members of industry, including members of Facebook/Oculus, Google, and Nvidia. Finally, past year has involved publications from the PerForM Laboratory in journals including PLOS ONE, Behavior Research Methods, in the proceedings of the Cognitive Science Society, and in SPIE Medical Imaging.

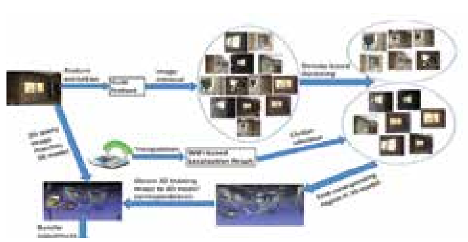
COMPUTER VISION AND ROBOTICS LAB

Laboratory Director's Comments by Dr. Guoyu Lu

Guoyu Lu's lab focuses on computer vision, especially on robot vision. His research topics on visual localization and odometry are key issues for mobile computing, robotics, autonomous driving, and augmented reality.

After joining RIT, his lab has built a collaboration with Ford to conduct research of common interests. As for mobile localization, his lab has developed a multi-view localization system, which is published on the Journal of Computer Vision and Image Understanding (CVIU). To overcome the issue of similar appearance existed in vision-based localization in indoor environment, he applied WiFi positioning together with images to take advantages of both methods to enhance the localization accuracy. This research is published on ACM International Conference on Multimedia Retrieval (ICMR)

To estimate the scientific cruise path in Arctic, Dr. Lu has developed a method to track images with limited textures, which is applied on Arctic sea ice. This research outcome is published on IEEE Transactions on Multimedia (TMM). His lab has investigated thermal images to deal with dark environment image retrieval and classification issues. To resolve the issue of limited training samples, he extracted multiple kinds of features and fuse them to make use of the evidences existed in the images to the utmost extent, which is published on International Conference on Pattern Recognition (ICPR). Dr. Lu also developed a method to accurately segment and detect cell branch tips on microscopy images, which has been published on IEEE International Conference on Image Processing (ICIP). His lab member, Makayla Roof, has conducted her senior project on visual odometry under thermal images, which is a particularly difficult research topic. In the coming year, another two final year students will join Dr. Lu's lab to conduct their senior projects related to augmented reality. Beyond these research outcomes, Dr. Lu's lab has organized the "2nd CVPR workshop on Visual Odometry and Computer Vision Applications based Location Clue" as the main organization.



Graduated student:

Makayla Roof (BS)

Undergraduate Advisees:

Sophia Kourian

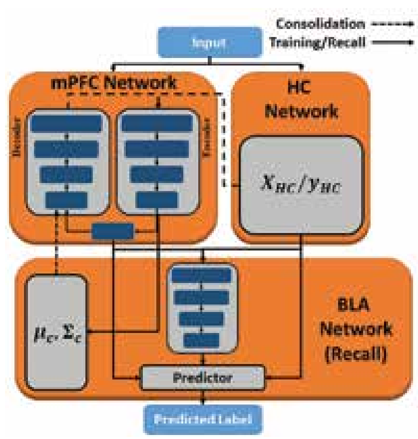
Donald Shultz

MACHINE AND NEUROMORPHIC PERCEPTION LAB

Laboratory Director's Comments by Dr. Chris Kanan

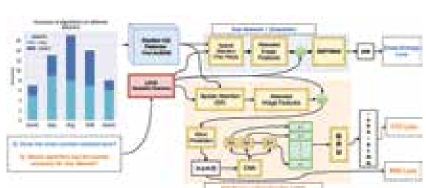
Christopher Kanan's lab works to advance the state-of-the-art in artificial intelligence (AI).

Most of the lab's efforts are directed toward advancing the capabilities of deep neural networks and on using machine learning to solve problems in computer vision. The lab's recent work can be divided into three main thrusts: 1) enabling lifelong learning in deep neural networks, 2) visual question answering (VQA), and 3) low-shot learning for problems in remote sensing.



The FearNet model created by Dr. Kanan's lab enables learning new information over time in a deep neural network. To do this, his lab took inspiration from the multiple memory systems used by the mammalian brain.

While deep neural networks are now capable of rivaling or exceeding human capabilities for some tasks, conventional methods cannot learn new information over time without suffering from catastrophic forgetting. In other words, a conventional network that learns to recognize ten people and then is later updated to recognize five new people will usually forget the initial ten. The naive fix is to mix the new data with the old data and re-train the model from scratch, but this is computationally wasteful. Enabling networks to learn over time is needed for many applications, including fast learning for embedded devices, robotics, and for user customization. Dr. Kanan, CIS PhD students Ronald Kemker and Tyler Hayes, and REU student Angelina Abitino presented a paper at AAAI-2018, in which they quantified catastrophic forgetting in a variety of neural networks and developed new metrics. Later in a paper presented at the International Conference on Learning Representations (ICLR-2018) with Ronald Kemker, his lab developed FearNet, which is one of the world's best networks for learning new information over time without catastrophic forgetting. The lab continues to push the state-of-the-art in this space, and Dr. Kanan has an ongoing collaboration with Dr. Nathan Cahill on lifelong learning in brain-inspired neural networks, which is supported by the Naval Research Laboratory (NRL).

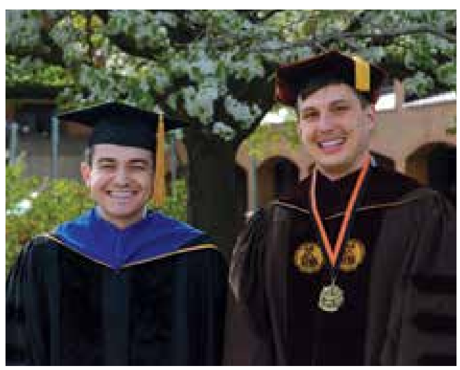


In a collaboration with Adobe Research, Dr. Kanan's lab built a system capable of answering questions about diagrams solely from their pixels. The system uses optical character recognition to read text from the bar chart and uses deep neural networks for answering the question. The work will be presented at CVPR-2018.

Another major research thrust in the lab is VQA. 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 fourth year CIS Ph.D. student Kushal Kafle, Dr. Kanan published a paper reviewing the state of VQA in the Journal Computer Vision and Image Understanding (CVIU). They later published a paper in the prestigious International Conference on Computer Vision (ICCV-2018) where they presented a new dataset known as the Task-Directed Image Understanding Challenge (TDIUC). TDIUC is one of the world's largest datasets for VQA and it is already being used by other labs around the world. In a collaboration with scientists at Adobe Research, Kushal Kafle and Dr. Kanan pioneered applying VQA to bar charts, which will enable large repositories of bar charts in business and scientific documents to be efficiently queried. Their work was accepted to the IEEE Computer IEEE Computer Vision and Pattern Recognition conference (CVPR-2018), one of the most prestigious publication venues in computer vision.

PhD student Kushal Kafle presents a poster at ICCV-2017 on the TDIUC dataset he created with Dr. Kanan.

The lab has also been pushing the state-of-the-art in remote sensing data analysis. His lab is has studied a variety of methods to make systems capable of labeling pixels in aerial imagery, which is also known as semantic segmentation. For typical day-to-day scenes, all state-of-the-art methods for semantic segmentation use deep neural networks. However, conventional methods require extremely large datasets for them to learn to do this task effectively. Dr. Kanan and his PhD student Ronald Kemker have explored low-shot learning techniques that can learn much more effectively with limited amounts of data. His lab has developed state-of-the-art methods for this task that use unlabeled data, synthetic data, and semi-supervised approaches., Dr. Kanan, Dr. Carl Salvaggio, and PhD student Ronald Kemker created the RIT-18 dataset for semantic segmentation of multispectral imagery, and they demonstrated that deep neural networks can be used even on smaller datasets by pre-training a network on synthetic DIRSIG imagery. Their work was published in the ISPRS Journal of Photogrammetry and Remote Sensing. Later, Dr. Kanan, Ronald Kemker, and high school student Ryan Luu, had a paper accepted to IEEE Transactions on Geoscience and Remote Sensing (TGRS) that achieved state-of-the-art results on hyperspectral semantic segmentation by using both unsupervised and semi-supervised learning. With Intelligent Automation, Inc., Dr. Kanan's lab received an award from the National Geospatial-Intelligence Agency (NGA), to further explore how to do low-shot machine learning in remote sensing imagery.



Dr. Kanan (left) and his PhD student Ronald Kemker (right). Mr. Kemker successfully defended his dissertation in April 2018.

Ronald Kemker successfully defended his PhD dissertation on low-shot learning for semantic segmentation of remote sensing imagery. He will graduate this summer and will become the first PhD earned in Dr. Kanan's lab.

Graduated Students

Ronald Kemker, PhD.

Thesis Title: Low-Shot Learning for the semantic segmentation of remote sensing imagery

Refereed Papers for 2017-2018

Kafle, K., Cohen, S., Price, B., Kanan, C. (2018) DVQA: Understanding Data Visualizations via Question Answering. In: Proc. *IEEE Conference on Computer Vision and Pattern Recognition (CVPR-2018).* [30% accept rate]

Kemker, R., Luu, R., Kanan, C. (2018) Low-Shot Learning for the Semantic Segmentation of Remote Sensing Imagery. *IEEE Transactions on Geoscience and Remote Sensing (TGRS).*

Kemker, R., Salvaggio, C., Kanan, C. (2018) Algorithms for Semantic Segmentation of Multispectral Remote Sensing Imagery using Deep Learning. *ISPRS Journal of Photogrammetry and Remote Sensing.*

Binaee, K., Starynska, A., Pelz, J., Kanan, C., Diaz, G. (2018) Characterizing the Temporal Dynamics of Information in Visually Guided Predictive Control Using LSTM Recurrent Neural Networks. In: *Proc. 40th Annual Conference of the Cognitive Science Society (CogSci-2018).*

Kemker, R., Kanan, C. (2018) FearNet: Brain-Inspired Model for Incremental Learning. In: *International Conference on Learning Representations (ICLR-2018).* [34% accept rate]

Kemker, R., McClure, M., Abitino, A., Hayes, T., Kanan, C. (2018) Measuring Catastrophic Forgetting in Neural Networks. In: *AAAI-2018.* [24.6% accept rate; Oral presentation]

Kafle, K., Kanan, C. (2017) An Analysis of Visual Question Answering Algorithms. 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

Kumra, S., Kanan, C. (2017) Robotic Grasp Detection using Deep Convolutional Neural Networks. In: *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS-2017).*

Graham, D., Langroudi, S., Kanan, C., Kudithipudi, D. (2017) Convolutional Drift Networks for Spatio-Temporal Processing. In: *IEEE International Conference on Rebooting Computing 2017.*

Kleynhans, T., Montanaro, M., Gerace, A., Kanan, C. (2017) Predicting Top-of-Atmosphere Thermal Radiance using MERRA-2 Atmospheric Data with Deep Learning. *Remote Sensing, 9(11), 1133; doi:10.3390/rs9111133*

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

New Awards & Grants

PI, DVQA. $29,000—Adobe Research

Co-PI, *Data-Driven Adaptive Learning for Video Analytics.* US Air Force Materiel Command—FA9550-18-1-0121. 2/22/2018—2/21/2021, $352,152.

Co-PI, Brain-*Inspired Deep Neural Networks for Incremental Learning.* Naval Research Laboratory (NRL). 9/1/2017 –8/31/2018, $80,295.

PI, GFNet: *Gnostic Fields based Low-Shot Learning for Target Detection in Remote Sensing.* Intelligent Automation, Inc. (Prime: DoD NGA) –HM047618C0005. 11/1/2017 – 7/31/2018, $33,000.

LABORATORY FOR ADVANCED OPTICAL FABRICATION, INSTRUMENTATION AND METROLOGY (AOFIM)

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.

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. Two PhD students, one Master student, one NSF REU, two visiting scientists, and one post-graduate researcher have been conducting their research projects at the AOFIM lab during the past academic year. During the fast academic year, Dr. Qiao has won new external funding from DOE/Lawrence Livermore National Laboratory and NSF/IUCRC/CeFO; her team has published two peer reviewed journal papers, and five conference proceedings and/publications. In addition, Dr. Qiao provided nine external invited talks on "Optical Differentiation Wavefront Sensing for Freeform Metrology and Ultrafast Lasers for Photonics Fabrication" and WiSTEE Connect: "Connecting Women in Science, Technology, Engineering, and Entrepreneurship," at nine combined universities, national labs, professional societies and companies. Dr. Jie Qiao received her tenure faculty position at the College of Science, Rochester Institute of Optics in April, 2018.

OUTREACH: LEADING WISTEE CONNECT TO MAKE GLOBAL IMPACT

WiSTEE will host the 2018 Global Women of Light Symposium on 16 September 2018 in Washington DC. The program highlights a panel and round-table discussions centered on the theme "Career Strategy for Women in Science, Technology, Engineering and Entrepreneurship." Panelists include Dr. Christie Canaria, director, U.S. National Cancer Institute, SBIR Development Center; Dr. Judith Dawes, professor, Macquarie University, Australia; Dr. Ulrike Fuchs, vice president, Asphericon GmbH, Germany; Dr. Deborah Goodings, director, U.S. National Science Foundation; and Cathy Long, associate division chief, NASA Goddard Space Flight Center. A workshop on "The Art and Science of Thriving Women" will be led by Mary Burkhardt, Lead Peak Performance LLC. Ms. Elizabeth Rogan, CEO of OSA, The Optical Society will give an opening speech on "Advancing Women in Optics;" and Dr. Jessie DeAro, Program Director for the ADVANCE Program, will give a keynote speech on "Changing the System Not the People." A networking session will close out the day and provide an opportunity for informal discussion. A community of women across career ranks and disciplines in STEM and Entrepreneurship will continue to be built, creating cross-pollinated best practices and strategies across sectors. Career growth, mobility, mentorship, and leadership will be collectively developed by this community. You can view the 3rd GWL program here.

SELECTVIE NEW FUNDING AWARDS FOR 2017 ACADEMIC YEAR

1. 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, RIT PI), January 01, 2017 – December 31, 2018 (anticipated three-year funding for a total of $143,199), year 1&2 awarded

2. DOE – Department of Energy / Lawrence Livermore National Lab, Ultrafast Laser Welding for Hermetic Packaging of Nano-implant Chip, ($24,985, PI), 08/02/2018 - 09/30/2018
3. Electro Scientific Industries, Inc (Oregon Portland), Equipment donation for a IR Solid State Laser, $40,000, Aug. 2018

SELECTIVE PUBLICATIONS AND PRESENTATIONS FOR 2017 ACADEMIC YEAR (* denotes student co-author)

1. C. Dorrer and J. Qiao, "Direct binary search for improved beam shaping and optical differentiation wavefront sensing," Applied Optics (accepted and in press) (2018)
2. L. Taylor*, R. Scott*, and Jie Qiao, " Predicting Femtosecond Laser Processing of Silicon via Integrating Thermal and Two-Temperature Models," Optics Materials Express, Optical Materials Express 8(3) 648-658 (2018)

   https://doi.org/10.1364 OME.8.000648

3. C Dorrer, J Qiao, "Improved Spatially Dithered Beam Shapers Using Direct Binary Search," in Conference on Lasers and Electro-Optics (CLEO), OSA Technical Digest (online) (Optical Society of America, 2017), Science and Innovations, SW3M. 6, San Jose, CA, 13–18 May 2018
4. L.Taylor*, J. Xu*, T.R. Smith*, M. Pomerantz, J.C. Lambropoulos, J Qiao, "Controlling Femtosecond Laser Ablation of Germanium for Laser Polishing Applications," in Conference on Lasers and Electro-Optics (CLEO), OSA Technical Digest (online) (Optical Society of America, 2017), Applications and Technology, AM1M. 2, San Jose, CA, 13–18 May 2018
5. 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
6. L. Taylor*, J. Xu, T. Smith, M. Pomerantz, J. C. Lambropoulos, and J. Qiao, "Achieving Efficacy in Femtosecond Laser Processing of Optical Materials", Corning Glass Summit, June 2018.
7. L. Taylor*, T. Feng, J, Xu, T. Smith, M. Pomerantz, J. C. Lambropoulos, and J. Qiao, "Controlling Femtosecond Laser Ablation for High-Precision Optics and Photonics Fabrication", CEIS Technology Showcase, April 2018.

SELECTED INVITED TALKS FOR 2017 ACADEMIC YEAR

Selected Invited Presentations on "Optical Differentiation Wavefront Sensing for Freeform Metrology and Ultrafast Lasers for Photonics Fabrication" at Other Universities, National Labs, Professional Societies and Companies

1. Institute of Photonics and Nanotechnologies - CNR, Milan, Italia, July 19, 2018
2. Bern University of Applied Sciences, Institute for Applied Laser, Photonics and Surface Technologies, July 5, 2018
3. ETH Zurich, Switzerland, Physics Department / Institute of Quantum Electronics Switzerland, July 5, 2018
4. Amplitude Systems Corp., Bordeaux, France, July 4, 2018
5. Laurence Livermore National Laboratory, May 18, 2018
6. University of California, Irvin, Department of Physics and Beckman Laser Institute, March 23, 2018
7. Apple Corp, February 1, 2018
8. University of Rochester, Institute of Optics, What's Up in Optics Seminar Series, December 14, 2017
9. US Army Research Laboratory, "WiSTEE CONNECT: Connecting Women in Science, Technology, Engineering, and Entrepreneurship," November 14, 2017

From Left to Right: Amber Dubill (RIT MS/BS Mechanical Engineering), Dr. Grover Swartzlander (RIT CIS Faculty), Les Johnson (NASA Marshall Space Flight Center). The deployed sail, an aluminum coated polyimide membrane, is seen in the background. NEA-Scout is a solar sail mission to explore a near-Earth asteroid, which will launch with the NASA's Space Launch System (SLS) sometime next year.

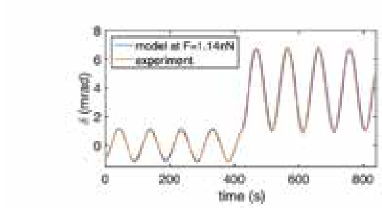
Laboratory Director's Comments By: Dr. Grover Swartzlander

Grover Swartzlander's team is exploring two different topics: (1) Solar and Laser Driven Diffrative Sailcraft for In-Space Propulsion and Navigation; (2) Point Spread Function Engineering for Sensor Protection.

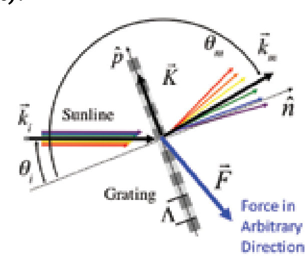
These projects are respectively supported by NASA and ONR. Prof. Swartzlander is a Fellow of the Optical Society of America, a NASA NIAC Fellow, a Cottrell Scholar, and an NSF Young Investigator. He is the Editor-in-Chief of the Journal of the Optical Society of America - B, and has been a past associate editor for Optics Letters. He has pioneered a number of topics in the field of optics, garnering over 5500 citations of his published work.

Solar and Laser Driven Diffrative Sailcraft for In-Space Propulsion and Navigation

Advanced diffractive metamaterial films, proposed by Swartzlander in 2017, affords advantages over passive reflective surfaces for a variety space missions that make use of radiation pressure, e.g., orbit raising from low earth orbit, Earth-to-inner/outer planet rendezvous, solar polar orbiter, and fly-by missions to distant stars. Together with graduate student Ying-Ju Lucy Chu, a sub-nano-Newton device called a torsion oscillator was constructed to measure the radiation pressure force on a diffraction grating. Assisting with the experiment was high school student Eric Jansson. Their experimental results will be published in Physical Review Letters. The experimental validation of Swartzlander's theory is inspiring researchers from around the world to develop diffractive membranes that will one day propel sailcraft through space. What is more, we received a coveted NASA Innovative Advanced Concepts award to further develop this novel concept. Swartzlander is organizing a conference on this topic in October 2018 to bring researchers from both the space and metamaterials communities together to develop a roadmap for the development of diffractive sails. A so-called diffractive beam rider is also being developed at RIT by Swartzlander and graduate students Prateek Srivastava and Lucy Chu. The figures below depict an example of the experimentally measured data (left) and the force owing to diffracted sunlight (right).



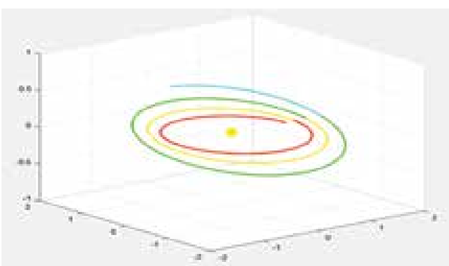
An example torsion pendulum oscillation (under vacuum) for laser radiation pressure exerting on a diffraction grating.



Schematic of broadband sunlight incident to a broadband, single order diffraction grating. The difference between (wavelength dependent) incident and diffracted wave vectors can results in force in arbitrary direction.

Dr. Swartzlander and summer intern Amber Dubill (ME undergraduate student) visited NASA's Marshall Space Flight Center in Huntsville, AL. The center is home to experts in solar sailing and orbital trajectories that are collaborating on a NASA Innovative Advanced Concepts Phase I with Dr. Swartzlander. While there, they were invited to join the test deployment of NASA's Near-Earth Asteroid Scout solar sail with the mission PI, Les Johnson. The test was done in a clean room at NeXolve outside of the center.

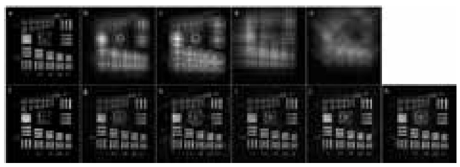
Ms. Dubill, a member of RIT's Space Exploration Group (SPEX), served as the RIT mission specialist while interning in Swartzlander's lab. Her work included the development of software to predict how a diffractive sail could be used to achieve a solar polar orbit (see figure below). NASA and other space worldwide space agencies have proposed polar orbits as a means to better understand the physics of the sun.



Orbit of a solar sail that is cranked to a high inclination angle above the orbital plane of the earth. The yellow center dot represents the sun. All axis are labeled in AU. In this simulation, the sailcraft traveled from 1 AU to 1.7 AU and raised the orbital inclination by 10 degrees in less than 5 years.

Point Spread Function Engineering for Sensor Protection

New methods are being developed for protecting focal plane sensors from laser radiation by means of point spread function engineering. When a phase mask is placed in the pupil plane of an imaging system a point object such as a laser beam can be made to produce a highly distorted image. Consequently, the laser irradiance is spread across many camera pixels, thereby lessening the risk for damage to the sensor. Although the image of a scene will also be distorted, deconvolution techniques may be applied to produce a visually acceptable restored image. Graduate student Jacob Wirth, together with partner Abbie Watnik at the US Naval Research Lab and RIT Prof. Swartzlander, are conducting both experimental and numerical research that seeks to design optimized phase masks. This process, also known as wavefront coding, allows the operation of an imaging system over a broad range of laser parameters, such wavelength, polarization, position, or power. Like many optimization problems, there is no closed form solution to aid the research, and thus, the design of phase masks requires both scientific intuition and numerically intensive calculations.



Experimentally recorded images using (a) no wavefront modulation, (b) vortex, (c) axicon, (d) cubic, and (e) rotated cubic masks. (f)–(j) Corresponding restored images and (k) joint deconvolution combining vortex and axicon images. Images are displayed in a log scale to aid in viewing artifacts in the dark regions of the images and around the laser spot.

Publications

Ying-Ju Lucy Chu, Eric M. Jansson, and Grover A. Swartzlander Jr., Measurements of Radiation Pressure owing to the Grating Momentum, to appear in Physical Review Letters (2018).

Jacob H. Wirth, Abbie T. Watnik, and Grover A. Swartzlander, "Optimized pupil-plane phase masks for high-contrast imaging," Appl. Opt. 57, 5688-5693 (2018).

Grover A. Swartzlander Jr., Flying on a Rainbow: A Solar-Driven Diffractive Sailcraft, arXiv preprint arXiv:1805.05864 (2018).

Grover A. Swartzlander, Jr., Diffractive solar sails could outperform reflective-metal-coated sails, Laser Focus World, 53 (10), 35-37 (2017).

Jacob H Wirth, Abbie T Watnik, Grover A Swartzlander Jr., Experimental observations of a laser suppression imaging system using pupil-plane phase elements, Applied Optics 56 (33), 9205-9211 (2017).

Xiaopeng Peng, Garreth J Ruane, Marco B Quadrelli, Grover A Swartzlander Jr., Randomized apertures: high resolution imaging in far field: erratum, Optics express 25 (17), 20952-20952 (2017).

Xiaopeng Peng, Garreth J Ruane, Marco B Quadrelli, Grover A Swartzlander Jr., Randomized apertures: high resolution imaging in far field, Optics Express 25 (15), 18296-18313 (2017).

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

Conference Presentations

Ying-Ju Lucy Chu, Eric M. Jansson, and Grover A. Swartzlander Jr. Radiation Pressure on a Transmissive Diffraction Grating. Frontiers in Optics, Laser Science, JTu3A. 95 (Sep 2017)

Ying-Ju Lucy Chu, Eric M. Jansson, and Grover A. Swartzlander Jr. Verification of Radiation Pressure owing to the Grating Momentum. SPIE Optics and Photonics (Aug 2018).

Grover A. Swartzlander Jr., Ying-Ju Lucy Chu, and Prateek Srivastava, Beam Riders and SailCraft Based on Diffractive Light Sails. Frontiers in Optics (Sep 2018).

Jacob H. Wirth, Abbie T. Watnik, Grover A. Swartzlander Jr., Computational imaging for reducing peak irradiance on focal planes, Proc. SPIE 10669, Computational Imaging III, 106690U (12 June 2018).

Jacob H. Wirth, Abbie T. Watnik, and Grover A. Swartzlander Jr., PSF Engineering for Sensor Protection, in Frontiers in Optics 2017, OSA Technical Digest (online) (Optical Society of America, 2017), paper JTu2A.95.

Patents

Grover A. Swartzlander Jr., Optical Vortex Coronagraph Scatterometer, US Patent App. 15/698,238 (2018).

Grover A. Swartzlander Jr., Optical Vortex Coronagraph Scatterometer, non-provisional, RIT ID 2017-007.

Journal of the Optical Society of America B—Editorials from the Editor-in-Chief

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

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

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.

The current problem we are addressing is changing the destructive nature of electron paramagnetic resonance (EPR) spectroscopy so it can be more useful to art conservators, art historians, conservation scientists, and archaeologists studying paintings, ceramics, and marble sculptures with cultural heritage significance.

Conventional EPR spectroscopy provides rich information about transition metal complexes and free radicals found in pigments, clay, and marble. Unfortunately, it is destructive or minimally invasive in that it requires a small on mm3 sample, excluding its applicability to precious objects with cultural heritage significance. Low frequency EPR (LFEPR) overcomes the EPR size limitation and hence destructive nature of EPR by lowering the operating frequency of the spectrometer, but has two limitations: poorer sensitivity and the absence of commercially available spectrometers.

This past year we continued our work on developing LFEPR. Our specific foci have been to publish much of our LFEPR instrumentation development work and to start on an automatic frequency control (AFC) for the LFEPR spectrometer.

LFEPR Instrumentation

Over the past five years, we have developed a LFEPR spectrometer capable of recording the LFEPR spectrum of 30 cm wide objects. The spectrometer has two surface coil (SC) and seven single turn solenoid (STS) sample probes, thus permitting the recording of LFEPR spectra at nine different frequencies between 150 and 450 MHz. The STS probes require 30 ml sample while the SC probes record the EPR signal from a small 3 mm or 1 cm diameter disc on the surface of an object. The magnetic field can be swept between 0 and 30 mT, thus permitting the recording of wide-line LFEPR spectra from a variety of samples. A block diagram of the LFEPR spectrometer including the radio frequency (RF) bridge is presented in Figure 1. A summary of this work appeared in issue 47 of the Journal Concepts in Magnetic Resonance Part B: Magnetic Resonance Engineering.

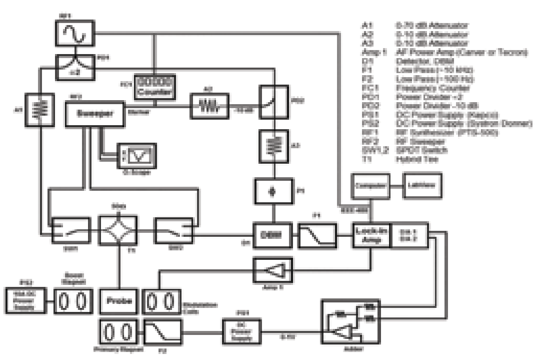


Figure 1. A block diagram of the RIT Magnetic Resonance Laboratory LFEPR spectrometer.

We also succeeded in getting our demonstration of the utility of LFEPR to nondestructively study the EPR signal from paramagnetic pigments in linseed oil based paints on canvas accepted for publication in the Journal of the American Institute for Conservation. This journal is the primary vehicle of the American Institute for the Conservation of Historic and Artistic Works for the publication of peer-reviewed technical studies, research papers, treatment case studies, and ethics and standards discussions relating to the broad field of conservation and preservation of historic and cultural works. We hope that our paper in this journal will help introduce the LFEPR technique to the community of art conservators.

EPR MOUSE

This past year we also finished work on version one of the EPR mobile universal surface explorer (MOUSE). The EPR MOUSE is a more versatile version of our LFEPR spectrometer. First, the MOUSE replaces the 30 cm diameter solenoidal magnet with a hand-held, unilateral or single-sided magnet, which is placed on the sample to be analyzed and produces the magnetic field in the sample. The smaller size of the magnet eliminates the need for the bulky 30 Amp power supply which drives the 30 cm solenoid and replaces it with a smaller six Amp supply. The MOUSE can be placed against any size object and records the LFEPR spectrum from an approximately 3 mm diameter disc shaped region of the object.

We demonstrated the utility of the MOUSE by recording LFEPR spectra from a Meissen Contemporary Böttger Red Stoneware candlestick, and the pigments ultramarine, rhodochrosite, blue vitriol, and Terracotta Red pigments in linseed oil on canvas. We also applied the MOUSE to image the ferromagnetic resonance signal from electro-photographic toner in a barcode on paper, and magnetic ink on the front of a United States one dollar bill. The images below compare the spatial distribution of the magnetic ink to the visible image of the bill. The details of this device and some applications were published in the Journal of Magnetic Resonance.

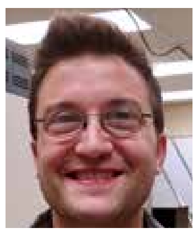
Figure 1. Images of the optical (top) and magnetic (bottom) inks on a US one dollar bill. Bottom image was recorded by rastering the bill over the surface of the EPR MOUSE.

Automatic Frequency Control

As stated above, one limitation of LFEPR has been sensitivity. The signal-to-noise ratio has been insufficient to record LFEPR signals from many transition metal samples. Signal averaging helps, but only in removing random noise. Because one of the main sources of spectral noise has been drift in the resonant frequency of the sample probe, which is not random, we have not been able to remove it with averaging. Our solution to this shortcoming is to utilize an automatic frequency control, which locks the frequency of the RF source to that of the probe. Thus keeping the probe matched to the 50Ω circuitry of the RF bridge. To implement this solution, we needed to rebuild the spectrometer RF bridge. Details of this AFC will be presented in next year's annual report.

Laboratory Staff

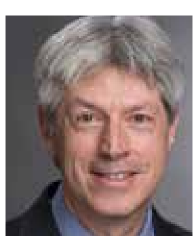
Dr. Joseph Hornak, Professor of Chemistry, Materials Science and Engineering, & Imaging Science in the College of Science at RIT.



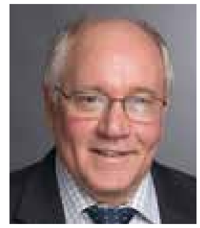
Baron Black, an undergraduate Physics major at Middle Tennessee State University, participated in the CIS Research Experience for Undergraduates (REU) program. He spent the summer working on the EPR MOUSE.

Celia Mercovich, an undergraduate Physics student at RIT and a participant in the Fast Forward Program, spent her summer measuring the magnetic field of the EPR MOUSE magnet as well as developing applications of the MOUSE

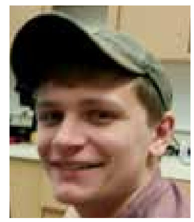
Anjana Seshadri, a student at Allendale-Colombia School in Rochester, was a high school intern working in the laboratory. She helped measure the magnetic field of the EPR MOUSE magnet and developed applications of the MOUSE.



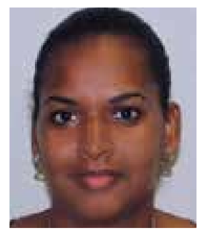
William Ryan, an adjunct faculty member in the School of Chemistry and Materials Science, is consulting on the LabView interface for the lab's low frequency electron paramagnetic resonance (LFEPR) spectrometer.



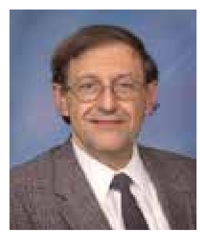
Dr. Hans Schmitthenner, a Research Scientist in the Center for Imaging Science and Lecturer in the School of Chemistry and Materials Science, is working on targeted contrast agents for magnetic resonance imaging.



Jordan Rabideau, a BS Chemistry undergraduate at RIT, joined the laboratory during the summer of 2018. He is evaluating the automatic frequency control for the LFEPR spectrometer.



Stephany Javier-Santana, a Chemistry Graduate Student at RIT, finished her MS in Chemistry and will return to the Dominican Republic. She was co-author on two papers during her one and a half year stay at RIT.



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.

Presentations

J.P. Hornak, Low Frequency Electron Paramagnetic Resonance for Studying Objects with Cultural Heritage Significance, Materials Science and Engineering Department, Washington State University, Pullman, WA, 8 May 2017.

J.P. Hornak, Low Frequency Electron Paramagnetic Resonance for Studying Objects with Cultural Heritage Significance, Rochester Cultural Heritage Imaging, Visualization and Education, (R-CHIVE), RIT & University of Rochester, 20 April 2018.

Publications

L.E. Switala, W.J. Ryan, M. Hoffman, S. Javier, B.E. Black, J.P. Hornak, A Wide-Line Low Frequency Electron Paramagnetic Resonance Spectrometer. Concepts Magn. Reson. Part B: Magnetic Resonance Engineering, 47B: e21355 (2017).

L.E. Switala, B.E. Black, C.A. Mercovich, A. Seshadri, J.P. Hornak, An Electron Paramagnetic Resonance Mobile Universal Surface Explorer. J. Magn. Reson. 285:18-25 (2017).

S. Javier, J.P. Hornak, A Nondestructive Method of Identifying Pigments on Canvas Using Low Frequency Electron Paramagnetic Resonance Spectroscopy. Accepted: Journal of the American Institute for Conservation 2018.

LABORATORY FOR MULTIWAVELENGTH ASTROPHYSICS

Laboratory Director's Comments By Prof. Michael Richmond

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 2017 was a bit of a mixed bag for LAMA: we produced a large number of papers and presentations describing our research, but did not win as many new funding awards as usual. Specifically, LAMA faculty, postdocs, and students were lead or co-authors of 25 refereed papers and 7 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. Two new grants, totaling $128 K in funding allocations, were initiated by LAMA PIs during CY 2017. LAMA continued its highly successful summer student research programs, again playing 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 2017, 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 25 refereed papers and 7 conference presentations and other non-refereed publications appearing in CY 2017 (see Sec. 6). A significant fraction of these publications resulted from projects in which LAMA personnel play leading roles within national and international teams of astrophysics researchers.
- **Two new grants, totaling $128 K in new funding allocations, were initiated during CY 2017. (see Sec. 3)**
- In summer 2017, 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: Jeyhan Kartaltepe (SoPA, Assistant Professor), Joel Kastner (CIS/SoPA, Professor; LAMA Director), Michael Richmond (SoPA, Professor), Andrew Robinson (SoPA, Professor)

Research Staff: Krystal Tyler (SoPA, Research Scientist)

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

Undergraduate Students: Dale Mercado, Sam Zimmerman, Isabella Cox, Christina Magagnoli, Caleb Wetherell, Victor Rau-Sirois, Bryanne McDonough, Lucas Shadler, (all Physics majors)

Finances: Two grants, totalling roughly $128K in new funding allocations, were successfully initiated in CY 2017 (see Table 1). A total of roughly $25K in overhead return was credited to the LAMA discretionary fund in CY 2017. The largest single expense was student stipends. A detailed breakdown of LAMA grants, grant expenditures, and lab account income and expenses for CY 2017 is available upon request.

Table 1: Funded LAMA Proposals, CY 2017

PI	Sponsor	Title	Total Funding
Robinson	NASA/STScI	Monsters on the Move: Confirming gravitational wave recoiling supermassive black hole candidates	$53,333
Robinson	NASA/STScI	Revealing the circum-nuclear torus: HST imaging of active galaxies observed during a Spitzer campaign	$73,394

4. Student Support, Community Building, Outreach

Immersive Summer Undergraduate Student Research Program. In summer 2017, 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 RIT undergraduates Dale Mercado and Christina Magagnoli, who classified galaxies in the CANDELS survey with Kartaltepe; Carly KleinStern (Brandeis) and Halle Parris (Penn Valley Community College), who also worked with Kartaltepe on galaxy research; and RIT undergraduate Bryanne McDonough, who used reverberation mapping to study the structure of active galactic nuclei with Robinson's research group. 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 2017 RIT Summer Undergraduate Research Symposium, as well as a poster at the 2018 January meeting of the American Astronomical Society (Chalifour et al., Bulletin of the AAS, 231, 349.29, 2018).

RIT Astrophysics Community Building. Via hospitality support in 2017, 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).

Astronomical Society of New York (ASNY). LAMA was well-represented at the annual ASNY meeting at Union College in November. The meeting was attended by Jeyhan Kartaltepe, Brittany Vanderhoof, Krystal Tyler, Ekta Shah, Kevin Cooke, Meaghann Stoelting, Trent Seelig, Yashashree Jahdav, and Annie Dickson-Vandevelde. Cooke and Jahdav both gave oral presentations at the meeting while Dickson-Vandervelde, Seelig, Stoelting, and Vanderhoof all presented posters.

Outreach within and beyond Rochester. In 2017, 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 2017 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 2017 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.
- **ASRAS.** The Astronomy Section of the Rochester Academy of Sciences (ASRAS) is Rochester's largest organization of amateur astronomers. LAMA members, both faculty and students, frequently give presentations to the group during their monthly meetings on the RIT campus. During 2017, Richmond talked gave a lecture in February on the recently-announced planet around Proxima Centauri (spoiler alert: not friendly to life), and also gave the keynote presentation at the annual RocheStarFest in July, describing the development of a new type of fast-readout camera by colleagues in Japan.

Figure 2: Students from the Young Women's College Prep Charter School visited the RIT Observatory on July 31, 2017.

- **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 2017, our largest event took place on July 31, when we hosted a group of students from the Young Women's College Prep Charter School. This group spent a week visiting RIT over the summer, and we showed them how to make and use planispheres, as well as giving them a look through our telescopes. LAMA members Richmond, Kartaltepe, Tyler, Vanderhoof, and Dickson-Vandervelde assisted NTID's Stacey Davis in the activities.

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. During 2017, she was a co-author on ten published refereed articles, including three that were led by graduate student Kevin Cooke. Kartaltepe is a co-I on an NSF REU program on Multimessenger Astrophysics that began in 2017 and is a leading co-I on a successful Early Release Science proposal for the James Webb Space Telescope. This program will be some of the first observations conducted by the telescope after launch.

Figure 3: HST images of some of the distant galaxies studied by Kartaltepe's group (see Barisic et al., ApJ 845, 41, 2017).

A number of RIT undergraduate and graduate students have been active participants in this research. Physics major Samuel Zimmerman completed his senior capstone project that tested various algorithms for quantifying the morphological properties of galaxies. Second year Isabella Cox worked on analyzing a large set of spectroscopic data taken with the Gemini Telescope's GMOS instrument and is currently working on a draft of a paper. Christina Magagnoli spent the summer working on a sample of galaxies with visual classifications from the CANDELS survey, compared their morphology to quantitative measures, and identified objects that were most likely to show evidence for merger activity. Dale Mercado worked on a comparison of different techniques for quantifying the AGN contribution to the spectral energy distributions of a sample of galaxies. He identified a subset of objects that clearly have a dominant AGN and we are in the process of determining how to find these objects efficiently (the analysis currently requires an enormous amount of computational power) and how to appropriately correct the derived star formation rates. Carly KleinStern from Brandeis University worked with the group through the Multimessenger Astrophysics REU program on a project to identify close galaxy pairs, galaxies that are expected to interact and eventually merge using photometric redshifts. Halle Parris from Penn Valley Community College worked with the group through the Imaging Science REU program on a comparison of galaxy star formation rates to the local environments of galaxies. Finally, incoming physics major Caleb Wetherell worked on a project comparing infrared and X-ray detected galaxies in a sample of moderate redshift galaxies with near-infrared spectroscopy.

Graduate student Kevin Cooke has reduced and analyzed a sample of archival observations from the Hubble Space Telescope and made these data available to the wider CSOMOS collaboration. This work was a component of two publications. He also led a first author paper on the evolution of stellar mass in brightest cluster galaxies since redshift 1 and presented his work at a COSMOS collaboration meeting and an ASNY (Astronomical Society of New York) meeting. Postdoc Krystal Tyler's 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 worked on optimizing spectral template fitting on RIT's computing cluster and has proceeded to fit the photometry for over 17,000 galaxies. She is also working on modifying a program to accurately measure the photometry for blended sources at far-infrared wavelengths. She has also been active in mentoring graduate and undergraduate students.

Graduate student Ekta Shah participated in an observing run, led by Kartaltepe, to use the DEIMOS instrument on Keck to observe a sample of candidate interacting galaxy pairs as a part of her PhD research. Graduate student Brittany Vanderhoof is working on a project using Keck MOSFIRE spectroscopy to analyze the kinematics of a sample of star forming galaxies at z~1.5 and presented preliminary results at the ASNY meeting in November. She is also working with Kartaltepe on a sample of z~2 galaxies that were observed in October with ALMA (the Atacama Large Millimeter Array). The goal of this project is to obtain resolved CO measurements in order to constrain the properties and physical distribution of molecular gas in extremely star forming high redshift galaxies. Graduate student Meaghann Stoelting is working on the resolved spectral energy distributions of galaxies using observations from the Hubble Space Telescope in order to investigate how their resolved properties relate to bulk properties such as star formation rate and stellar mass. Additionally, Meaghann worked on a NASA funded Education and Public Outreach project that uses Hubble observations in a mobile game focusing on galaxy evolution. Meaghann's work focuses on the scientific content of the game and ensuring that it meets specific education standards. Caitlin Rose joined the group as a first year PhD student and is working on applying several morphological measurements to simulated observations of galaxies to quantify the ability of the James Webb Space Telescope to identify mergers as a function of redshift.

Andy Robinson and the RAGE group: Dr Robinson took sabbatical leave during the Fall Semester, 2017. He spent approximately half his time at RIT, working on two projects: (1) a multiwavelength study of the "changing look" AGN NGC6418, which was captured undergoing a dramatic change in its spectral properties, and (2) the implementation of a detailed treatment of dust sublimation in the dust reverberation computer code developed by Dr. Triana Almeyda during her Ph.D. During the latter half of his leave he visited the Federal University of Rio Grande in Brazil and the University of Southampton, UK. Whilst in Rio Grande, he worked with Dr. De Sales and Ms. Hekatelyne Carpes on a multi wavelength study of OH Megamaser galaxies and also delivered the keynote lecture for the "School of Physics of the Extreme South". At the University of Southampton, he worked with Dr. Almeyda, on computer simulations of the reverberation response of the AGN torus, and with Drs Alessandro Capetti, Ranieri Baldi and Ari Laor, on the polarization properties of the broad emission lines of quasars.

Supermassive black holes (SMBH) reside in the cores of most, if not all galaxies. During growth phases, when accreting interstellar gas from the host galaxy, they are observed as hugely luminous sources known as Active Galactic Nuclei (AGN). The RIT AGN-Galactic Environments (RAGE) group studies various aspects of the AGN phenomenon and the nature of relationships between SMBH and their host galaxies, using a combination of observational techniques and computer simulations. During the 2017 calendar year, the group included Drs Robinson and Richmond, AST Ph.D. students Triana Almeyda, Yashashree Jadhav and Ashley Frank, AST M.S. student Trent Seelig and Physics undergraduates Bryanne McDonough and Lucas Shadler. Members of the group worked on the several research projects during the year, most of which involve external U.S. and international collaborations.

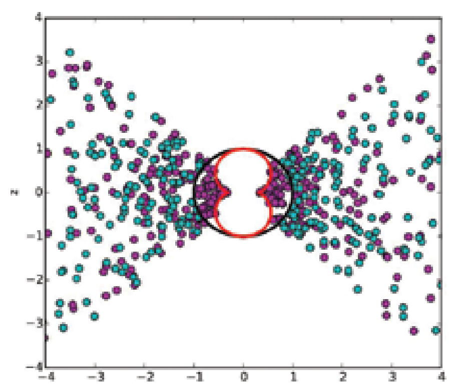


Figure 4: A side view of the clouds of dust and gas arranged around a central supermassive black hole, from a computer simulation used to determine the response of infrared light to variations in an AGN (see Almeyda et al., ApJ 843, 3, 2017).

Research projects include:

- an optical-infrared reverberation mapping study of a sample AGN, using observations from the Spitzer Space Telescope, the Hubble Space Telescope and several ground-based telescopes (Robinson, Richmond, Almeyda, Frank and external collaborators). The goal of this study is to determine the size and structure of the circum-nuclear dusty "torus".

Figure 5: An optical image of the quasar Markarian 876, obtained with the Hubble Space Telescope by the RAGE group as part of the project to map infrared ``light echoes'' from the AGN circumnuclear dusty torus in AGN. The figure shows a zoomed in view of the quasar nucleus (the bright object marked by diffraction spikes) and reveals a previously unknown companion galaxy which appears to be in the process of being cannibalized by the quasar's host galaxy.

- The development of a computer simulation of the response of the torus dust emission torus to temporal variations in the AGN luminosity (Almeyda/Robinson). The computer code (TORMAC) was used by Ms. Almeyda to conduct the most comprehensive study to date of the torus response function. Ms. (now Dr.) Almeyda successfully defended her Ph.D. dissertation and was subsequently selected for the 2018 RIT Graduate Education Dissertation Award for exceptional PhD-level research. After graduating, she moved to the UK, where she is now a Postdoctoral Research Fellow in the Astronomy Group at the University of Southampton.
- A search for displaced supermassive black holes in nearby elliptical galaxies using Hubble Space Telescope images (Jadhav, Robinson). A sample of nearly 100 galaxies has been analyzed to date of which 20 have been found where the SMBH is displaced from the center of the galaxy by distances range from 2 to 100 parsecs. Such displacements may be signposts of gravitational recoil due to gravitational wave emission during the merger of an SMBH binary.
- A multiwavelength study, using data from the Hubble Space Telescope, Spitzer Space Telescope, the Very

Large Array radio telescope and the Gemini Telescopes, of a sub-class of Luminous Infrared Galaxies that exhibit strong OH masers (Robinson, with Dr. Dinalva de Sales of the Federal University of Rio Grande, Brazil, and others). The goal of the project is to determine the nature of the nuclear activity in these galaxies, which in are fact often found to be late stage galaxy mergers. The team completed detailed studies of three such galaxies during the year.

- A study of the circumnuclear ionized gas flows in a sample of hard X-ray selected Active Galaxies, using Integral Field Spectroscopy observations obtained with the Gemini North and South Telescopes (Robinson/Seelig and external collaborators). The aim of this project is to map the velocity field and ionization structure of the circumnuclear gas to isolate the main components and in particular identify signatures of inflows or outflows, which may trace, respectively, the gas inflows that “fuel” the AGN, or the gas outflows that transfer mechanical energy “feedback” to the host galaxy. Detailed studies of several galaxies were completed during the year.
- A polarization study of the broad emission lines of luminous AGN (quasars), using spectropolarimetry observations from the European Southern Observatory’s Very Large Telescope (Robinson, with Dr. Alessandro Capetti of the INAF-Osservatorio Astrofisico di Torino, Italy,and Dr. Ranieri Baldi of the University of Southampton, UK, and others). Observations of 25 quasars have been obtained to date. The aim of this investigation is to characterize the polarization properties of the broad emission lines and in particular to determine if they are consistent with the “equatorial scattering” model originally developed by Robinson and former Ph.D. student Dr. James Smith.

Joel Kastner: Kastner's 2016-2017 sabbatical leave was organized around the general theme of investigating the origins of exoplanets, i.e., the formative stages of planetary systems orbiting stars other than the Sun. This research is aimed at understanding the astonishing variety of exoplanet systems that have been discovered over the past two decades, as well as the earliest evolution of our own solar system. In winter and spring 2017, Kastner spent sabbatical residencies at the Carnegie Institution's Department of Terrestrial Magnetism in Washington, DC, as Merle A. Tuve Senior Fellow, and at the Radio and Geoastronomy Division of the Smithsonian Astrophysical Observatory in Cambridge, MA, as a Smithsonian Institution Visiting Fellow.

During these fellowships, Kastner and colleagues published three major studies of the nearest-known planet-forming ("protoplanetary") disk, which orbits the nearby star TW Hya. 1) Repeated observations of the TW Hya disk with the Hubble Space Telescope yielded the detection of a pattern of rapidly rotating shadows on the disk. The relatively short (~16-year) period of rotation of the shadow pattern implies the presence of a warp in the inner (terrestrial, i.e., ``rocky'' planet-forming) regions of the disk. This warped disk structure is most likely maintained by a newly formed planet orbiting interior to the warp (Debes et al. 2017, "Chasing Shadows: Rotation of the Azimuthal Asymmetry in the TW Hya Disk," The Astrophysical Journal, 835, 205). 2) Deep imaging of the disk with the Keck Telescope in the thermal infrared wavelength regime places very stringent limits on the masses of planets that can already have formed in the disk, as well as on the mass accretion rates of any such newborn planets (Ruane et al. 2017, "Deep imaging search for planets forming in the TW Hya protoplanetary disk with the Keck/NIRC2 vortex coronagraph", The Astronomical Journal 154, 73). 3) The Atacama Large Millimeter Array's detection of the TW Hya disk in emission from CN molecules carrying both common and rare nitrogen isotopes offers strong evidence that CN traces the dominant reservoir of nitrogen that is presently being incorporated into the star and any giant planets forming in the disk; by extension, CN also must trace the main nitrogen reservoir in the present-day solar neighborhood (Hily-Blant et al. 2017, "Direct evidence of multiple reservoirs of volatile nitrogen in a protosolar nebula analogue," Astronomy & Astrophysics, 603, L6).

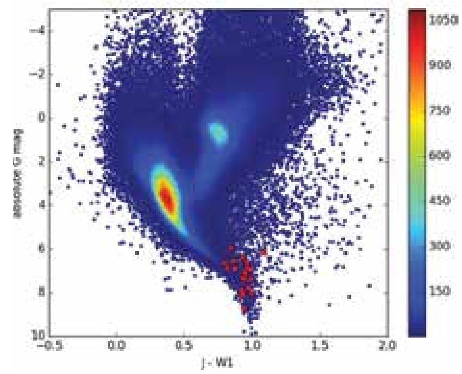


Figure 6: Red dots indicate the objects recognized as nearby young stars, uncovered by the Gaia space astrometry mission (see Kastner et al., ApJ 841, 73, 2017).

In addition to the above, Kastner exploited newly available data from the Gaia space astrometry mission to identify more than a dozen new examples of stars of age less than 100 million years old within 300 light years of our solar system (see Fig. 5 above). A paper describing these results was initiated during Kastner's (Nov 2016) Study Abroad Faculty Fellowship at Italy's Arcetri Observatory, further developed and refined during his Carnegie DTM residency, and then finalized and published during his SAO residency (Kastner et al. 2017, ``Nearby Young, Active, Late-type Dwarfs in Gaia's First Data Release'', The Astrophysical Journal 841, 73).

Michael Richmond: Richmond was on sabbatical leave during the spring semester of 2017. During that time, he was invited to teach a graduate-level class at the National Astronomical Observatory of Japan, near Tokyo. The topic was “The Cosmological Distance Ladder,” a close look at the range of techniques astronomers use to determine the distances to nearby stars, less-nearby objects, and very distant galaxies. The very interactive approach used during class meetings (see Figure 6, below) surprised the students, but in a pleasant way. Richmond also used this visit to continue his work with a team of Japanese astronomers at NAOJ and the Institute of Astronomy in Tokyo who are developing a new wide-area, fast-readout camera: the Tomoe Gozen project (http://www.ioa.s.utokyo.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.

Figure 7: In Richmond's class on the Cosmological Distance Ladder at the National Astronomical Observatory of Japan, students use a series of measurements to estimate how many spoonsful of water it takes to fill a big plastic storage container.

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 Andy Lipnicky, Trent Seelig, and Ekta Shah, the group collected images for a range of projects, including interacting galaxies, ionized gas in star-forming galaxies, and the variable stars HT Cas and HH UMa.

Richmond, together with Connelly, acted as co-advisor for physics major Victor Rau-Sirois' capstone project, a search for variable stars in the NSVS catalog. Using both the WIYN and RIT Observatory telescopes, Rau-Sirois monitored a set of stars over a period of several months, looking for evidence for significant variations in brightness.

6. Publications

(1) Almeyda, Triana, et al., 2017. Modeling the Infrared Reverberation Response of the Circumnuclear Dusty Torus in AGNs: The Effects of Cloud Orientation and Anisotropic Illumination. ApJ 843, 3

(2) Brum, Carine, et al., 2017. Dusty spirals versus gas kinematics in the inner kiloparsec of four low-luminosity active galactic nuclei. Monthly Notices of the Royal Astronomical Society, 469, 3405

(3) Schnorr-Muller, Allan, et al., 2017. Gas inflows towards the nucleus of NGC 1358. Monthly Notices of the Royal Astronomical Society, 471, 3888

(4) Kashino, D., et al., 2017. The FMOS-COSMOS Survey of Star-forming Galaxies at $z \approx 1.6$. IV. Excitation State and Chemical Enrichment of the Interstellar Medium. ApJ, 835, 88

(5) Simmons, B. D., et al., 2017. Galaxy Zoo: quantitative visual morphological classifications for 48 000 galaxies from CANDELS. Monthly Notices of the Royal Astronomical Society, 464, 4420

(6) Darvish, B., et al., 2017. Cosmic Web of Galaxies in the COSMOS Field: Public Catalog and Different Quenching for Centrals and Satellites. ApJ, 837, 16

(7) Puglish, A., et al., 2017. The Bright and Dark Sides of High-redshift Starburst Galaxies from Herschel and Subaru Observations. ApJ, 838, 18

(8) Casey, C. M., et al., 2017. Near-infrared MOSFIRE Spectra of Dusty Star-forming Galaxies at $0.2 < z < 4$. ApJ, 840, 101

(9) Kirkpatrick, Allison, et al., 2017. A Controlled Study of Cold Dust Content in Galaxies from z = 0-2. ApJ, 843, 71

(10) Kashino, D., et al., 2017. The FMOS-COSMOS Survey of Star-forming Galaxies at Z ˜ 1.6. V: Properties of Dark Matter Halos Containing Hα Emitting Galaxies. ApJ, 843, 138

(11) Barisic, I., et al., 2017. Dust Properties of C II Detected z ˜ 5.5 Galaxies: New HST/WFC3 Near-IR Observations. ApJ, 845, 41

(12) Faisst, Andreas L., et al., 2017. Are High-redshift Galaxies Hot? Temperature of $z > 5$ Galaxies and Implications for Their Dust Properties. ApJ, 847, 21

(13) Chang, Y., et al., 2017. Infrared Selection of Obscured Active Galactic Nuclei in the COSMOS Field. ApJS, 233, 19

(14) Principe, D., et al., 2017. The multiple young stellar objects of HBC 515: An X-ray and millimeter-wave imaging study in (pre-main sequence) diversity. A&A, 598, 8

(15) Debes, J. H., et al., 2017. Chasing Shadows: Rotation of the Azimuthal Asymmetry in the TW Hya Disk. ApJ, 835, 205

(16) Hughes, A. M., et al., 2017. Radial Surface Density Profiles of Gas and Dust in the Debris Disk around 49 Ceti. ApJ, 839, 86

(17) Montez, Rodolfo, et al., 2017. A Catalog of GALEX Ultraviolet Emission from Asymptotic Giant Branch Stars. ApJ, 841, 33

(18) Kastner, J. H., et al., 2017. Nearby Young, Active, Late-type Dwarfs in Gaia's First Data Release. ApJ, 841, 73

(19) Hily-Blant, P., et al., 2017. Direct evidence of multiple reservoirs of volatile nitrogen in a protosolar nebula analogue. A&A, 603, 6

(20) Ruane, G., et al., 2017. Deep Imaging Search for Planets Forming in the TW Hya Protoplanetary Disk with the Keck/NIRC2 Vortex Coronagraph. AJ, 154, 73

(21) Otsuka, Masaaki, et al., 2017. The Herschel Planetary Nebula Survey (HerPlaNS): A Comprehensive Dusty Photoionization Model of NGC6781. ApJS, 231, 22

(22) Bodman, E. H. L., et al., 2017. Dippers and dusty disc edges: new diagnostics and comparison to model predictions. MNRAS 470, 202

(23) Richmond, M. W., and Vietje, B., 2017. BVRI Photometry of SN 2016coj in NGC 4125. JAVSO, 45, 65

(24) Kato, Taichi, et al., 2017. Survey of period variations of superhumps in SU UMa-type dwarf novae. IX. The ninth year (2016-2017). PASJ, 69, 75

(25) Wakamatsu, Yasuyuki, et al., 2017. ASASSN-16eg: New candidate for a long-period WZ Sge-type dwarf nova. PASJ, 69, 89

Other (Non-refereed) Publications

(1) Couto, Guilherme S., et al., 2017. Circumnuclear gaseous kinematics and excitation of four local radio galaxies. RevMexAA, 49, 115 458, 855

(2) Mantha, K., et al., 2017. Constraining the Merging History of Massive Galaxies Since Redshift 3 Using Close Pairs. I. Major Pairs from Candels and the SDSS. AAS 229, 347.15

(3) Grogin, N. A., et al., 2017. Constraining the Merging History of Massive Galaxies Since Redshift 3 Using Close Pairs. I. Major Pairs from Candels and the SDSS. Galaxy Evolution Across Time, Proceedings of a conference held 12-16 June, 2017 in Paris.

(4) Gingerich, Lydia, et al., 2017. Dippers and dusty disc edges: new diagnostics and comparison to model predictions. AAS 229, 154.22

(5) Punzi, K. M., et al., 2017. An X-ray and Optical Spectroscopic Study of the Perplexing Star RZ Piscium. AAS 229, 230.01

(6) Drew-Moyer, Hannah, et al., 2017. Interpreting Infant Stars: SOFIA Imaging of Protostars in L1630 and NGC 2264. AAS 229, 241.07

(7) Richmond, M. W., 2017. Technical Summary of the Half-Degree Imager (HDI). AAS 229, 329.01

Laboratory Director's Comments By Professor Rich Hailstone

The image on the opposite page shows a suite of electron microscopes available to support research in the NanoImaging Lab and elsewhere on the RIT campus.

The top row shows two transmission electron microscopes (TEMs) —on the left for soft or bio materials and on the right for harder inorganic materials. The bottom row shows two scanning electron microscopes (SEMs), both of which have electron guns which enable high-resolution imaging of materials. Each of these microscopes has its own strengths, but as a suite the imaging capability is quite impressive.

Visualizing Astigmatism in the SEM Electron Probe (PhD student Mandy Nevins). In this study, we investigate beam shape variation at different beam voltages. Astigmatism describes uneven focus in the electron probe of the scanning electron microscope (SEM) which results in distorted, blurred, or stretched images. Factors such as column alignment, the emission pattern from the gun, the lenses, and contamination can cause the desirable circular probe footprint of minimum size to become larger and distorted. Historically, detecting astigmatism relied on going through focus and looking for streaking in any particular direction. The astigmatic beam shape can now be visualized and studied using a modern probe shape determination technique.

In this study, we investigated a new approach to characterize astigmatism at different beam voltages based on earlier work in this project. The following protocol was used at 2kV, 5kV, 10kV, and 20kV. First, a best focus image was obtained using standard focusing practices, with the aim of achieving the circular beam footprint with minimum diameter. From there, a series of stigmated images were collected by changing the x stigmator alone, the y stigmator alone, or the x and y stigmators. Individually, one stigmator was held constant at the best focus value, while the other was adjusted to the best focus value ±0.2%, ±0.4%, and ±0.6%. Together, the stigmation was adjusted to the four combinations of best focus values ±0.4% between both stigmators.

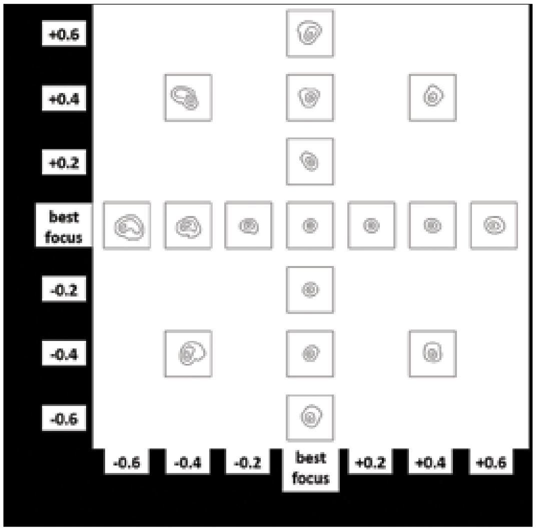


*Figure 1. Astigmatism Series at 10kV. Each box contains a contour plot of a point spread function (PSF). The contours shown are 0.9*max (inner), 0.5*max (middle), and 0.1*max (outer), where max is the maximum intensity of the current PSF. Each PSF was calculated from a calibration image taken with the given stigmator settings. The box size is of scale 85nm x 85nm.*

To visualize the probe shape, we utilized the point spread function (PSF) determination ability of the Aura Workstation, where the PSF represents the shape of the electron beam. Backscattered electron images were captured with a TESCAN MIRA3 field emission SEM. For the astigmatism series, a calibration sample of 18.2nm gold nanoparticles on graphene was imaged for PSF determination purposes. At 10kV, an image of a gold-on-carbon standard was also collected with each beam shape to picture the effect of astigmatism on a sample-of-interest, as well as for testing Aura's image restoration capability.

As the amount of astigmatism increased, the beam became more misshapen (Figure 1). The shape of the astigmatic beam was not necessarily elliptical, and this aspect is now accessible for study. When stigmating the beam along one axis, the shape was not reflected from one side of best focus to the other (especially notable along the x stigmator axis in this case). The behavior shown at 10kV was mimicked at the other voltages, along with the expected change in diameter of the PSF.

In addition to determining PSFs for the series, image restoration by PSF deconvolution was performed on astigmatic images at 10kV. Overall, the method was able to restore information lost to astigmatism, resulting in improved image clarity. The images captured with highly distorted probe shapes (e.g., x stigmator = best focus-0.4%, y stigmator = best focus+0.4%) required more attention and finer tuning of processing parameters when performing restorations to minimize processing artifacts.

Possible applications of astigmatism measurement include characterizing electron focusing elements for a particular microscope, developing or improving an auto-stigmation routine, and as a tool for realizing a basic understanding of how astigmatism affects beam shape in the SEM.

Quantitaive Elemental Mapping of Alkali-Activated Slag Cement (MS student Najat Alharbi). Blast furnace slag is a non-metallic byproduct generated by the production of iron and steel in a blast furnace at temperatures in the range of 1400°-1600° C. The alkali activation of blast furnace slag has the potential to reduce the environmental impact of cementitious materials and to be applied in geographic zones where weather is a factor that negatively affects performance of materials based on Ordinary Portland Cement. Alkali-activated blast furnace slag cements have been studied since the 1930s due to its high compressive strength; they can exceed 100 MPa in 28 days. The low Ca/Si ratio in slag improves its resistance to aggressive chemical materials such as acids, chlorides and sulphates.

Blast furnace slag is a highly heterogeneous material. It is well known that its chemical composition affects the physical properties of the alkali activated material, however there is little work on how these inhomogeneities affect the microstructure and pore formation. In this study we characterize slag cement activated with KOH using scanning electron microscopy (SEM), x-ray microanalysis and quantitative element mapping. Attention is focused on delineating the phases induced by the alkali activation, as these phases are important in determining the mechanical properties of the material. Quantitative elemental mapping was done with Bruker Qmap software on spectrum images using standards-based elemental quantification to show the quantitative spatial distribution of each element of interest.

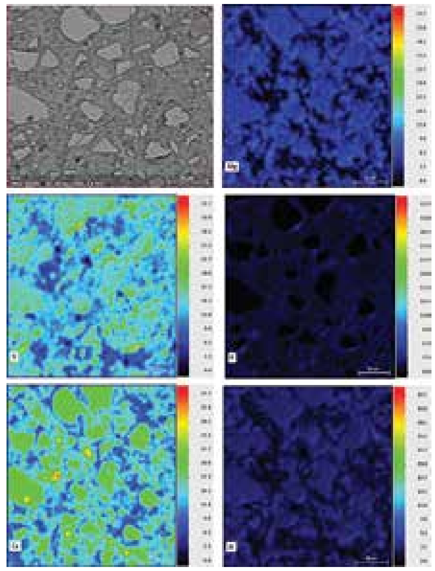


Figure 2. Backscattered electron image of the alkali activated slag (top left), and quantitative mapping of the elements. Color scale in atom%.

Figure 2 shows the BSE image of the cement sample (top left) and quantitative mapping images for the elements magnesium, silicon, potassium, calcium, and aluminum. The BSE image is divided into "particles" (bright features) and "background" (nonbright features). Magnesium and aluminum show a uniform distribution over the particles areas while potassium appears only in the matrix areas that correspond to the paste where a calcium aluminosilicate phase is possibly formed. Silicon and calcium show a relatively high concentration in the particles with concentration between 14-20 for Si and 17-25 for Ca, with much lower concentration in the matrix.

CuNi Alloy Formation by Printing Techniques (In collaboration with Professor Denis Cormier and graduate student Chaitanya Mahajan). CuNi nanoalloys are used in hyperthermia treatment in which the malignant cancer tumors are treated by raising its temperature above 40 °C. The CuNi nanoalloy was produced by mixing copper and nickel inks in desired proportions. The formation of nanoalloy with different sintering profiles was studied at the micro- and nano-scale by electron microscopy techniques.

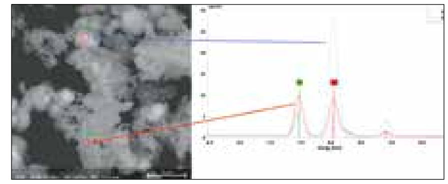


Figure 3. Left, SEM image of printed CuNi alloy. Right, X-ray microanalysis spectrum at the indicated areas in the left-hand image.

The SEM image in Fig. 3 shows the printed material at the microscale is composed of roughly spherical particles and fibrous-type material. X-ray microanalysis was done in the two circled areas and the resulting spectra indicate the relative concentrations of Ni and Cu are different in these types of structures. Semi-quantitative analysis showed that the fibrous type material is roughly equal amounts of Ni and Cu, whereas the spherical particles are very Cu rich.

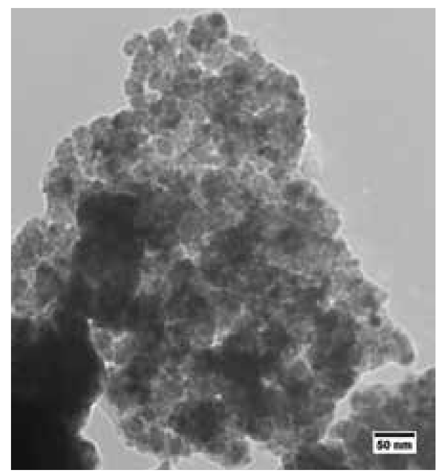


Figure 4. A, TEM image of printed CuNi alloy. B, Electron diffraction pattern of the area in Fig. 4A.

Fig. 4A is a TEM image of the material at the nanoscale and Fig. 4B is an electron diffraction pattern of this area. The numbers in the diffraction pattern indicate the lattice plane spacings for this material. Two other areas were similarly analyzed. None of the spacings were consistent with a pure Cu or a pure Ni phase, indicating an alloy had been formed. However, upon using Vegard's law to determine the atomic ratios, the three areas gave quite different results, indicating that the printed material was quite heterogeneous.

Publications, Conference Presentations, and Patents Issued 2017-2018

1. Najat Alharbi, Richard Hailstone, Benjamin Varela (2017). Multiple Phase Identification in Alkali-Activated Slag by SEM-EDS. Non-Traditional Cement and Concrete, 761, 49-56.
2. Matthew Zotta, Mandy Nevins, Richard Hailstone, and Eric Lifshin (2018). The Determination and Application of the Point Spread Function in the Scanning Electron Microscope. Microscopy and Microanalysis, in press.
3. Najat A. Alharbi, Benjamin, Varela, Richard K. Hailstone (2018). "Alkali-Activated Slag Characterization by Scanning Electron Microscopy, X-Ray Microanalysis, and Nuclear Magnetic Resonance Spectroscopy." Cement and Concrete Research, submitted.
4. Najat A. Alharbi, Richard K. Hailstone, and Benjamin Varela (2017). "EDS-Based Phase Analysis of Alkali-Activated." Microscopy & Microanalysis 2017, St. Louis, MO, August.
5. Mandy C. Nevins, Matthew D. Zotta, Richard K. Hailstone, and Eric Lifshin (2017). "Viability of Point Spread Function Deconvolution for SEM." Microscopy & Microanalysis 2017, St. Louis, MO, August.
6. Najat A. Alharbi, Richard K. Hailstone, and Benjamin Varela (2017). "New Developments in the Characterization of Alkali-Activated Slag." Third International Conference on Innovative Materials, Structures and Technologies, Riga, Latvia, September.
7. Najat Alharbi, Richard Hailstone, and Benjamin Varela (2017). Multiple Phase Identification in Alkali-Activated Slag by Scanning Electron Microscopy and X-Ray Microanalysis. RIT Graduate Showcase, November.
8. Mandy Nevins, Matthew Zotta, Richard Hailstone, and Eric Lifshin (2017). An Image Restoration Technique for Low-Voltage Scanning Electron Microscopy. RIT Graduate Showcase, November.
9. Mandy Nevins (2018) "Using Electrons to Explore on the Nanoscale." Presentation to 2018 summer REU students.
10. K. J. Reed, A. G. DiFrancesco, R. K. Hailstone, G. R. Prok, and T. D. Allston (2107). Structured Catalytic Nanoparticles and Method of Preparation, European Patent 2545147 B1 Sept.
11. K. J. Reed, A. G. DiFrancesco, G. R. Prok and R. K. Hailstone (2017). Method for Producing Cerium Containing Nanoparticles, European Patent 2907794 Dec.

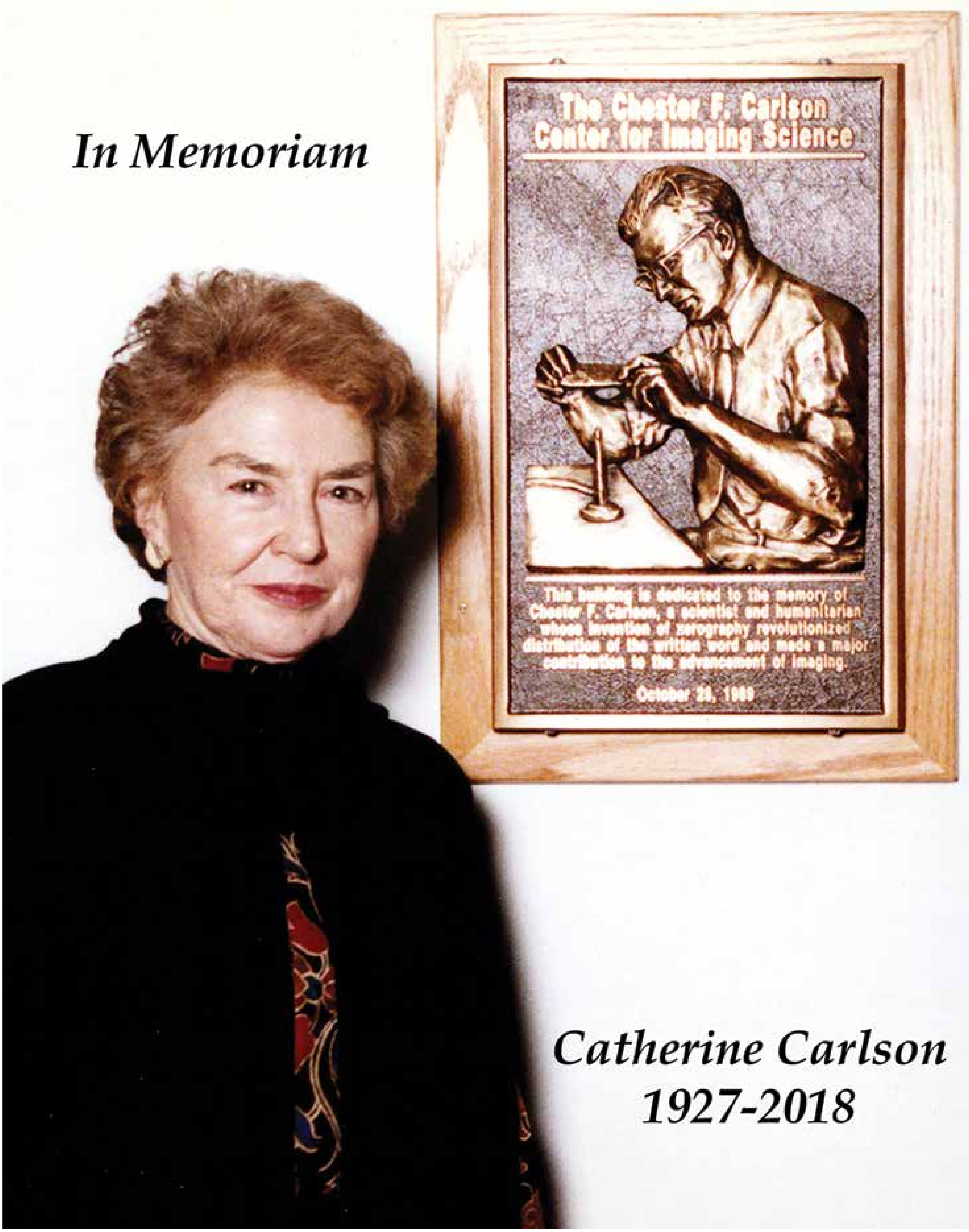
Grants and Contracts 2017–2018

Cerion Advanced Materials, $28k

Other Income 2017–2018

Microscopy Facility User Fees, $55k

In Memoriam



Catherine Carlson
1927-2018

I am saddened to pass along the news that Catherine Carlson passed away on September 27, 2018. Catherine was a great friend and supporter of the Center and she will be missed dearly. Many of our students have been direct recipients of her generosity through the scholarship that she endowed in her name. She supported the Center in many ways, often meeting with faculty and students just to chat about their experience here and the work they were doing. More information about her life can be found in the University News article below.

David W. Messinger, PhD, Director

Chester F. Carlson Center for Imaging Science

RIT mourns the loss of honorary trustee Catherine Carlson

September 30, 2018

Catherine Carlson, who generously gave of her time and family fortune to support RIT and many institutions in Greater Rochester, died Thursday.

Ms. Carlson, whose father Chester Carlson invented the technology that launched Xerox Corp., was 91 and served the university as an honorary trustee.

RIT's Chester F. Carlson Center for Imaging Science, a 70,000-square-foot facility with 20 laboratories, five classrooms, 40 offices and a 150-seat auditorium dedicated in 1989, benefitted from her family's philanthropy, as did the College of Science.

"Although Chester Carlson prized his anonymity, it seems right to honor a man who has contributed so much to the well-being of so many people and to the technological advancement of the 20th century," Ms. Carlson said in her remarks during the 1989 dedication, which was attended by imaging leaders from as far away as London and Tokyo. "He had a great affection for this institute and would be proud of the leading, comprehensive university RIT has become. RIT has indeed honored this great man by naming this center for imaging science for him."

RIT President David Munson said the Carlson legacy will long be remembered.

"Not only did Chester Carlson's xerography invention change the world, the Carlsons—Chester, Dorris and Catherine—continued to quietly change the world through financial support for education, health care, civil rights, public television and so much more," Munson said.

Catherine Carlson with recipients of the Carlson Scholarship in 2005.

Originally from Milton, Mass., Ms. Carlson graduated from Boston University with a degree in philosophy. She studied medicine and business, and moved to Rochester in 1969 to work with Chester Carlson. She was adopted as an adult by Chester and his wife, Dorris.

Chester Carlson, who avoided the spotlight and wanted to give away his fortune to better the community, his wife and Ms. Carlson cumulatively gave away hundreds of millions of dollars throughout the years, Ms. Carlson had said.

Retired RIT President Albert Simone, who also grew up in Massachusetts, immediately connected with Ms. Carlson. She traveled with Simone to RIT Croatia in Dubrovnik to help launch RIT's first overseas campus in 1997, and also accompanied Simone on a visit to the local Congressional delegation in Washington, D.C.

"We had a lot in common and had an early, quick and immediate connection," Simone said. "What I'll remember about her was her quiet smile, her dancing eyes and her energy and willingness to do something new, to take on a new challenge."

He said Ms. Carlson gladly helped RIT start its first Ph.D. program, in imaging science.

"It was just an extension of the imaging Chester was doing, looking at the heavens, stars, planets, and looking at the tiniest things in medical imaging," he said.

When it came time to ask for financial support at RIT, Simone said Ms. Carlson was "was willing to listen. She loved exploration – that's what she did. We had these discussions and she'd just light up and ask how she could help. She tried to learn, innovate and then contribute."

Also on the trip to Croatia was RIT trustee Ann Mulligan, RIT Provost Emeritus and former Vice President for Academic Affairs Stan McKenzie, and Simone's wife Carolie, who combined the trip to Croatia with some tourism in Turkey and Greece.

"We were like the gang of five," he said. "We had some exciting times."

Ms. Carlson enjoyed traveling the world and attending theater and performing arts. Her love of art was evident when she served as a co-chair with Mulligan in the fundraising effort to bring a large Albert Paley sculpture, known as "The Sentinel," to RIT in 2003.

She also was personally interested in the community. To better understand the duties of police officers, Ms. Carlson attended – and graduated – from a 12-week citizens police academy offered by the Rochester Police Department. And for many years, Ms. Carlson bought dictionaries for every student in the Rochester City School District —in many cases, they were the first books the students had ever owned.

"She was an eclectic, renaissance sort of person, very humble and unassuming and always talking about something new and exciting for her," Simone said. "She was just fun to be around. She'll be missed."

Details about services were not immediately available.

The RIT flag will be lowered in her memory at a future date to be determined.

R·I·T

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