2018

Center For Detectors Annual Report

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CENTER FOR DETECTORS 2018

Director's Comments

A little over 10 years ago, I tried an experiment. I had just arrived at RIT and heard about "experiential" learning. Wanting to put the concept to the test, I wondered what would happen if I treated undergraduate students as full-fledged research team members in my group.

This concept deviates from what I had seen at other universities where very few undergraduate students participate in research groups. Even when they do, it is usually in the form of a project created for the student, not one that requires deliverables to external funding entities.

As part of my experiment, I conceived of a set of conditions to engage the students:

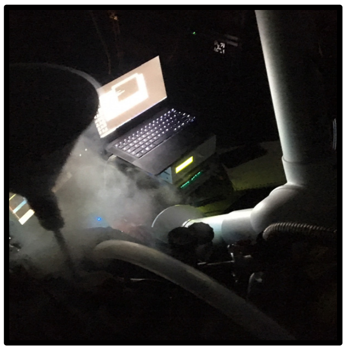
1. Students work on projects that solve real problems funded by the outside world.
2. Students contribute just like any other professional team member.
3. Students interact with other team members, regardless of discipline or rank, to solve problems.
4. Students, regardless of major, employ knowledge and techniques in any field, including project management, budgeting, procurement, and recruiting other students.
5. Student's start-and-end dates would mirror the project schedule, not the academic calendar.

The results of this experiment have been somewhat surprising. I found that many RIT undergraduate students crave authentic research programs beyond the more common vehicles, such as Capstone or Senior projects; in those cases, a professor assigns a student "research experiences" and "experiential learning experiences," often with comparatively low expected time commitment. I also found that employers desire students who had authentic research experiences, working in genuinely interdisciplinary teams, and tackling real-world problems.

Our students make vital contributions to our projects while obtaining experiences that reflect authentic real-world need. I hope you enjoy reading about recent research in RIT's Center for Detectors and our extraordinary students who think outside of their discipline to solve problems.

Dr. Donald Figer
Professor, RIT College of Science
Director, Center for Detectors
Director, Future Photon Initiative

Highlights



Research

- CfD research included work on imaging detectors, cosmology, micromirror development, and new material systems for photonics. NSF funded Dr. Jing Zhang for a CAREER award to develop new, highly efficient ultraviolet light sources. For details and a full list of research, see the Research Projects section of this report.

New Members

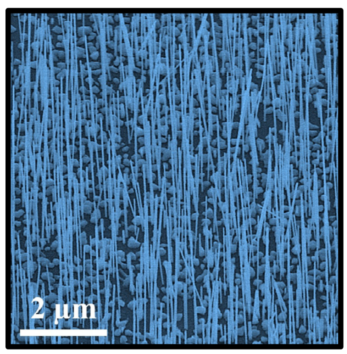
- The CfD hosted over 15 new students this past year, in addition to personnel from Precision Optical Transceivers, a local company that is a part of the Future Photon Initiative Industry Partnership Program. A full list of personnel can be found in the Personnel section of this report.

Collaborations

- CfD teamed with Columbia University, Precision Optical Transcievers, AIM Photonics, and SUNY Polytech Insitute to begin the the development of the Engineering Verification Test (EVT) Station for AIM Photonics's Test, Assembly, and Packaging facility in downtown Rochester. The CfD continues to work with organizations like Raytheon Vision Systems and Thermo Fisher.

Publications

- CfD team members published over 35 papers in journals such as The Astrophysical Journal and Optics Express. CfD research was highlighted in popular publications such as the Scientific American and Forbes online. CfD members served as expert commentators in articles Astronomy Magazine and New Scientist and as expert authors of strategic planning documents for NASA.



Executive Summary

The Center for Detectors (CfD), established in January 2010, began as an expansion of the Rochester Imaging Detector Laboratory. The mission of the CfD is to enable scientific discovery, national security, better living, and commercial innovation through the design and development of advanced photon detectors and associated technology. CfD strives to accomplish our mission by leveraging collaborations with students, scientists, engineers, and business partners at academic, industrial, and national research institutions. This report summarizes activities from July 2017 through June 2018.

Research

Research and development in the CfD included over 25 projects during the past year. Our six professors secured approximately $1.7M in new research funding this year. New research includes developing an Engineering Verification Testing system for the AIM Photonics facility in downtown Rochester, NY, funded by the U.S. Air Force and the Research Foundation of SUNY. Other new research includes developing a commercially-available Digital Micromirror Device (DMD) with an ultraviolet transparent window suitable for a multi-object spectrograph (MOS) funded by NASA. PhD student Chi Nguyen won a NASA Earth and Space Science Fellowship, supporting her research to integrate and simulate the Cosmic Infrared Background ExpeRiment (CIBER-2).

Personnel

CfD included six professors, 56 students, three Postdoctoral Researchers, and eight staff. The student population consisted of 19 pursuing a PhD, four pursuing a Master's degree, 32 undergraduate students, and one high school intern. Personnel spanned four colleges, with a plurality of students in the Kate Gleason College of Engineering and the majority of the remainder in the College of Science.

Student Vignettes

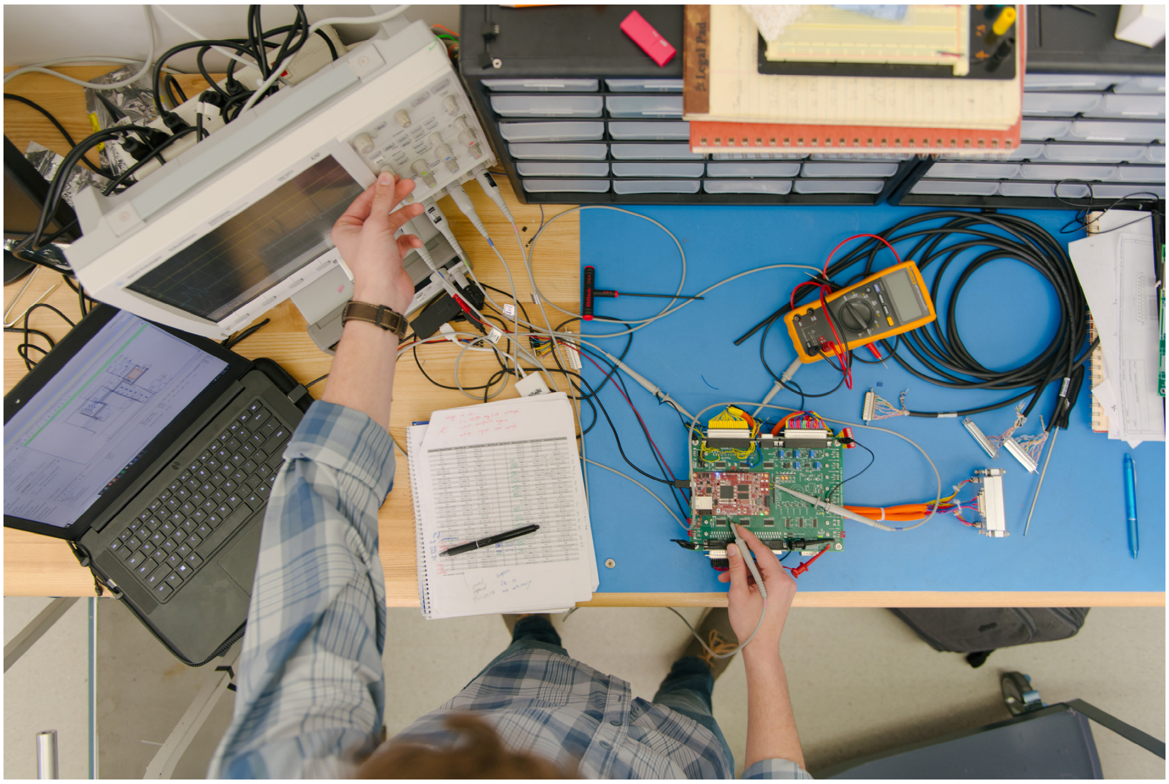
This section of the report describes the research work done by 20 of our students with guidance from their faculty advisors. These students contributed to projects like designing and fabricating a 6-junction high concentration photovoltaic device with Dr. Parsian K. Mohseni, and developing etching techniques to create GaN nanowires with Dr. Jing Zhang.

Publications

CfD researchers published in journals such as, The Astrophysical Journal, Astronomy and Astrophysics, and Optical Engineering. CfD research caught the eye of both local and national media. Dr. Michael Zemcov received attention for his work in proposing to utilize New Horizon's telescope, called the Long Range Reconnaissance Imager (LORRI), to find distant objects beyond the solar system's boundaries.

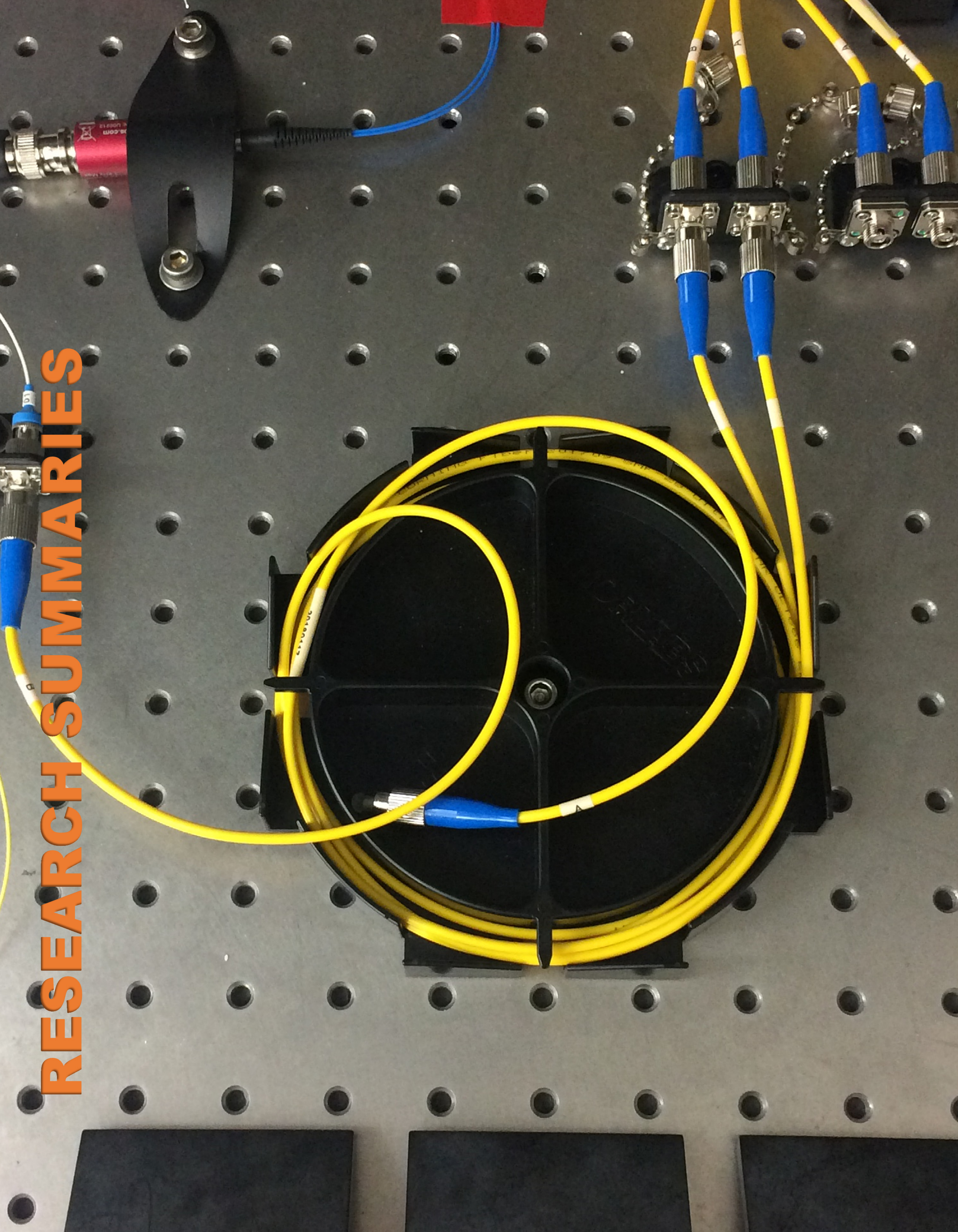
Equipment and Facilities

CfD has its largest footprint in Engineering Hall, with four laboratories and offices to accommodate approximately 20 people. Outside of Engineering Hall, the CfD has laboratories in the Chester F. Carlson Center for Imaging Science.



Research

RESEARCH SUMMARIES



Research Projects

New Infrared Detectors for Astrophysics

NSF/NASA
Donald Figer

The aim of this project is to develop infrared detectors that use HgCdTe material grown on silicon substrates, thus dramatically reducing the cost and increasing the potential size of sensors for ground- and space-based astronomy missions. In previous years, the team validated the concept through several cycles of designing, fabricating, and testing devices in the CfD Rochester Imaging Detector Laboratory (RIDL). In the previous year, the team tested the most recent versions of the device design and also made a new design for improved performance that are now being fabricated by Raytheon Vision Systems (RVS).

Traditionally, manufacturers use CdZnTe (CZT) substrates for HgCdTe detectors because those two materials have similar lattice spacing, providing fewer possibilities for undesired energy states where atoms in the lattice do not meet. CZT substrates are relatively expensive and come in small sizes, both effects increasing the cost of HgCdTe detectors. The high cost of HgCdTe FPAs has been, and will be, a major constraint on more widespread use of these detectors.

The silicon substrates absorb light with wavelengths less than 1.1 μm. Over the past year, we removed this substrate, a process known as "thinning," in one of the final processing steps before finishing fabrication. In all, we thinned and characterized four devices. We found that the performance changed very little, except in a few areas.

The crosstalk increased, presumably due to the epoxy back-fill surrounding the bump bonds associated with each pixel. This epoxy serves the purpose of providing mechanical integrity to the parts during the thinning process. Figure 1 shows pre- and post-thinning crosstalk measurements for part F13. The numbers reflect signal measured in a 3 by 3 grid of pixels where the central pixel has a signal that is normalized to 100%. Notice that the signal in the nearest neighbors surrounding the central pixel is greater in the diagram on the right, reflecting increased crosstalk after thinning. Based on these findings, RVS is implementing alterations to their hybridization process.

−0.31	0.40	−0.33
0.50	100.00	0.57
−0.27	0.42	−0.23

−0.28	0.90	−0.18
1.43	100.00	1.61
−0.29	0.83	−0.25

Figure 1. The crosstalk of part F13, before (left) and after the substrate removal (right), is shown.

Quantum efficiency (QE) is the fraction of photons that produce a signal in a detector. We measure it by using the diode replacement method in which an absolutely calibrated photodiode is placed at the same location as the detector in the experimental apparatus. The photodiode response and the detector response are measured, and a ratio of the detector response and the photodiode response is calculated, yielding the QE. The detector and the photodiode are illuminated with a flat field monochromatic light source using an integrating sphere and a monochromator. A photodiode monitors fluctuations in the light level at all times.

The QE for F10 is shown in Figure 2. Its short and long wavelength cutoffs are 400 nm and 2700 nm, respectively. F10 is a thinned device, thus the short wavelength coverage extends below 1000 nm. For an unthinned device, the short wavelength cutoff is 1000 nm. The QE is nearly identical on all of the thinned devices from the latest fabrication round.

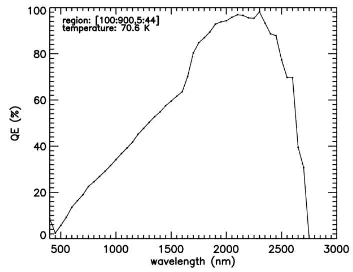


Figure 2. The QE of a thinned part extends below 1.1 µm, as expected.

Based on work over the past year, two performance areas need improvement — dark current and persistence. While the dark current is still higher than desired, the dark current tail is smaller than it was in a previous fabrication run. The persistence is relatively high in the last batch of devices, but it is similarly high for some of the parts before thinning, suggesting that the thinning process itself has not introduced extraordinary persistence.

Two hybridizations are in process and we expect results late fall of 2018. These new parts represent the culmination of lessons learned through this project. Early measurements show that the defect density for the die that will be used for these parts has been reduced according to expectations. If this design works as intended, then the dark current will be less.

Development of the Next Large Space Telescope

Donald Figer

CfD Director Figer Co-chaired a NASA technology working group with Eric Schindhelm (Ball Aerospace & Technologies Corp.) to assess the current state of the art in detectors for ultraviolet, optical, and infrared wavelengths. This activity is a precursor to the plans for the further development of competing technologies to fly on the next large space telescope after the James Webb Space Telescope (JWST). The new telescope has a notional design and is generically being called the Large Ultraviolet Optical Infrared Survey (LUVOIR) telescope. Just as with previous NASA missions, this somewhat awkward name will be likely be replaced with a name that memorializes a prominent figure in the advancement of science.

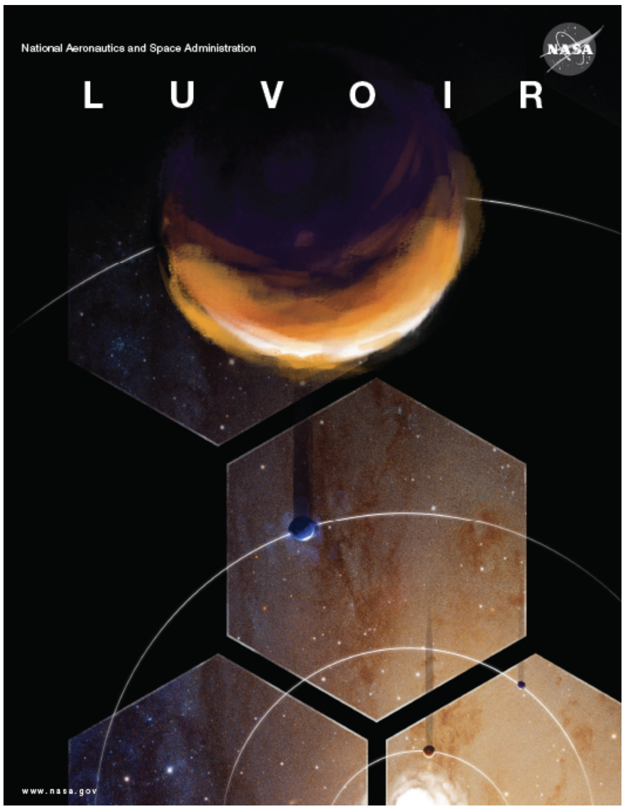


Figure 3. LUVOIR is a proposed future space telescope that will replace the James Webb Space Telescope.

The LUVOIR point design considers the use of a large (8-12 m) primary mirror that capitalizes on the emerging heavy lift capabilities, such as the Big Falcon Rocket (BFR) to be made by SpaceX and the Space Launch System (SLS) being developed by NASA and partners. Just like JWST, the telescope will be launched in a furled configuration to be expanded and phased on orbit.

The detector technology working group solicited information concerning the technology readiness level of approximately a dozen competing detector types that could fly on LUVOIR, either in the wide area imaging camera or the coronagraph instrument. For most science applications on the proposed telescope, detectors will need to have very low noise. In fact, for the goal of measuring the atmospheres of exoplanets, the detectors will need to have single photon sensitivity.

A sampling of the potential competing detector technologies for LUVOIR, along with relevant requirements, is shown in Figure 4.

Instrument Channel	Driving Requirements	Technical Challenges	Solution Paths	Development status and path ahead Current TRL	Path to TRL 4	Path to TRL 5	Path to TRL 6	Note
LUMOS Far-UV Multi-object Spectrograph and LUMOS Far-UV Imager	**Wavelength Range:** 100 - 200 nm **Array Size:** 200 mm × 200 mm, Tileable to larger arrays **Resol Size:** ≤ 20 μm **Read Noise:** 0 e- **Dark Current:** ≤ 0.1 counts/cm^2/s	Sensitivity Array sizes Dynamic range / bright object sensitivity	Micro-channel plates	4	✓	Sounding rocket test of 200 mm sized arrays; Demo of tiling capability	Full qualification of flight-packaged devices	Long development heritage through sounding rocket program, HST, etc.
LUMOS Near-UV Multi-object Spectrograph	**Wavelength Range:** 200 - 400 nm **Array Size:** ≥ 8k × 8k, Tileable to larger arrays **Quantum Efficiency:** ≥ 50% **Pixel Size:** ≤ 7 μm **Read Noise:** ≤ 5 e- **Dark Current:** ≤ 1e-3 e-/pix/s	Sensitivity Array sizes Radiation hardness	delta-doped CCD	5	✓	✓	Full qualification of flight prototype devices; Demo tiling of arrays	Sounding rocket heritage devices. Would need to show ability to tile multiple devices. Smaller pixels and better radiation tolerance would be desireable.
			delta-doped CMOS	4	✓	Sounding rocket demo; radiation testing	Full qualification of flight prototype devices; Demo tiling of arrays	
ECLIPS UV Channel	**Wavelength Range:** 200 - 525 nm **Array Size:** ≥ 1k × 1k **Quantum Efficiency:** ≥ 50% **Read Noise:** < 1 e- **Dark Current:** ≤ 1e-4 e-/pix/s	Radiation hardness High sensitivity in near-UV while maintaining performance through 500 nm	delta-doped EMCCD	5	✓	✓	Full qualification of flight prototype devices; Demo tiling of arrays	Sounding rocket heritage devices. Better radiation tolerance is desireable.
ECLIPS Visible Channel	**Wavelength Range:** 500 - 1000 nm **Array Size:** ≥ 4k × 4k **Read Noise:** < 1 e– **Dark Current:** ≤ 1e-4 e–/pix/s	Radiation hardness Sensitivity at 1000 nm for exoplanet characterization Large formats for use in integral field spectrographs	EMCCD	5	✓	✓	Demo improved radiation hardness and larger array size	Under development by WFIRST in 1k x 1k formats Radiation tolerance is low; lifetime of current devices is limited < 5 years Path to 4k x 4k devices is established
			HMCCD	3	Lab demo of device with similar capabilities to existing EMCCD devices	Flight package device with; Radiation testing	Full qualification of flight prototype device	Potential to deliver same performance as EMCDD, but with inherent radiation hardness.
ECLIPS NIR Channel	**Wavelength Range:** 1000 - 2000 nm **Array Size:** ≥ 4k × 4k **Read Noise:** < 3 e– **Dark Current:** ≤ 1e-3 e–/pix/s	Read noise Dark current	HgCdTe Photodiode Array	6	✓	✓	✓	Devices developed for WFIRST wide-field instrument Lower read noise and dark current desireable; potentially achievable through readout electronics optimization
			HgCdTe Avalanche Photodiode Array	4	✓	Reduce dark current to acceptable levels; Radiation testing	Full qualification of flight prototype device	Currently exhibit desired read noise, but need significant improvements in dark current Larger array sizes also needed

Figure 4. The table shows potential competing detector technologies for LUVIOR.

Integrated Quantum Photonics for Photon-Ion Entanglement

Air Force Research Laboratory
Stefan Preble

The primary objective of this project is the realization of an integrated photonics platform compatible with photon-ion entanglement. The platform will consist of photon sources and entangling circuits that interface with the visible/UV wavelengths of ion (such as Yb+, Ca+, Be+, Mg+, Sr+, Ba+, Zn+, Hg+ and Cd+) transitions. The challenge with realizing such a platform is that integrated photonic chips are not well developed at visible wavelengths because of the traditional focus on telecom wavelength compatibility. We are developing a platform that does operate at short wavelengths by using Aluminum Nitride (AlN), which is a large bandgap semiconductor that is transparent to the deep-UV (Figure 5). In parallel, we are leveraging our successes in quantum integrated photonics in telecom-compatible platforms, particularly silicon photonics. This will allow rapid validation of high performance photon sources, entanglement circuits and quantum sensors. These circuits will then be transitioned to the new visible/UV platform, or interfaced with ions directly by using frequency conversion.

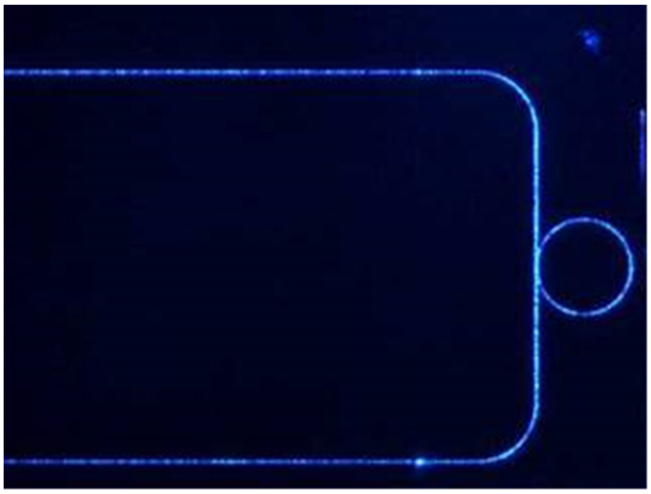


Figure 5. The image shows visible light propagating in an aluminum nitride waveguide and ring resonator.

Quantum Optical Resonators: A Building Block for Quantum Computing and Sensing Systems

National Science Foundation
Stefan Preble

The overall goal of this project is to experimentally demonstrate the quantum optical response of ring resonators and use them as a robust building block for quantum information processing. We have shown that ring resonators operating in the quantum regime exhibit a resonant response that depends on the photon state. Unlike beam splitters, which operate with maximum fidelity with only one set of parameters, the unique passive feedback in ring resonators ensures high fidelity quantum interference over effectively an infinite device parameter space. The devices compact size and ability to be reconfigured dynamically with low energy requirements ensures that ring resonators are the ideal building block for realizing complex quantum optical circuits (Figure 6).

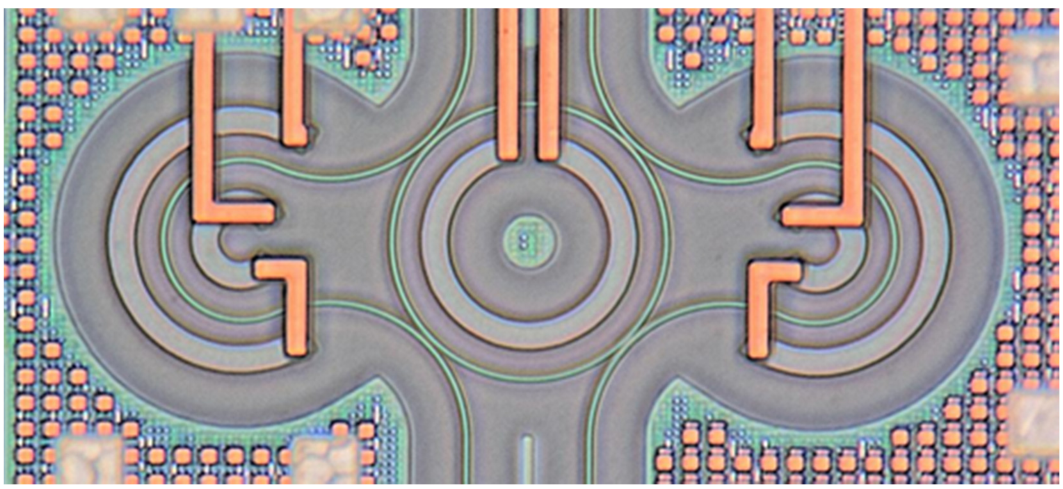


Figure 6. Above is a microscope image of an entangled photon source on an integrated photonic chip.

Quantum Silicon Photonics Measurement System

Air Force Office of Scientific Research (AFOSR)
Stefan Preble

The primary objective of this Defense University Research Instrumentation Program (DURIP) project is to demonstrate quantum photonic circuits on a silicon chip by using a quantum photonic measurement system with ultra-low noise and high efficiency. Quantum information science has shown that quantum effects can dramatically improve the performance of communication, computational and measurement systems. However, complex quantum systems have remained elusive due to the large number of resources (photon sources, circuits and detectors) that need to be tightly integrated. Professor Preble is realizing breakthroughs by integrating quantum circuits on a silicon chip and developing scalable building blocks based on ring resonators, which dramatically reduce the footprint of the circuits and enable novel functionalities. The quantum measurement system, (Figure 7) consisting of a low-noise tunable laser and high efficiency single photon detectors, is a critical enabler of these Quantum Silicon Photonic chips.

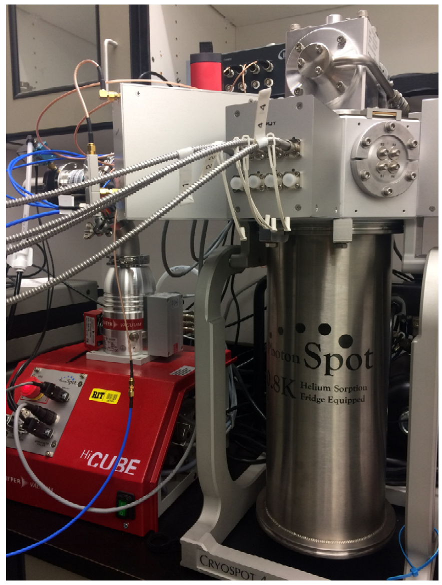


Figure 7. The Integrated Photonics Laboratory has a single photon detector system.

Integrated Photonics Education at RIT

Empire State Development/Research Foundation of SUNY
Stefan Preble

Figure 8. Dr. Stefan Preble takes questions during a lecture for his degree course, Photonic Integrated Circuits, a course developed through the Integrated Photonics Education at RIT project focusing on the overall photonics manufacturing process.

The objective of this project is to support AIM Academy (the education arm of AIM Photonics) by providing education modules for integrated photonics design, manufacturing, packaging and testing. This activity directly benefits the future workforce that will enable the silicon photonics economy.

This project works to educate students, workforce, veterans and the community with short and degree courses (Figure 8), establish an integrated photonics practice facility, assess workforce needs, and develop an ME degree in Integrated Photonics Manufacturing in collaboration with MIT.

Understanding and Engineering Valence Band Structures of III-Nitride Semiconductors for High-Efficiency Ultraviolet Lasers and Emitters

Office of Naval Research
Jing Zhang

The purpose of this research is to develop solutions to key challenges in achieving high-efficiency single-mode GaN-based ultraviolet (UV) lasers with wavelength ranging from 220 nm up to 300 nm. Particularly, this research focuses on the fundamental physics understanding of the valence band structure of lll-Nitride wide bandgap gain active region, and develop promising solutions on nanostructured quantum wells and fabrication approach of large area GaN-based UV laser arrays. Those lasers would be a promising candidate for various naval applications in sensing and communication.

Rare Massive Stars Near the Galactic Center

Donald Figer

During the past year, CfD Director Figer, and collaborators, identified more massive stars near the Galactic center (GC). Some of these stars are of the rarest types, representing exotic evolutionary stages of the most massive stars.

In one study, the team validated a hypothesis that they made in the late 1990's that the enigmatic red stars in the Quintuplet Cluster are of the rare late-type carbon Wolf-Rayet type. There are only a few hundred such stars, out of a few hundred billion, in the Galaxy. These types of stars are evolved forms of stars that have approximately a hundred solar masses of material. To find five such stars in one cluster is unprecedented.

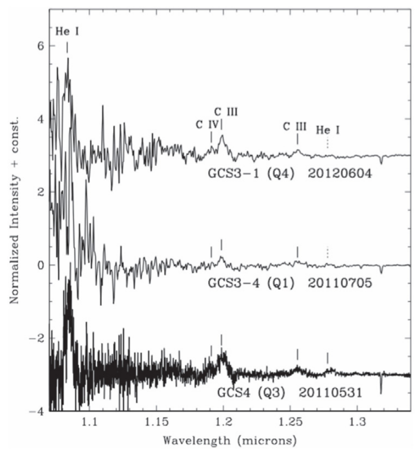


Figure 9. The curves represent infrared spectra of massive stars in the Quintuplet star cluster. They have ionized carbon emission lines, demonstrating that the stars are of a rare species of massive carbon-rich stars.

In a paper in the Astrophysical Journal, we reported the detection of a number of emission lines in the 1.0–2.4 μm spectra of four of the five of the Quintuplet stars. Spectroscopy of the central stars of these objects is hampered not only by the large interstellar extinction that obscures all of the objects in the GC, but also by the large amounts of warm circumstellar dust surrounding each of the five stars. The pinwheel morphologies of the dust observed previously around two of them are indicative of Wolf–Rayet colliding wind binaries; however, infrared spectra of each of the five have until now revealed only dust continua steeply rising to long wavelengths and absorption lines and bands from interstellar gas and dust (Figure 9). The emission lines detected, from ionized carbon and from helium, are broad and confirm that the objects are dusty late-type carbon Wolf–Rayet stars.

In another study, published in Astronomy and Astrophysics, CfD Director Figer was part of a team that reported a new stellar census of massive stars in the Quintuplet Cluster.

The Quintuplet is one of the most massive young clusters in the Galaxy and thus holds the prospect of constraining stellar formation and evolution in extreme environments. Current observations suggest that it comprises a remarkably diverse population of very high-mass stars that appears difficult to reconcile with an instantaneous star-formation event. The team used new, and existing, observations of stars in the cluster to better understand the origin and nature of the cluster, including from the Near Infrared

Camera and the infrared channel of the Wide Field Camera 3, both on the Hubble Space Telescope, and SINFONI and KMOS on the Very Large Telescope. In all, the team observed approximately 100 cluster members.

Spectroscopy of the cluster members reveals that the Quintuplet is more homogeneous than previously expected (Figure 10). All supergiants are classified as either O7-8 Ia or O9-B0 Ia, with only one object of earlier (O5 I-III) spectral type. These stars form a smooth morphological sequence with a cohort of seven early-B hypergiants and six luminous blue variables and WN9-11h stars; these comprise the richest population of such stars of any stellar aggregate known. In parallel to these, we identify a smaller population of late-O hypergiants and spectroscopically similar WN8-9ha stars. No further H-free WC or WN stars are identified, leaving an unexpectedly extreme ratio of 13:1 for this population.

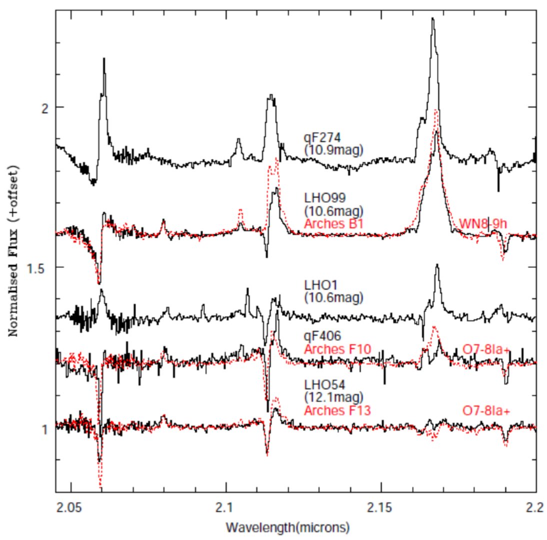


Figure 10. These spectra are of late O hypergiant and WN8-9h Quintuplet cluster members (black) compared to spectra of stars within the Arches cluster (red).

Photometric data reveals a subset of the O9-B0 supergiants to be unexpectedly faint, suggesting they are both less massive and older than the greater cluster population. Finally, no main sequence objects were identifiable. Due to uncertainties in the correct extinction law, it was not possible to quantitatively determine a cluster age via isochrone fitting.

Fortuitously, we find an impressive coincidence between the properties of cluster members preceding the hydrogen-free WR phase and the evolutionary predictions for a single, non-rotating 60 M_{Sun} star; in turn this implies an age of ~3.0 – 3.6 Myr for the Quintuplet. Neither the late O-hypergiants, nor the low luminosity supergiants, are predicted by such a path; we suggest that the former result from either rapid rotators are the products of binary driven mass-stripping, while the latter may be interlopers. The hydrogen-free WRs must evolve from stars with an initial mass in excess of 60 M_{Sun}, but it appears difficult to reconcile their observational properties with theoretical expectations. This is important since one would expect the most massive stars within the Quintuplet to be undergoing core-collapse/SNe at this time; since the WRs represent an evolutionary phase directly preceding this event their physical properties are crucial to understanding both this process and the nature of the resultant relativistic remnant. As such, the Quintuplet looks set to provide unique observational constraints on the evolution and death of the most massive stars forming in the local, high-metallicity Universe.

A Cryogenic Optical Camera for Attitude Control of Low-Temperature Sub-Orbital Payloads

NASA
Michael Zemcov

CCDs have been the dominant optical-wavelength detector architecture for high-end optical imaging applications for decades. However, CCDs are inoperable below 120 K due to electron freeze-out effects, prohibiting their use in space exploration applications requiring cryogenic temperatures. Megapixel CMOS devices are known to work at temperatures as low as 10 K, suggesting that imaging devices based on this technology would operate in cryogenic environments without requiring active heating. In this program, we take the first step to maturing this technology for flight applications in the cryogenic regime by developing and flying an attitude-sensing camera employing a low noise, high quantum efficiency cryogenic CMOS detector. By implementing an alternative imaging technology, we address NASA's major objective to “transform NASA missions and advance the Nation’s capabilities by maturing crosscutting and innovative space technologies.” This technology enables instruments ranging from actively cooled star trackers for sounding rockets to low-temperature deep space cameras.

The progress made by the undergraduate CSTARS (Cryogenic Star Tracking Attitude Regulation System) team has proven instrumental in the design of a second revision of the star tracker to support the Cosmic Infrared Background ExpeRiment (CIBER). The rocket skin of CIBER-1 underwent thermal contraction when exposed to the cryogenic temperatures, resulting in a noticeable drift in the measured data. CSTARS-2 will serve as a secondary star-tracking system on the CIBER-2 payload, located within the cryogenically cooled portion of the rocket. This will allow it to maintain the attitude of the rocket while the CIBER-2 detectors are capturing data. To support a higher resolution sCMOS detector operating at twice the frame rate, new focal plane and interfacing hardware was designed and tested. The new detector (Figure 11, *right*) has proven fully functional at 80K and the telemetry streams have been validated against NASA ground stations (Figure 11, *left*). Remaining work includes finalizing the star-tracking algorithm, as well as reliability and vibration testing. Integration and final testing for the CSTARS-2 system will begin late summer of 2018.

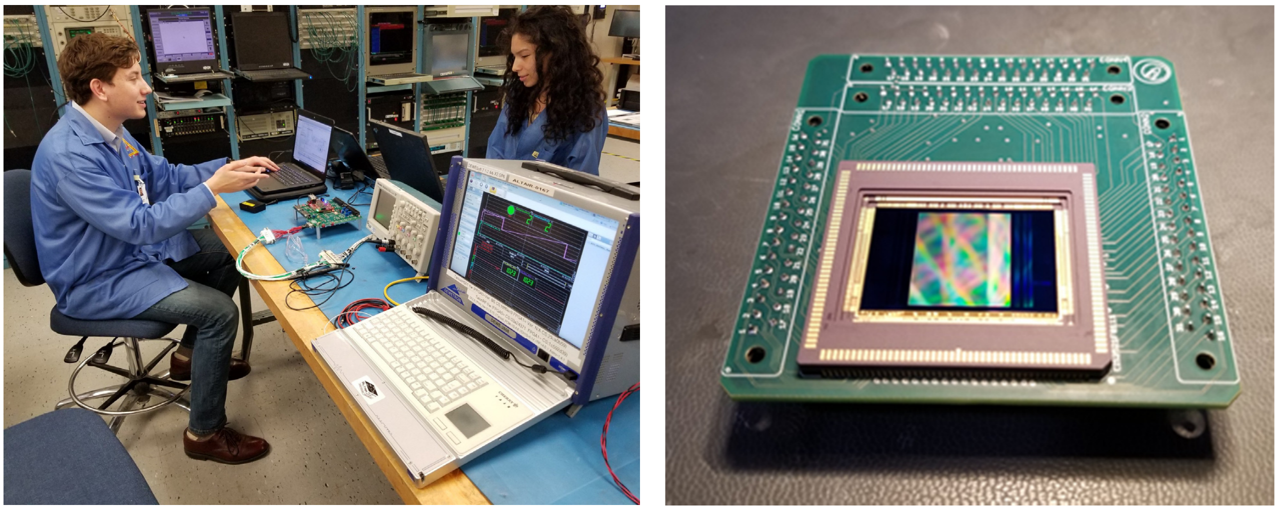


Figure 11. (left) Undergraduate students Ben Stewart and Ambar deStantiago complete telemetry stream interfacing at the NASA Wallops Flight Facility. (right) The project used a 5.5 megapixel sCMOS detector mounted on a custom printed circuit board.

Bifacial III-V Nanowire Array on Si Tandem Junctions Solar Cells

National Science Foundation
Parsian Katal Mohseni

Escalating trends in global energy consumption, mandates for increased national energy independence, and mounting alarm regarding anthropogenic climate change, all demand improved sustainable energy solutions. While the theoretical power generation potential of solar photovoltaics (PV) in the United States is greater than the combined potential of all other renewable resources, substantial market penetration of PV sand realization of grid-parity have been obstructed by high materials and manufacturing costs, as well as limitations in solar power conversion efficiencies (PCE). A pressing need exists for tandem solar cells utilizing two dissimilar materials (TDM) or more that are capable of PCE values beyond the ~30% Shockley-Queisser limit. In this program, we explore a transformative, bifacial solar cell design that employs arrays of TDM III-V compound semiconductor nanowires in tandem with a thinned, intermediate Si sub-cell. The use of epitaxial nanowire arrays overcomes the lattice matching criteria and enables direct III-V on Si monolithic integration. This design eliminates the need for high-cost wafers, growth of graded buffer layers, and anti-reflection coatings, while permitting ideal solar spectrum matching and capture of albedo radiation. The high risk-high payoff and exploratory research fits the NSF EAGER program, as it involves a radically unconventional approach with transformative potential to enable cost-effective manufacturing of high-efficiency TDM solar cells.

The technical approach of this EAGER project relies on selective-area heteroepitaxy of a GaAsP (1.75 eV) nanowire array on the top surface of a thinned Si (1.1 eV) sub-cell by metal-organic chemical vapor deposition. A bifacial, three dissimilar materials, tandem junction device is formed via monolithic integration of a backside InGaAs (0.5 eV) nanowire array. The vertical nanowires comprising the top- and back-surface arrays will contain radially-segmented p-i-n junctions and will be serially connected to the central Si sub-cell via epitaxial tunnel junctions. This design enables absorption of broadband incident solar energy as well as albedo radiation. Standard lattice-matching constraints are overcome via strain relaxation along nanowire free surfaces. Therefore, ideal spectral matching is realized without a need for graded buffer layers or dislocation mediation strategies. Use of vertical nanowire arrays with coaxial p-i-n junction geometries permits key advantages, including near-unity absorption of solar irradiance at normal and tilted incidence without the use of anti-reflection coatings, decoupling of photon absorption and carrier collection directions, and dramatic reduction of 95% in epitaxial volumes. Rigorous modeling of device parameters will be iteratively coupled with extensive materials characterization and property correlation experiments for optimization of III-V sub-cell structure on the single nanowire and ensemble array levels. The ultimate target of this work is demonstration of a functional bifacial, three dissimilar materials, nanowire-based tandem junction solar cell with one Sun power conversion efficiency of 30% or better.

Acquisition of an Inductively Coupled Plasma Reactive-ion Etching System

NSF
Jing Zhang

This is a project to procure and install an inductively coupled plasma reactive-ion etching (ICP-RIE) system. The ICP-RIE system provides dry etching capability for various material systems such as compound semiconductors, dielectric materials, and metals with fast etching rate, well-controlled selectivity, and promising uniformity. The instrument is essential to enable fundamental research and education on III-Nitride based light emitting diodes (LEDs) and lasers, seamless integration of robust and low-powered III-V quantum dot (QD) lasers with silicon photonics, III-V tunneling field effect transistors, memory devices for computing, QD and nanowire photovoltaics, III-Nitride photodetectors for inertial confinement fusion research, nanoplasmonic devices, and nan-bio devices for efficient biomolecule transfer. This is the first ICP dry etcher tool at RIT. Research groups across all disciplines in science and engineering with students trained from the Microsystems Engineering PhD program and the Engineering PhD program share the tool. External research groups in the Rochester region have access to the ICP dry etcher to enhance research and collaborations between RIT and other colleges, national labs, and small business.

The ICP-RIE system is a shared user facility, available to new curriculum and lab section development on device fabrications for both undergraduate and graduate students at RIT, whom can be trained for next-generation scientists and engineers. The fabrication capability provided by the instrument benefits curriculum development at RIT for several fundamental courses and lab sections focused on nanofabrication and semiconductor devices. Demonstration experiments on photonic and electronic devices can also be designed to K-12 students and teachers through RIT outreach activities by the use of the dry etcher, which can stimulate K-12 students' interest to pursue science, technology, engineering, and mathematics (STEM) disciplines in the future. Connectivity with such demonstration experiments are promoted to train existing women and underrepresented minority students at RIT.

AIM Photonics Test Assembly and Packaging Hub Planning

Air Force/Research foundation of SUNY
Stefan Preble

This project complements the planning, construction, and implementation of the Rochester, NY testing assembly and packaging (TAP) hub by coordinating process development with equipment installation and qualification. AIM Photonics has divided the hub stand-up into centrally funded operations activities (facilities, tool installation, baseline packaging etc.) and comprehensive process and platform development activities. The TAP hub project is organized along the following technical categories of Optical I/O, Testing, Metrology, and Reliability. We have set several tasks for specific Key Technology Manufacturing Areas (KTMA) support, planning, documentation, and technology transfer. The hub will be equipped for 2.5 electronic/photonic packaging, attach and align tools for fibers and fiber/waveguide arrays, functional testing equipment as well as a full line of metrology tools. The project emphasizes the most significant gaps in the manufacturing of Photonic Integrated Circuit (PIC)-enabled systems by enabling and ensuring access to standardized package designs, integrate the photonic, electronic and physical designs, ensure that metrology tools are available to test the physical integrity of the packages, and provide functional testing for digital, analog, and sensor-based photonic systems. (Figure 12.) The current activities are concentrating on establishing packaging design and test support for AIM Photonics members through the Rochester Hub, developing the tool qualification plans for optical I/O and testing, and planning release 0.5 of the AIM Photonics design guide.

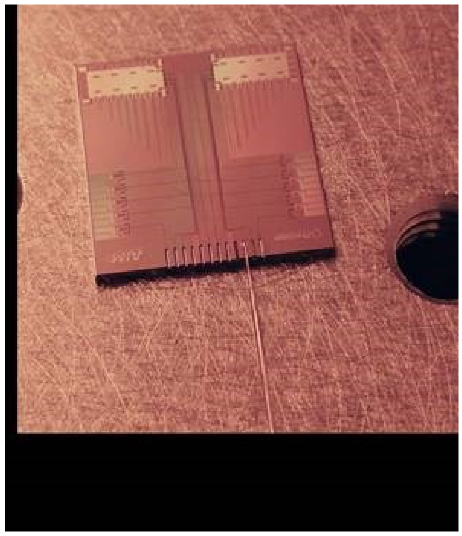


Figure 12. This integrated photonic chip, designed by Precision Optical Transceivers and fabricated by AIM Photonics uses an optical fiber for input and output.

A Data Analysis Pipeline Simulator for a Millimeter-Wavelength Imaging Spectrometer

RIT
Michael Zemcov

This program is a design study for software and data analysis for the Tomographic Ionized-carbon Mapping Experiment (TIME-Pilot) instrument, which is designed to make pioneering measurements of the redshifted 157.7 μm line of singly ionized carbon from the Epoch of Reionization (EoR). The EoR is the period in the Universe's history during which the first stars and galaxies formed, and whose intense ultra-violet (UV) radiation fields ionized the intergalactic medium. The New Worlds, New Horizons 2010 Astrophysics Decadal Report recognized the EoR as one of five scientific discovery areas where "new technologies, observing strategies, theories, and computations open opportunities for transformational comprehension". This investigation has helped break ground for future investment from government and private funding agencies by improving our understanding of the instrument design and expected performance. The Office of the Vice President for Research at RIT funding has enabled us to build a data acquisition simulation system, and software to talk with the detector readout electronics. A PhD student is currently working on the system, building a real-time data acquisition visualizer and storage code (Figure 13).

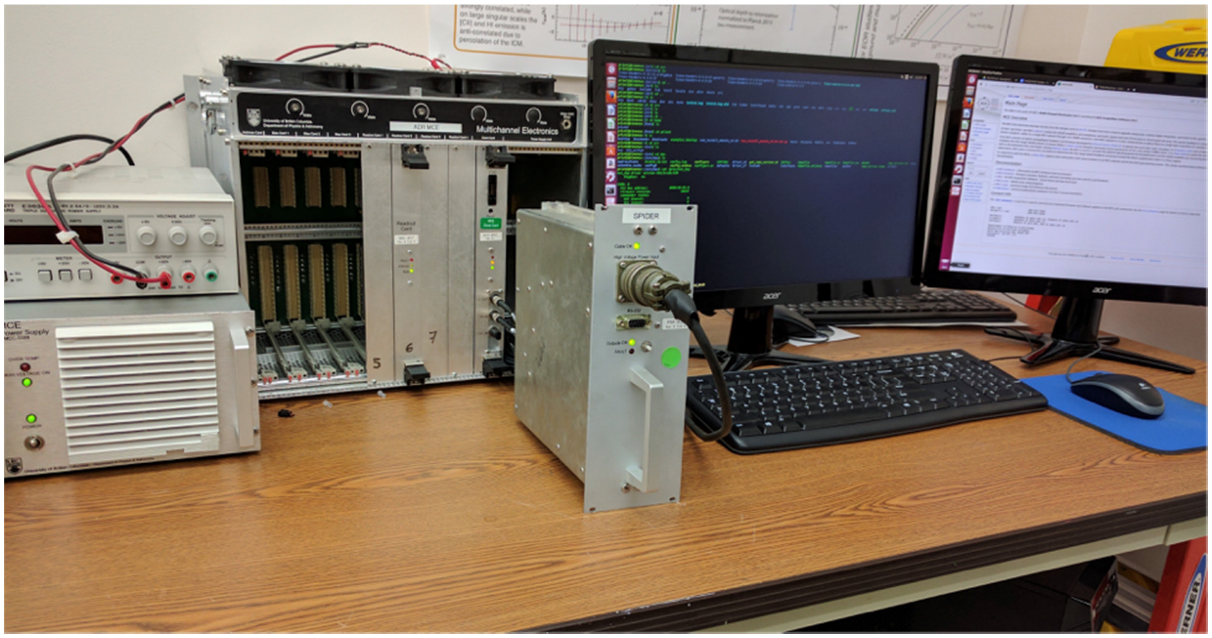


Figure 13. The image shows the benchtop setup used to develop a data acquisition and analysis system for the TIME-Pilot instrument.

Selective Area Epitaxy of III-V Nanocrystals on Graphene and MoS_2 for Flexible Optoelectronics Application

RIT
Parsian Katal Mohseni

Atomically-thin, two-dimensional nanomaterials such as single-layer graphene (SLG) and monolayer molybdenum disulfide (MoS_2) have emerged as essential building blocks that can enable the development of a widely encompassing class of next-generation nanoelectronic devices. However, these monolayer materials have a critical drawback for applications in optoelectronic, in that they are either inherently incapable (*i.e.*, SLG) of, or are fundamentally inefficient (*i.e.*, MoS_2) in, absorbing and emitting light. The purpose of this work is to overcome this limitation through the monolithic integration of highly optically efficient 111-V semiconductor nanostructures with SLG and MoS_2 by selective area epitaxial (SAE) crystal growth. This effort aims to combine the characteristic benefits of monolayer materials and 111-V nanocrystals through the synthesis of novel types of hybrid nanostructures. The correlation of extensive structural and optical characterization experiments enables the optimization of SAE growth parameters, and subsequently enable the development of low-cost and high-efficiency flexible light emitting diodes and photodetectors.

Development of High Efficiency Ultraviolet Optoelectronics: Physics and Novel Device Concepts

National Science Foundation
Jing Zhang

III-nitride-based semiconductor (AlN, GaN, and InN) ultraviolet (UV) optoelectronics have great potential in replacing bulky mercury lamps and excimer lasers attributing to their compact size, lower operating voltage, excellent tunability, higher energy efficiency and longer lifetime. As a result, wide-bandgap AlGaN-based UV light-emitting diodes (LEDs) and laser diodes have attracted significant attentions recently as new UV light sources for various applications such as semiconductor photolithography, resin curing, water and air purification, sterilization, and biological/chemical sensing.

The objective of this project is to develop fundamental physics from the III-Nitride emitters and to propose novel materials and device concepts to address the issues from semiconductor UV LEDs, in order to achieve UV emitters with significantly improved efficiency covering 220 nm – 300 nm spectral regimes. The proposed research efforts will be divided into three major thrusts: Thrust 1: Development of delta quantum well (QW) UV LEDs covering ~240 nm – 250 nm; Thrust 2: Exploration of alternative UV active regions: III-Nitrides and beyond; and Thrust 3: Novel UV emitter device concepts.

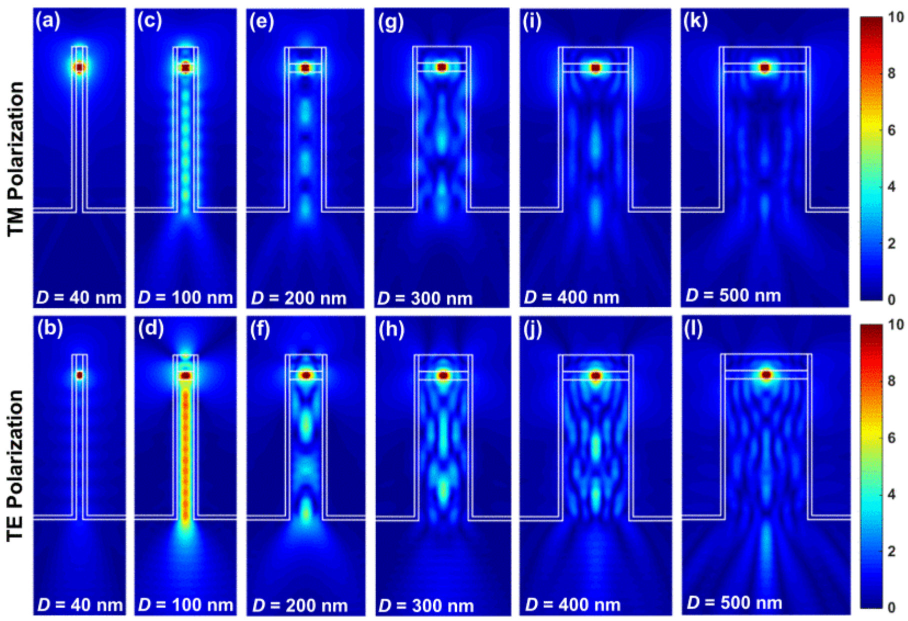


Figure 14. (top) This shows the cross-sectional near-field electric field intensity of nanowire UV LEDs with H = 1 µm and various diameters for TM-polarization (bottom) and TE-polarization.

Concept Study Report Preparation for SPHEREx MIDEX Phase A

NASA/Jet Propulsion Lab
Michael Zemcov

SPHEREx (Spectro-Photometer for the History of the universe, Epoch of Reionization, and ices Explorer) is a proposed NASA mid-range explorer (MIDEX) mission that will perform an all-sky spectral survey in near-infrared bands. After being selected for a Phase A study, a concept study report on the planned SPHEREx instrument and its science goals was submitted to NASA in mid-2018. The mission is designed to map the large-scale structure of galaxies in the universe, to help study the process of inflation, measure the light produced by stars and galaxies over time by using multiple wavelength bands to study galaxy clusters. The mission will also investigate how water and biogenic ices influence the formation of planetary systems by studying the abundance and composition of interstellar ices. RIT was responsible for contributing to the concept study report as well as ongoing development of the data analysis pipeline, with plans for future publications on the analysis methods presently being developed. Funding selection for the MIDEX program is expected in early 2019.

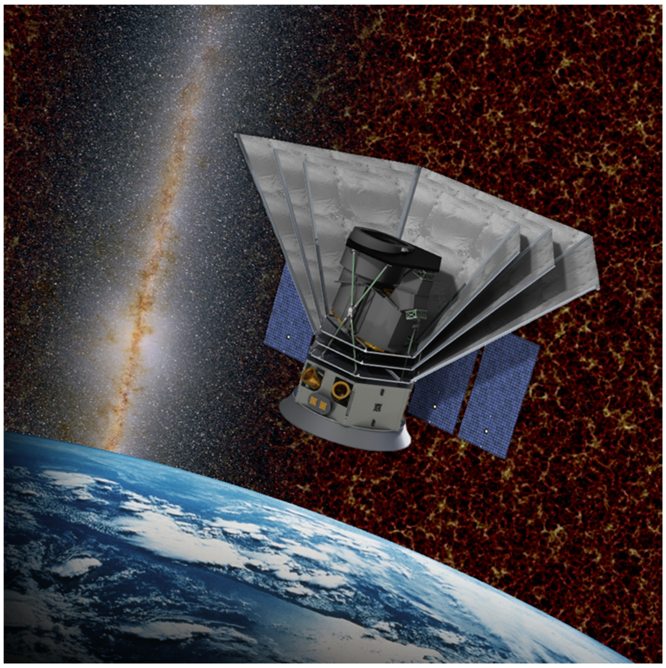


Figure 15. Above is an up to date graphic of SPHEREx.

Multi-Color Anisotropy Measurements of Cosmic Near-Infrared Extragalactic Background Light with CIBER-2

NASA/Caltech
Michael Zemcov

The Cosmic Infrared Background ExpeRiment (CIBER-2) is a near-infrared rocket-borne instrument designed to conduct comprehensive multi-band measurements of extragalactic background light anisotropy on arcsecond to degree angular scales. Recent measurements of the near-infrared extragalactic background light (EBL) anisotropy find excess spatial power above the level predicted by known galaxy populations at large angular scales. CIBER-2 is designed to make measurements of the EBL anisotropy with the sensitivity, spectral range, and spectral resolution required to disentangle the contributions to the EBL from various sources throughout cosmic history. CIBER-2 consists of a 28.5 cm Cassegrain telescope assembly, imaging optics, and cryogenics mounted aboard a sounding rocket. Two dichroic beam-splitters spectrally subdivide the incident radiation into three optical paths, which are further subdivided in two wavelength bands per path, for a total of six observational wavelength bands that span the optical to the near-infrared and produce six 1.2×2.4 degree images recorded by three 2048×2048 pixel HAWAII-2RG detector arrays. A small portion of each detector is also dedicated to absolute spectrophotometric imaging provided by a linear-variable filter. The instrument has several novel cryogenic mechanisms, a cryogenically-cooled pop-up baffle that extends during observations to provide radiative shielding and an electromagnetic cold shutter. Over the past year, our local team has been contributing to the international collaboration by assisting with: overall instrument design, including mechanical and electronic systems; integrating and characterizing the mechanical and optics elements at Caltech; and flight planning activities. A current model of the CIBER 2 payload can be seen in Figure 16. In addition, the RIT team is responsible for delivering the cryogenic star tracking camera system, which has been fabricated and is in validation phase.

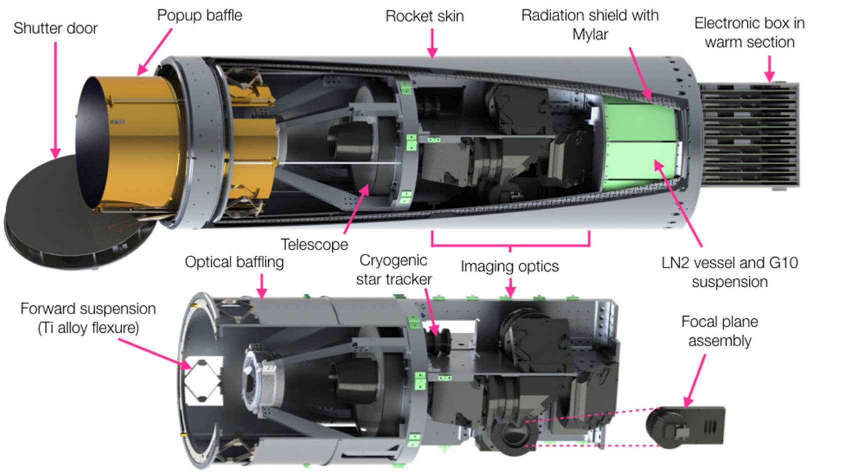


Figure 16. Seen above is a solid model of the CIBER-2 Payload. All components are being integrated and validated.

Cosmic Dawn Intensity Mapper

NASA/University of California, Irvine
Michael Zemcov

The NASA Probe-Class Mission Concept Cosmic Dawn Intensity Mapper (CDIM) is designed to make pioneering observations of the Lyman-alpha, H-alpha and other spectral lines of interest throughout the history of the cosmos. Capable of spectro-imaging observations between 0.7 to 7 µm in the near-Infrared, CDIM will help move the astronomical community from broad-band astronomical imaging to low-resolution (R=300-400) 3D spectro-imaging of the universe to perform the science of the 2030s. In this program, we are performing a mission concept study that will be submitted to both NASA and the US astronomical community in preparation for the 2020

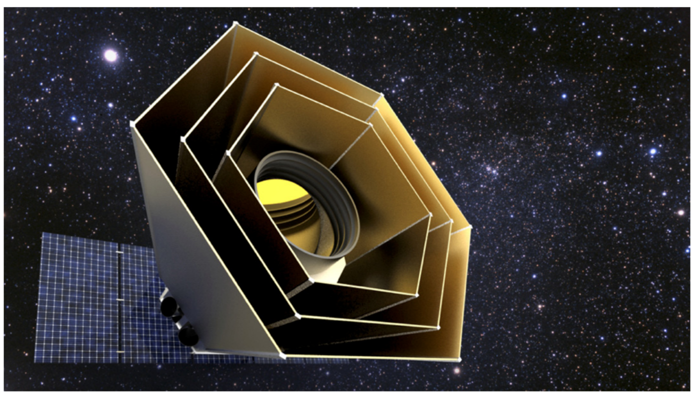


Figure 17. Shown above is a rendering of the Cosmic Dawn Intensity Mapper.

Astronomy Decadal Report. The RIT team lead by Dr. Michael Zemcov is performing initial engineering and instrument design work in support of detailed science requirements being derived by the science team. This work has lead to a fully functional instrument sensitivity calculator, and a complete mission initial engineering study performed by an RIT Engineering MS student.

Probing the History of Structure Formation through Intensity Mapping of the Near Infrared Extragalactic Background Light

NASA
Michael Zemcov

In 2017, the CfD was selected to receive a NASA Earth and Space Science Fellowship (NESSF), which supports a student's work on the instrument integration and data analysis of CIBER-2. NESSF support enables the student to participate fully in CIBER-2 and gain invaluable experience working on a suborbital project. This experience includes integrating and characterizing the rocket-home instrument at flight facilities; analyzing and interpreting observational data into science findings; and communicating progress to the CIBER-2 collaboration, NASA, and the public. In Figure 18, Chi Nguyen is shown characterizing the CIBER 2 telescope at Caltech over the summer of 2018. The fellowship has recently been renewed for a second year of funding.

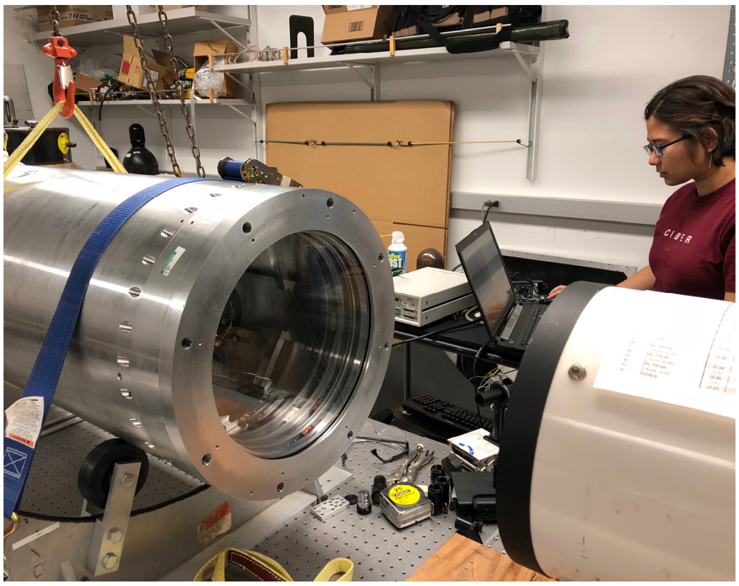


Figure 18. Chi Nguyen takes test images to characterize the CIBER-2 telescope as the payload is being cooled to 77 K.

Engineering Verification Test (EVT) Station

DoD, Department of the Air Force, Materiel Command, Research Foundation of SUNY
Don Figer

This project will develop testing capabilities to the Testing Assembly and Packaging (TAP) Hub that AIM Photonics is building in downtown Rochester, NY. The EVT is a generalized testing tool for validating functionality and performance specifications of integrated silicon circuits, such as optical switches, transceivers, photonic biosensors, lasers, etc. It is a crucial element of AIM Photonics and represents a much-anticipated capability that customers will use to prove the validity of their circuit designs.

Over the past year, several students have developed concepts, written code, and demonstrated basic functionality of EVT components. Sean Rogerson (BS/MS EE) developed software flow and communication flow diagrams (Figure 19, *top*). Anthony Palumbo (BS SE), Arturo Kuang (BS Game Design), and Andrew Min (BS Game Design) wrote software classes to control hardware through the Prober Control software program (Figure 19, *bottom*). Austin Ford (BS Game Design) documented EVT code and maintained code consistency through GitHub.

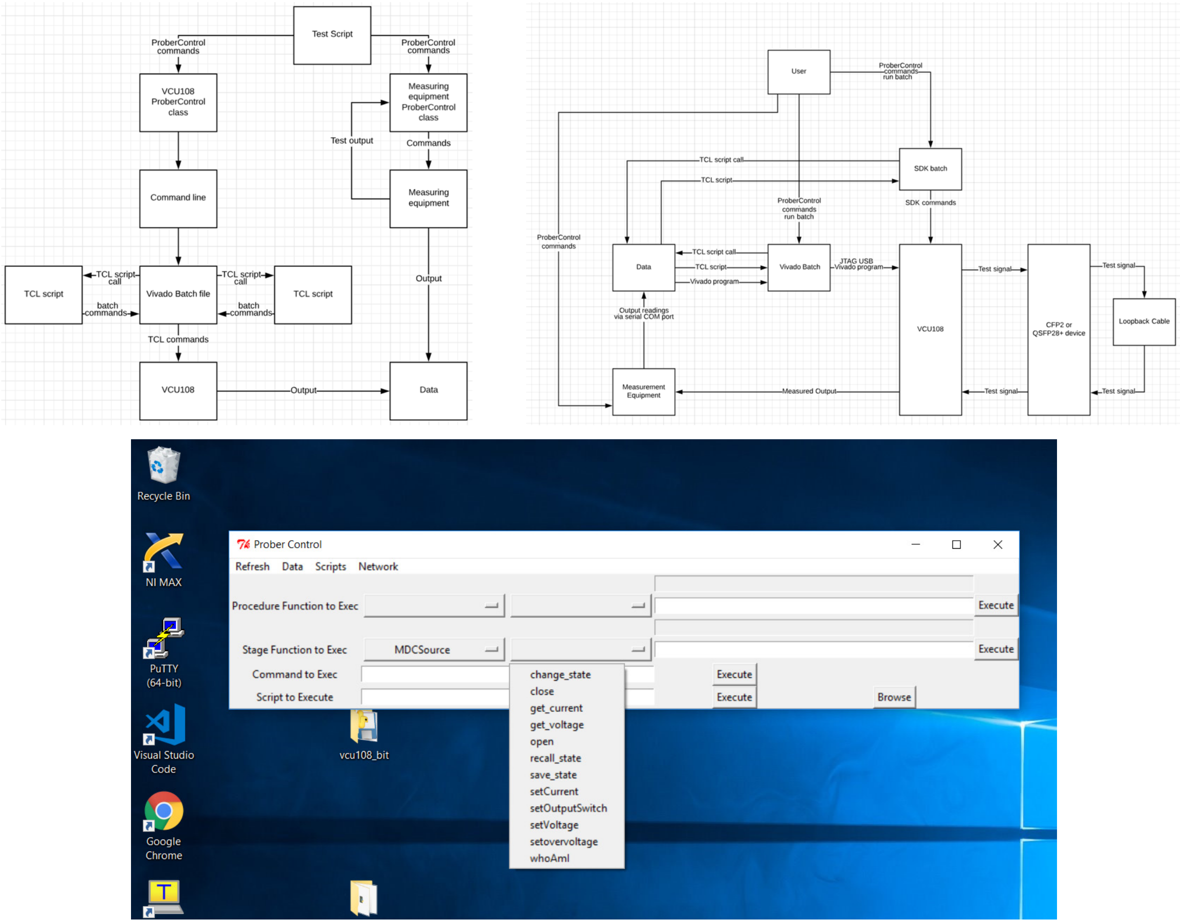


Figure 19. The charts show draft versions of the software flow (top, left) and communication flow (top, right) diagrams for the EVT project. The Prober Control software program (bottom) is the executive processor for scripts used in the EVT.

Cosmic Ray Damaged Image Repair (CRDIR)

Private Donations
Donald Figer

This project continues efforts over the past few years to remove the effect of cosmic ray damage in pictures obtained on the International Space Station. This damage can lead to aberrant pixel values scattered throughout the images obtained with the sensor. This project was conceived by NASA astronaut, Donald Pettit, RIT alumnus, Peter A Blacksberg (BFA Photo '75), and Center for Detectors (CfD) Director, Don Figer. Several student researchers worked on the project over the past year, including Justin Beigel (Electrical Engineering), HanSoo Lee (Game Design and Development), and Sean Scannell

(Motion Picture Science). During the past year, the students created a new user interface and implemented video processing capabilities.

Imaging Polarimetry with Microgrid Polarizers

Moxtek, Inc.
Zoran Ninkov

Light is polarized, a property that humans cannot see but that detectors can sense. CfD researchers are developing polarization sensors using micropolarizer arrays. This research program includes high resolution 3D simulations and strategies for fabricating and characterizing micropolarizer-based imaging polarimeters. Furthermore, we created software tools to produce synthetic observations of various scenes. These synthetic data are a powerful tool to study the many effects that can give rise to systematic and/or random errors during the data analysis process. Using the RIT Polarization Imaging Camera (Figure 20), we are able to achieve a polarimetric accuracy of ~0.3% in images of extended objects and unresolved sources. Dmitry Vorobiev successfully defended his PhD Thesis based on this project.

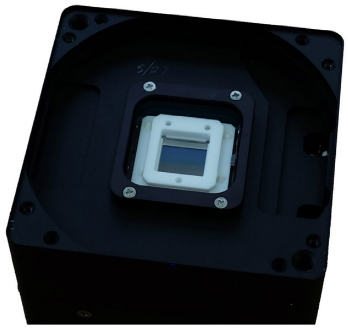


Figure 20. RITPIC uses a CCD and a MOXTEK, Inc. micropolarizer array. Shown above, the micropolarizer array (silver square) is aligned and affixed to the CCD using a white ceramic carrier. The polarization-sensitive imager is inside a camera body, allowing thermoelectric cooling.

The current generation of the RIT Polarization Imaging Camera (RITPIC) was deployed on a Boller & Chivens 36" telescope at the Cerro Tololo InterAmerican Observatory (CTIO) for seven nights. RITPIC observed several objects, including unpolarized stars, a supernova remnant, and Saturn.

Saturn is weakly polarized; however, some features are clearly visible (Figure 21). The north pole of Saturn and the equatorial regions are negatively polarized. Higher latitude regions show a positive polarization. The rings have a more-or-less uniform polarization. The angle of linear polarization of Saturn shows strong, large scale patterns.

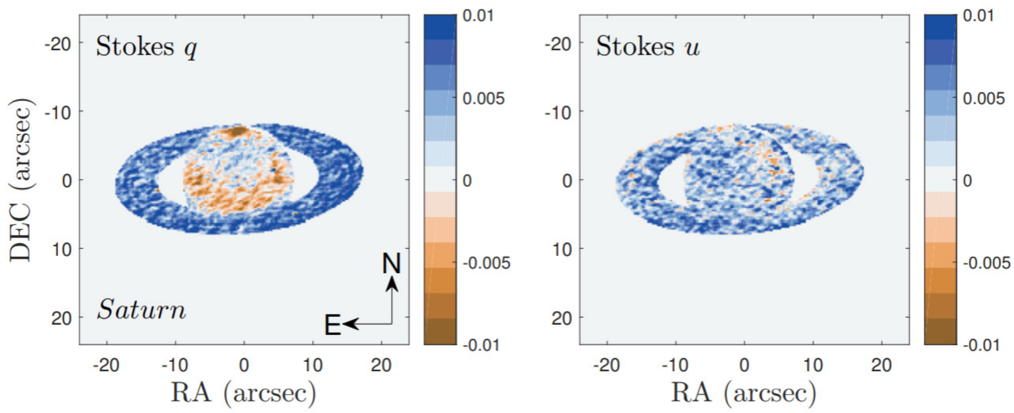


Figure 21. Shown above is the polarization of Saturn and its ring system in Stokes q and u. Although the overall polarization is low, some large scale features are clearly seen, such as the polarization of the rings, the northern and southern hemisphere and the south pole.

The Development of Digital Micromirror Devices for use in Space

NASA
Zoran Ninkov

This project is developing a commercially available Digital Micromirror Device (DMD) with an ultraviolet transparent window suitable for use in a multi-object spectrograph (MOS) in future NASA missions. The device directs light at the focal plane of a telescope into two different directions, one containing an imaging camera and another containing a spectrograph (Figure 22). This type of device allows one to obtain spectra of many objects in a single exposure, thus vastly improving observing efficiency as compared to existing technologies.

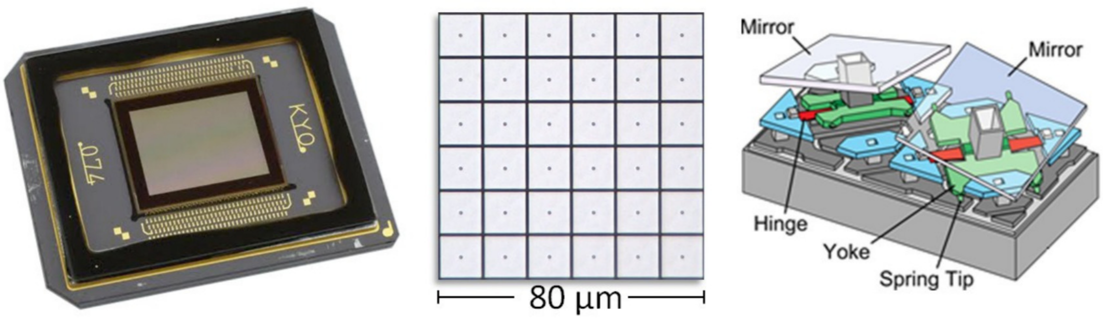


Figure 22. (left) The picture shows a DMD with a custom UV-enhanced sapphire window. (middle) A microscope image shows 36 individual micromirrors. (right) A schematic shows the hinge and tilt mechanism for two micromirrors.

CfD researchers modified an existing instrument for testing the DMD on a telescope. The Rochester Institute of Technology Multi-Object Spectrometer (RITMOS) had an older-generation DMD - an array of 848×600 micromirrors with 17 µm pitch and a tilt angle of 10°. We upgraded it with a newer model consisting of an array of 1024×768 micromirrors with 13.68 µm pitch and a flip angle of 12°. This DMD has superior scattering properties, and comes with a designated development kit that allows flexible and customized software control. To accommodate this change in the flip angle, the optics of the imaging arm were rotated by additional 4°. Figure 23 (*top*) shows a graphic demonstrating the light paths for the imaging and spectrographic channels in RITMOS. The spectral arm was left unaltered due to the inherent complexity of the assembly and therefore high costs of re-design. About 20% of the field of view of the spectral channel was sacrificed. Test observations show that the new DMD successfully directed light from a star into the spectral channel (Figure 23, *bottom*).

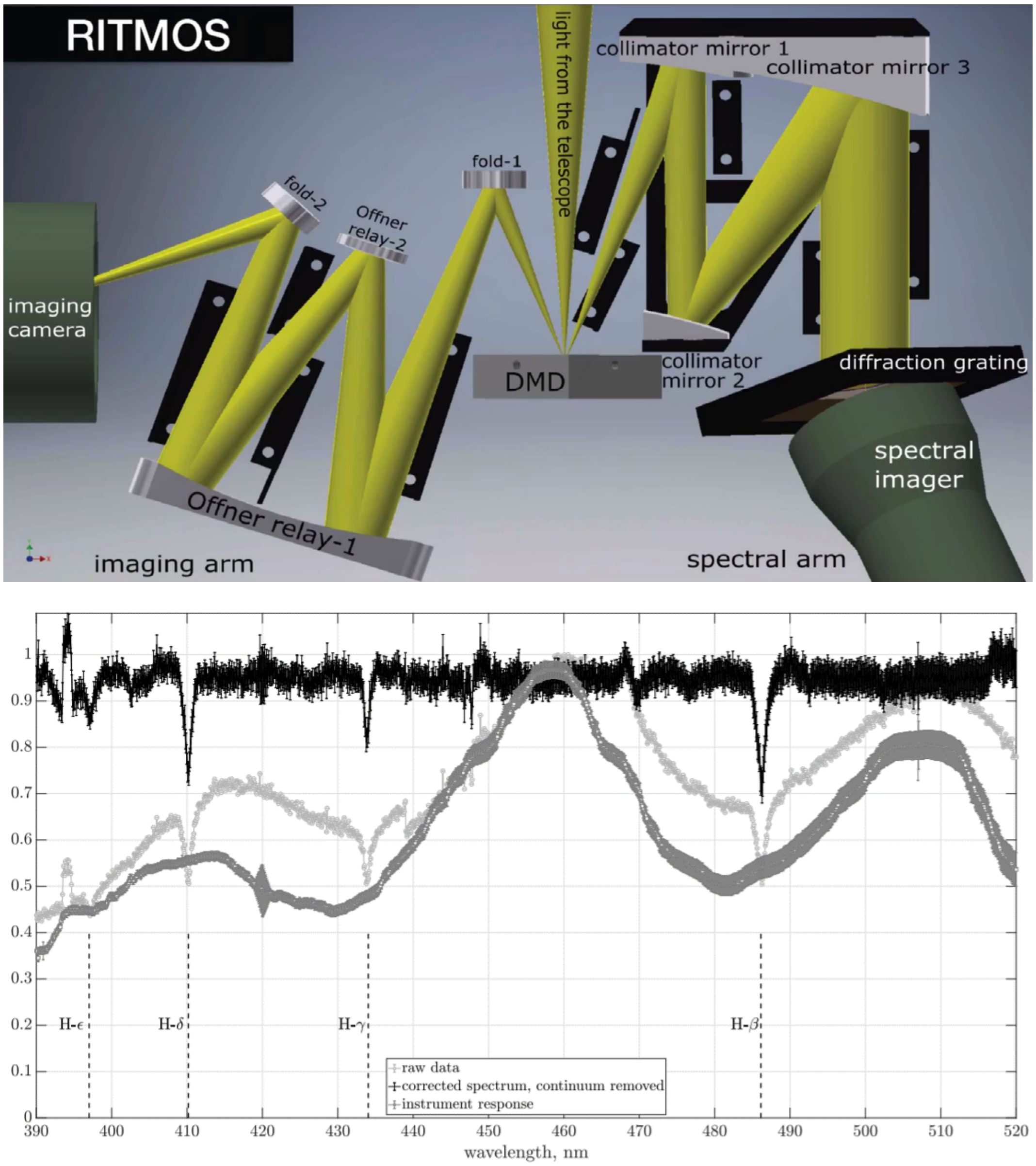


Figure 23. (top) This graphic shows how a DMD splits light into a spectral imaging arm and an imaging arm within the RIT Multi-Object Spectrograph (RITMOS). (bottom) These are spectra of Beta Per, obtained by RITMOS using the new DMD device. Hydrogen absorption lines are marked for better visibility. Y-axis represents normalized intensity and is unitless.

In addition to telescope testing, we performed an extensive suite of characterization experiments in the laboratory in order to measure reflectance, intramirror reflectivity and scattering, and robustness against the type of strong vibration experienced during launch on a rocket. Figure 24 shows some of the experimental setups used for this testing done at NASA's Goddard Space Flight Center.

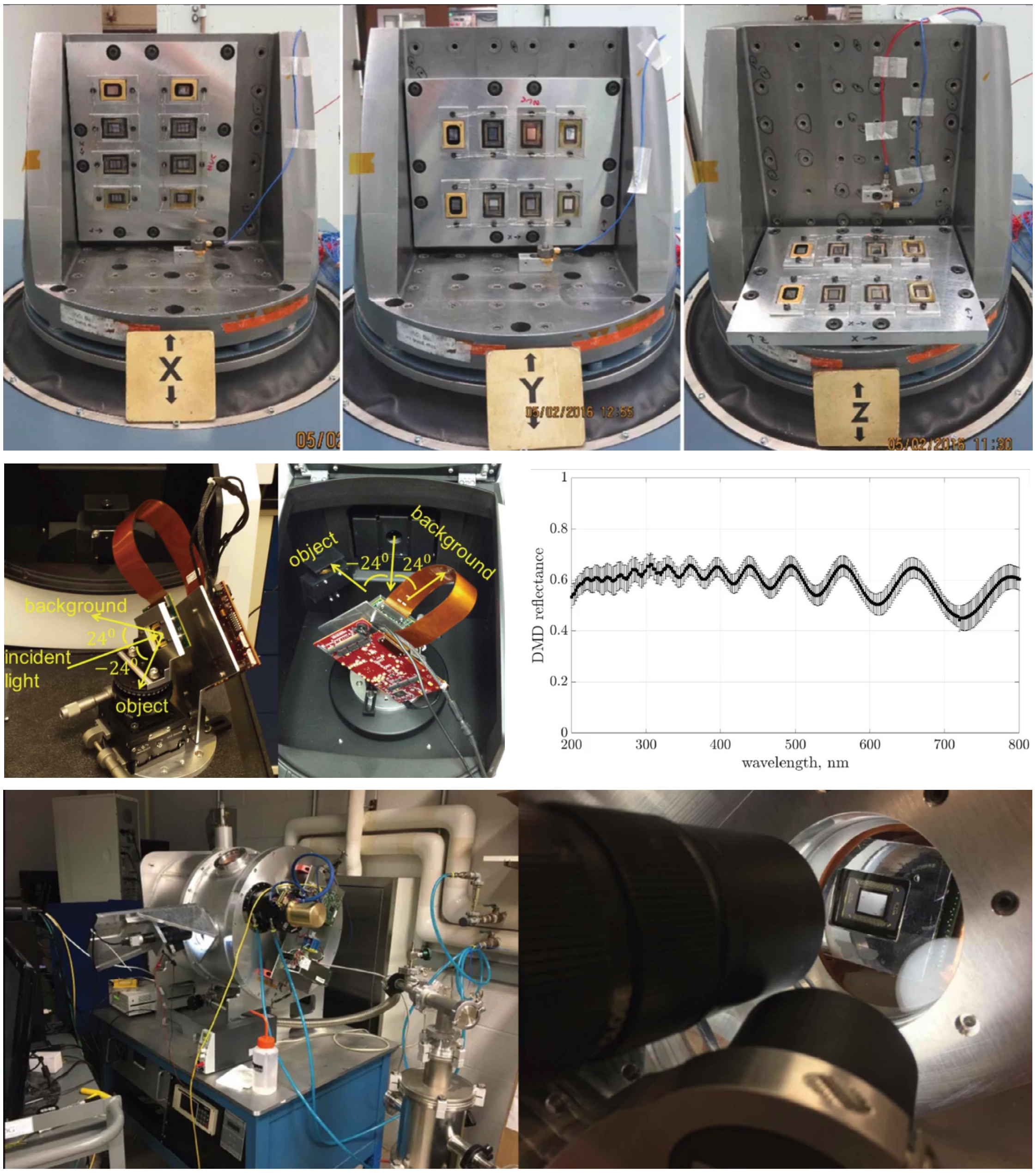


Figure 24. (top) Eight DMD test devices are in three orientations for vibration and shock testing. A spectrophotometer (middle, left) measures the reflectance properties of the DMD (middle, right). The images show the cryogenic testing system (bottom, left) and the DMD illuminated by a spot projector (bottom, right). This system exercises the DMD to determine if it is robust enough to accomplish the approximately 200,000 flips required in a typical space mission. It also determines if the micromirrors get stuck when operated at cryogenic temperatures.

Measuring the Pixel Response Function of Kepler CCDs to Improve the Kepler Database

NASA
Zoran Ninkov

The aim of this project is to accurately characterize the intrapixel response function of Kepler's CCDs and develop a procedure to calibrate data in the Kepler archive and data from the K2 mission. We are measuring the intrapixel response function (IPRF) using residual e2v CCD90 detectors, identical to those on the spacecraft, provided to us by the Kepler Project. This IPRF is being used to develop a method to improve the photometry and astrometry of archival NASA Kepler data and data from the K2 mission. The calibration procedure, software, and documentation are being made available to the Kepler community through a new task in the open source community-developed data reduction pipeline, PyKE.

The measurement system illuminates a subpixel region on the CCD and measures the response in that location. The spot projector consists of a fiber-illuminated parabolic collimating mirror and a Mitutoyo Plan Apo 20x infinity-corrected microscope objective. This objective is corrected for chromatic aberration over the wavelength range 380 nm – 900 nm to provide diffraction-limited performance. Furthermore, the objective has a long working distance (20 mm) which allows us to focus on the pixel surface through the window of a cryogenic dewar. The objective's focal ratio of f/1.25 is well matched to that of Kepler, f/1.47 (Figure 25).

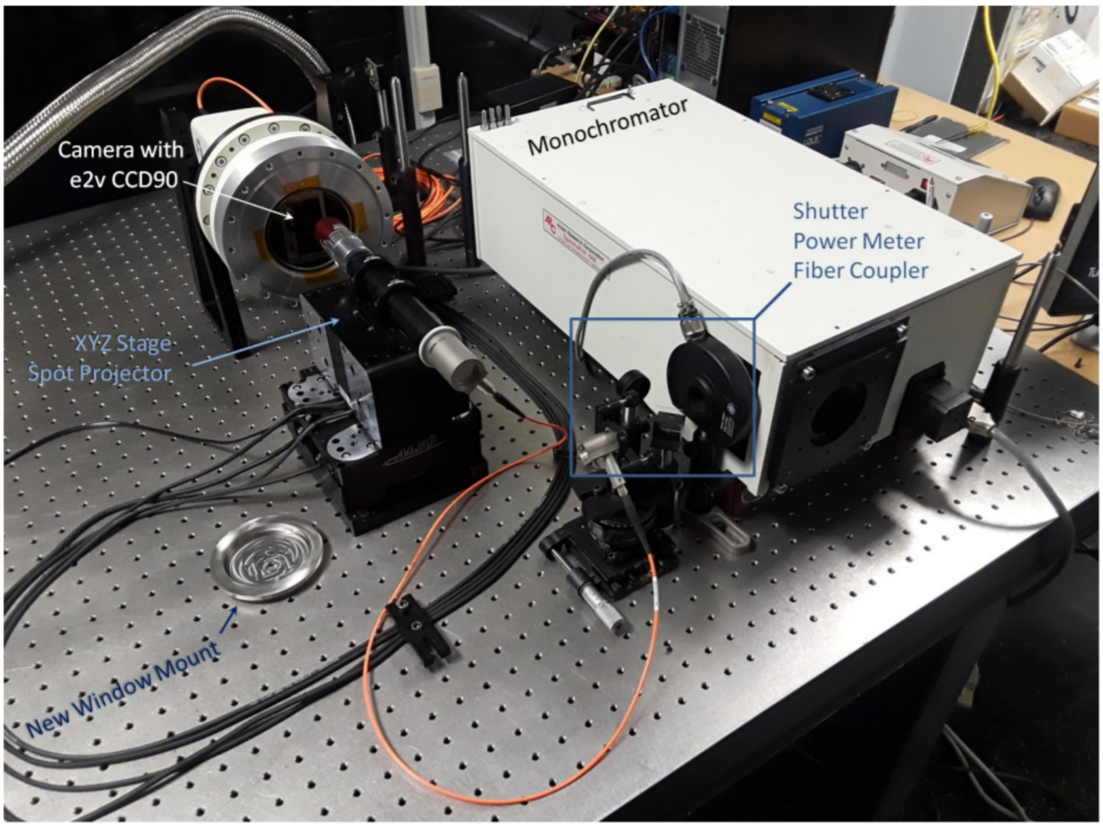


Figure 25. A new apparatus to measure the intrapixel response function of a range of imaging arrays was built in RIT's Laboratory for Advanced Instrumentation Research. This system produces small spots of light across a wide range of wavelengths.

Our initial scans covered a 70 μm × 70 μm region of interest, with steps of 1 μm in each direction. The measurements were performed at 450 nm, 600 nm, and 800 nm (with a passband of Δλ ~ 15 nm). The entire scan region at 450 nm is shown in Figure 26. To determine the IPRF, we normalize the intensity measured by the brightest pixel at each position of the spot scanner. This relative measurement must be combined with the quantum efficiency of the CCD at the appropriate wavelength to obtain the absolute IPRF. The response is similar to other back-illuminated devices, showing a considerable amount of diffusion and round contours. The peak response decreases by ~70% at the corners of each pixel.

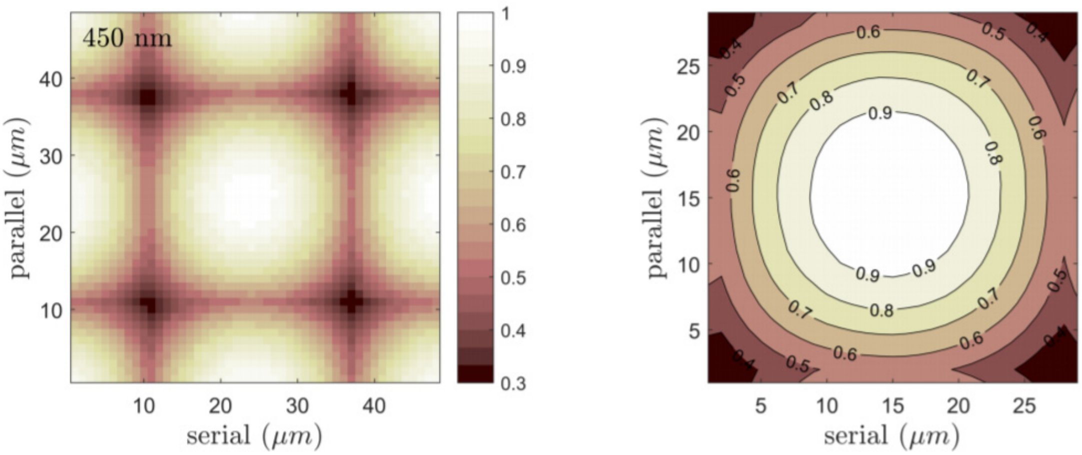


Figure 26. The normalized intrapixel response of Kepler 's CCD at 450 nm, as measured by a spot scanner at RIT, are shown using an intensity map (left) and a contour plot (right). The response is maximal in the central third of a pixel, and rapidly decreases towards the pixel edges.

Developing THz Detector Technology for Inspection Applications

RIT
Zoran Ninkov

The terahertz frequency (THz) region provides a means of using non-ionizing radiation to perform a variety of non-invasive sensing tasks. Commercial cameras systems are available that utilize microbolometer or pyroelectric detectors to detect THz wavelength radiation, but these devices lack sensitivity, stability, or readout speed. RIT and its collaborators at the University of Rochester and Harris Corporation are developing a room-temperature imaging THz frequency detector using Si-MOSFET (Silicon Metal Oxide Semiconductor Field Effect Transistor) CMOS devices. The devices are implemented into a focal plane imaging array for use in many applications, such as transmission or penetration imaging and spectroscopy. Technology for THz detection is often extremely costly, due to either expensive detector materials or cryogenic cooling systems. The devices tested here, however, are low-cost due to the use of conventional room temperature silicon CMOS technology. The devices operate from 170 to 250 GHz, with an additional detector design fabricated for 30 THz (10 μm wavelength).

Over the past year, we obtained results for the initial testing of single test structure FETs (Figure 27). These devices have several different antenna configurations and a range of MOSFET design variations. The primary goal of this project is to determine the optimized detector design for the subsequent focal plane array implementation based on the largest responsivities and lowest noise-equivalent power (NEP). Transmission testing of the devices yields responsivities of about 100 to 1000 V/W and a NEP of about 0.5 to 10 nW·Hz$^{-1/2}$. Through this evaluation and by utilizing signal amplification on the chip, signal modulation at higher frequencies, and smaller process sizes the performance of these devices will continue to improve in future designs.

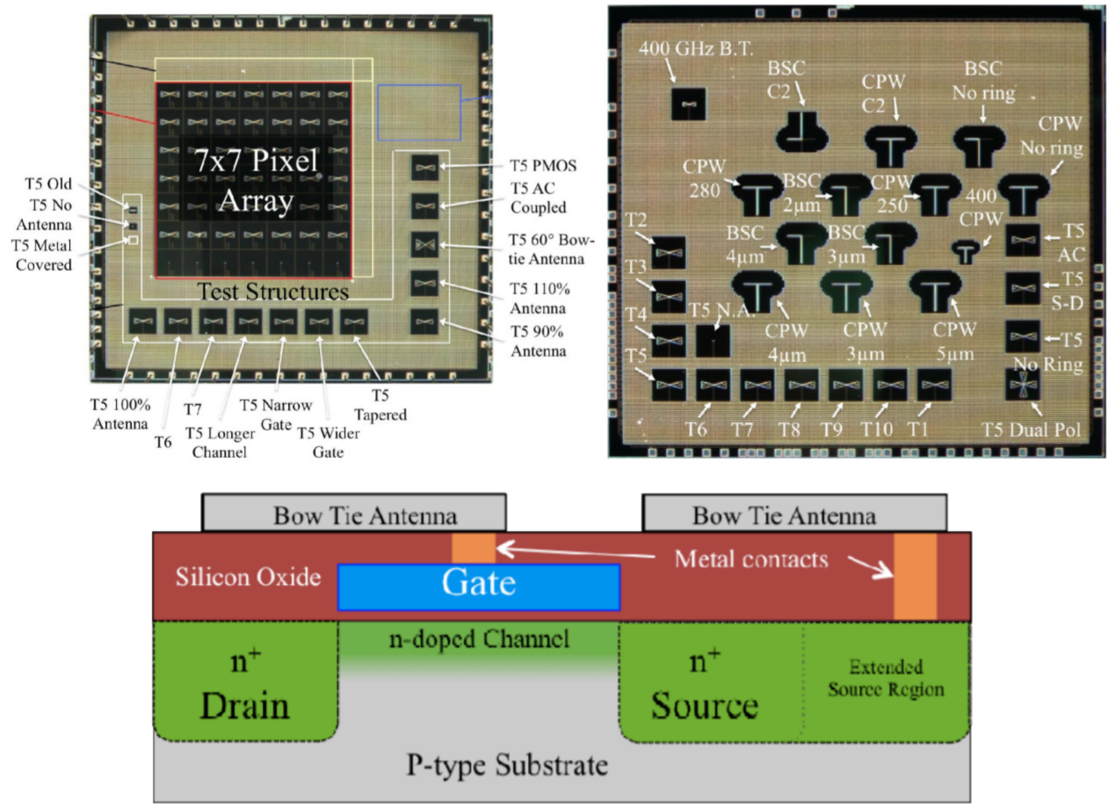


Figure 27. (top) The micrographs show two chips with the test structures. T5 refers to the baseline detector design. The larger the number after the T, the more of an extended source region there is with T1 being symmetric. The sets of dipole antennas consist of co-planar waveguides so both of the petals of the antenna are in the same metal layer and broad-side connections so one petal is in a different metal layer than the other. (bottom) A cross-sectional representation of the FET geometry shows the extended source region and the source-gate antenna petal connections.

SOAR/SAM Multi Object Spectrograph (SAMOS)

National Science Foundation/John Hopkins University
Zoran Ninkov

RIT is collaborating in a project to build the SOAR Multi-Object-Spectrograph (SAMOS) for the SOAR 4.1 m telescope. SAMOS takes advantage of the Ground Layer Adaptive Optics laser guided system that routinely delivers exceptional image quality at visible wavelengths over a large field. There is great demand for a facility capable of efficiently performing spectroscopic studies of crowded fields, *e.g.*, the Magellanic Clouds, globular dusters, the galactic bulge, and galaxy clusters. SAMOS can take hundreds of spectra in parallel over the full corrected field using a commercial Digital Micromirror Device (DMD) as a slit selector mechanism. Figure 28 shows a rendering of the instrument.

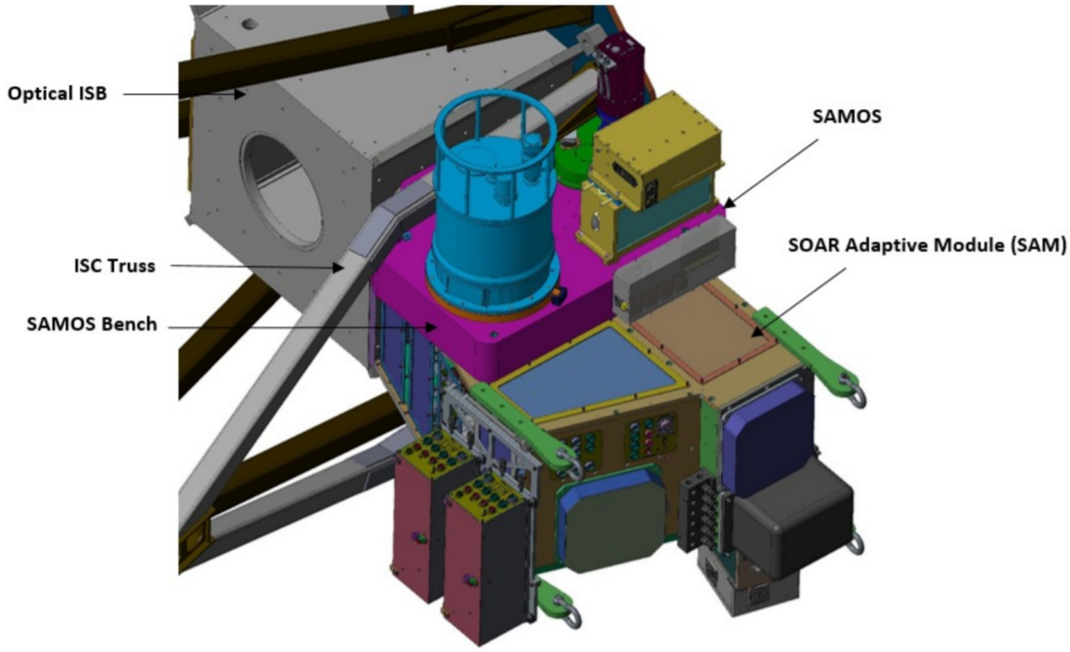


Figure 28. In the rendered image, the SAMOS is mounted to the SOAR Adaptive Module.

Development of Quantum Dot Coated Detector Arrays

NYSTAR/University of Rochester
Zoran Ninkov

Improving the sensitivity of silicon-based CMOS and CCD detectors in the deep-UV is an area of interest. Lumogen has been previously used for this purpose but has limitations in its use in both vacuum and radiation harsh environments. Quantum Dots (QD) offer a robust alternative to Lumogen (Figure 29). The fluorescence wavelength of QDs is tunable and can match the peak sensor quantum efficiency. Aerosol jet printing (AJP) is being used at RIT for the deposition of QDs on substrates and commercial sensor arrays. Insights obtained and improvements in the equipment permitted commercially ready devices to be fabricated and tested this past year.

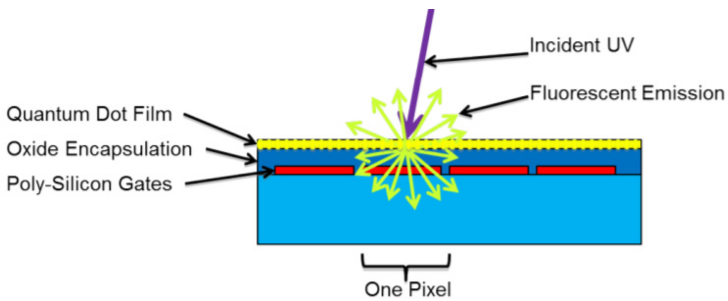


Figure 29. The cross-section schematic shows a quantum dot coated device.

Student Vignettes

Chi Nguyen

Chi H. Nguyen is a graduate student in the Astrophysical Sciences and Technology (AST) PhD program and a member of the Center for Detectors. Her advisor is Dr. Michael Zemcov. Before coming to Rochester, she received a BS degree in Astronomy with a Math minor from the University of Arizona (Tucson, AZ).

For her senior thesis, Nguyen built a support structure with robotic actuator for one of the mirrors in the South Pole Telescope Very Long Baseline Interferometry (SPT VLBI) project. The SPT VLBI is part of the Event Horizon Telescope, which uses a network of radio telescopes around the world to image the supermassive black hole at the center of the Milky Way. Her instrument was verified and implemented successfully in Antarctica in 2015. In addition to this research, Nguyen worked on various observational projects like studying the properties of exoplanet magnetic fields using planet transit data.

Her PhD research focuses on understanding the Extragalactic Background Light (EBL). The EBL probes the history and origin of stellar emission, which allows astronomers to constrain models of star and galaxy formation. She is currently working on the Cosmic Infrared Background ExpeRiment 2 (CIBER-2), which uses a small telescope launched on a Black Brant IX sounding rocket to map the fluctuations in the EBL intensity at near infrared wavelengths. Nguyen leads the mechanical design of many CIBER-2 sub-systems including the payload forward suspension and the radiation shield. In addition, she serves as the graduate mentor of project CSTARS (Cryogenic Star Tracking Attitude Regulation System), in which a group of RIT undergraduate students verifies the feasibility of flying a scientific CMOS detector on a sounding rocket at cryogenic temperature.

The technology of CSTARS will be implemented into the CIBER-2 star tracker. After the construction of CIBER-2 is completed, she will develop a data analysis pipeline to extract EBL information from the flight data. As part of the integration process, she travels frequently to the California Institute of Technology (Pasadena, CA) to work directly with the payload (Figure 30). In 2017, she won a NASA Earth and Space Science Fellowship to support her work on CIBER-2.

Besides CIBER-2 and CSTARS, Nguyen is also involved with measuring the EBL intensity at visible wavelength using data from the LORRI camera onboard the New Horizons spacecraft. The early result of this project was published in Nature Communications in April 2017. Nguyen presented the New Horizons study at the 231st meeting of the American Astronomical Society in Washington D.C. in early 2018. Her poster presentation was met with positive feedbacks from the astronomy community and earned her a Chambliss Astronomy Achievement Student Award.

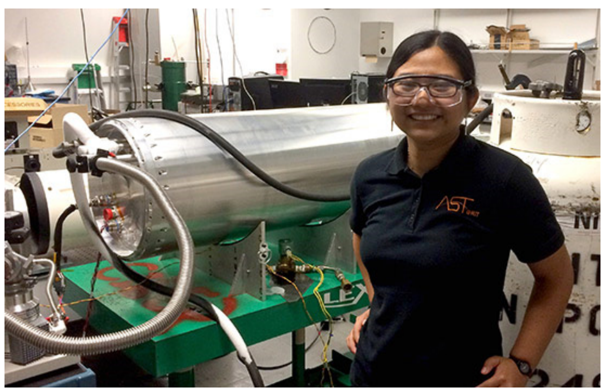


Figure 30. Chi Nguyen stands in front of the CIBER2 payload.

Victoria Butler

Victoria Butler is a second year graduate student pursuing her PhD in the Astrophysical Sciences and Technology program. She received her BS in Applied Physics with an Astronomy concentration at Rensselaer Polytechnic Institute (Troy, NY) in 2016.

Her current research is on the evolution of galaxies and galaxy clusters through the Epoch of Reionization and the Epoch of Peak Star Formation. She focuses primarily on the kinetic Sunyaev-Zel'dovich Effect (kSZE) in galaxy clusters, which is caused by the inverse Compton Scattering of Cosmic Microwave Background (CMB) photons due to the kinematic motions of intracluster gas, and can be detected through the change in intensity of the CMB. Through measurement of the change in intensity, the peculiar motions of the clusters can be determined, and the gravitational potential of the cluster system can be studied. This will lead to insights into the role of dark matter in the evolution of large-scale structure through cosmic history. Her contribution to the project is the development of software (Figure 31, *right*) that will be used to communicate with the instrument designed to detect this phenomenon, and the subsequent data analysis suite after the instrument begins operations.

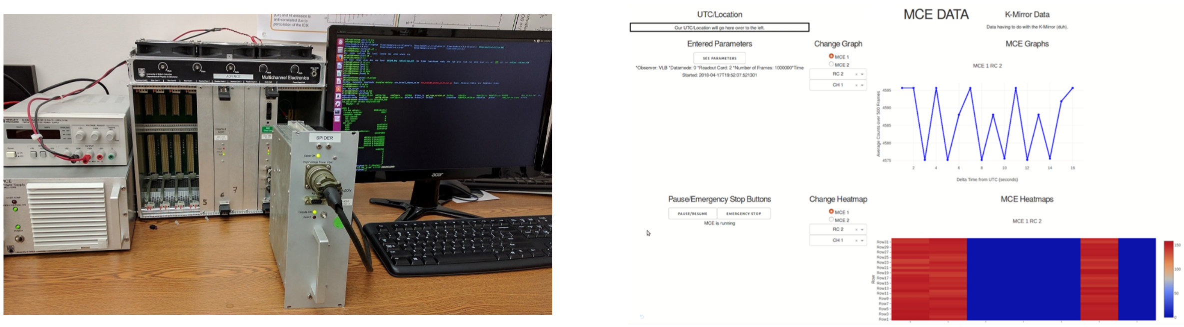


Figure 31. (left) Shown in the photo is the equipment and workspace used by Victoria in her PhD research. (right) The data analysis suite shown here will be used after the instrument begins operations.

Ben Stewart

Ben Stewart is a graduate researcher at the Center for Detectors completing his BS and MS in Electrical Engineering in 2018. Throughout his undergraduate education, his work included safety critical embedded systems and lithium ion battery management. Prior to joining the CfD, his industry experience included a sensor-engineering co-op at Bosch. His primary focus is on the development and testing of ruggedized spaceflight instrumentation and electronics.

Within the CfD, his involvement has been on the cryogenic star tracking attitude regulation systems (CSTARS), and the cosmic infrared background experiment (CIBER-2). With a focus in electrical hardware and embedded software, his contributions have included the development of focal plane and interfacing printed circuit boards, as well as the software necessary to readout the detector during its main flight. The focal plane electronics were designed to withstand the roughly 80 Kelvin temperatures of the experiment, while the interface electronics required careful attention to heat dissipation. Preliminary integration testing was performed with NASA ground stations at the Wallops Flight Facility. CSTARS will play an integral role in the success of the CIBER-2 payload, tentatively scheduled to launch October of 2018. Upon completion, this will be the first successful rocket payload to utilize a cryogenic sCMOS detector.

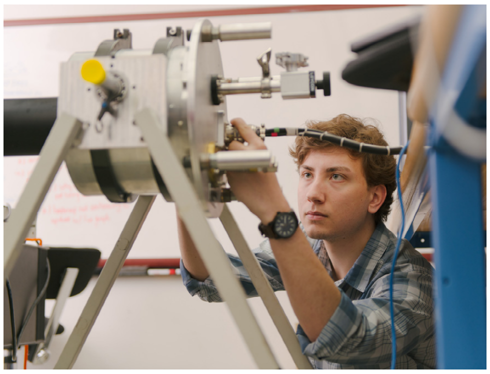
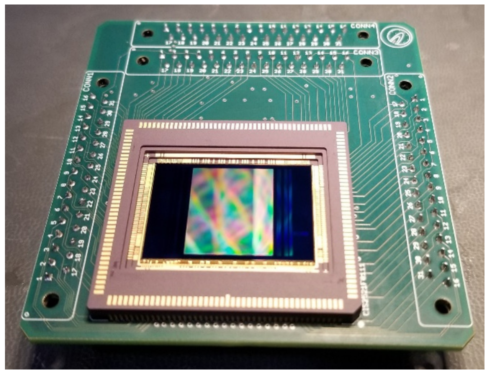



Figure 32. (left) Ben Stewart works on the creation of the cryogenic star tracking attitude regulation system. (right) Shown here is a sCMOS detector mounted to focal plane printed circuit board.

James Emerson Parkus

James Emerson Parkus is currently pursuing a Bachelor of Science degree in Mechanical Engineering with an Aerospace Option in the Kate Gleason College of Engineering. He is an undergraduate student researcher at the Center for Detectors that has been working on CSTARS since fall 2016, CIBER2 since summer 2017, and RAxDEx. His focus on the rocket-borne experiment CSTARS was integration of the payload and design and testing of the optical baffle for the telescope. He designed the electronics box for the rocket-borne CIBER2 mission. James is continuing to work on vibration testing of the PCBs to ensure their survival of the high stress environment. James built an entire mechanical model for a NASA proposed project, the Rocket Axion Decay Experiment (RAxDEx). (Figure 33). He continues to work on the CIBER2 mission and CSTARS, focusing on vibration testing and payload integration.

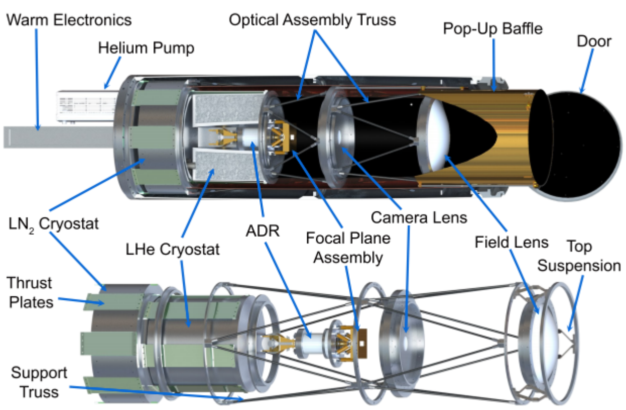


Figure 33. The image above is a mechanical model for a NASA proposed project, the Rocket Axion Decay Experiment (RAxDEx)

Matthew Hartensveld

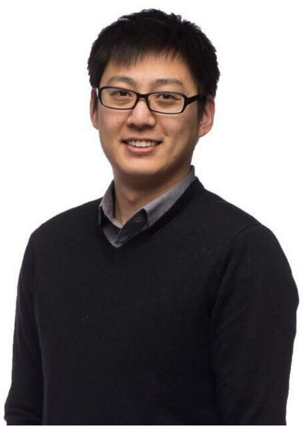
Matthew Hartensveld is a graduate student in the Microsystems PhD program and a member of the Center for Detectors. His advisor is Dr. Jing Zhang. Hartensveld received his Bachelor's and Master's degrees from RIT in Microelectronic Engineering and Materials Science respectively.

For his Master's thesis Hartensveld developed etching techniques to create GaN nanowires. LEDs are made of GaN, which is a wide bandgap semiconductor. GaN nanowire LEDs are purposed for future display applications as well as general purpose lighting due to their higher performance. Both dry and wet etching methods were explored to engineer tall, perfectly vertical, wire arrays.

Hartensveld expanded on this work to create novel GaN nanowire Field Effect Transistors (FETs) for his senior capstone project. These devices were designed to be used to control nanowire LEDs. Nanowire FETs are desired as they outperform their planar counterparts and allow for new possible integration schemes as flexible devices, and LED displays.

His PhD research focuses on continued nanowire fabrication and exploring new device applications. These nanowire devices will include nanowire LEDs tailored for both visible and deep ultra violet light.

Cheng Liu



Cheng Liu is a graduate student in the Microsystems Engineering PhD program and a member of the Center for Detectors. He is currently under the guidance of Dr. Jing Zhang. Before coming to Rochester, he received a BS degree in Physics from Wuhan University, China.

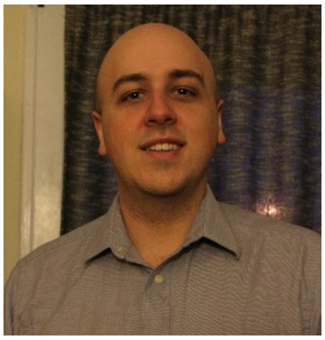
His PhD research focuses on improving efficiency of deep-ultraviolet (DUV) light-emitting diodes (LEDs). UV light with emission wavelength of 200 nm – 280 nm have shown great potential in numerous applications such as water purification, free space communication and optical storage. UV-LEDs are developed as potential substitutes for traditional bulky mercury lamps because they are extremely robust, compact, environmentally friendly, and can exhibit very long lifetime. Cheng started the project with investigating the physics of DUV LED, especially the polarization properties by using an in-house numerical model. He leads the active region designs for realizing high-efficiency DUV LEDs such as AlGaN-delta-GaN QW and AlInN-delta-GaN QW.

In addition, Cheng is also in charge of developing a polarization properties measurements setup. His collaborative projects with Jena-Xing's group (Cornell): "Physics and polarization properties study of 298 nm AlN-delta-GaN quantum well ultraviolet light-emitting diodes" and "234 nm and 246 nm AlN-delta-GaN quantum well deep ultraviolet light-emitting diodes" have been published in Applied Physics Letters based on the polarization properties measurements results.

Besides theoretical study and device characterizations, Cheng is currently working on the heterostructure epitaxy growth by using the plasma-assisted Molecular Beam Epitaxy (MBE) system. The early result of the project was presented in SPIE Photonics West in February 2018, and received positive feedback from multiple experts in photonics research area. Another project he is engage in recently is DUV LED nano-fabrication. He is developing various methods to improve UV LEDs light extraction efficiency, such as nanowire LEDs and inverted pyramid photonic crystal UV LEDs, which have been theoretically demonstrated by the use of finite-difference time-domain simulation.

With his help, other projects including 3D-printing white LED, effect of KOH on InGaN/GaN nanowires, patterned sapphire substrate for UV LEDs were published in journals like IEEE Photonics Journals and presented in SPIE Photonics West and MRS Fall Meeting.

Kevan Donlon



Kevan Donlon is a graduate student in the Imaging Science PhD program in the Chester F. Carlson Center for Imaging Science at RIT. His advisors are Dr. Zoran Ninkov and Dr. Stefi Baum. He received a BS degree in Physics from Rensselaer Polytechnic Institute in 2012 with a senior culminating experience study of non-linear optical materials for photonic applications.

His PhD research focuses on furthering the understanding of interpixel capacitive coupling hybridized arrays. His work on physical simulations, characterization methods, science impact and mathematical/computation correction methods has been published in SPIE's journal of Optical Engineering, Publications of the Astronomical Society of the Pacific, and presented at astronomical conferences and workshops internationally.

Katherine Seery

Katherine E. Seery is a graduate student in the Astrophysical Sciences and Technology (AST) PhD program and a member of the Center for Detectors. Her advisor is Dr. Zoran Ninkov. During her time at RIT, she has received her MS in Imaging Science. Before coming to Rochester, she received a BA degree in Physics and Mathematics with an Astronomy minor from Alfred University (Alfred, NY). She also received Alfred University's Natasha Goldowski Renner Prize in Physics. As an undergraduate student, Katherine completed summer internships on a variety of projects at NASA's Goddard Space Flight Center including creating a demonstration of active vibration isolation control environment for future instruments on board the International Space Station, designed and carried out vacuum chamber and vibrational testing of instruments for evaluation of future flight hardware, and more.

Since coming to RIT in 2014, Katherine's PhD research focuses on developing a Terahertz (THz), or sub-millimeter/millimeter waves, detector using Si-MOSFET CMOS devices and evaluating the devices for possible astrophysical applications. The devices are designed locally and fabricated using the MOSIS facility. The Terahertz project is a collaboration between RIT, the University of Rochester, and Harris Corporation. Katherine tests the individual MOSFETs that have varied designs to characterize the devices so that they can be implemented into a future large focal plane arrays for a variety of applications. She created a custom low noise setup to test the devices. The pixel characterization includes measuring the pixel-to-pixel frequency response, calculating responsivity, NEP, et cetera. In addition to pixel characterization, she will be attempting to fit theoretical curves to the responses of the devices to attempt to better understand the underlying detection mechanism and optimize the devices. The optimization would then be integrated into a THz imaging system with a larger focal plane array.

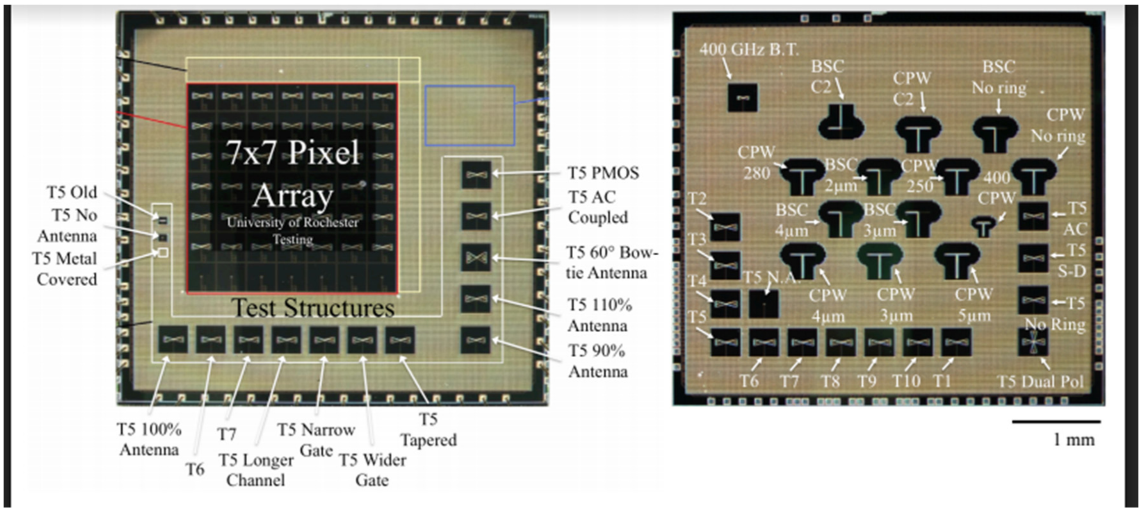


Figure 34. The above devices were designed locally for the THz imaging project.

Thomas Wilhelm

Thomas S. Wilhelm is a 3rd-year Microsystems Engineering PhD student, and a member of the Center for Detectors (CfD), the NanoPower Research Laboratory (NPRL), and the Epitaxially-Integrated Nanoscale (EINS) laboratory. Additionally, he is a member of the Materials Research Society (MRS), the Institute of Electrical and Electronics Engineers (IEEE), the Society of Photo-optical Instrumentation Engineers (SPIE), and the Order of the Engineer. He completed his B.Sci. In Physics from Calvin College in 2011, and his M.Eng. In Mechanical Engineering from Lehigh University in 2014. Thomas joined the Microsystems Engineering PhD Program after working as an optical metrology engineer for two years.

In 2017, the National Renewable Energy Laboratory accepted a research proposal submitted by Thomas, and he spent four months at their Colorado campus working on a project titled “Enabling High Concentration Photovoltaics with 50% Efficient Solar Cells.” The goal of the project was to design and fabricate a 6-junction high concentration photovoltaic device using the inverted metamorphic growth technique. Thomas’ role was to quantify and reduce parasitic resistance losses during contact layer etching and mesa etching (*i.e.*, device isolation).

Thomas works with Dr. Parsian K. Mohseni towards exploring metal-assisted chemical etching (MacEtch) of various semiconductor materials for the fabrication of nanostructures with photovoltaic applications. Wilhelm et al. were the first to demonstrate MacEtch of the ternary III-V alloy, InGaP, in January 2018 (Figure 35, *left*) and have recently submitted a manuscript demonstrating the first successful MacEtch of another ternary III-V material, AlGaAs (Figure 35, *middle*).

Thomas’ doctoral thesis is on the design, fabrication, and characterization of novel photovoltaic devices. In particular, his dissertation aims to compare conventional devices with junctions generated via epitaxy or implantation, and devices utilizing carrier-selective asymmetric heterojunction (CSAH) architectures generated via chemical and physical vapor deposition. Additionally, the goal of his work is to marry MacEtched III-V nanostructures with CSAH photovoltaic designs to fabricate cost-effective solar cells that will improve upon the “dollars-per-watt” metric of today’s state-of-the-art devices.

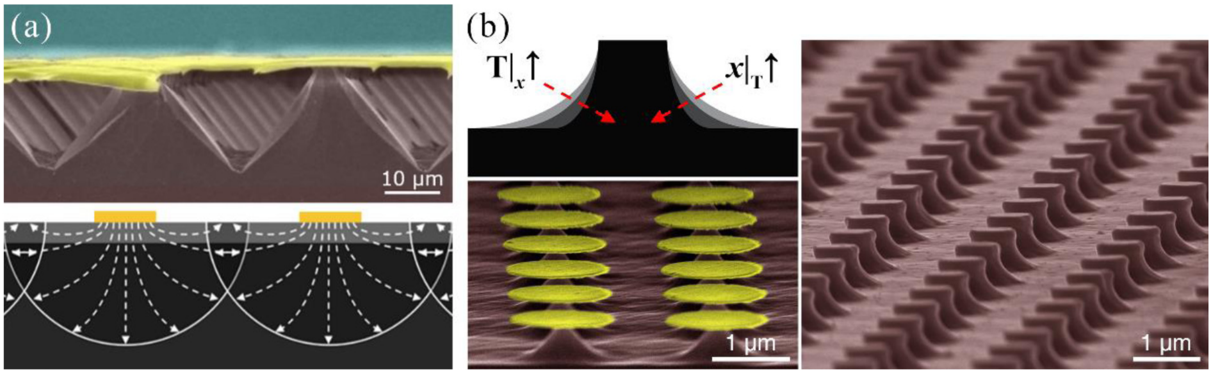


Figure 35. (left) This image shows the fabrication of suspended III-V nanofoils by inverse metal-assisted chemical etching of $In_{0.49}Ga_{0.51}P$/GaAs heteroepitaxial films, and (middle) ordered $Al_xGa_{1-x}As$ nanopillar arrays via inverse metal-assisted chemical etching.

Justin Parra

Justin Parra is a recently graduated Mechanical Engineering student from the Kate Gleason College of Engineering at RIT.

For his multidisciplinary senior design project he helped design a k-mirror for the Kitt Peak 12M radio telescope for use by the Tomographic Ionized-Carbon Mapping Experiment (TIME).

The k-mirror will be a subsystem of the telescope, lying in the signal path. It will rotate the "image" based on the time and where the telescope is pointing in the sky. This is done because the telescope at Kitt Peak has an Alt-Azimuth mount, which when combined with the low number of detectors requires some means of rotating the signal as the scan progresses.

Over this summer he is finishing his last co-op following up on the k-mirror project by ordering and testing the mechanical side. (Figure 36). The structure on the right attaches to a flange in the telescope cabin and supports the rotation assembly. Said assembly is supported by the gearbox and a large bearing, and holds the three mirrors. They rotate around the axis formed by the centerpoints of the two angled mirrors.

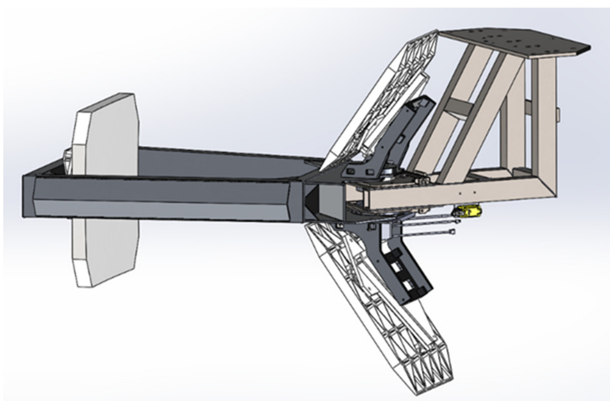


Figure 36. Shown above is a current model of the k-mirror project.

Sean Rogerson

Sean Rogerson is an undergraduate engineering student working at the Center for Detectors (CfD). He is working towards completing a BS and MS in Electrical Engineering with a minor in Physics. Prior to working at the Center for Detectors, he worked as a biometrics engineering co-op at Synaptics.

While working at the CfD, he has been involved in the development of an engineering verification test (EVT) system for use in the validation of a photonic integrated circuit (PIC) evaluation assembly. His contributions to the EVT project have included work on programming of the field-programmable gate array (FPGA) based board to drive digital data to the installed PIC assembly. He has done work to integrate the software used for FPGA programming into the ongoing Prober Control project which seeks to allow automation of the EVT project and its component devices. The EVT system will be used for the testing of a C form-factor pluggable (CFP) based package that is currently being developed at Columbia University for the purpose of controlling complex PICs including high speed transceivers and photonic switch fabrics. The EVT will also be able to test a quad small form-factor pluggable (QSFP) based package that is being developed by Precision Optical Transceivers. As the project proceeds, work will continue to be done to create software for functional and performance tests in order to validate the EVT station for photonic switches.

Figure 37. (left) A Xilinx VCU108 FPGA will be used in the EVT station to host various devices, such as a QSFP based package developed by Precision Optical Transceivers (right).

Michael Fanto

Michael Fanto is a graduate student member of the Future Photon Initiative (FPI) and Center for Detectors conducting research in integrated quantum photonics. He completed his BS degree in Physics from Utica College in 2002. His senior research project was on ultra-fast mode-locked fiber lasers, which gave him tremendous experience with nonlinear interactions with materials.

After completing his BS degree, he accepted a position with the United States Air Force/Air Force Research Laboratory (AFRL) in Rome, NY as a research physicist (2002-Present). While at AFRL he has conducted research in a number of areas including fiber laser systems, optical modulators, laser radar, and quantum information science, including quantum computation.

In the summer of 2015, Michael was awarded an Air Force Development Opportunity package and accepted the admission to RIT to start his PhD in Microsystems Engineering in the Integrated Photonics Group with Dr. Stefan Preble. He has been conducting research on photon pair sources utilizing the third order nonlinearity in silicon and the enhanced efficiency gained from a microring resonator. This research has broadened to include photon generation in the ultraviolet regime, beyond the typically generated infrared photons from silicon. To accomplish this task, one needs a larger bandgap material, and a candidate that can be fabricated into integrated waveguide circuits. The chosen material was aluminum nitride with a bandgap of 6.2 eV, allowing optical transparency well into the ultraviolet.

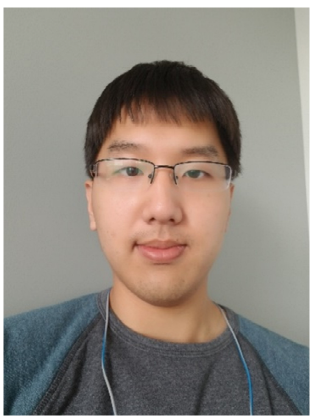
Jeffrey Steidle

Jeffrey Steidle is a PhD candidate in the Microsystems Engineering PhD program. He received his Bachelor of Science in Applied Physics from SUNY Geneseo in 2014. During his undergraduate studies, he worked as a research assistant in the nuclear physics laboratory operating SUNY Geneseo's 1.7 MV Tandem Pelletron Accelerator.

After completing his BS in 2014, he joined the RIT Nanophotonics Group as a graduate research assistant under the advisement of Dr. Stefan Preble and as a member of the Future Photon Initiative. Over the summers of both 2015 and 2016, he has had the opportunity to work with collaborators at the Air Force Research Laboratory (AFRL) in Rome, NY as a visiting scholar as part of their Visiting Faculty Research Program (VFRP). His research is in photonic devices for UV, visible, and IR wavelengths, specifically, with ring resonator photon sources and their application to quantum-integrated photonics. He has experience with all stages of the experiment including design, fabrication, and testing of the photonic circuits.

Jeffrey was involved with an experiment in which a silicon ring resonator was used as a photon-pair source (via the third order nonlinear process Spontaneous Four Wave Mixing) and was combined with an on-chip Mach-Zehnder interferometer for the purpose of N00N (N=2) state generation. The state was confirmed through high visibility quantum interference.

HanSoo Lee



HanSoo Lee is a student software engineer at the Center for Detectors completing his BS in Game Design and Development in May 2019. Throughout his undergraduate education, his work focused on team based software development, which allowed him to transition easily to working on the CRDIR Project.

Within the CfD, his work has been on the Cosmic Ray Damaged Image Repair (CRDIR) project, where his programming skills went towards bug fixing and developing more features for the application. CRDIR is an application designed to find bad pixels within images that were taken by a Nikon camera up in a space satellite. These bad pixels are caused by high-speed particles up in space, and it is the software's job to minimize the amount of bad pixels within the image. As of now, his contributions consist of optimizing the run time of the application for video conversion, as well as general fixes for the GUI like file type selection and searching for the necessary programs for the application to run. He is currently researching methods to improve the image-processing algorithm, and iterate through different versions of the GUI.

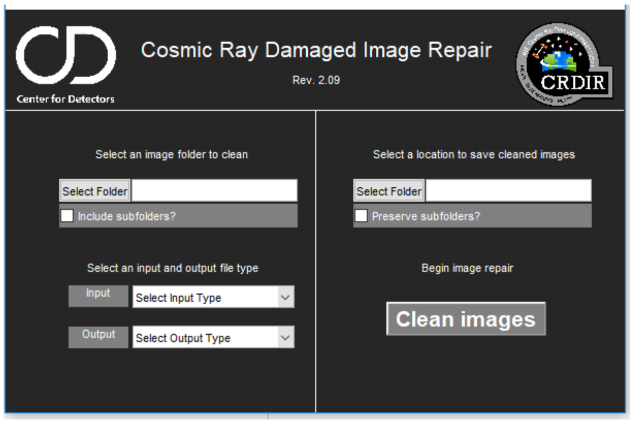
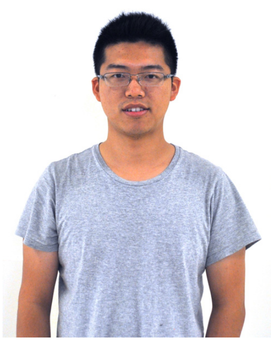


Figure 38. Shown above is the new GUI iteration for CRDIR.

Zihao Wang

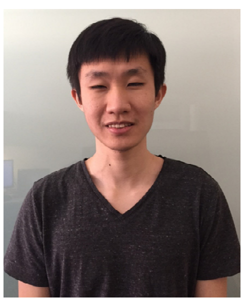


Zihao Wang is a graduate student member of the CfD who started his PhD in the Microsystem Engineering program in September 2012. He completed his BS degree in opto-electronics in 2012 from Huazhong University of Science and Technology (HUST) in China.

In the senior year of his undergraduate studies, Zihao had the opportunity to exchange to University of Michigan-Dearborn while working on his senior design project developing a method to fabricate an anodic aluminum oxide (AAO) membrane template. After completing his BS degree in 2012, Zihao decided to continue to study nanotechnology, with an emphasis on photonic technologies. Zihao has been pursuing a PhD with research focused on integrated photonic lasers at RIT.

At RIT, Zihao demonstrated a method to integrate InAs quantum dot (QD) lasers on silicon substrate through palladium (Pd) mediate wafer bonding which is an alternative to achieve III/V laser on silicon platform. He presented the results of bonded laser as well as QD laser butt-joint coupled to silicon photonic circuits at Integrated Photonics Research (IPR) in Boston, MA, and Photonic West in San Francisco, CA, respectively.

Arturo Kuang



Arturo Kuang is a student member of the Center for Detectors who is pursuing a bachelor's degree in Game Design and Development with two minors in Computer Science and Mathematics.

Arturo has had the opportunity to start developing an Engineering Verification Test (EVT) for photonic integrated circuits (PIC). Throughout his time at the Center of Detectors, Arturo worked as a Lab Programming Assistant in partnership with Columbia and AIM Photonics to create specific drivers for the realization of the EVT. In collaboration with Columbia, Arturo has helped aid the ongoing project Prober Control, an automated testing framework, by researching data visualization, data modelling, data automation, and setting up an Ethernet interface server.

The EVT is a generic reference test platform to be used to measure optical transceivers implementing photonic integrated circuits. The EVT will run certain testing methodologies in relation to the photonic integrated circuit and help us determine the capabilities of these circuits and our testing station. The photonic integrated circuits will be presented in two form factors a QSFP from AIM Photonics and a CFP from Columbia. Arturo has helped research possible implementation of a FPGA for the use of this project (Figure 39). Specifically, he has employed the use of VHDL and Vivado to research possible experiments that involves system noise, insertion loss, modulator efficiency, photo detector responsibility, dark current, laser efficiency, and laser noise. Arturo aims to expedite the testing framework in the field of photonics.

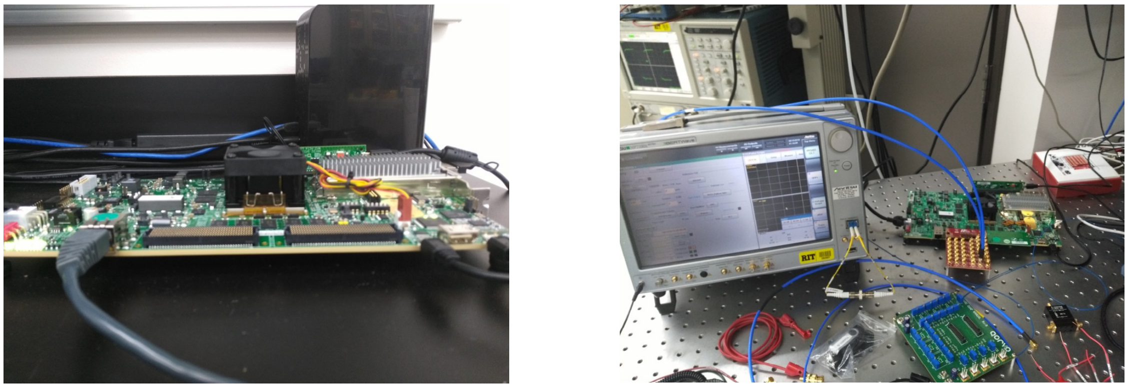


Figure 39. (left) The picture shows the initial setup of the VCU108 FPGA. (right) The image shows the FPGA connected to a RF analyzer.

Austin Ford

Austin Ford is an undergraduate student working at the Center for Detectors, who is currently pursuing a Bachelor of Science degree in Game Design and Development and a minor in Film Studies. Austin began working in the CfD May of 2018 as a Software Engineer working on the Engineering Verification Test system (EVT), a collaborative effort between Columbia University, RIT, and Precision Optical Transceivers. He has been working on the development of the ProberControl project; a python program used to control devices and will be used to monitor the EVT system. During the summer, he worked on source control for ProberControl, documenting the history of code alterations and making efforts to update code repositories. As well as continuing work on and testing ProberControl code on different devices and checking for bugs and logic errors. ProberControl will be used for testing the EVT system and for automation of the testing process, which is still in development. He has also been assisting with work on the Field Programmable Gate Array (FPGA) board; this device is what the project will be using to handle its tests (Figure 40). Austin has assisted work on sending code to the FPGA board with python classes and Vivado VHDL files to test the board. As well as research into procedures on how to further control the board through python and other scripting software. Austin will continue to further work on the FPGA board and ProberControl's processes for handling experiments throughout his time at CfD.

Figure 40. (left) Show in the photo is a VCU108 FPGA board made by Xilinx used in the EVT system. (right) The AgilnetE3649A power supply is being used in testing ProberControl.

Andrew Min

Andrew Min is an undergraduate student member of the Center for Detectors and Future Photon Initiative who is pursuing a Bachelor's degree in Game Design and Development.

His first involvement with the Future Photon Initiative was in January of 2018, when he joined as a Lab Programming Assistant, aiding in the development of software in the Engineering Verification Test (EVT) system. In collaboration with Columbia University, he aided in the development of the ongoing project ProberControl, a program written in Python used to monitor and automate the EVT system and its components. In regards the development of ProberControl, Andrew has researched implementation of various elements, including asynchronous object oriented programming, Network/Ethernet integration, data modeling, data visualization, and automation. The EVT will be used to monitor and automate integrated photonic circuits, which are currently in development.

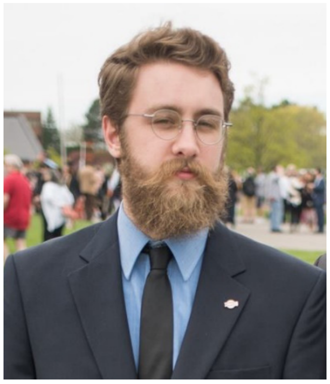
In addition to ProberControl, Andrew is researching possible uses of FPGA boards pictured in Figure 39 in relation to the EVT. He will utilize various FPGA technologies in programming languages such as C/C++ and VHDL in order to explore the possibilities of using FPGA technology to process various data, including shorted input, insertion loss, gain, dark current, and RF frequency. Andrew's work investigates the possible uses of automation software in the field of photonics.

Mohadesh A. Baboli

Mohadesh A. Baboli is a graduate student pursuing her PhD degree in the Microsystems Engineering Program. She is a member of the Center for Detectors (CfD) and the NanoPower Research Laboratories (NPRL). Mohad received her BS degree in Electrical Engineering from Babol Institute of Technology in 2010. As a 3rd year undergraduate student, Mohad joined the Integrated Circuits Research Laboratory and conducted research on swarm intelligence-based computational algorithms for discrete optimization problems. In 2011, Mohad continued her studies toward a MS degree in Electrical Engineering at Tehran Azad University. Her focused research areas were on the optical properties of multi-wall carbon nanotube arrays, slow light in infiltrated hole-type photonic crystals, and all-optical logical gates with hopping surface plasmons.

After joining the Microsystems Engineering PhD Program at Rochester Institute of Technology, Mohad began working on selective area epitaxy of III-V semiconductor nanowires by metal-organic chemical vapor deposition (MOCVD), as part of Dr. Parsian Mohseni's research group. Nanowires are interesting structures because of their relaxed lattice matching capacities and large surface area to volume ratios. In addition, nanowires offer three-dimensional degree of freedom in modifying complex and novel heterostructures. Mohad uses various techniques including scanning transmission electron microscopy (STEM) and photoluminescence (PL) spectroscopy for characterization of semiconductor nanowires, toward device applications in optoelectronics and photovoltaics.

Sean Scannell



Sean Scannell is an undergraduate student software engineer in the CfD. Scannell will complete his BS in Motion Picture Science in May of 2019. Prior to joining the CfD, his education and fieldwork included image processing for display and camera calibration and technical analysis.

Within the CfD, his involvement has been on the Cosmic Ray Damaged Image Repair (CRDIR) project, performing bug fixing and feature additions. His imaging science background helps in identifying and solving image-processing problems for the preservation of data integrity. Current contributions include redesigning the GUI to be more user friendly and navigable, alongside extensive bug testing, identification, and problem addressing for image quality output related issues within the application. Presently he is iterating through implementations of potential solutions for an image processing bug related to raw image outputs, this is in addition to continuing development and simplification of the GUI together with user feedback (Figure 41). Upon completion this summer, CRDIR will be available for use to repair images taken in outer space, where camera sensor photosites can be damaged by the impact of high-energy particles that would normally be filtered out by the atmosphere.

Figure 41. The old graphical user interface (left) was modernized and streamlined (right) to make a new interface for CRDIR.

External Funding and Collaborating Partners

CfD external funding last year was approximately $2.5M. Figure 42 shows funding per year since the inception of the Rochester Imaging Detector Laboratory in 2006, and continuing through the period after the CfD was established. A breakdown of current grants and contracts are on the following pages.

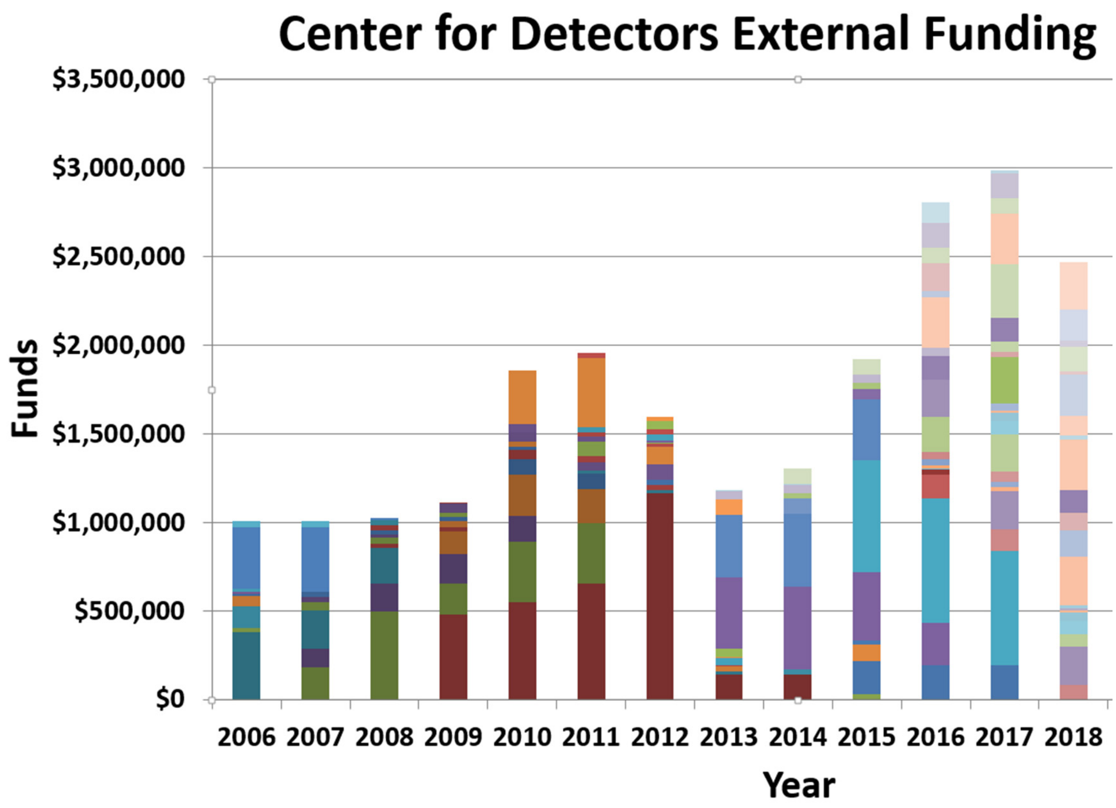


Figure 42. Over $22M in research funding has been awarded since the Center for Detectors inception in 2006. The largest contributions are from the Moore Foundation, United States Air Force, SUNY Research Foundation, and NASA. Each color in the bar chart above represents a unique research program and budget. Most projects have budgets that span multiple years.

Grants and Contracts - New

Title	Funding Source	Dates	Amount
CAREER: Development of High-Efficiency Ultraviolet Optoelectronics: Physics and Novel Device	NSF	3/15/2018-2/28/2023	$500,145
Development of Digital Micromirror Devices for Far-UV Applications	NASA	1/1/2018-12/31/2019	$224,421
Concept Study Report Preparation for SPHEREx MIDEX Phase A	NASA/JPL	2/15/2018-9/30/2018	$33,035

Title	Funding Source	Dates	Amount
Probing the History of Structure Formation through Intensity Mapping of the Near-Infrared Extragalactic Background Light	NASA	9/20/2017-9/19/2018	$39,990
Collaborative Research: SOAR/SAM Multi Object Spectrograph (SAMOS)	NSF/JHU	8/17/2017-8/31/2019	$66,930
Development of Quantum Dot Coated Detector Arrays	Thermo Fisher	7/1/2017-6/30/2018	$18,000
Development of Quantum Dot Coated Detector Arrays	NYSTAR/UR	7/1/2017-6/30/2018	$9,000
Developing the THz detector technology for inspection applications	Harris	7/1/2017-6/30/2018	$60,000
Developing the THz detector technology for inspection applications	NYSTAR/UR	7/1/2017-6/30/18	$30,000
TAP Process Development 2018	USAF/Research Foundation of SUNY	1/1/2018-5/31/2019	$265,033
TAP Process Development 2018- EVT	USAF/Research Foundation of SUNY	1/1/2018-5/31/2019	$233,456
Future Leaders in Integrated Photonics (FLIP)	D.O.D., Dept of the Air Force, Materiel Command/ Research Foundation of SUNY	4/4/2018-12/31/2018	$17,480
DURIP - Equipment for Silicon Photonics Research	D.O.D., Dept of the Air Force, Materiel Command	11/1/2017-10/31/2018	$178,236

Grants and Contracts - Ongoing

Title	Funding Source	Dates	Amount
EAGER: TDM solar cells: Bifacial III-V nanowire array on Si tandem junctions solar cells	NSF	5/1/2017-4/30/2019	$299,808
Cosmic Dawn Intensity Mapper	NASA/Caltech	4/17201/-8/31/2018	$39,143
Air Force STTR Phase 1 AF16-AT01: "Wafer-Level Electronic-Photonic Co-Packaging"	USAF/hase Sensitive Innovations Inc.	11/15/2016-8/14/2017	$49,030
MRI: Acquisition of an Inductively Coupled Plasma Reactive Ion Etching System for Research and Education in Nanophotonics, Nanoelectronics and NanoBio Devices	NSF	9/1/2016-8/31/2017	$305,000
TAP Process Development 2017 (Rochester Hub)	USAF/SUNYRF	1/1/2017-5/31/2019	$262,573

Title	Funding Source	Dates	Amount
AIM Academy Photonic Integrated Circuit Design and Test Education Curricula	USAF/Research Foundation of SUNY	1/1/2017-10/31/2018	$136,435
OVPR (GWBC 2016) - A Data Analysis Pipeline Simulator for a Millimeter-Wavelength Imaging Spectrometer	RIT	5/1/2016-8/31/2017	$5,000
OVPR (GWBC 2016) - Selective Area Epitaxy of III-V Nanocrystals on Graphene and MoS2 for Flexible Optoelectronics Application	RIT	5/1/2016-8/31/2017	$5,000
Understanding and Engineering Valence Band Structures of III-Nitride Semiconductors for High-Efficiency Ultraviolet Lasers and Emitters	D.O.D., Dept. of the Navy, Office of the Chief of Naval Research	06/1/2016-5/31/2019	$260,100
A Cryogenic Optical Camera for Attitude Control of Low-Temperature Sub-Orbital Payloads	NASA	05/9/2016-05/8/2018	$199,534
Multi-Color Anisotropy Measurements of Cosmic Near-Infrared Extragalactic Background Light with CIBER2	NASA/CALTECH	05/2/2016-05/1/2021	$127,416
Integrated Quantum Photonics for Photon-Ion Entanglement	USAF	03/14/2016-03/13/2019	$850,000
Measuring the Pixel Response Function of Kepler CCDs to Improve the Kepler Database.	NASA	02/17/2016-02/16/2018	$246,920
A Photon counting Imaging Detector for NASA Exoplanet Mission	NASA	02/10/2016-08/31/2018	$133,000
Phase II: New Infrared Detectors for Astrophysics	NSF	09/15/2015-08/31/2018	$1,983,212
TAP Process Development 2018	USAF/Research Foundation of SUNY	1/1/2017-5/31/2018	$262,573
The Development of Digital Micromirror Devices for use in Space	NASA	05/19/2014-05/18/2018	$565,275
Quantum optical resonators: a building block for quantum computing and sensing systems	NSF	08/1/2014-07/31/2018	$349,789
Quantum Silicon Photonics Measurement System	D.O.D., Dept. of the Air Force, Materiel Command	9/15/2016-9/14/2017	$276,475

Grants and Contracts - Completed within the Past Year

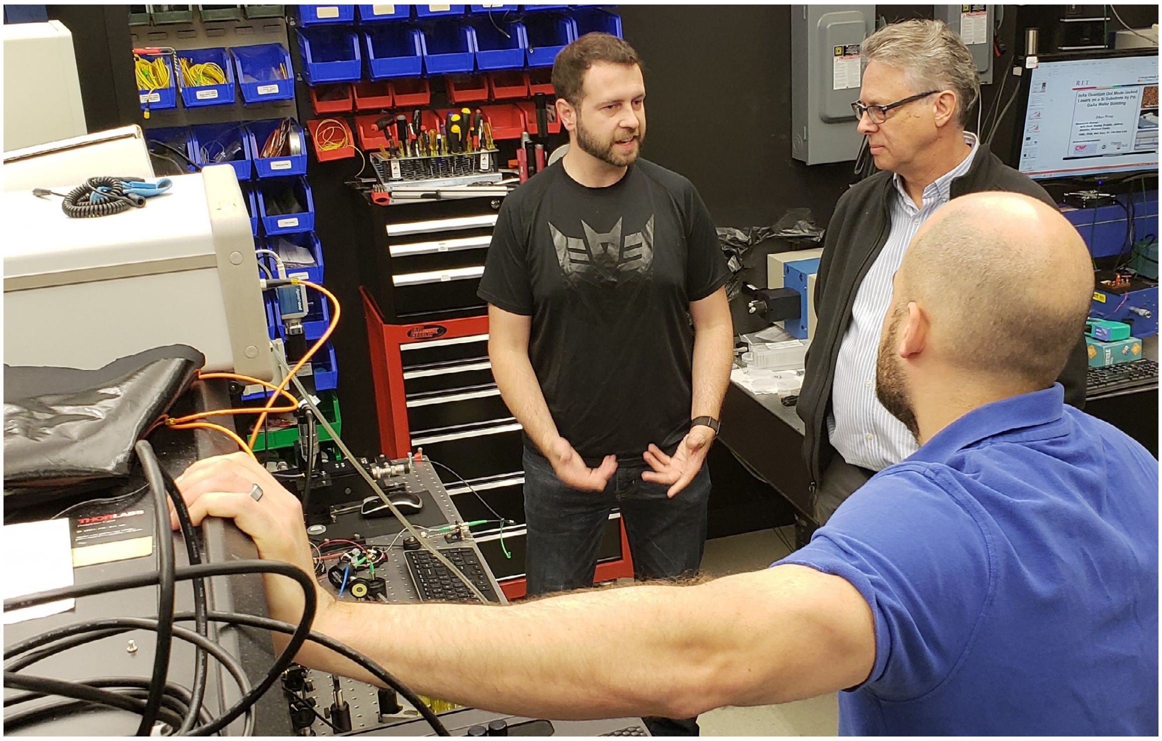
Title	Funding Source	Dates	Amount
Enhancing the UV/VUV/X-ray sensitivity of CMOS image sensors	Thermo Fisher	07/01/2016-06/30/2017	$18,000
THz Modeling and Testing	Harris Corporation	07/01/2016-06/30/2017	$60,000
THz Modeling and Testing	NYSTAR/UR-CEIS	07/01/2016-06/30/2017	$30,000
Enhancing the UV/VUV/X-ray sensitivity of CMOS image sensors	NYSTAR/UR-CEIS	07/01/2016-06/30/2017	$4,500
Integrated Photonics Education at RIT	D.O.D., Dept. of the Air Force, Materiel Command/ Research Foundation of SUNY	1/16/2016-6/30/2017	$155,026

Collaborating Partners

The CfD collaborates extensively with a broad range of organizations, including other academic institutions, government agencies, and industry leaders. Some examples are, Caltech, Cornell University, University of Rochester, NASA, NSF, Thermo Fisher Scientific, Raytheon Vision Systems and Precision Optical Transceivers. The vision of the CfD is to be a global leader in realizing and deploying ideal detectors and associated systems, which requires the support of brilliant engineers, passionate philanthropists, and truly inspired industrial partners. Our mission requires a team effort, distributed across several organizations, each with its own excellent expertise and often-significant facilities developed over decades of past projects.

Because of our collaborative approach, and the centrality of student involvement in all of our projects, CfD students benefit from the exposure to a wide range of research and development environments. This is consistent with another major goal of the CfD to train students through deeply immersive work with authentic externally funded research that defines the cutting edge of what is possible. Some students have the opportunity to visit partner organizations for extended periods. This training and preparation in the CfD helps students launch their careers after graduation.

Universities			
University of Rochester	Columbia University	SUNY Polytechnic Institute	Caltech
Johns Hopkins University	The University of New Mexico	UC Irvine University of California	University of Pittsburgh
Gordon and Betty Moore Foundation	University of Hawaii Institute for Astronomy	NYSTAR	Leland Stanford Junior University 1891
National Research Laboratories			
National Optical Astronomy Observatory	NASA	NSF	JPL
Office of Science U.S. Department of Energy	MIT Lincoln Laboratory	Marshall Space Flight Center	LSST
CSIC	Sandia National Laboratories	Department of Energy United States of America	Space Telescope Science Institute
Berkeley Lab	SNAP	Spitzer Space Telescope	SLAC
Industry			
Precision Optical Transceivers	Raytheon	AIM photonics	Thermo Scientific
Teledyne Scientific & Imaging, LLC A Teledyne Technologies Company	BAE Systems	Kodak	ON Semiconductor®
Ball	Harris®	New York Photonics Photonics Rochester	Infotonics technology center inc



Communication

COMMUNICATION

In the News

Newer Horizons: Scientists Pitch Pluto Probe as a Unique Deep-Space Telescope

Published March 12, 2018
By John Wenz, Scientific American

A maverick group of astronomers is proposing to radically reshape one of NASA's most successful missions in the modern era, the New Horizons probe that flew by Pluto in 2015 and is now continuing its voyage into the depths of the outer solar system.

Figure 43. An artist's depiction of New Horizons' planned late-2019 encounter with 2014 MU69, a small object well beyond the orbit of Pluto. A new proposal suggests that New Horizons could be repurposed to become a novel space telescope after this encounter. Credit: NASA, JHUAPL and SwRI

The group's paper describing their proposal, submitted to the *Publications of the Astronomical Society of the Pacific* and available as a preprint, suggests that before its fuel is spent and some of the systems are shut down to conserve power, New Horizons should be repurposed as a space telescope that can take advantage of the near-lightless conditions in the outer solar system to study stars, galaxies and more.

According to the paper's lead author Michael Zemcov, an astrophysicist at the Rochester Institute of Technology, the idea is largely meant to "catalyze the discussion." At the very least, some members of the New Horizons team approached him to try to incorporate the idea into an upcoming mission review. (Only one of the paper's co-authors is part of the New Horizons mission.)

The plan calls for utilizing the Pluto probe's eight-inch telescope, called the Long Range Reconnaissance Imager (LORRI), to peer at distant, dim objects beyond the solar system's boundaries. LORRI, the group says, could be used to support NASA's upcoming Transiting Exoplanet Survey Satellite (TESS), a planet-hunting space telescope launching in April.

Co-author Diana Dragomir, an MIT planetary scientist who works on TESS, says this mission will need all the backup help it can get. That is because it is set to find tens of thousands of candidate planets—many of which will require time-consuming independent confirmation using other telescopes.

Beyond boosting exoplanet research, New Horizons could also use its ultraviolet and infrared sensors to study the early universe. Whereas the cosmic microwave background, an information-packed afterglow of the big bang, is perhaps the most well known, there are also ultraviolet and infrared backgrounds that come from stars and active galaxies lighting up cosmic dust in a faint, universe-spanning glow. This could provide insights into how the early universe came together. "The further you get out of the solar system, the more you can do these kind of observations," says Michele Bannister, a planetary scientist at Queen's University Belfast who was not involved in the study. She points out one NASA spacecraft—Deep Impact, which studied Comet Tempel 1 in 2005—was later retooled into a new mission dubbed "EPOXI" in order to assist with exoplanet hunts.

Reality Check

So how realistic is the group's proposal?

"It's really an issue of logistics and timing, and making sure the resources are available and we're doing nothing to put the mission at risk," Zemcov says. Convincing others there's no risk involved may be a tall order, however.

New Horizon's extended mission after Pluto involves flying by an ancient remnant from the solar system's birth, a chunk of rock and ice known as 2014 MU69. After that encounter, the craft will transmit its data to Earth—which, due to the immense distances, will take about two years to completely trickle back home.

After MU69 the craft will be low on propellant—less than a quarter of a tank. That could be enough to pursue a third flyby target during a second mission extension, as many senior New Horizons team members would prefer. But that encounter—plus keeping the spacecraft pointed at Earth for the subsequent data transmission—would probably use most if not all of the remaining fuel.

Those preexisting plans—plus the fundamental impracticalities of efficiently controlling and getting data from a telescope at the edge of the solar system—could crowd out Zemcov and company's proposal. "These types of proposals are generated by the dozens, if not hundreds, so it's not uncommon to see them come up and then go nowhere," says Jason Callahan, a space policy advisor at The Planetary Society.

Another factor is funding. NASA's spending is highly compartmentalized to protect its top-priority programs from cannibalizing one another—money for astrophysics, for example, is considered separately from funding for planetary science. But the system is flexible—some would say vulnerable—because Congress ultimately defines the details of the space agency's budget.

There is some precedent for thinking outside of these budgetary boxes—EPOXI, for instance, although a planetary science mission like New Horizons, performed its astrophysics observations during an otherwise inactive cruise phase. Those observations were funded by NASA's planetary science budget partly for that reason. And other missions have entirely switched budget lines, Callahan says, such as the Voyager 1 and 2 probes, which were moved from a planetary budget into a heliophysics one after their encounters with the outer planets were concluded. But "this is sort of a different animal altogether," Callahan says. "This is a science team asking to use another science team's mission at the end of its extended mission."

Mission Impossible?

To have any realistic chance of moving forward, the proposal to use New Horizons as an astrophysics platform must pass muster with the mission's principal investigator, Alan Stern, a planetary scientist at the Southwest Research Institute in Boulder, Colo. Callahan, for one, is doubtful that can happen, even though the proposal has tacitly received modest support from some members of the New Horizons team. "Alan Stern is never going to be done with New Horizons until the day he dies—so if he's not down with it, it won't happen," Callahan says. Stern drafted his first proposals for a Pluto mission in the 1980s, and faced repeated setbacks before New Horizons finally launched in 2005—making this, in many ways, his life's work.

Stern, for his part, has already stated in a tweet there is simply “no fuel, no money” for such a radical repurposing of his cherished mission.

In the end, the push to make New Horizons the first truly far-out space telescope, like many extended mission concepts, may never see the light of day—or the pitch-black cosmic vista of the outer solar system. “This idea has been around in the community for years and years but the problem is opportunity,” Zemcov says. For now, as New Horizons continues its journey beyond Pluto, that opportunity is slipping further out of reach.

RIT researchers improve fabrication process of nano-structures for electronic devices

Published March 20, 2018
By Michelle Cometa, RIT University News

Figure 44. (top) Semiconductor devices are created on wafers through a multi-step process to coat, remove or pattern conductive materials. Dr. Parsian Mohseni (bottom left) and Thomas Wilhelm (bottom right) participated in this research detailed in the article below.

Researchers at RIT have found a more efficient fabricating process to produce semiconductors used in today's electronic devices. They also confirmed that materials other than silicon can be used successfully in the development process that could increase performance of electronic devices. This fabrication process—the I-MacEtch, or inverse metal-assisted chemical etching method—can help meet the growing demand for more powerful and reliable nano-technologies needed for solar cells, smartphones, telecommunications grids and new applications in photonics and quantum computing.

"What is novel about our work is that for the first time we are looking at applying I-MacEtch processing to indium-gallium-phosphide materials. I-MacEtch is an alternative to two conventional approaches and is a technique that has been used in the field—but the materials that have been explored are fairly limited," said Parsian Mohseni, assistant professor of microsystems engineering in RIT's Kate Gleason College of Engineering. He is also director of the EINS Laboratory at the university.

Demands for improved computer processing power have led researchers to explore both new processes and other materials beyond silicon to produce electronic components, Mohseni explained. The I-MacEtch process combines the benefits of two traditional methods—wet etching and reactive ion etching, or REI. Indium-gallium-phosphide is one of several materials being tested to complement silicon as a means to improve current capacity of semiconductor processing.

"This is a very well-known material and has applications in the electronics and solar cell industries," he said. "We are not re-inventing the wheel; we are establishing new protocols for treating the existing material that is more cost effective, and a more sustainable process."

Semiconductor devices are created on wafers through a multi-step process to coat, remove or pattern conductive materials. Traditional processes are wet etch, where a sample with blocked aspects is immersed in an acid bath to remove substances, and reactive ion etching, where ions bombard exposed surfaces on the wafer to change its chemical properties and remove materials in those exposed regions. Both have been used to develop the intricate electronic patterns on circuits and use silicon as a foundation for this type of patterning. Improving patterning methods by I-MacEtch could mean reducing fabrication complexity of various photonic and electronic devices.

Researchers and semiconductor fabrication scientists have been using MacEtch extensively for processing silicon. At the same time, assessments of other materials in the III-V range of individual elements that may be conducive to this same type of fabrication with similar advantages are underway. In his research, Mohseni is also looking at different alloys of those III-V materials, namely the ternary alloys such as indium-gallium-phosphide (InGaP).

The research detailed in the upcoming issue of the American Chemical Society's *Applied Materials and Interfaces* journal highlights how the nanofabrication methodology was applied to InGaP and how it can impact the processing of device applications and generation of high aspect ratio and nano-scale semiconductor features, said Thomas Wilhelm, a microsystems engineering doctoral student and first-author of the paper. The novel processing method can be significant in the development of ordered arrays of high aspect ratio structures such as nanowires.

For solar cells, the goal is to minimize the cost-to-power-produced ratio, and if it is possible to lower the cost of making the cell, and increasing the efficiency of it, this improves the device overall. Exploring new methods of fabricating the existing, relevant materials in a way that allows for faster, less expensive and more controlled processing by combining the benefits of wet etching and RIE has been the focus of Mohseni's work. The improved process means avoiding expensive, bulky, hazardous processing methods.

“We are using a simple benchtop set up and we end up with very similar structures; in fact, one can argue that they are higher in quality than the structures that we can generate with RIE for a fraction of the cost and with less time, less steps throughout, without the higher temperature conditions or expensive instrumentation,” he said.

Nobody knows how these baby stars got so close to our black hole

Published August 30, 2017
By Leah Crane, New Scientist

Nobody knows how these baby stars got so close to our black hole

A SWARM of baby stars live just a fraction of a light year from our galaxy’s central supermassive black hole. But no one can explain how they ended up so close in their short lifetimes.

Figure 45. The image shows the region of the Galactic center that contains the baby stars near the supermassive black hole. Credit - NASA/CXC/JPL-Caltech/ESA-STSCI/Science Photo Library

Stars form by coalescing out of a cloud of dust and gas. But this can’t happen close to the Milky Way’s centre as the gravity from the supermassive black hole rips apart nearby clouds before any stars can grow.

“These stars are so close to the black hole that no formation mechanism could work there, so you need some time to bring them in from somewhere else,” says Maryam Habibi at the Max Planck Institute for Extraterrestrial Physics in Garching, Germany.

Previous explanations had suggested that the stars might not be young after all, but old ones in disguise, giving them more time to move into position. They could appear younger thanks to mergers with other stars, tidal heating or by having their outer envelopes of gas stripped away.

To investigate further, Habibi and her colleagues took a closer look at the stars. Since they are almost 25,000 light years away and too dim to examine in visible wavelengths, it is difficult to get any detailed information about them. To get around this, Habibi’s team looked at 12 years of data from the infrared portion of the stars’ light.

The team found that the stars have masses between 8 and 14 times that of the sun, have bulk temperatures ranging from 20,700 to 28,200°C – more than three times as hot as the sun – and rotate at 60 to 170 kilometres per second at the equator.

The stars are also far younger than the sun. By comparing their observations with models of star evolution, the researchers found that the stars are less than 15 million years old (arxiv.org/abs/1708.06353). This rules out the possibility that they are older than they look. In comparison, the sun is about 4.5 billion years old.

"There's very little wiggle room now for these to be anything other than garden-variety massive stars," says Don Figer at the Rochester Institute of Technology in New York. "The problem is that they're in a very odd place."

"It's still not clear whether they formed outside the danger zone and wandered in or if they formed there"

One previous idea for how they got so close to the galaxy's supermassive black hole is that they formed in binary systems much further out in the galaxy. Then, when the pair of stars was disrupted by a black hole or other massive object, one shot away from the centre of the galaxy and one shot towards it and was trapped in orbit.

That process would require the stars to travel for a long time toward the galaxy's centre, however – potentially longer than their current ages. "I was hoping that maybe the ages would be older, so we could solve this by saying that these stars are old and there's more time to bring them in," says Habibi.

Instead, the stars' youth implies that they must have formed in a kind of middle ground closer in, possibly in a disc of stars and dust that orbits just a few light years from the black hole. If they started there, they could have migrated even further inward as drag from the material in the disc slowed down their orbital speed.

Even that process might take too long, though. "It's still not clear whether they formed outside of the danger zone and then wandered in or whether they actually formed in the danger zone," says Figer. While the colossal gravitational pull of the supermassive black hole makes it unlikely that the stars could have formed where they are, Figer says that it might be possible.

"This is presenting a paradox," says Habibi. "We might have to come up with a new theory to answer how these stars at these young ages could get there."

This article appeared in print under the headline "Young stars live too close to our galaxy's black hole"

RIT astrophysics PhD student wins competitive NASA Fellowship

Published August 16, 2017
By Susan Gawlowicz, RIT University News

Rochester Institute of Technology graduate student Chi Nguyen was selected for a NASA Earth and Space Science Fellowship in Astrophysics Research.

Nguyen, originally from Vietnam, is a PhD. student in RIT's astrophysical sciences and technology program. She is one of eight fellowship recipients selected from 141 applicants to the Astrophysics Science Research Program, a division of the NASA Earth and Space Science Fellowship Program.

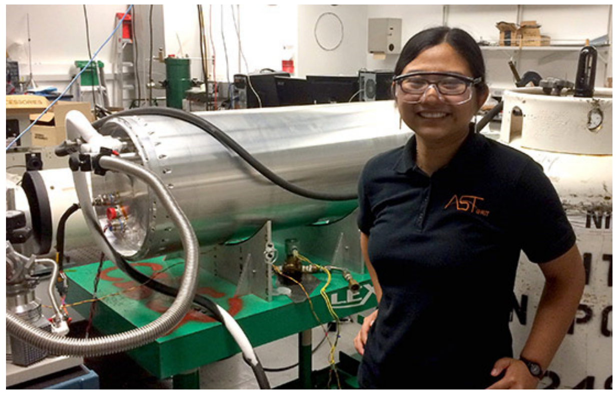


Figure 46. Chi Nguyen, a PhD student in RIT's astrophysical sciences and technology program, won a NASA Earth and Space Science Fellowship. She is collaborating on a Caltech-led experiment to measure light from the early universe. Nguyen is shown here with the Cosmic Infrared Background ExpeRiment 2 at Caltech.

The NASA fellowship carries a $45,000 award, including a student stipend and funding for student- and university expenses. It will support Nguyen's continued research investigating how astronomical structures like galaxies and stars formed after the Big Bang.

Nguyen and Michael Zemcov, assistant professor in RIT's School of Physics and Astronomy, use an observational technique known as intensity mapping to build a picture of astronomical objects in the early universe. Distribution and size of structures can be inferred by studying fluctuations of light and multiwavelength data in the cosmic infrared background—the historical record of light from ancient stars and galaxies that makes up a portion of all the light in the universe.

"Because intensity mapping uses the ensemble of light from all galaxies [extragalactic background light], rather than individual ones, this technique is faster than source surveys—where you have to search and count every galaxy—and is more powerful at detecting very faint signals at large distances," Nguyen said.

Nguyen and Zemcov are members of RIT's Center for Detectors and the Future Photon Initiative. Through their collaboration, Nguyen spent the summer at Caltech working on the Cosmic Infrared Background ExpeRiment 2. Zemcov is a co-PI of the Caltech-led CIBER-2 project. The experiment measures light in the cosmic infrared background from a rocket launched above the Earth's atmosphere. Short flights in a sounding rocket allow the CIBER 2 instruments—a small telescope and multiple near-infrared cameras—to collect information unobscured by the atmosphere's brightness.

"I am designing various sub-systems like the light baffles which will prevent light from the surrounding environments from getting into the telescope during flight, and a star tracker that will tell us where the telescope is pointing on the sky," Nguyen said. "I am also assembling the parts we already fabricated into the rocket skin and characterizing their performances."

This includes a forward suspension system that connects the telescope and optics to the rocket skin and a system to filter out unwanted thermal light during lab tests, she said.

The NASA Earth and Space Science Fellowship focuses on the four research programs of the Science Mission Directorate: astrophysics, earth science, heliophysics and planetary science. The four science divisions received a total of 764 applications this year. The fellowship program is designed to ensure continued training of a highly skilled workforce in disciplines specific to NASA's objectives.

Proposed astrophysics mission to conduct the first infrared spectral survey of the entire sky

Published August 28, 2017
By Tomasz Nowakowski, Astrowatch.net

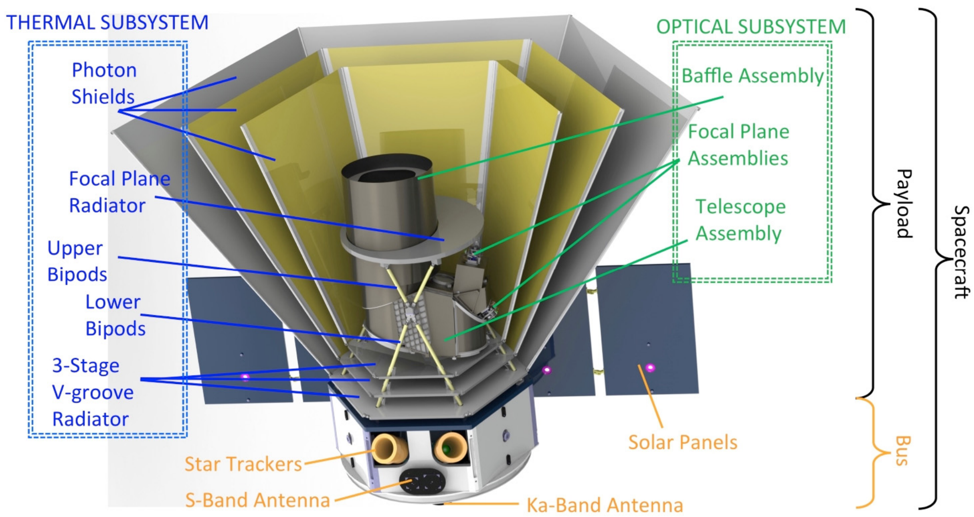


Figure 47. The image shows the design of SPHEREx. Credit: NASA.

NASA has recently chosen six proposed astrophysics mission for concept studies. Among them is the Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer, or SPHEREx, which aims to unlock the mysteries of the universe by performing the first all-sky spectral survey.

If selected for construction and launch, the survey provided by the SPHEREx spacecraft could provide crucial insights into the origin and evolution of galaxies, and could help scientists explore whether planets around other stars might harbor life.

"SPHEREx will produce the first infrared spectral survey of the entire sky. This survey will have broad applications in astronomy, providing rich spectra of galaxies, quasars, stars, clusters and our galaxy. Following the wide usage of previous all-sky surveys like the Infrared Astronomical Satellite (IRAS) and the Wide-field Infrared Survey Explorer (WISE), SPHEREx will have a lasting value for the astronomy community," James Bock, Principal Investigator of SPHEREx at the California Institute of Technology (Caltech), told Astrowatch.net.

SPHEREx will be based on a small satellite bus fitted with star trackers, S and Ka-Band antennas and solar panels. The spacecraft will carry a scientific payload up to 69 kilograms, including a telescope for its observation purposes. It will also have photon shields designed to protect the payload from radiation from the sun and Earth.

The mission managers emphasize that the spacecraft will have a simple and robust design that maximizes spectral throughput and efficiency. It will have no moving parts except for a sunshield and aperture cover that will be deployed only once.

The optical payload of the SPHEREx mission will be a 20-centimeter, all-aluminum telescope with a wide 3.5°×7° field of view, imaged onto four 2k×2k HgCdTe detector arrays. This imaging system will allow SPHEREx to obtain spectra through multiple exposures, placing a given source at multiple positions in the field of view, where it will be measured at multiple wavelengths by repointing the spacecraft.

"With multiple wavelengths, SPHEREx can assess the light production from all galaxy populations, including the first generation of galaxies formed from primordial material," Bock said.

He said that SPHEREx is designed to address three core science themes. Firstly, it will search for a signature of inflation called "non-Gaussianity," a signature of multi-field models of inflation.

"SPHEREx probes inflation by making a large volume survey of galaxies specializing in lower redshifts than Euclid," Bock noted.

Secondly, the mission will survey water and biogenic ices in the interstellar medium. Given that the bulk of water in the dense molecular clouds that seed star formation is in the form of ice on interstellar dust grains, scientists are particularly interested in how it gets to forming protoplanetary systems.

"SPHEREx will measure the abundances of water and other biogenic ices throughout the early phases of star formation, from dense molecular clouds to young stars with protoplanetary disks," Bock said.

Finally, SPHEREx will study the history of galaxy formation by mapping large-scale clustering fluctuations in two deep survey fields located at the ecliptic poles. According to Bock, the clustering signal results from galaxies tracing dark matter, and scales with the total light production.

SPHEREx is expected to operate in space for 25 months. During its nominal lifetime, it should map the entire sky four times. The data provided by the spacecraft could then be used by the scientific community worldwide for many investigations and studies, yielding new results and discoveries.

"We can also look forward to many discoveries by the astronomy community using the all-sky spectral survey archive that we cannot anticipate now," Bock said.

He hopes that SPHEREx could provide some important hints into the origin of the universe, improving our knowledge about its birth and evolution. For instance, there is compelling evidence that the birth of the universe is intimately associated with inflation, a violent exponential expansion. While the basic idea of inflation has passed multiple observational tests, the physics that drive inflation are mysterious, and probably rooted in exotic physics at high energy scales beyond the reach of the standard model in particle physics.

"Yet nature offers ways to constrain inflationary physics. Non-Gaussianity is characteristic of a class of inflationary models with multiple fields instead of a single field. SPHEREx will improve the errors on non-Gaussianity by more than a factor of 10 to distinguish these two scenarios," Bock concluded.

The SPHEREx mission is currently in the initial phase of studies known as "Phase A," lasting nine months. After this phase of concept studies and detailed evaluations, NASA will decide by 2019 if the mission should be developed and launched into space. The earliest launch date is currently set for 2022.

AIM-ing up: Student-researchers help build the photonics ecosystem

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By Michelle Cometa, RIT Athenaeum

Figure 48. (left) Sanjna Lakshminarayanamurthy, Tayler Swanson and Thomas Kilmer discuss building prototype photonic devices in a course about manufacturing photonics manufacturing processes. It will be one of the first modules for workforce development programming through the AIM Academy, the educational arm of AIM Photonics. (right) Alexandria Cervantes presented research about communication skills needed in the photonics and optics industry at this summer's Undergraduate Research Symposium.

Rochester is making an impact in photonics manufacturing, and RIT is playing a central role as a key partner in AIM Photonics, a national manufacturing initiative expected to stimulate economic development and global competitiveness.

Photonics is an intricate science about harnessing the power of light. RIT's numerous experts are contributing to photonic device manufacturing, industry assessment to improve workforce training and education, and device packaging and assembly solutions—all critical areas necessary for the growing photonics ecosystem.

RIT students are a big part of that system, creating photonics devices and solutions in classes and through research projects that will also become foundational materials to help train others for an industry expected to transform manufacturing.

"Photonics is the future," said Sanjna Lakshminarayanamurthy, a microelectronic engineering graduate student from India. "I do live in the present, but we need to have an eye for the future. I know I can contribute; I felt this work would bring out the best in me."

Lakshminarayanamurthy was one of 20 students taking Photonic Integrated Circuits, an upper-level course, delivered by Stefan Preble, associate professor of microsystems engineering in RIT's Kate Gleason College of Engineering, and several other faculty this past spring. Focused on learning the overall photonics manufacturing process, students designed a prototype photonics chip where laser light is precision-placed onto silicon.

"All the courses I took in microelectronics helped me in the clean room to work on this project. We tried different chemistries we had not used here before," she said. "Silicon photonics is just growing, and it can be compatible with the existing integrated circuit process."

Lakshminarayanamurthy helped define the preparation, etching steps and processing necessary to fabricate chips. Her project information will be integrated into the curriculum RIT is helping develop for AIM Academy, the educational arm of AIM Photonics. She will also use this knowledge in her new position as a process engineer at Global Foundries in Albany.

Once an optical fiber is aligned to a feature on silicon, the challenge becomes holding that fiber in place, protecting it during testing before packaging and assembly. Keyla Bastardo-Ramirez works closely with Martin Anslem, director of the Center for Electronics Manufacturing and Assembly, to produce solutions that ensure manufacturing processes are efficient, cost effective and sustainable. Her literature review on fiber attachment challenges, current solutions and those being developed is extensive. It also highlights the need to develop novel research programs that can eventually bridge the gap for adopting photonics integration technology in high volume production applications, she explained.

"When I started my master's degree in manufacturing and mechanical system integration, I already had experience working in manufacturing firms, not in the electronics industry, but I was already fascinated with manufacturing processes of any kind," said Bastardo-Ramirez, who is from Santo Domingo, Dominican Republic. "I would like to continue working on developing this technology in industry or in academia."

Industry will need students like Bastardo-Ramirez, who will be entering the photonics workforce once she graduates in December. Other workforce needs—from entry-level positions to research and development—are being assessed through the Photonics and Optics Workforce Education Research (POWER) group, founded by Ben Zwickl and Kelly Martin, both assistant professors in RIT's colleges of Science and Liberal Arts, respectively. POWER's research is on skills needed for photonics and optics; the group explores how academia and industry define, perceive, influence and value STEM workforce development.

Alexandria Cervantes, an undergraduate on one of several projects within the research group, did in-depth interviews with managers and new hires from local companies as well as graduate research assistants at universities. Preliminary data revealed that supplementing current technical coursework with communications and interpersonal skills can benefit all students in STEM programs to better prepare them for success in their respective fields. Cervantes' study was part of the Research Experiences for Undergraduates, where undergraduates from RIT and other national universities can apply for directed projects related to their degree programs and interests. Her work, titled, "Values and perception of communication in photonics and optics," and featured at this summer's Undergraduate Research Symposium, will become part of POWER's contribution to AIM's comprehensive workforce needs assessment studies.

Students are involved in many more projects related to photonics technology and education, and their work will reap dividends, not only for AIM Photonics, but for their own careers.

RIT's role

RIT's photonics connections include several multidisciplinary research labs and project teams:

- Future Photon Initiative: rit.edu/fpi
- Integrated Photonics Laboratory: rit.edu/nanophotonics

- Center for Electronics Packaging and Assembly: rit.edu/cema
- Photonics and Optics Workforce Education Research: rit.edu/power

About AIM Photonics

The American Institute for Manufacturing Integrated Photonics is part of the federal government's National Network for Manufacturing Innovation. Created in July 2015, it is run by a consortium of 90 university, government and corporate partners, led by SUNY Polytechnic, RIT, University of Rochester and MIT.

The Galactic Center's Mysterious Quintuplet Stars Unmasked

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By Tom Geballe, Gemini.edu

Gemini astronomer Tom Geballe describes his recent infrared spectroscopic observations of a mysterious quintuplet of stars. Each of these stars is embedded in its own cocoon of dust in a cluster of massive stars near the center of the Milky Way. The research, using the Gemini Near Infrared Spectrograph (GNIRS) and Near-infrared Integral Field Spectrometer (NIFS) on the Gemini North telescope, confirms that four of the five stars are evolved massive stars which have expelled their outer hydrogen layers, and are rapidly approaching the explosive ends of their relatively short lives. Until this work astronomers were unable to detect the stars inside the cocoons and thereby directly discern their natures. The existence of this Infrared Quintuplet is yet another illustration of the effects of high densities of massive stars in some clusters and of the extreme conditions at the very heart of our galaxy.

Most objects in the center of the Milky Way are so highly obscured from our view by intervening dust that, at wavelengths visible to the naked eye, only about one photon out of every trillion emitted by them toward the Earth actually reaches our planet. This makes it impossible to observe the copious visible light emitted by the Galactic center's stars, hot gas, the accretion disk encircling the supermassive black hole, and many other objects. The amount of obscuration decreases rapidly with increasing wavelength and thus most of our information about the Galactic center's resident objects and gas comes from infrared and radio observations.

For some Galactic center stars, those that are embedded in dust shells of their own making, the obscuration is even more extreme. Among these are five infrared-luminous objects known as the Infrared Quintuplet, located at the center of a cluster of hundreds of hot and massive stars, which has been given the name Quintuplet Cluster. The Quintuplet Cluster is only 30 parsecs (100 light years) distant from the central massive black hole at the very center of our galaxy.

The difficulty in observing these five stars is greater, not only due to the additional obscuration by their dust shells, but also because the shells are warmed by their central stars and emit bright infrared continuum radiation, diluting any infrared light from the stars themselves. The combination of these effects has made it very challenging, if not impossible, at any infrared wavelength to detect light from the interiors of the shells leaking through the dust "cocoons" and surviving the journey through the interstellar dust to our telescopes, or so it was thought. Thus, little has been learned about natures of these objects since they were discovered over a quarter century ago. The only clues were high-resolution infrared images which showed that the dust emission from two of the five resembled pinwheels. Previously this phenomenon had only been seen outside of the Galactic center, in a few objects identified as Wolf-Rayet colliding wind binaries, which are double star systems comprised of extremely luminous hot stars with massive winds.

Several years ago, while using NIFS at Gemini North for an unrelated research program I (Tom Geballe) serendipitously discovered a very faint and broad emission line due to hot helium gas near 1.7 µm in the infrared spectrum of one of the Quintuplet stars. Prompted by this, a team consisting of myself, Paco Najarro (Centro de Astrobiología, Spain), Don Figer (Rochester Institute of Technology), and Diego de la Fuente (Universidad Nacional Autónoma de México) successfully proposed to use NIFS and GNIRS to obtain sensitive spectra of all five members of the infrared Quintuplet, not only near 1.7 µm but also down to wavelengths as short as 1.0 µm. Near the short end of that wavelength range, one photon in several thousand survives the journey first through the dust cocoon and then from the Galactic center to Earth. That fraction is much larger than the one in a trillion at visible wavelengths, but is still tiny. However, the contaminating emission from the warm dust shells is greatly reduced, increasing the contrast between any spectral features emitted from inside the dust shells and the continuum emission from the shells themselves. Thus, we reasoned that with a large telescope, a sensitive spectrograph, and less dilution from the warm dust, we would be able to detect the faint light coming from within the cocoons.

Our team's spectra, recently published in The Astrophysical Journal, reveal the presence of emission lines from four of the five members of the Quintuplet, and have allowed us to definitively identify the four as containing late-type, carbon-rich Wolf-Rayet stars, as was suspected based on the earlier imaging. These massive stars are only a few million years old, but have completely lost their outer hydrogen-rich layers and probably do not have much longer to exist before exploding violently as supernovae.

This research was published in the August 20, 2017, edition of The Astrophysical Journal.

RIT scientist modifies digital cinema technology for future space missions

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By Michelle Cometa, RIT University News

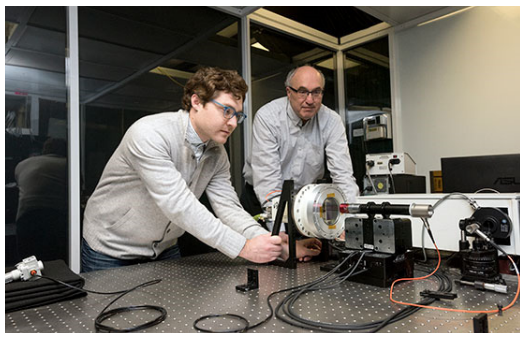


Figure 49. RIT professor Zoran Ninkov, right, and Dmitry Vorobiev '17 (astrophysical sciences and technology), a postdoctoral researcher in RIT's Chester F. Carlson Center for Imaging Science, work on a new astronomical imaging system using technology found in Texas Instruments' digital cinema projectors.

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.

RIT faculty wins National Science Foundation CAREER Award for research on novel ultraviolet photonics technology

Published May 16, 2018
By Michelle Cometa, RIT University News

Jing Zhang, a faculty member at Rochester Institute of Technology, received a prestigious CAREER award from the National Science Foundation for work to develop new, highly efficient ultraviolet light sources.

Figure 50. Above is RIT assistant professor Jing Zhang.

Devices Zhang's research group is creating have the potential to demonstrate that a deeper, fairly unrealized range of the ultraviolet (UV) light spectrum is as efficient as current near-UV used in today's LED lights. Increasing the efficiencies of optoelectronic devices, specifically using ultraviolet LED technologies, could advance important applications in photolithography, 3D printing, purification systems and a variety of sensing applications.

The challenge is, the further along the UV range, the less efficient the technology being produced; however, preliminary physics analysis and tests on device prototypes show promise, she explained.

"What I propose to do is on semiconductor-based UV optoelectronic devices, which are efficient, compact and the lifetime of the devices is very long compared to mercury-based, UV light sources," said Zhang, an assistant professor in the electrical and microelectronic engineering department in RIT's Kate Gleason College of Engineering. "Semiconductor materials are environmentally-friendly compared to mercury-based UV bulbs. That is why this new type of device we are developing is very promising—if we can deliver higher efficiencies toward those devices."

The UV light spectrum is being explored further because differing aspects react well with certain bio and chemical agents, which are beneficial for biomedical applications, Zhang continued. UV light has also been used for air and water purification systems and to cure resins for 3D printers. Advancing these technologies is becoming more important, but the efficiencies of the UV LEDs are low compared to current, visible LEDs, a mature technology that has been commercially available for more than two decades.

"Shorter wavelengths with the UV devices have efficiencies less than 10 percent, sometimes even as low as 1 percent. This is the reason why we really don't have reliable, commercially available UV LEDs based on semiconductors yet," she said, adding that the material used for current microchips for LEDs is indium gallium nitride—considered a narrow band gap material. In this new project, Zhang will explore use of aluminum gallium nitride—a much wider band gap material. It is essentially from the same family of materials—III nitrides—but with distinctly different material properties and physics.

Aluminum gallium nitride, however, is less developed because the material is more difficult to grow and often has more defects and dislocations. Zhang has been able to make inroads in this area.

RIT has considerable fabrication capabilities in its Semiconductor Manufacturing and Fabrication Laboratory, located in the engineering college. In 2016, Zhang also attained an NSF grant to acquire an ICP-RIE system—an inductively coupled plasma reactive ion etching system—equipment used to create specific structural patterns, or to expose different conductive layers on the integrated circuits found in electronic devices. Researchers are capable of fabricating prototype device in-house at RIT.

"We have already developed the fabrication process for the UV LEDs; it is already mature in our group," said Zhang, whose research expertise is in the area of III-Nitride semiconductors for photonics and energy applications. "We have developed the physics, and we have promising preliminary results on very initial UV LEDs. We are going to continue the research with these results and see how we can achieve optimized novel device structures."

Zhang's NSF award of $500,145 is for five years for "Development of high-efficiency ultraviolet optoelectronics: physics and novel device concepts." This project goal is to realize high-efficiency ultraviolet photonic devices. The Faculty Early Career Development (CAREER) Program is one of the National Science Foundation's most prestigious awards in support of early-career faculty who have the potential to serve as academic role models in research and education and to lead advances in the mission of their department or organization.

Publications

- Content, Robert, Wang, Yun, Robberto, Massimo, Barkhouser, Robert, Ninkov, Zoran, Smee, Stephen, Dickinson, Mark, Ferguson, Henry C., Hillenbrand, Lynne, Hirata, Christopher, Fraser, Wesley, Bartlett, James, Benjamin, Robert, Brinchmann, Jarle, Chary, Ranga, Cimatti, Andrea, Conroy, Charlie, Daddi, Emanuele, Donahue, Megan, Doré, Olivier, Eisenhardt, Peter, Helou, George, Kirkpatrick, J. Davy, Malhotra, Sangeeta, Moscardini, Lauro, Ressler, Michael, Rhoads, James, Rhodes, Jason, Shapley, Alice 2018, ATLAS probe for the study of galaxy evolution with 300,000,000 galaxy spectra, Proceedings of the SPIE, Volume 10698-17
- Donlon, Kevan, Ninkov, Zoran, and Baum, Stefi 2018, Point-spread Function, Ramifications and Deconvolution of a Signal Dependent Blur Kernel Due to Interpixel Capacitive Coupling, Publications of the Astronomical Society of the Pacific, 130, 074503
- Donlon, Kevan, Ninkov, Zoran, and Baum, Stefi 2018, Signal dependent interpixel capacitance in hybridized arrays: simulation, characterization, and correction, Proceedings of the SPIE, Volume 10709-117
- Duivenvoorden, S., and 30 colleagues 2018, Red, redder, reddest: SCUBA-2 imaging of colour-selected Herschel sources, Monthly Notices of the Royal Astronomical Society, 477, 1099
- Fanto, M. L., Tison, C. C., Steidle, J. A., Lu, T., Wang, Z., Mogent, N. A., Rizzo, A., Thomas, P. M., Preble, S. F., Alsing, P. M., and Englund, D. R. 2017, Integrated photon sources for quantum information science applications, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, 10442, 104420K
- Figer, Donald, Lee, Joong Y., Corrales, Elizabeth, Getty, Jonathan, Mears, Lynn, Stassinos, Erik 2018, Progress in development of SWIR HgCdTe detectors grown on silicon substrates, Proceedings of the SPIE, Volume 10709-83
- Hartensveld, M., Ooi, Y.K., Liu, C., Zhang,J. 2017,Effect of KOH Concentrations and Temperatures on Photoluminescence from Top-Down Fabricated InGaN/GaN Nanowires, 2017 MRS Fall Meeting
- Hunacek, J., and 22 colleagues 2018, Hafnium Films and Magnetic Shielding for TIME, A mm-Wavelength Spectrometer Array, Journal of Low Temperature Physics
- Hunacek, Jonathon, Bock, James C., Bradford, Matt, Butler, Victoria, Chang, Tzu-Ching, Cooray, Asantha, Crites, Abigail, Frez, Clifford, Hailey-Dunsheath, Steve, Hoscheit, Benjamin, Kim, Dae Wook, Li, Chao-Te, Marrone, Daniel, Megerian, Krikor, Moncelsi, Lorenzo, Sun, Guochao, Trumper, Isaac, Turner, Anthony, Weber, Alexis, Zemcov, Michael 2018, TES detectors and instrument design for TIME, a mm-wavelength spectrometer array, Proceedings of the SPIE, Volume 10708-25
- Kim, Junhan, Marrone, Daniel P., Beaudoin, Christopher, Carlstrom, John E., Doeleman, Sheperd S., Folkers, Thomas W., Forbes, David, Greer, Christopher H., Lauria, Eugene F., Massingill, Kyle D., Mayer, Evan, Nguyen, Chi H., Reiland, George, SooHoo, Jason, Stark, Antony A., Vertatschitsch, Laura, Weintroub, Jonathan, Young, André 2018, A VLBI receiving system for the South Pole Telescope, Proceedings of the SPIE, Volume 10708-97
- Korngut, Phillip, Bock, James J., Akeson, Rachel, Ashby, Matthew, Bleem, Lindsey, Boland, Justin, Bolton, Douglas, Bradford, Samuel, Capak, Peter, Chang, Tzu-Ching, Coffey, Andrew, Cooray, Asantha, Crill, Brendan, Doré, Olivier, Eifler, Tim, Habib, Salman, Heitmann, Katrin, Hirata, Chris, Minjin Kim, Woong-Seob Jeong, Kirkpatrick, Davy, Kowalkowski, Theresa, Krause, Elisabeth, Lisse, Carey, Mauskopf, Philip, Masters, Daniel, McGuire, James, Melnick, Gary, Nguyen, Hein, Öberg, Karin, dePutter, Roland, Purcell, Bill, Rocca, Jennifer, Runyan, Marcus, Sandstrom, Karin, Smith, Roger, Song, Yong-Seon, Stober, Jeremy, Susca, Sara, Teplitz, Harry, Tolls, Volker, Unwin,

Stephen, Werner, Michael, Rogier, Windhorst, Zemcov, Michael, Sean, Bryan, Braun, David, Feng, Cheng, Nayyeri, Hooshang, Stickley, Nathaniel, Hemmati, Shoubaneh 2018, SPHEREx: an all-sky NIR spectral survey, Proceedings of the SPIE, Volume 10698-64

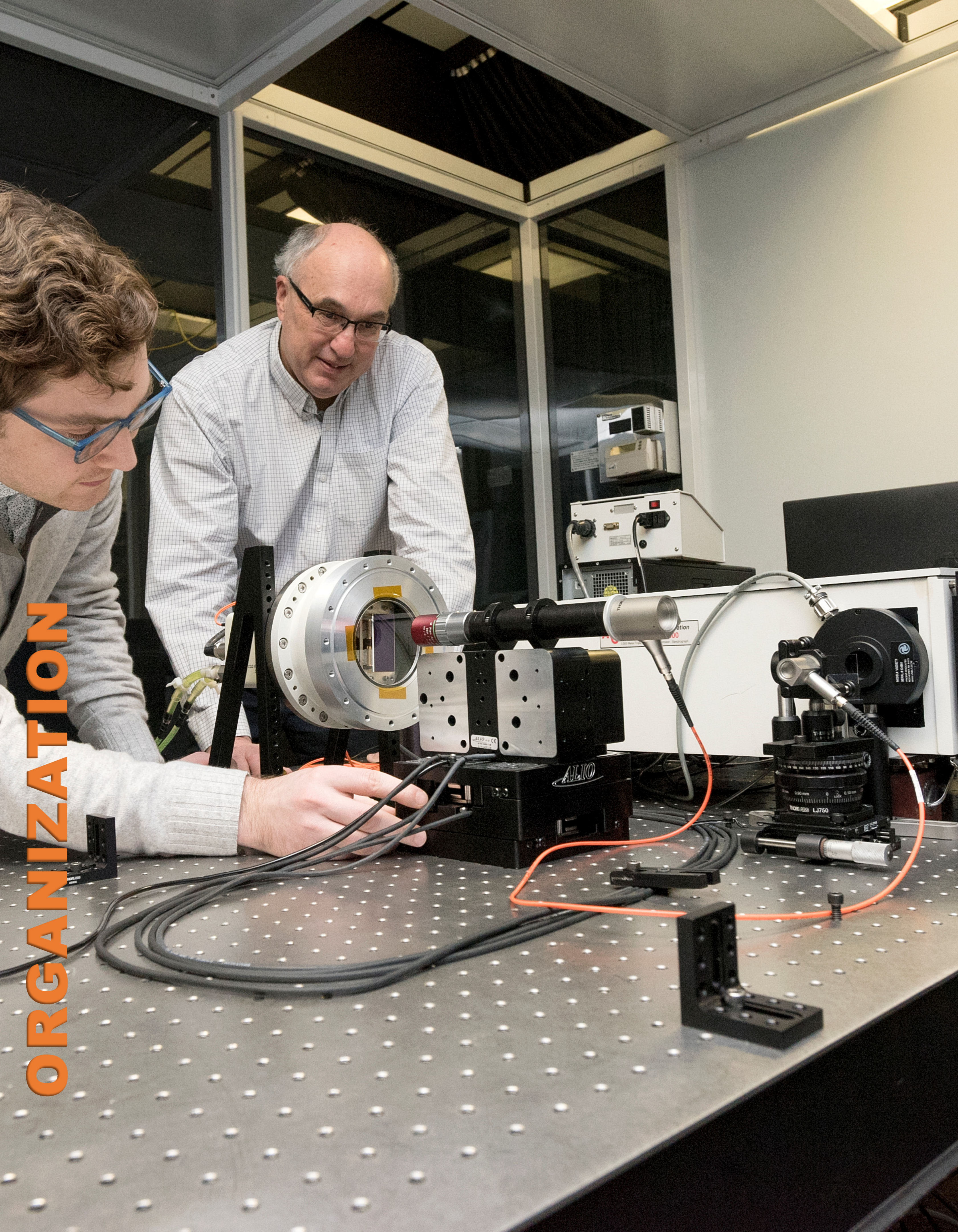
- Liu, C., Ooi, Y.K., Islam, S.M., Verma, J., Jena, D., Zhang, J. 2017, Physics and polarization characteristics of 298 nm AlN-delta-GaN quantum well ultraviolet light-emitting diodes, Applied Physics Letters 110, 071103, 9
- Liu, C., Ooi, Y.K., Islam, S.M., Xing, H., Jena, D., Zhang, J. 2018, 234 nm and 246 nm AlN-Delta-GaN quantum well deep ultraviolet light-emitting diodes, Applied Physics Letters, 2018
- Liu, C., Ooi, Y.K., Islam, S.M., Xing, H., Jena, D., Zhang, J. 2017, 246 nm AlN-delta-GaN Quantum Well Ultraviolet Light-Emitting Diode, CLEO: Science and Innovations 2017
- Liu, C., Ooi, Y.K., Islam, S.M., Xing, H., Jena, D., Zhang, J. 2017, Dominant transverse-electric polarized emission from 298-nm MBE-grown AlN-delta-GaN quantum well ultraviolet light-emitting diodes, SPIE Photonics West 2017
- Lu, Tsung-Ju, Fanto, Michael, Choi, Hyeongrak, Thomas, Paul, Steidle, Jeffrey, Mouradian, Sara, Kong, Wei, Zhu, Di, Moon, Hyowon, Berggren, Karl, Kim, Jeehwan, Soltani, Mohammad, Preble, Stefan, and Englund, Dirk 2018, Aluminum nitride integrated photonics platform for the ultraviolet to visible spectrum, Optics Express, 26, 11147
- Manzotti, A., and 62 colleagues 2017, CMB Polarization B-mode Delensing with SPTpol and Herschel, The Astrophysical Journal, 846, 45
- Messineo, M., Zhu, Q., Figer, D. F., Menten, K. M., Ivanov, V. D., Kudritzki, R.-P., and Chen, C.-H., Rosie 2017, A new sample of red supergiants in the Inner Galaxy, The Lives and Death-Throes of Massive Stars, Proceedings of the International Astronomical Union, IAU Symposium, Volume 329, pp. 425
- Messineo, M., Zhu, Q., Menten, K. M., Ivanov, V. D., Figer, D. F., Kudritzki, R.-P., and Rosie, Chen C.-H. 2018, VizieR Online Data Catalog: Observed red supergiants in the inner Galaxy (Messineo+, 2016), VizieR Online Data Catalog, 182
- Michalstrokowski, J., Dunlop, J. S., Koprowski, M. P., Cirasuolo, M., Geach, J. E., Bowler, R. A. A., Mortlock, A., Caputi, K. I., Aretxaga, I.,Arumugam, V., Chen, Chian-Chou, McLure, R. J., Birkinshaw, M., Bourne, N., Farrah, D., Ibar, E., van der Werf, P., and Zemcov, M. 2017, The SCUBA-2 Cosmology Legacy Survey: the nature of bright submm galaxies from 2 deg^2 of 850-μm imaging, Monthly Notices of the Royal Astronomical Society, 469, 492
- Najarro, F., Geballe, T. R., Figer, D. F., and de la Fuente, D. 2017, Emission Lines in the Near-infrared Spectra of the Infrared Quintuplet Stars in the Galactic Center, The Astrophysical Journal, 845, 127
- Najarro, Francisco, de La Fuente, Diego, Geballe, Tom R., Figer, Don F., and Hillier, D. John 2017, The Massive stellar Population at the Galactic Center, The Lives and Death-Throes of Massive Stars, 329, 287
- Nayyeri, H., and 21 colleagues 2018, Spitzer Observations of the North Ecliptic Pole, The Astrophysical Journal Supplement Series, 234, 38 Wang, Yun, and 28 colleagues 2018, ATLAS Probe: Exploring Frontiers in Galaxy Evolution, Cosmology, and Milky Way Science, American Astronomical Society Meeting Abstracts #231, 231, 402.01
- Nguyen, Chi H., Stewart, Benjamin, Bang, Seung-Cheol, Battle, John, Bock, James, Cooray, Asantha, Danbayashi, Kenta, DeSantiago, Ambar, Hristov, Viktor, Kojima, Tomoya, Korngut, Phillip, Kruse, Kevin, Lanz, Alicia, Lee, Dae-Hee, Liu, Lunjun, Loewenthal, Jared, Mason,Peter, Matsumoto, Toshio, Matsuura, Shuji, Ohta, Ryo, Pape, Christian, Park, Won-Kee, Patru, Dorin, Parkus,James, Sano, Kei, Takahashi, Aoi, Peryer, Mark, Takimoto, Kohji, Tsumura, Kohji, Wada, Takehiko, Wang, Shiang-Yu, Yamada, Yasuhiro, Zemcov, Michael 2018, Integration and

instrument characterization of the cosmic infrared background experiment 2 (CIBER-2), Proceedings of the SPIE, Volume 10698-156

- Nguyen, Chi, Zemcov, Michael, Cooray, Asantha, Lisse, Carey, and Poppe, Andrew 2018, The Science and Prospects of Astrophysical Observations with New Horizons, American Astronomical Society Meeting Abstracts #231, 231, 153.07
- Nikzad, Shouleh, Hennessy, John, Hoenk, Michael E., Kiessling, Alina, Bolcar, Matthew R., Figer, Donald F., Martin, Stefan, Morgan, Rhonda 2018, Solid state detectors for the Habitable Exoplanet imaging mission (HabEx) and the large UV/optical/infrared (LUVOIR) surveyor mission concepts, Proceedings of the SPIE, Volume 10699-6
- Ooi,Y.K., Chowdhury, R.R., Zhang, J.2017, Investigation of light extraction efficiency comparison of AlGaN-based deep- and mid-ultraviolet flip-chip light-emitting diodes with patterned sapphire substrate, SPIE Photonics West 2017
- Ooi,Y.K., Liu, C., Zhang,J. 2017, Analysis of Polarization-Dependent Light Extraction and Effect of Passivation Layer for 230-nm AlGaN Nanowire Light-Emitting Diodes, IEEE Photonics Journal 9 (4), 4501712
- Ooi,Y.K., Ugras, C, Liu, C., Hartensveld, M., Gandhi, S., Cormier, D., Zhang, J. 2017, Integration of 3D printed lens with InGaN light-emitting diodes with enhanced light extraction efficiency, SPIE Photonics West 2017
- Park, Won-Kee, Bang, Seung-Chul, Battle, John, Bock, James, Cooray, Asantha, Danbayashi, Kenta, DeSantiago, Ambar, Hristov, Viktor, Kojima, Tomoya, Korngut, Phillip, Lanz, Alicia,Lee, Dae-Hee, Liu, Lunjun, Loewenthal, Jared, Mason, Peter, Matsumoto, Toshio, Matsuura, Shuji, Nguyen, Chi H., Ohta, Ryo, Patru, Dorin, Peyer, Mark, Sano, Kei, Takahashi, Aoi, Takimoto, Kohji, Tsumura, Kohji, Wada, Takehiko, Wang, Shiang-Yu, Yamada, Yasuhiro, Zemcov, Michael 2018, Development of data storage system and GSE for cosmic infrared background experiment 2 (CIBER-2), Proceedings of the SPIE, Volume 10698-146
- Smee, Stephen A., Barkhouser, Robert, Harding, Albert, Hope, Stephen, Robberto, Massimo, Ninkov, Zoran, Gennaro, Mario 2018, The opto-mechanical design of SAMOS: a DMD-based spectrograph for the SOAR telescope, Proceedings of the SPIE, Volume 10702-60
- Sun, G., Moncelsi, L., Viero, M. P., Silva, M. B., Bock, J., Bradford, C. M., Chang, T.-C., Cheng, Y.-T., Cooray, A. R., Crites, A., Hailey-Dunsheath, S., Uzgil, B., Hunacek, J. R., and Zemcov, M. 2018, A Foreground Masking Strategy for [C II] Intensity Mapping Experiments Using Galaxies Selected by Stellar Mass and Redshift, The Astrophysical Journal, 856, 107
- Tison, C. C., Steidle, J. A., Fanto, M. L., Wang, Z., Mogent, N. A., Rizzo, A., Preble, S. F., and Alsing, P. M. 2017, Path to increasing the coincidence efficiency of integrated resonant photon sources, Optics Express, 25, 33088
- Travinsky, Anton, Vorobiev, Dmitry, Ninkov, Zoran, Raisanen, Alan, Quijada, Manuel A., Smee, Stephen A., Pellish, Jonathan A., Schwartz, Tim, Robberto, Massimo, Heap, Sara, Conley, Devin, Benavides, Carlos, Garcia, Nicholas, Bredl, Zach, and Yllanes, Sebastian 2017, Evaluation of digital micromirror devices for use in space-based multiobject spectrometer application, Journal of Astronomical Telescopes, Instruments, and Systems, 3, 035003
- Travinsky, Anton, Vorobiev, Dmitry, Oram, Kathleen, Nero, Gregory M., Ninkov, Zoran 2018, On-sky performance evaluation of RITMOS, a micromirror-based multi-object spectrometer, Proeceedings of the SPIE, Volume 10702-59
- Vernon, Z., Menotti, M., Tison, C. C., Steidle, J. A., Fanto, M. L., Thomas, P. M., Preble, S. F., Smith, A. M., Alsing, P. M., Liscidini, M., and Sipe, J. E. 2017, Truly unentangled photon pairs without spectral filtering, Optics Letters, 42, 3638

- Vorobiev, Dmitry and Ninkov, Zoran 2017, High-resolution two-dimensional and three-dimensional modeling of wire grid polarizers and micropolarizer arrays, Optical Engineering, 56, 113113
- Vorobiev, Dmitry V., Ninkov, Zoran, and Brock, Neal 2018, Astronomical, Polarimetry with the RIT Polarization Imaging Camera, Publications of the, Astronomical Society of the Pacific, 130, 064501
- Vorobiev, Dmitry, Ninkov, Zoran, Caldwell, Douglas, Mochnacki, Stefan 2018, Direct measurement of the intrapixel response function of the Kepler Space Telescope's CCDs, Proceedings of the SPIE, Volume 10698-193
- Vorobiev, Dmitry, Travinsky, Anton, Ninkov, Zoran, Quijada, Manuel 2018, Development of digital micromirror devices for use in the far-ultraviolet regime, Proceedings of the SPIE, Volume 10706-211
- Zemcov, Michael and SPHEREx Science Team 2018, SPHEREx: Understanding the Origin and Evolution of Galaxies Through the Extragalactic Background Light, American Astronomical Society Meeting Abstracts #231, 231, 354.24

Organization



ORGANIZATION

Personnel

Don Figer

Director, Professor

Degrees: PhD in Astronomy, 1995, UCLA; MS in Astronomy, 1992, U. Chicago; BA in Physics, Math, Astronomy, 1989, Northwestern U.

Dr. Figer is the Director of both the Center for Detectors and the Future Photon Initiative, as well as a Professor in the College of Science. Dr. Figer dedicates his research within the Center for Detectors to the development of advanced imaging detectors for cross-disciplinary applications.

Some of the major projects led by Dr. Figer over the fiscal year are New Infrared Detectors for Astrophysics, the development of an Engineering Verification Test Station in support of AIM Photonics' the Testing Assembly and Packaging (TAP) Hub, and identifying more massive stars near the Galactic center. Research interests of Dr. Figer are developing integrated sensor systems on a wafer and determining the massive star content in the Local Group of galaxies.

Dr. Figer has received numerous awards for his work, including the NYSTAR Faculty Development Award, The NASA Space Act Award, and the AURA STScI Technology and Innovation Award.

Zoran Ninkov

Professor

Degrees: PhD, Astronomy, University of British Columbia, 1986; MSC Physical Chemistry, Monash University, 1980; BSC (1st class honors), Physics, University of Western Australia, 1977.

Dr. Ninkov's scientific background includes Solid State Image Sensors, Robotic Astronomy, Planetary Searches, Astronomical Imaging, and Digital Radiography.

Dr. Ninkov's current research is focused on the development of novel two dimensional detector arrays for use in spaceborne and ground based astronomical imaging and spectroscopy, in particular polarization detectors and multi-mirror devices. Dr. Ninkov's efforts involve the design and fabrication of these devices in the RIT Micro-Electronics and Electrical Engineering Department. Other research concentrations are the development of image processing techniques for optimal analysis of two dimensional imaging array detectors (InSb, NICMOS, CCD, CID and APS arrays) astronomical image data and the study of fundamental limitations of such devices.

Dr. Ninkov also serves as the Associate Director at the C. E. K. Mees Observatory at the University of Rochester, a position he has held since 1995.

Stefan Preble

Associate Professor

Degrees: PhD, Electrical & Computer Engineering, 2007, Cornell University; BS in Electrical Engineering, 2002, Rochester Institute of Technology

Dr. Preble is Associate Professor in the College of Engineering and the lead of the Lobozzo Photonics and Optical Characterization Lab. Dr. Preble's research concentrations are Quantum Computing, Communication and Sensing, Photonics Packaging, and integrated photonics education. This research is focused on novel silicon photonic devices with the goal of realizing high performance computing, communication, and sensing systems that leverage the high speed, bandwidth, and sensitivity of light.

Dr. Preble has received numerous awards recognizing his work, including a DARPA (Defense Advanced Research Projects Agency) Young Faculty Award and an AFOSR (Air Force Office of Scientific Research) Young Investigator Award. He has numerous publications in high impact journals, such as Nature Photonics, Optics Express, Applied Physics Letters, and Physical Review Letters. He is a member of the Optical Society of America.

Jing Zhang

Assistant Professor

Degrees: PhD in Electrical and Computer Engineering, 2013, Lehigh University, BS in Electronic Science and Technology, 2009, Huazhong University of Science and Technology.

Dr. Zhang is an Assistant Professor in the College of Engineering. Dr. Zhang's research areas use III-Nitride semiconductors for photonics and energy applications. Her research interests include the pursuit of novel materials for large thermoelectric figure of merit, semiconductor Ultraviolet Light Emitting Diodes (LEDs) and lasers, as well as III-Nitride solid state lighting devices.

Dr. Zhang has worked on compound semiconductors, and gallium nitride as an emerging material system. Gallium nitride-based semiconductors are integrated into optoelectronics, such as LEDs, to power electronics for smart grid applications and power management for electric vehicles. These semiconductors find solar applications as well. She has expertise in the area of ultraviolet and visible LEDs, and in developing semiconductors for optoelectronic and electronic devices.

Dr. Zhang has published more than 22 refereed journal papers and 30 conference publications, including invited talks.

Michael Zemcov

Assistant Professor

Degrees: PhD in Physics, Cardiff University, 2006, Cardiff, United Kingdom; BS in Physics, 2003, University of British Columbia, Canada

Dr. Zemcov is an Assistant Professor in the College of Science and an experimental astrophysicist at the Future Photon Initiative and Center for Detectors. His scientific background and interests are centered on cosmological observations of the large-scale structure of the universe, and studies of fundamental physics. His expertise includes studies of the diffuse radiation in the cosmos, particularly the cosmic microwave and infrared background radiation, and the development of enabling technologies for ground-based, sub-orbital, orbital, and deep-space platforms.

Dr. Zemcov works on a number of projects, which aim to elucidate the nature of the cosmos on the largest scales and most distant times. He is also engaged in efforts to deploy CMOS devices for astronomy, develop technologies for astrophysics from the outer solar system, various large mission concept studies, and other niche cosmological and physics experiments requiring bespoke instrumentation.

Parsian K. Mohseni

Assistant Professor

Degrees: PhD in Engineering Physics, 2011, McMaster University, Canada; B.Eng. in Engineering Physics, 2005, McMaster University, Canada

Dr. Mohseni is an Assistant Professor in the College of Engineering, and Head of the Epitaxially-Integrated Nanoscale Systems Laboratory. Dr. Mohseni's research interests are cross-disciplinary, spanning the fields of solid state physics, optoelectronics, materials characterization, nano-engineering, and physical chemistry. He is interested in novel, bottom-up and top-down methods for fabrication of III-V and Si nanostructures for applications including solar cells and photodetectors.

Dr. Mohseni's research involves epitaxy of III-V semiconductors on 2-D nanosheets, and focuses on the growth of various nanostructures, including nanowires and nanofins, by metal-organic chemical vapor deposition (MOCVD) through a synthesis process known as selective area epitaxy (SAE). Additional research paths include metal-assisted chemical etching for room temperature and benchtop fabrication of flexible III-V nanostructure-based optoelectronic and photovoltaic devices.

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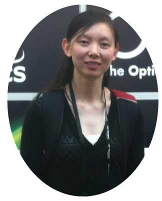

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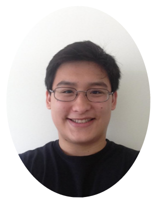

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Charter

About the Center for Detectors

The CfD designs, develops, and implements new advanced sensor technologies through collaboration with academic researchers, industry engineers, government scientists, and students. The CfD operates four laboratories and has approximately 20 funded projects to advance detectors in a broad array of applications, *e.g.*, astrophysics, biomedical imaging, Earth system science, and inter-planetary travel. Our observational astrophysics programs include studies of massive stars, massive star clusters, the Galactic center, the interstellar medium, the history of structure formation in the Universe, and cosmology.

Vision and Mission

Our Vision is to be a global leader in realizing and deploying ideal detectors and associated systems. Our Mission is to enable scientific discovery, national security, better living, and commercial innovation through the design and development of advanced photon detectors and associated technology by leveraging collaborations with students, scientists, engineers, and business partners, at academic, industrial, and national research institutions.

Goals

- Develop and implement detector technologies and material systems that enable breakthroughs in science, defense, and better living.
- Train the next generation of U.S. scientists and engineers in conducting team-based, interdisciplinary, world-class research.
- Create opportunities for faculty, students, and international leaders to advance the field of detectors and its relevant application areas.
- Grow externally supported research at RIT.
- Increase economic activity for local, regional, and national companies.

Capabilities, Equipment, and Facilities

The Center for Detectors (CfD) is located in Engineering Hall (Building 17) at the Rochester Institute of Technology. The CfD headquarters consists of 5,000 square feet of office and research laboratory space. The lab space includes the Rochester Imaging Detector Laboratory (RIDL, see Figure 51), the Laboratory for Experimental Cosmology, the Lobozzo Photonics and Optical Characterization laboratory, the Laboratory for Advanced Instrumentation Research (LAIR), and the Semiconductor Device Optical Property Measurement Laboratory.

Figure 51. The photo shows cryogenic dewars in the Rochester Imaging Detector Laboratory.

Facilities within in CfD include a permanent clean room, ESD stations, vacuum pumping systems, optical benches, flow tables, light sources, UV-IR monochromators, thermal control systems, cryogenic motion control systems, power supplies, general lab electronics, and data reduction computers. The equipment is capable of analyzing both analog and digital signals. In addition to these dedicated facilities, the CfD has access to facilities within the Semiconductor and Microsystems Fabrication Laboratory (SMFL) and other areas across the RIT campus.

The RIDL detector testing systems use four cylindrical vacuum cryogenic dewars. Each individual system uses a cryocooler that has two cooling stages: one at ~60 K (10 W) and another at ~10 K (7 W). The cold temperatures yield lower detector dark current and read noise. The systems use Lakeshore temperature controllers to sense temperatures at 10 locations within the dewars and to control heaters in the detector thermal path. This thermal control system stabilizes the detector thermal block to 400 μK RMS over timescales greater than 24 hours. The detector readout systems include an Astronomical Research Camera controller having 32 digitizing channels with 1 MHz readout speed and 16-bit readout capability, two Teledyne SIDECAR ASICs having 36 channels and readout speeds up to 5 MHz at 12-bits and 500 kHz at 16-bits, custom FPGA systems based on Altera and Xilinx parts, and a JMClarke Engineering controller with 16 readout channels and 16-bit readout designed specifically for Raytheon Vision System detectors. Figure 52 shows the electronics packages.

Figure 52. The three electronics packages used to test detectors are the Astronomical Research Camera Controller (left), JMClarke Engineering (middle), and the Teledyne SIDECAR ASIC (right).

The controllers drive signals through cable harnesses that interface with Detector Customization Circuits (DCCs) consisting of multi-layer cryogenic flex boards. The DCCs terminate in a single connecter, which then mates to the detector connector. Three-axis motorized stages provide automated lateral and piston target adjustment. Two of the dewars have a side-looking port that is useful for exposing detectors to high energy radiation beams. The RIDL also has two large integrating spheres that provide uniform and calibrated illumination from the ultraviolet through the infrared. The dewars are stationed on large optical tables that have vibration-isolation legs (Figure 53).

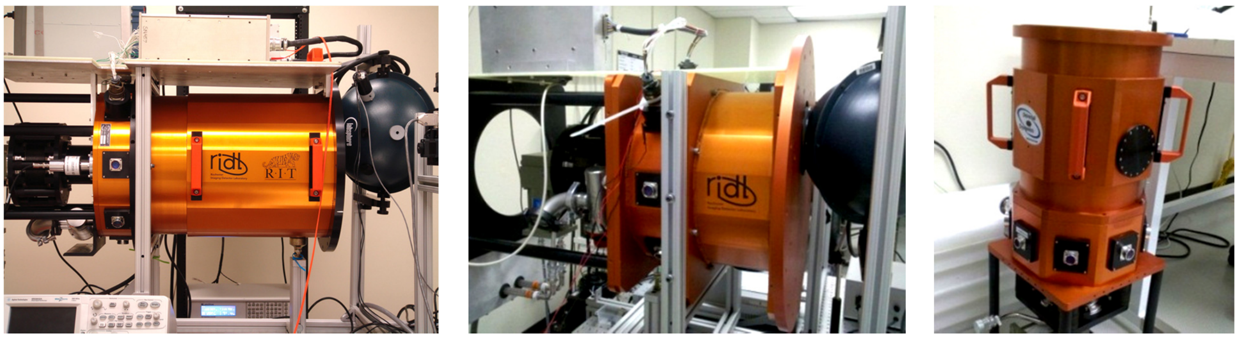

Figure 53. Detectors are evaluated in four custom dewar test systems. The fourth dewar (not pictured) is a duplicate of the one on the left.

The lab equipment also includes a PicoQuant laser for LIDAR system characterization and other testing that requires pulsed illumination. In addition, the lab has monochromators with light sources that are able to produce light ranging from the UV into the IR, with a wavelength range of 250 nm – 2500 nm. NIST-traceable calibrated photodiodes (with a wavelength range of 300 nm – 5000 nm) provide for absolute flux measurements. CfD also has a spot projector to characterize the interpixel response of the detectors, including optical and electrical crosstalk. Figure 54 shows a laser spot projection system on a 3D motorized stage that produces a small (~few µm) point source for measurements of intrapixel sensitivity.

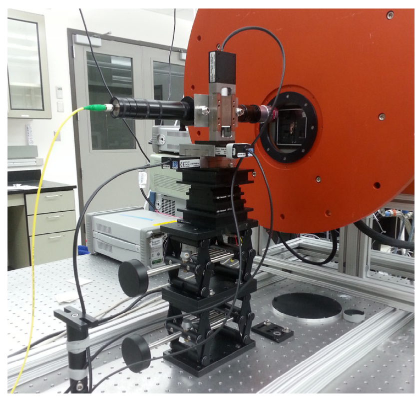

Figure 54. A laser spot projector with three-axis motion control system is used to project a small spot of light within individual pixels of detectors in order to measure the response in all regions of a pixel.

RIDL has many data acquisition and reduction computers, each with eight to twenty-four threads and up to 32 GB of memory for data acquisition, reduction, analysis and simulations. A storage server with 10 Gbps optical network connection is the primary data reduction computer; it has 50 TB of mirrored storage space. Custom software runs an automated detector test suite of experiments. The test suite accommodates a wide variety of testing parameters through the use of parameter files. A complete test suite takes a few weeks to execute and produces ~0.5 TB of data. The data reduction computers reduce and analyze the data using custom automated code, producing publication-quality plots in near-real time.

In addition to the RIDL, CfD conducts research in the Lobozzo Photonics and Optical Characterization lab (Figure 55), home to the Nanophotonics Group led by CfD professor Dr. Stefan Preble. This group develops high performance nanophotonic devices and systems using complementary metal–oxide–semiconductor compatible materials and processes. Their work will enable unprecedented performance and efficiency by leveraging the inherently high bandwidths and low power of photons with the intelligence of electronics. The Lobozzo lab includes a Ti:sapphire laser, optical parametric oscillator, atomic force microscope, ion mill, cryogenic optoelectronic probe station, and telecom test equipment. Other CfD faculty and students use the lab for terahertz measurements and time-resolved photoluminescence.

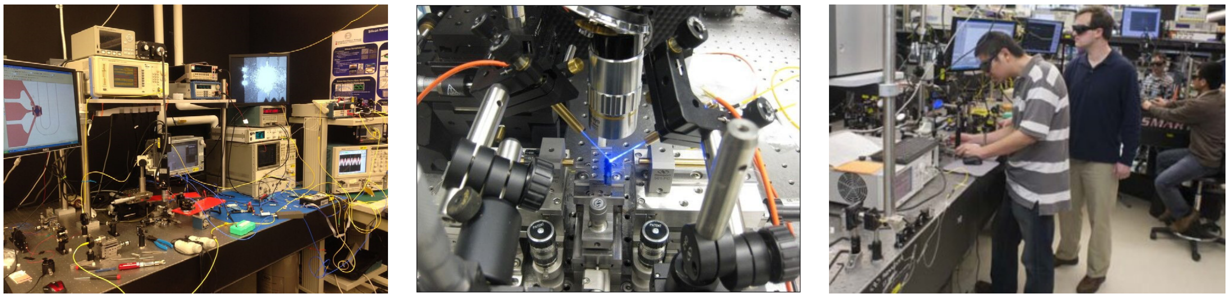

Figure 55. Shown here are Images of the Nanophotonics lab and Professor Stefan Preble working with graduate students.

Within the past year, The RIT Integrated Photonics Group, led by Professor Stefan Preble has added a laboratory within the CfD for quantum integrated photonic experiments. This lab is developing scalable quantum computing, communication and sensing circuits integrated on Silicon Photonic chips. These chips densely integrate photon sources, entanglement circuits and single photon detectors onto a phase stable platform. The laboratory is partially supported by Air Force Office of Scientific Research (AFOSR) which provided funding (Defense University Research Instrumentation Program [DURIP]) for a Photon Spot single photon detector system (Figure 56, *right*) which has high detection efficiencies (>85%) and very low dark counts (<200Hz). The system has detectors for both SWIR and UV wavelengths. The National Science Foundation, Air Force Research Laboratory, and the Gordon and Betty Moore Foundation fund the laboratories' research projects.

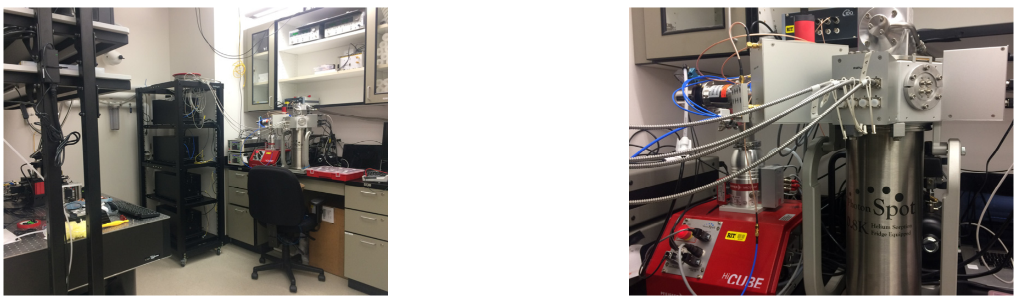

Figure 56. (left) The Integrated Photonics Group acquired space to create the Integrated Photonics Lab to run quantum integrated photonic experiments. (right) Located in the lab is a Photon Spot single photon detector system funded by AFOSR.

CfD professor Dr. Jing Zhang leads a semiconductor device optical property measurement lab located within the Lobozzo laboratory. This lab contains a photoluminescence (PL) system, seen in Figure 57, including an iHR320 spectrometer, a Syncerity CCD Array detector, a liquid helium cyrostat and a 325 nm HeCd laser. There is LabSpec software capable of measuring semiconductor luminescence spectrum with wavelengths ranging from 325 nm – 800 nm. The liquid helium cyrostat enables the system to conduct measurements at temperatures as low as 4 K.

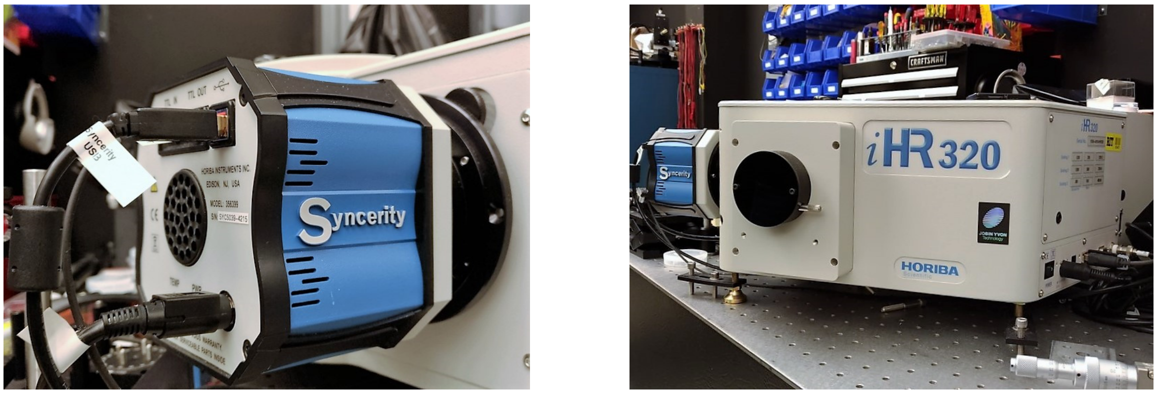

Figure 57. The Syncerity CCD Array detector (left) and the HR320 spectrometer (right) are part of the photoluminescence system.

The lab also includes an electroluminescence (EL) measurement setup (Figure 58) including a FLAME-S-UV-VIS-ES spectrometer (200 nm – 850 nm) and a rotatable stage that enables polarization-dependent and angle-dependent measurements. In addition, an 843-R handheld Laser Power Meter is used for device power measurements.

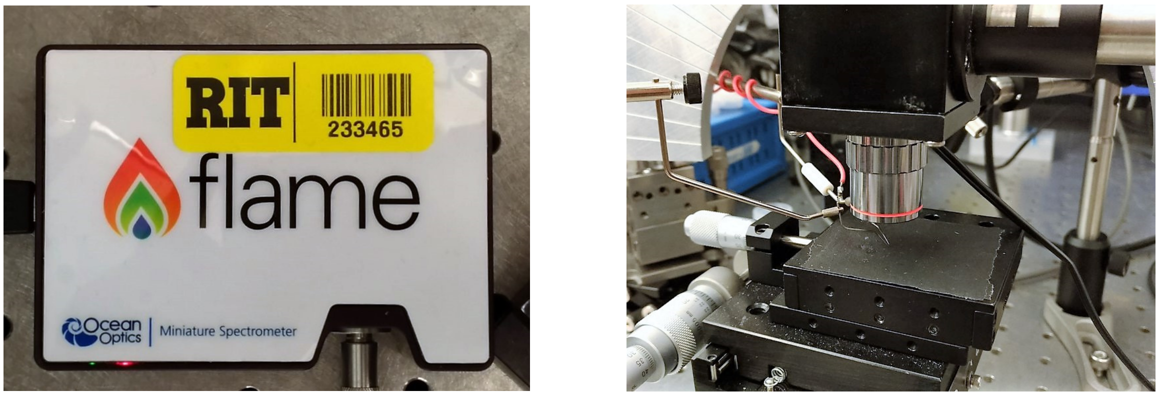

Figure 58. The electroluminescence measurement setup includes a rotating testing stage (right) and a FLAME 200 nm – 850 nm spectrometer (left).

CfD uses the SMFL, a 10,000 ft^2 cleanroom space in class 1000, 100, and 10. Using the SMFL's resources, the Center can fabricate detectors with custom process flows and multiple process variations.

The Center's flow bench and probe stations offer wafer-level testing, even during the fabrication process, allowing mid-process design changes (Figure 59). The probe station accommodates electrical and circuit analysis of both wafers and packaged parts, including low current and radio frequency (RF) probing.

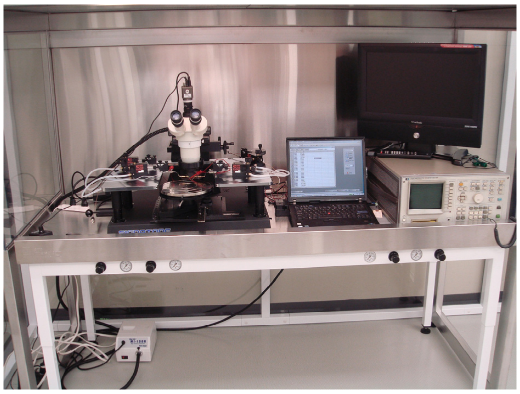

Figure 59. Device wafers are tested in the flow bench lab probe station in the photo above.

The Amray 1830 Scanning Electron Microscope (SEM; see Figure 60), in the SMFL is used for high-magnification imaging of devices, and the WYKO white light interferometer is used for surface topography measurements. The SMFL also has other in-line fabrication metrology capabilities, including material layer thickness, refractive index, and wafer stress characterization tools.

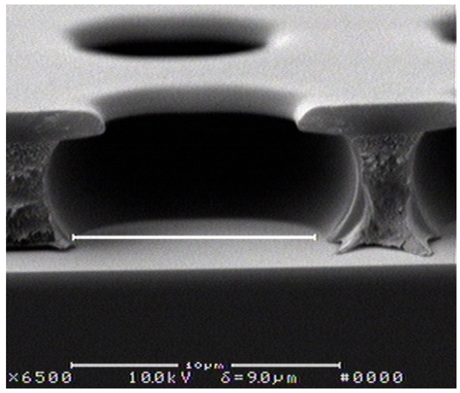

Figure 60. (left) The Amray 1830 Scanning Electron Microscope is used to image devices. (right) The SEM image shows a sample prepared for indium bump deposition.

Figure 61 shows a customized setup consisting of two voltage power supplies, an oscilloscope, an LCD screen for viewing devices through the microscope probe station, and a custom circuit board for specific device diagnostics. The dedicated lab computer also runs a specially designed data acquisition program to collect and analyze data from prototype devices.

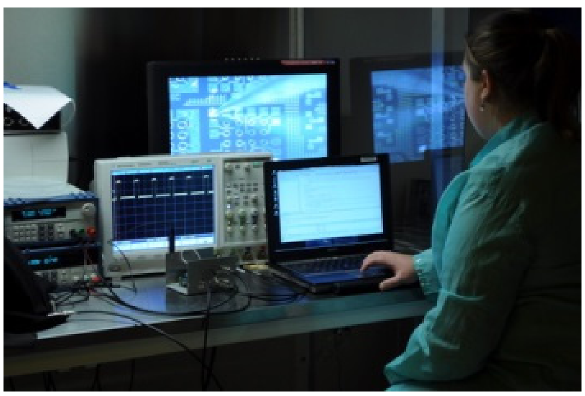

Figure 61. Former PhD student Kimberly Kolb conducts electrical experiments on one of the devices being characterized in the CfD.

The entire probe station is covered so that no stray light enters the testing environment. These conditions provide the basis for valuable testing and data analysis. In the figure, the probe tip is in contact with a single test device via a metal pad with dimensions of only 70 µm by 70 µm (an area of 0.005 mm^2), seen in Figure 62.

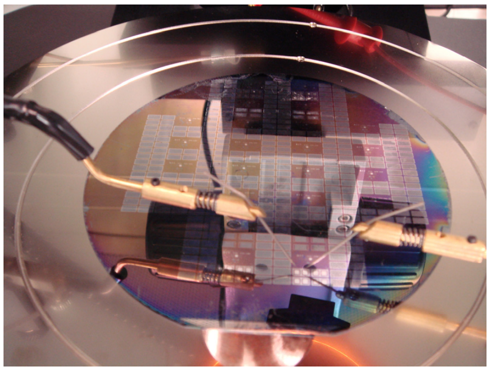

Figure 62. This image is a close-up of a device wafer being tested on the probe station.

In addition to fabrication and testing capabilities, the CfD has access to sophisticated simulation software to predict the performance of devices, from fabrication processes to performance of a completed device. Silvaco, Athena, and Atlas are powerful software engines that simulate the effects of processing on device substrates and the electrical characteristics of a fabricated device. Athena simulations can describe all of the processes available in the SMFL, building a physics-based model in 3D space of a device from initial substrate to completed device.

The CfD uses many other RIT facilities, including the Brinkman Lab, a state-of-the-art facility for precision machining, and the Center for Electronics Manufacturing and Assembly (CEMA), a facility for electronics packaging (Figure 63).

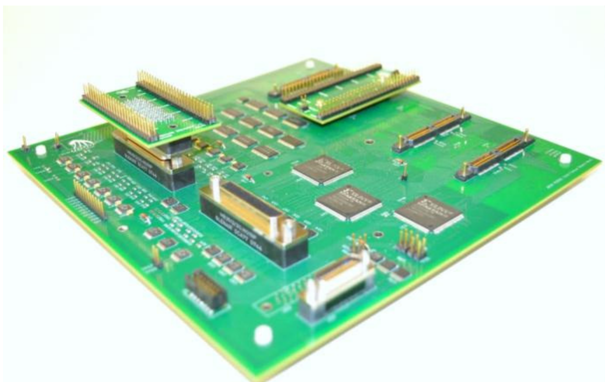

Figure 63. This image shows a cryogenic multi-layer circuit board designed in the CfD and populated in CEMA. All of the components on this board work at temperatures as low as 40 K, nanoTorr pressure levels, and in the presence of high energy particle radiation.

Another CfD lab is the Experimental Cosmology Laboratory, directed by CfD professor Dr. Michael Zemcov. This 375 ft^2 lab is capable of creating technologies for ground- and space-based applications in experimental astrophysics. The lab has equipment for fabricating and testing physical components and complementary software (Figure 64). The laboratory contains two Oerlikon Leybold Turbolab turbo-molecular pump systems, optical benches, lifting equipment, and tooling and component fabrication equipment. There are multiple computers capable of running sophisticated algorithms for astrophysics simulations. The lab also includes a millimeter wave spectrometric readout system for transition edge superconducting bolometers, as well as two liquid helium cryostats and an electronic fabrication station. A new vibration test system and a rapid-prototyping PCB mill were procured during the past year.

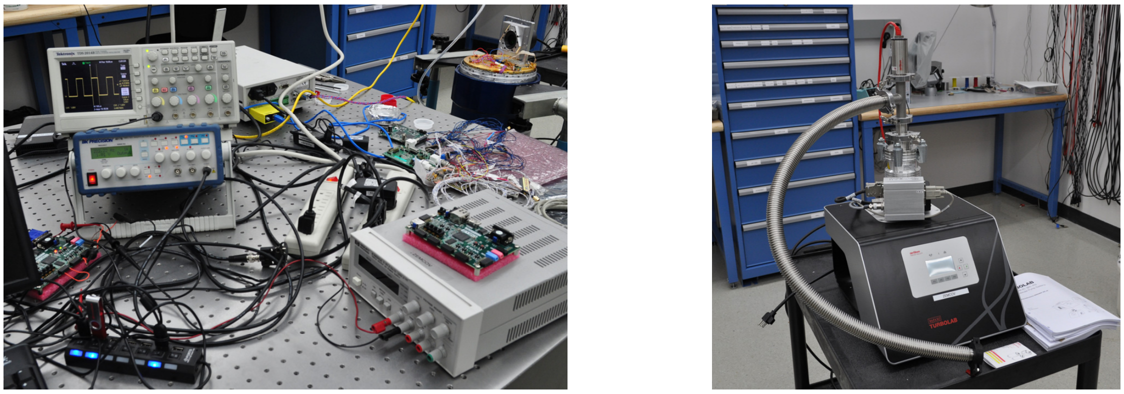

Figure 64. (left) Pictured here are the function generators, oscilloscopes, and FPGA-based control boards used to develop an image sensor readout package that will fly on a suborbital platform. (right) The picture shows one of the Oerlikon Leybold Turbolab turbo-molecular pumping stations in the lab.

CfD professor Dr. Parsian Mohseni leads the Epitaxially-Integrated Nanoscale Systems Laboratory (EINSL). This lab, part of RIT's Nanopower Research Laboratory (NPRL), focuses on atomic-level semiconductor assembly and metalorganic chemical vapor deposition (MOCVD). The lab develops devices used for photovoltaics, optoelectronics, and nanoelectronics. Their research finds real-world applications in solar energy, solid-state lighting, and lasing. Current research areas in the EINSL include metal-assisted chemical etching of semiconductors using non-conventional catalysts, multi-junction III-V nanowire on silicon solar cells, and GaAsP/GaP nanowire white light LEDs.

Researchers in the EINSL have access to the wide range of capabilities provided by the NPRL, seen in Figure 65, which include a Perkin Elmer Lamda 900 UV-Vis-NIR optical spectrometer and a metal organic vapor phase epitaxy (MOVPE). NPRL also has multiple advanced microscopic imaging systems, including a Nikon Eclipse Digital Nomarski microscope, Hitachi S-900 High Resolution Near Field FE-SEM, and Zeiss Digital Microscopic Imaging System.

Figure 65. (left) PhD student Mohad Baboli loads a sample in the AIXTRON 3×2 Close Coupled Showerhead metal-organic chemical vapor deposition reactor, part of the MOVPE. (right) PhD student Thomas Wilhelm uses a TESCAN MIRA3 scanning electron microscope to analyze samples for use in metal-assisted chemical etching experiments.

The Laboratory for Advanced Instrumentation Research (LAIR), led by CfD professor Dr. Zoran Ninkov, is in the CAR building, a short distance from the CfD Headquarters. The LAIR develops instruments for gathering data from a wide range of physical phenomena. It includes hardware and software for developing Terahertz (THz) imaging detectors using Si-MOSFET CMOS technology (Figure 66).

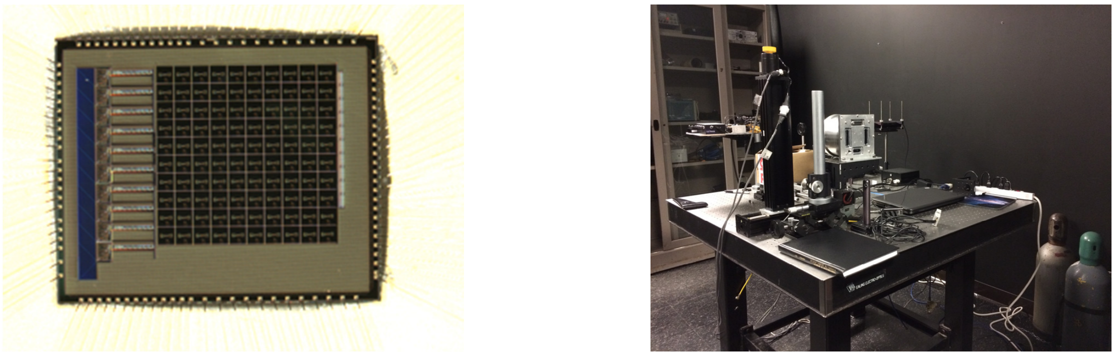

Figure 66. Student researchers in the LAIR developed a terahertz detector (left) and characterized it in the laboratory (right).

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