Center for Detectors

Annual Report

2020

RIT | Rochester Institute of Technology

CONTENTS

Center for Detectors Annual Report 2020
July 1, 2019 – June 30, 2020

CENTER FOR DETECTORS 2020

Director's Comments

When I joined RIT and started the Rochester Imaging Detector Laboratory (RIDL), it was clear to me that our laboratory systems needed to be automated so we could perform experiments from anywhere. I often said, "We need to design the systems so that they would work remotely during a nuclear war!" This year, we learned that it was built to work through a global health pandemic, too. COVID-19 hit New York especially hard, and the Center for Detectors (CfD) went into remote operation in mid-March.

In some cases, experiments continued just as normal by design. This was especially true when running the detector characterization test suite for the NSF near-infrared detector project in the RIDL. These experiments thoroughly characterize a detector over two weeks of automated testing that generates roughly a terabyte of data that the reduction servers automatically reduce and analyze without any human intervention. The whole sequence is triggered by typing a few commands in a remote desktop application.

In other cases, like many research labs in 2020, CfD overcame barriers and challenges in response to the COVID-19 pandemic and shutdown. The CfD's growing number of students and staff quickly switched to remote work. Our students navigated new online courses and logged regular research hours at the same time. Graduate students turned their apartments into offices, and many undergraduate students turned their parents' homes into research office space. Some faculty members made the switch from performing tests to writing proposals. A lot of faculty began working alone in their lab once they were able, allowing for ongoing research projects to be their focus.

CfD faculty member Dr. Michael Zemcov's CIBER-2 project, a near-infrared rocket-borne instrument, had to postpone a test flight at Las Cruses, NM due to the pandemic, but continued alterations and tests remotely. Dr. Gregory Howland co-led efforts in quantum research proposals like the NSF Quantum Leap Center Institutes (NSF QLCI) proposal. Howland's new research lab continued renovations and additions that started before RIT closed due to the pandemic. Dr. Stefan Preble created a detailed social distancing and COVID plan to re-open his lab with limited capacity and staggered work times that allowed his team to continue photonic integrated wafer development and characterization.

While working on proposals, and continuing work with the AIM TAP Hub, CfD expanded partnerships with Xanadu, MIT, IBM, and L3 Harris.

With new challenges, our group still had a productive year. We won $3.2M in new research funding, increasing our funding under management from $6.7M to $9.7M, and published 48 papers.

I encourage you to read all the details in this report and am interested in any feedback you have. Be safe.

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

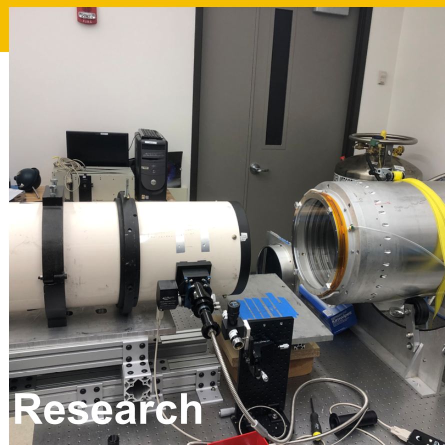
Highlights

Collaborators

- During the past year, CfD collaborated with Gigajot Technologies and Dartmouth University on the Single Photon Sensing and Photon Number Resolving Detector.
- CfD members continue to collaborate with Caltech on a number of projects including SPHEREx and TIME (Tomographic Ionized-carbon Mapping Experiment) and Stanford University and University of Bonn on the Diagnosing, Addressing, and Forecasting CIB Contamination in Spectral Measurements of the Sunyaev Zel'dovich Effect project.
- CfD continued long-term projects with organizations such as NASA, AFRL, ONRL, ONL, DOD, Raytheon, and Thermo Fisher. Collaborations grew between CfD members and L3Harris, University of Waterloo, University of Toronto, TOPTICA Photonics, and Xanadu Quantum Technologies.

Events

- This year we hosted the 12th Great Lakes Cosmology Workshop in summer 2019. The workshop included 12 invited talks and over 45 contributed talks and 10 poster presentations.
- CfD members planned other events that were rapidly adjusted or postposed due to the COVID-19 pandemic. Stefan Preble's AIM Photonics PIC Testing Workshop @ RIT, a hands-on workshop where participants learn how to test, characterize, and analyze PIC's with a Mach-Zehnder Modulator and waveguide integrated Germanium photodetector, will take place later in 2020.
- The second Photonics for Quantum Workshop, PfQ2, used an extended online series format to better accommodate the 28 scientific talks, and 2 panel discussions. The archived workshop videos and slides are available on the FPI website.



Research

- CfD Members won $3.2M in new research grant funding and continued work on 41 active projects.
- Michael Zemov's work on SPHEREx was selected for Phase B funding by NASA. His group will be responsible for setting high-level requirements on the data analysis pipeline.
- In a newly-funded NASA project, Zoran Ninkov's group provide digital micromirror devices (DMDs) with standard protective windows replaced by ultraviolet transparent windows for studies of DMDs optical properties in the ultraviolet regime.
- Stefan Preble and Gregory Howland are developing a quantum optical semiconductor chip with AdvR. They will demonstrate its application to efficient photonic entanglement and quantum communication protocols through fiber optical channels.

Charter

About the Center for Detectors

The Center for Detectors (CfD) is an RIT academic research center established in 2010 in the College of Science. CfD designs, develops, and implements photon devices to enable scientific discoveries. CfD educates and trains students through research and development in detectors, instrumentation, observational astrophysics, nanostructures, silicon photonics, quantum optics and photonics, and wide-bandgap materials. Staff and student researchers investigate high impact engineering and development problems through external financial support from federal agencies, private foundations, national laboratories, and industry. CfD has nine labs on RIT's campus, including the Rochester Imaging Detector Lab, the predecessor to CfD.

Vision

The CfD vision is to be a global leader in the development of advanced photon detectors and their use in instrumentation applications spanning a variety of fields.

Mission

The CfD mission is to leverage multi-disciplinary and symbiotic relationships between students, staff, faculty, and external partners to improve the design and development of advanced photon detectors and associated technologies. CfD realizes this mission by developing and deploying detectors to enable space missions, exploiting detectors for quantum optics, developing material systems for detectors, and implementing detectors for integrated photonic chips.

Goals

- Create opportunities for faculty, students, and international leaders to advance the field of detectors and relevant areas of application
- Increase externally supported research
- Cultivate existing and new external collaborations
- Enhance collaborations with industry
- Develop and use low noise large format detectors for Astrophysics
- Develop single-photon detectors for quantum applications
- Pilot local and national education programs in integrated photonics

Executive Summary

Research

The CfD had 41 active projects during the past year (28 ongoing and 13 new), and won $3.2M in new research grant funding.

Dr. Don Figer continued to develop infrared detectors that use HgCdTe material grown on silicon substrates. He and his team obtained funding for their work with Dartmouth College to characterize the Quanta Image Sensor. The device is a megapixel focal plane array that delivers photon counting capability at room temperature, and will thus be valuable for low light applications, such as astrophysics space-mission concepts. Dr. Figer is PI on an RIT-led NSF Quantum Leap Challenge Institute (QLCI) Conceptualization Grant for the "Quantum Photonic Institute." The team will submit a preliminary proposal in the funding program's second round.

Dr. Parsian Mohseni continued his development of low-cost and high-efficiency flexible light emitting diodes and photodetectors and explored answers to enabling cost-effective manufacturing of high-efficiency solar cells. Dr. Moheseni is a member of the QLCI proposing team.

Dr. Zoran Ninkov is at NSF serving as a program manager through the Intergovernmental Personnel Act program this year. His group continues research in imaging polarimetry, detector advancements, and micromirror development. His group further developed a method of coating detector arrays with nanomaterials for improved detector sensitivity in ultraviolet (UV) and blue light. The group continued developing their terahertz detector architecture and Digital Micromirror Devices for inspection and space applications.

Dr. Stefan Preble and his Integrated Photonics Group continued developing integrated photonics platforms. The group explored ways to implement quantum photonic circuits on a silicon chip. Dr. Preble and other CfD members continued to establish packaging design and test support for AIM Photonics. Dr. Preble and Dr. Gregory Howland will start to develop a quantum optical semiconductor chip and demonstrate its application to efficient photonic entanglement, efficient logic gates such as Hadamard and CNOT, and quantum communication protocols through fiber optical channels for AdvR. Both Drs. Preble and Howland are Co-PIs on the QLCI proposal team.

Dr. Michael Zemcov and his student-based group are delivering instrument control/interfacing software for a real-time data reduction package to be used at the Kitt Peak 12m ALMA prototype antenna, or while observing remotely for the Measuring Reionization and the Growth of Molecular Gas with TIME project for NSF in collaboration with Caltech. His team continues to develop the CIBER2 sounding rocket payload designed to probe the extragalactic background light the newest version will identify the sources of the excess fluctuations by probing their spectral signatures from the optical to NIR. He also continued research to measure the cosmic background from the outer solar system using the New Horizons spacecraft. He won a new grant to develop the data analysis pipeline for SPHEREx, one of NASA's next mid-sized missions that will map the large-scale structure of galaxies in the Universe.

Dr. Jing Zhang and her PhD students developed high efficiency ultraviolet optoelectronics and solutions to key challenges in achieving high-efficiency single-mode GaN-based UV lasers.

Personnel

With the addition of Dr. Howland, CfD now has seven faculty research members, in addition to two Post-Doctoral Researchers and five staff members. 33 undergraduate and 19 graduate students conducted research with CfD professors this year. These student researchers represent four different colleges. CfD students are majority (57%) engineering students from the Kate Gleason College of Engineering. 38% of our students study in the College of Science and 3% from the Golisano College of Computing and Information Sciences, and 2% from the School of Design.

Student Vignettes

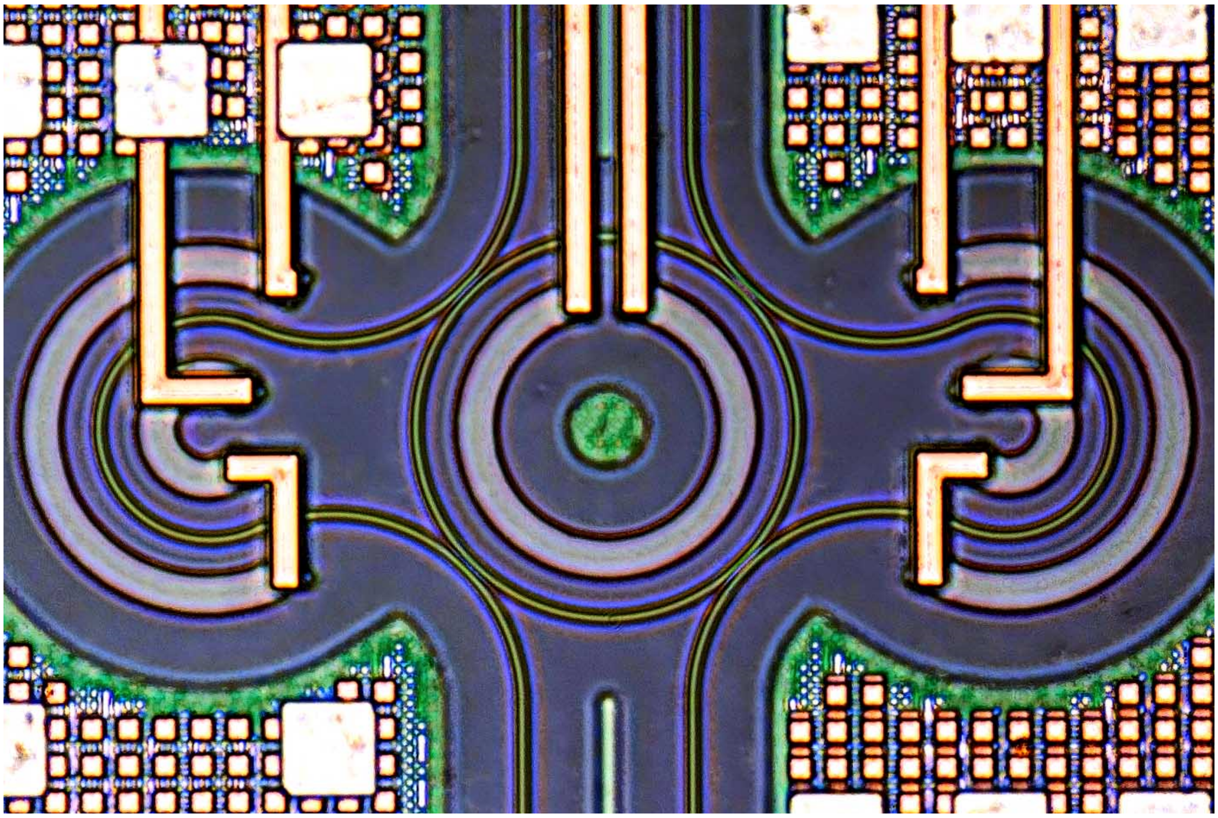
Student researchers in the CfD spend their time working on externally funded projects with guidance from their faculty advisors. In the Student Vignette section of this report, 17 of these students describe their contributions to projects over the past year.

Publications and News

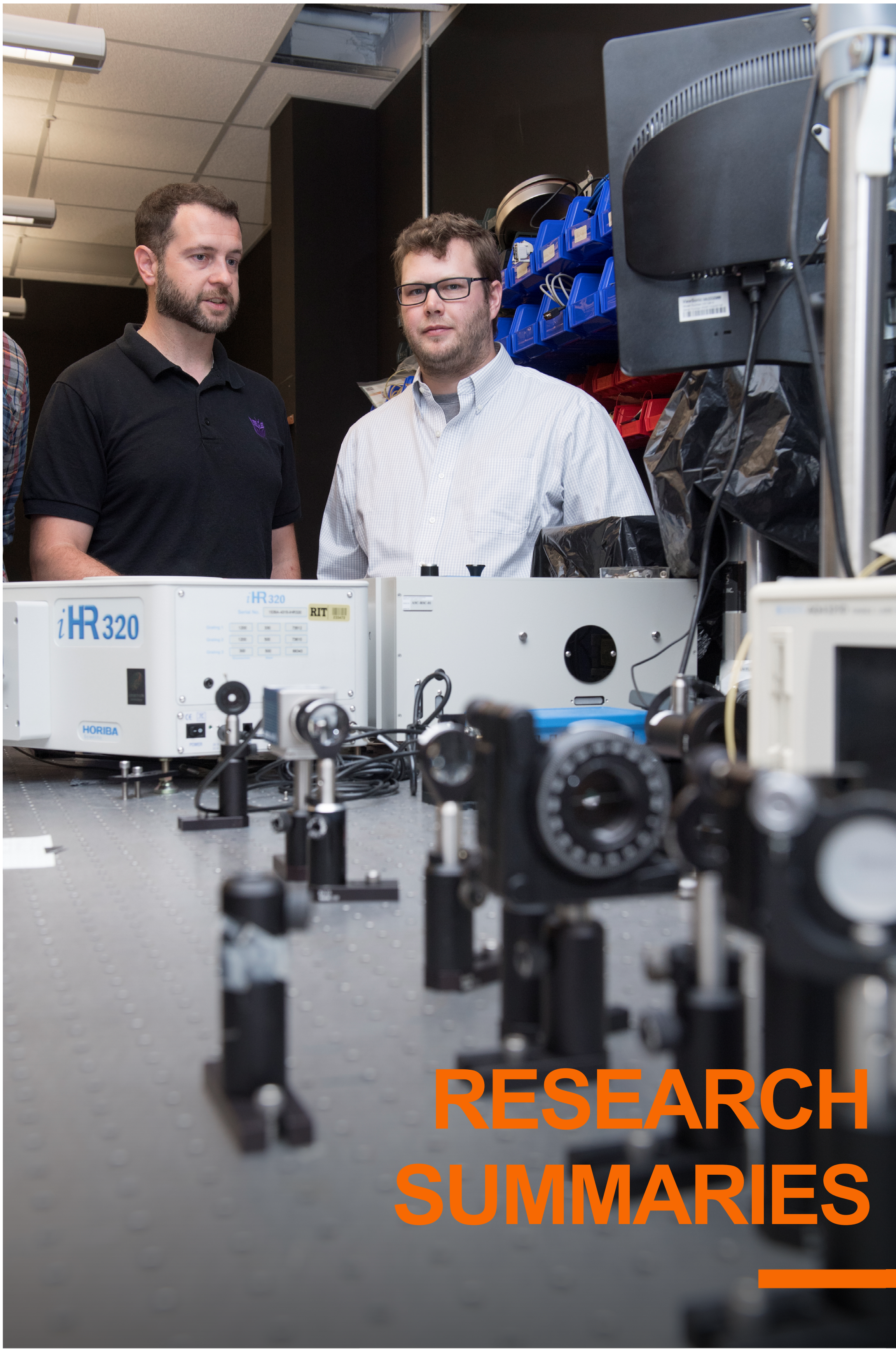
CfD researchers published 48 articles in journals such as Journal of Applied Physics, the Astrophysical Journal, Astronomy and Astrophysics, Nature Communications, and the Journal of Optics. CfD research caught the eye of both local and national media. Drs. Preble and Howland received media coverage for their work with ARFL in developing the Department of Defense's first-ever fully integrated quantum photonics wafer. Dr. Figer and the QLCI team gained attention for the Conceptualization Grant and for the Photonics for Quantum Workshops.

Equipment and Facilities

CfD refined the two new research labs of Dr. Howland (Quantum Information) and Dr. Zemcov (Suborbital Astrophysics). Dr. Zhang expanded her research space to the Electrical and Optical Characterization Lab for LED devices. The largest footprint of CfD is in Engineering Hall, with six 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 and Gosnell Hall.



Research



RESEARCH SUMMARIES

Research Projects

Studies of the Diffuse Optical Background with New Horizons

NASA
Michael Zemcov

The goal of this project is to measure the cosmic optical background (COB), which is the sum of all emission from sources beyond the Milky Way at optical wavelengths, using images taken by the Long Range Reconnaissance Imager (LORRI) on New Horizons. This allows for a comparison between this measurement and all expected sources of emission such as galaxies and potential identification of the source of any excess component of diffuse emission.

Over the past year, we have estimated LORRI's dark current stability (Figure 1) and calibrated our selected LORRI data in preparation for measuring the COB. We have used a point spread function (PSF) reconstruction algorithm to combine cut-outs of multiple stars in each image and deconvolved these stacked PSFs to return an estimate of the optical PSF, seen in Figure 2. We have also been working on estimating astrophysical foregrounds so that they can be effectively removed from the LORRI images for a more accurate measurement of the COB. These include the integrated star light (ISL), which results from faint stars that cannot be masked out, and the diffuse galactic light (DGL), which is light that is reflected from dust in the Milky Way.

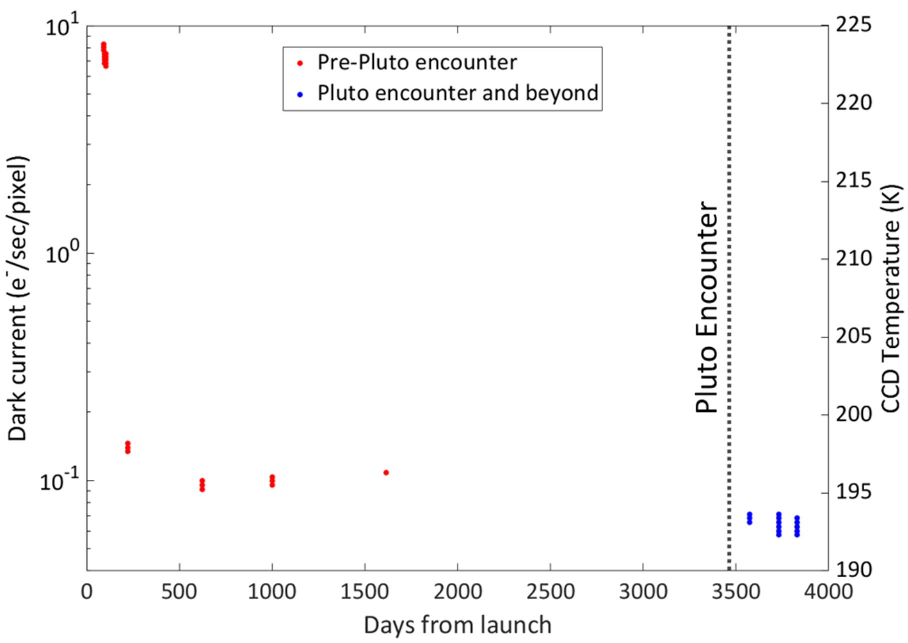


Figure 1. As expected, dark current and CCD temperature continue to decrease with increasing mission time and distance from the Sun during the New Horizons' space mission. The error in the LORRI images due to dark current becomes more negligible compared to other sources.

Future plans include improved estimates of the ISL and DGL resulting in a definitive measurement of the COB, estimates of LORRI's pointing stability, and a similar measurement of the COB using the LEISA instrument on New Horizons.

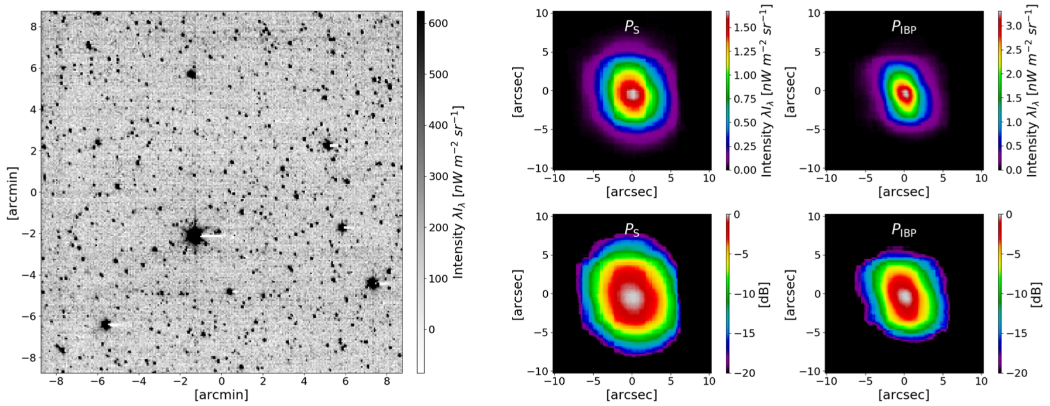


Figure 2. (left) Here is an example of an image taken by LORRI. (right) The graphs show comparisons of a PSF made by stacking stars in that image together (P_S) versus a final deconvolved reconstructed PSF (P_{IBP}) in both linear (top row) and logarithmic (bottom row) scales.

A Single Photon Sensing and Photon Number Resolving Detector for NASA Missions

NASA
Donald Figer

Single photon counting large-format detectors will be a key technology for the future NASA Astrophysics missions such as the LUVIOR and HabEx mission concepts. The NASA Cosmic Origins office funded this project under the Strategic Astrophysics Technology program. The goal of this project is to characterize single photon-sensing and photon-number resolving CMOS (Complementary Metal Oxide Semiconductor) image sensors. Dr. Eric Fossum at Dartmouth College developed the sensors and refers to them as Quanta Images Sensors (QIS). After extensive laboratory characterization, we will irradiate one device to simulate damage from high-energy radiation in space while we take another device to a telescope for characterization in an end-application environment. In the final part of the project, we will redesign the image sensor in collaboration with Dartmouth.

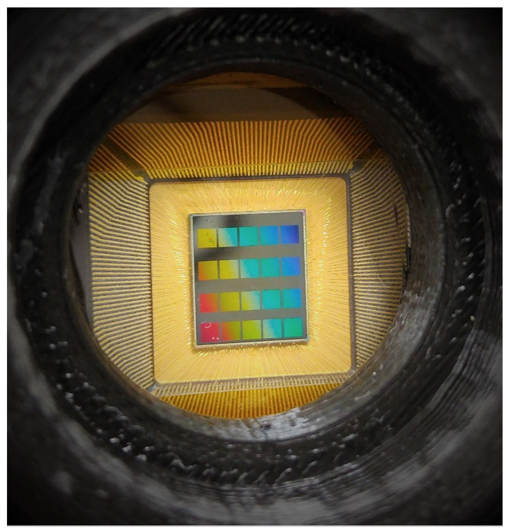


Figure 3. The image above shows twenty megapixel QIS arrays residing in the detector housing. Each detector has a side length of 1.1 µm. All twenty detectors fit within a square millimeter.

We assembled a team of graduate and undergraduate students to design the new electronics system based upon the design of the existing systems at RIT and a Dartmouth design. Many students worked on the project, including five RIT undergraduate students, three RIT graduate students, and one Dartmouth graduate student.

RIT purchased the QIS Pathfinder (QISPF) packaged camera system from Gigajot Technology Inc. in fall 2018 (Figure 3), and modified the pre-existing CfD test and characterization infrastructure to enable automated data collection. We used this to characterize the QISPF at room temperature to validate the published metrics and support the design of cryogenic and vacuum safe hardware (Figure 4). The results were presented at the 2019 Single Photon Workshop in Milian, Italy and the 235th Meeting of the American Astronomical Society in Honolulu, Hawaii.

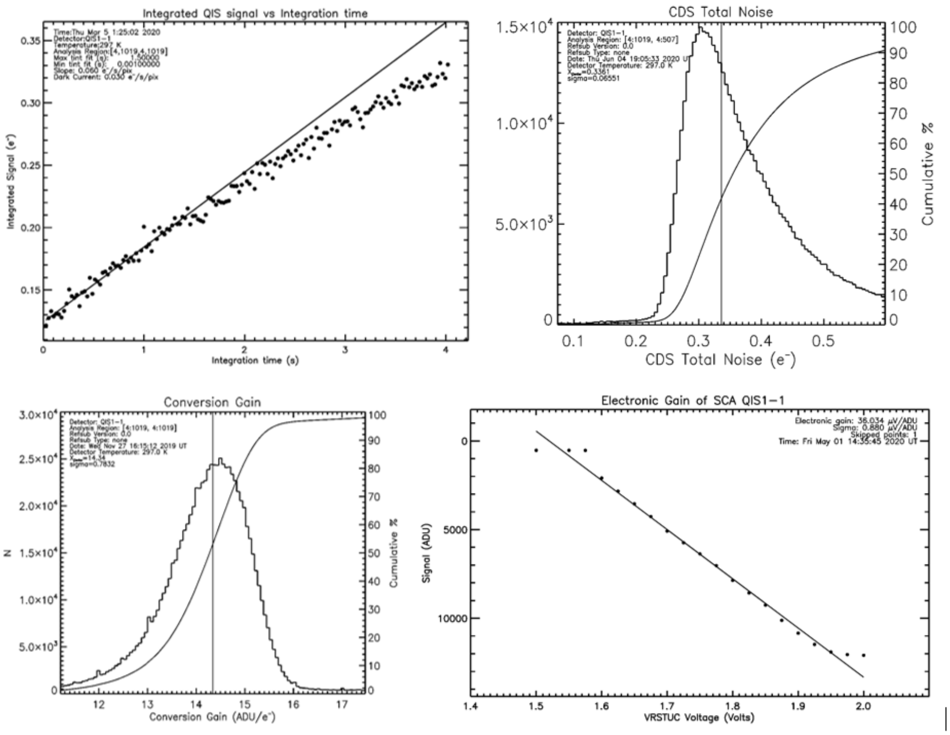


Figure 4. (top left) This figure shows room temperature results for the QISPF. A linear fit gives dark of 0.03 e^-/s/pix. (top right) The average total noise of the detector array is 0.34 e^-. (bottom left)The average conversion gain of the detector array is 14.4 ADU/e^- . (bottom right) The electronic gain of a pixel is 36.0 µV/e^-which is estimated through a linear fit to the digitized reset signal as a function of reset voltage.

The team is generating requirements for the electronics design and adding further modifications to the existing test infrastructure. We will hold the radiation testing program next year using our determined NASA mission parameters.

We held requirement reviews for the fabrication of new electronics pertaining to the image sensor packaging onto a Printed Circuit Board (PCB), the Cold Electronics Board (CEB) to operate the detector inside our dewar, and the FPGA programming to control the electronics.

We are currently creating the final designs for the detector PCB, CEB, and PCB mechanical mounts. The pre-existing detector housing for optical testing constrained the physical dimensions of the PCB. To validate that the detector PCB would satisfy the determined requirements, we performed SPICE simulations for a rigid-flex cable and thermal contraction calculations at the hardware interfaces. The preliminary design of the mechanical mount was created in SOLIDWORKS 3D software (Figure 5) based on previous optical and radiation testing programs performed at CfD.

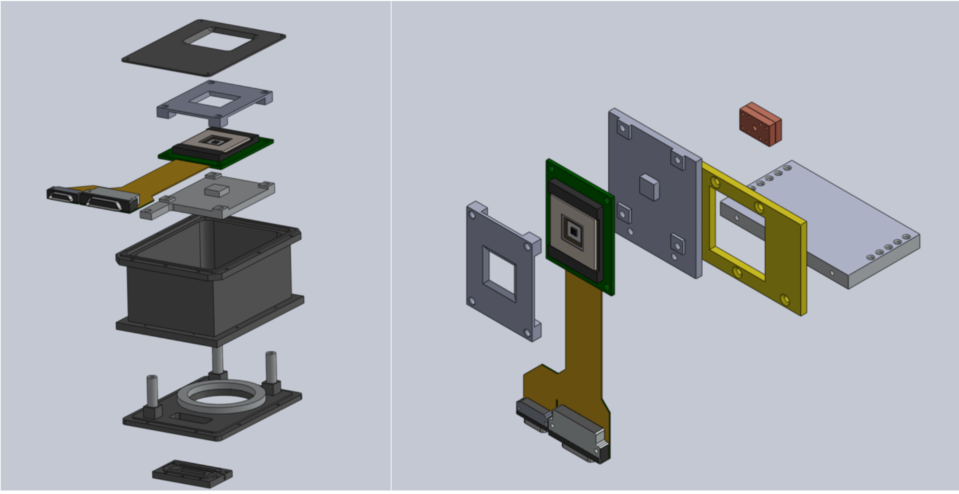


Figure 5. The image above shows the detector PCB and mechanical mount design for optical testing (left) and radiation testing (right).

Integrated Quantum Photonics for Photon-Ion Entanglement

Air Force Research Laboratory
Stefan Preble

The primary objective of this project is the realization of integrated quantum photonic platforms. We are developing platforms for UV-visible and separately for telecommunication wavelengths.

The UV-Vis platform uses AlN (Aluminum Nitride) waveguides, which is a large bandgap semiconductor that is transparent into the deep-UV (Figure 6). Consequently, it is ideal for interfacing with the visible/UV wavelengths of ion (such as Yb+, Ca+, Be+, Mg+, Sr+, Ba+, Zn+, Hg+ and Cd+) transitions. In this project, we have demonstrated the first high-Q ring resonators that operate at UV wavelengths.

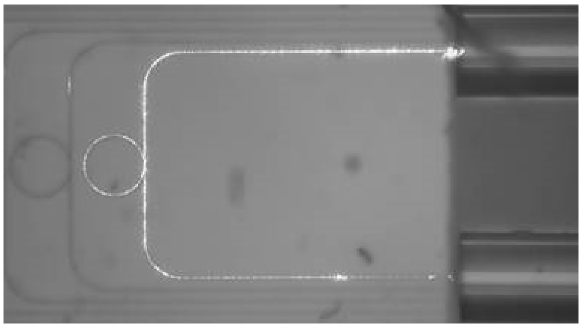


Figure 6. The image above shows a ring resonator operating at UV wavelengths. The photo is curtesy of Michael Fanto, RIT and AFRL.

The telecommunication platform leverages the mass production of CMOS manufacturing to realize high quality, reproducible quantum photonic circuits in Silicon and Silicon Nitride. In collaboration with AFRL (Air Force Research Laboratory), RIT produced the Department of Defense's first-ever fully integrated 300mm diameter quantum photonics wafer (Figure 7). The wafer contains circuits for producing, entangling and manipulating quantum states of light. These are being used for quantum computing, communication and sensing applications. The wafer includes chip designs from both RIT and Air Force Research Laboratory, along with designs by collaborators at MIT, Purdue University, Oak Ridge National Laboratory, Army Research Lab.

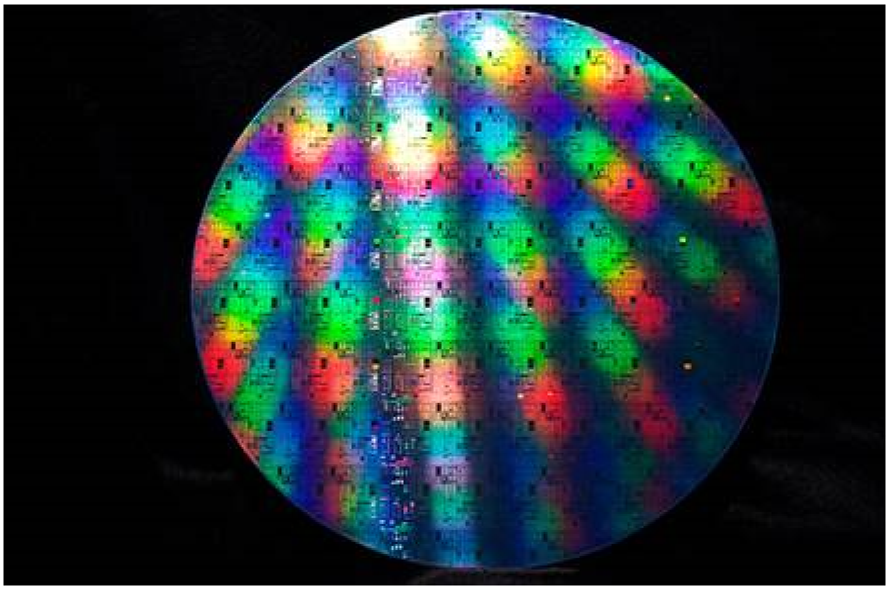


Figure 7. RIT researchers produced the Department of Defense's first-ever fully integrated quantum photonics wafer. This photo is curtesy of Michael Fanto and Christopher Tison, AFRL.

New Infrared Detectors for Astrophysics

NSF/NASA
Donald Figer

This project aims to develop infrared detectors that use HgCdTe material grown on silicon substrates (MCT/Si). Traditionally, manufacturers use CdZnTe (CZT) substrates because they have the same lattice spacing as MCT, providing fewer possibilities for undesired energy states where atoms in the lattice do not meet. Unfortunately, CZT substrates are expensive and come in small sizes. Both factors increase the cost of MCT detectors. In contrast, Si wafers are widely available and in large sizes. MCT/Si technology will dramatically reduce the cost and size constraints imposed by CZT substrates used in sensors for ground- and space-based astronomy missions.

Previous work on this project included targeted design changes to MCT/Si detectors that improved operation. The CfD tested multiple detector lots designed and fabricated by Raytheon Vision Systems (RVS). As an example of a successful design change, RVS excluded epoxy backfilling from the thinning process during detector substrate removal. This decreased interpixel capacitance, or an undesired transfer of charge between pixels, caused by the epoxy filling.

Changes in the lot of detectors we received from RVS in late 2018 targeted improving dark current. Dark current measures signal when there is no illumination on the detector. As temperature increases, some lattice vibrations are larger than the bandgap energy of the detector material and cause an electronic transition to the conduction band, resulting in a signal. We take many long exposures with no illumination to measure dark current. Figure 8 (left) is an example of a dark current histogram for F13, a detector from a previous lot. F13 has a large tail in the dark current histogram, and only about 65% of all pixels have a dark current below 0.6 e^{-}/s. We hypothesized that mismatches in the lattice of the HgCdTe and Si substrate formed coupled dislocations, resulting in higher dark current.

The new detectors contained a thicker buffer layer to mitigate these lattice mismatches. Unfortunately, cracking in two of these detectors prevented their complete characterization. This mechanical failure during processing was likely an effect of the thicker buffer layer. RVS used a modified substrate-removal process for the third detector, F17, that addressed this issue. Figure 8 (right) shows the dark current histogram of F17. Compared with F13 in Figure 8 (left), the histogram tail in F17 is significantly smaller.

Approximately 88% of all pixels have a dark current of 0.6 e−/s or lower. This shows that the change in buffer layer design improved dark current.

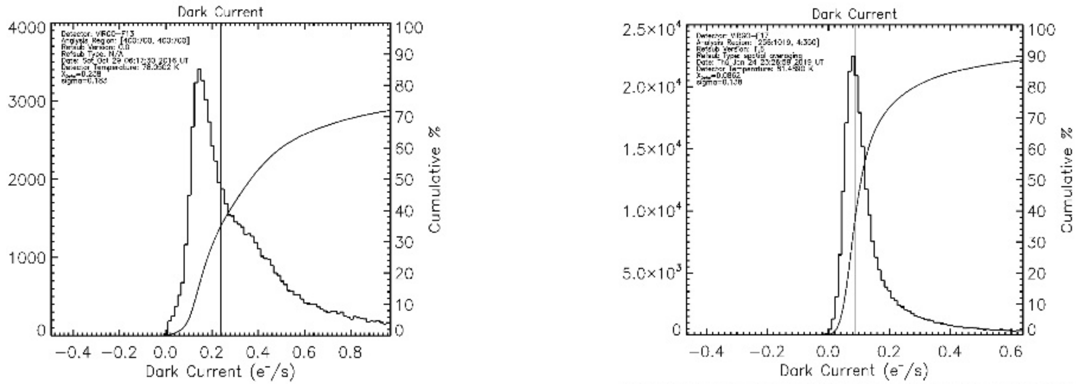


Figure 8. This figure shows the dark current histograms for detectors F13 (left) and F17 (right) at 80 K.

In F17, we also noticed an increase in the magnitude of the high dark current tail to the detector after exposure to air at room temperature before testing. This is easily removed by warming the detector to room temperature under vacuum in the dewar testing system or by removing it and baking it in an oven. These warming cycles recover the original dark current results by removing moisture from the detector surface. Warming does not influence the performance of detectors from previous lots that have inherently high dark current.

Previous work on this project identified persistence as another area of detector performance to improve. Also called latent charge or memory, persistence is the portion of the detector signal produced from photoelectron generating sources in previous images. In applications where illumination levels are low, like astronomy, persistence can add significant noise to images. We measure persistence by comparing the decay of signal in images after an illumination period to initial dark images. Figure 9 shows that persistence in F17 is wavelength dependent and decreases as a percentage of fluence during illumination. Previously characterized detectors, like F17, share these trends. Overall persistence in F17, however, is lower, reduced by approximately half at lower well capacities.

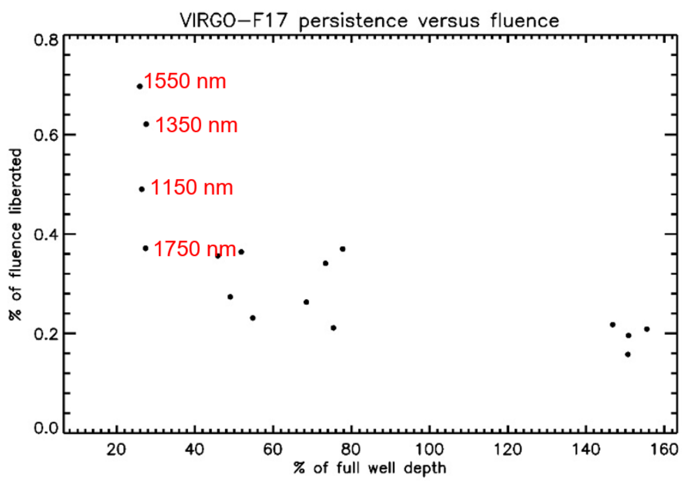


Figure 9. This figure shows the persistence vs fluence plot for F17 at 1150, 1350, 1550, and 1750 nm.

The decrease in dark current and persistence of F17 represents the success of design modifications by RVS in this detector lot. To complete the analysis of this detector, we will focus on understanding the origin of the observed increase in read noise with temperature. Once we have achieved this understanding, we will execute plans to test F17 for ground-based astronomy applications at a telescope.

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

Office of Naval Research
Jing Zhang

The objective of this project is to advance the fundamental understanding of the physics of GaN-based active regions in nitride heterostructures in order to enable high-efficiency electrically-injected UV lasers and emitters with wavelengths ranging from 220 nm to 300 nm at room temperature. Particularly, this research focuses on the fundamental understanding of the valence band structure of lll-Nitride wide bandgap gain active region, and develop promising solutions for nanostructured quantum wells and the 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.

QLCI - CG: Quantum Photonic Institute

NSF
Donald Figer

Quantum-photonic technologies will form the backbone of future quantum networks, interface/manipulate atomic and solid state platforms, realize sensors and imagers, and process quantum information. Scaling quantum optical systems to many components requires a paradigm-shift from traditional bulk-optics to stable, integrated platforms. Most quantum integrated photonics (QIP) research groups fabricate their devices in-house at academic institutions, but there is increasing interest in instead using foundry-based processes, such as those our NSF Quantum Leap Challenge Institutes Conceptualization Grant (QLCI-CG) team are developing for the American Institute for Manufacturing (AIM) Photonics.

In this successful QLCI-CG, the RIT lead team proposed and executed planning activities to allow the team to write a compelling full proposal for a Quantum Photonic Institute in August 2020. This Quantum Photonic Institute would create and use the only U.S-based open-access Quantum Foundry for quantum photonic circuits, including spectral-domain quantum processors, large-scale programmable unitary circuits, high-dimensional quantum light sources, single-photon detectors, and single-photon emitters. The proposed Institute features a strong workforce and development plan including: 1) K-12 and Informal Science Education, 2) recruiting in quantum, expanding a hands-on QIST Education Lab at RIT for undergraduate and graduate students and for on-campus workshops, 3) creating a Women in Quantum community, 4) supporting inclusion and career preparation in QIST graduate education, 5) internship/co-op programs for undergraduate and graduate students, 6) continuing learning for industry professionals, and 7) bringing QIST to all of stem.

During the Conceptualization Grant project duration, the team refined the vision, chose the research themes (Figure 10), defined projects within the teams, built the leadership team, and expanded overall team membership. We assessed infrastructure capabilities and gaps, recruited institutional support, and engaged industry.

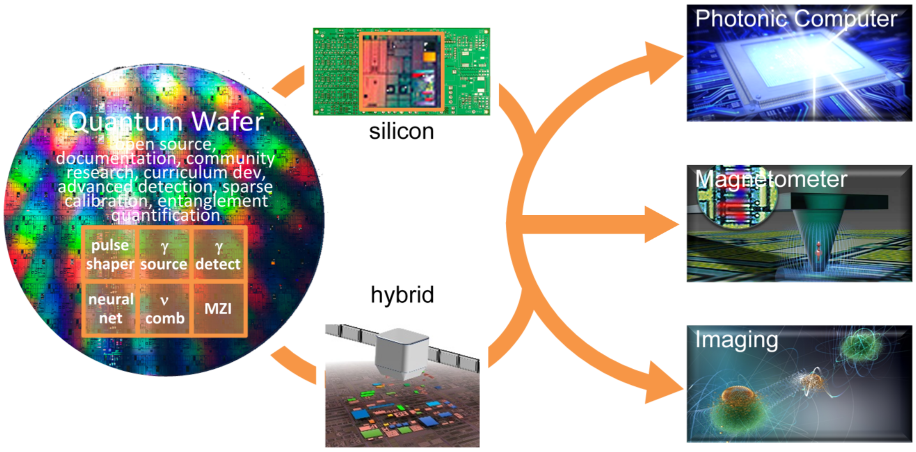


Figure 10. This graphic demonstrates the process flow for the QPI research themes and projects in QPI. The 300mm wafer on the left represents Integrated Quantum Photonic circuits; the picture shows the wafer fabricated by AIM Photonics. It densely integrates hundreds of devices and circuits optimized for quantum applications. The project that produced the wafer was led by AFRL and RIT, with collaborators from MIT, Purdue University, Oak Ridge National Lab, Army Research Laboratory, RPI. DISTRIBUTION A. Approved for public release: distribution unlimited PA 88ABW-2019-3436. The orange squares represent notional circuits to be produced by QPI. The arrows to the immediate right of the wafer show packaging of all-silicon quantum circuits (Theme 1) and hybrid material integration (Theme 2), leading to further arrows to the right to applications in all three Themes.

The workforce and education lead, Ben Zwickl, surveyed academic administrators in approximately a dozen departments and colleges at RIT to determine interest and needs for developing quantum curricula across a broad range of related majors. The team met with museums to begin developing community engagement including K-12 curricula and activities to highlight and explore foundations of quantum learning and future education opportunities.

Our team organized the second Photonics for Quantum Workshop to connect international experts, industry, and students in quantum photonic information science and technology in support of efforts to fulfill the promise of the Quantum 2.0 Revolution. The meeting was moved online due to COVID-19, and was extended to allow maximum participation. The agenda included panels to foster discussions on new curriculum development and research on student learning that aligns with contemporary quantum topics, creating space for women in quantum and increasing diversity in industry and academia, and current government plans for quantum initiatives and quantum research opportunities. The recorded talks from all Photonics for Quantum Workshop events are available on the FPI website.

On-chip quantum photonic sensors using entangled photons and squeezed states

US Government/Oak Ridge National Lab
Stefan Preble

As a part of this project, we have designed and tested new components that are more efficient and effective at manipulating the physical properties of light. These results have also demonstrated unique applications in quantum information science specifically for processing and sensing. We have also started laying out the design work for a different integrated photonics platform, aluminum nitride, which will be fabricated in a standard CMOS foundry.

SPHEREx: An All-Sky Spectral Survey, Phase B

NASA/Jet Propulsion Lab
Michael Zemcov

SPHEREx (the 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. NASA selected SPHEREx for development in February 2019. SPHEREx is designed to map the large-scale structure of galaxies in the universe to shed light on the first instants of the universe, measure the light produced by stars and galaxies over time by using multiple wavelength bands, and investigate how water and biogenic ices influence the formation of planetary systems by studying the abundance and composition of interstellar ices. RIT is responsible for the ongoing development of the data analysis pipeline, with plans for future publications on the analysis methods that Zemcov's team is developing. We recently submitted a paper on advanced point spread function reconstruction techniques for the instrument (Figure 11). Over the past year, the SPHEREx team has remained busy executing the program's Phase B, during which final mission trades are studied and preliminary designs are drawn up. We expect a preliminary design review sometime in autumn 2020, after which we will begin the instrument build phase. SPHEREx is currently scheduled to launch in 2024 and is funded for a full mission through 2027.

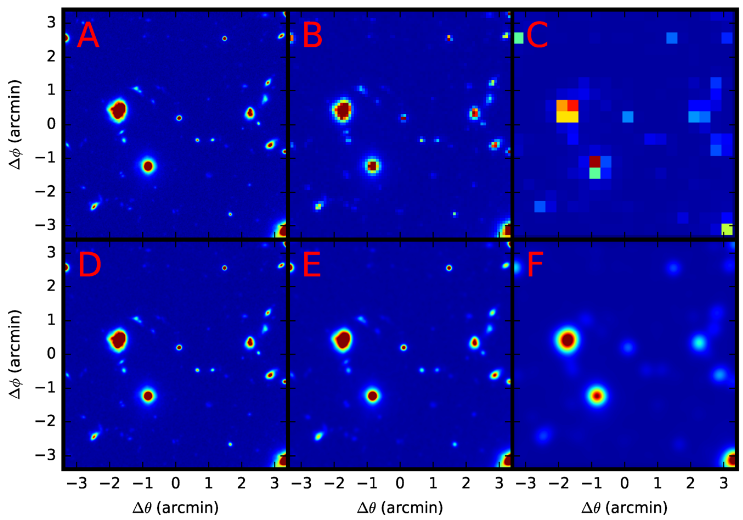


Figure 11. This figure shows Examples of the relationship between pixelization and PSF. The top row shows the effect of changes in the pixel gridding of the input images, shown in Panel A, while the bottom row shows the effect of changing the width of the PSF. In Panel A, the pixelization is matched to the optical PSF, so that the FWHM∼ 1 pixel. In this case, the spatial resolution of the telescope dominates the spatial resolution of the image. In Panel B, we show the case where θpix/FWHM∼ 5 and the image spatial resolution is dominated by the pixel grid. Panel C shows the θpix/FWHM∼ 20 case where the image spatial resolution is heavily gridding-dominated. The method described here takes advantage of the fact that the PSF is sampled in many different ways with respect to the pixel grid to allow reconstruction of the sub-pixel PSF shape. In the bottom row, we show examples of FWHMPSF/θpix = {2,5,20} in Panels D, E and F, respectively. In these cases, the sub-pixel PSF can be easily measured from point-like sources, and the method described here offers no improvement.

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. In addition, each detector has a small portion 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. In summer 2019, CIBER-2 was integrated into the rest of the sounding rocket at the Wallops Flight Facility (WFF). The experiment was later sent back to RIT for further calibration and improvement during fall-winter 2019. In early spring 2020, CIBER-2 and an RIT-led field team returned to WFF for vibration test. The experiment is now qualified and awaiting a new launch opportunity following COVID-19 outbreak. In the meantime, the CIBER-2 collaboration is re-designing the survey strategy for the new launch date and refining the data analysis pipeline.

Figure 12. The CIBER-2 field team (2020) posing with international collaborators from the Kwansei Gakuin University. The photo is provided by Wallops Flight Facility.

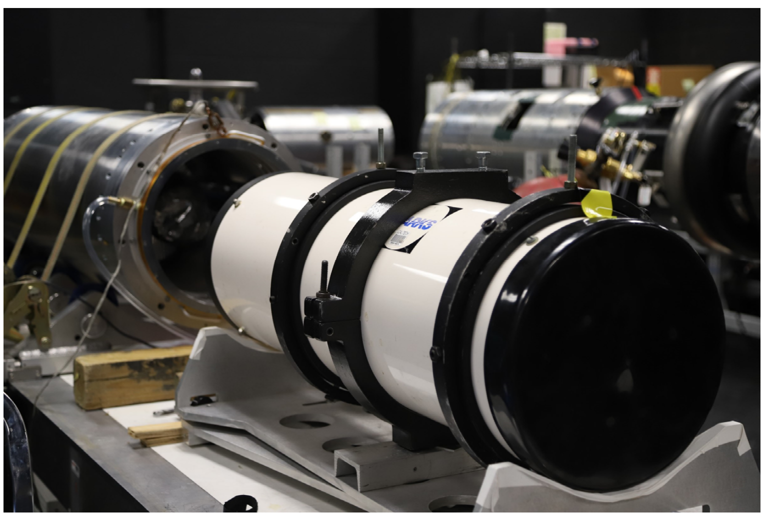


Figure 13. The CIBER-2 payload (left) is undergoing focus testing for post-shipping verification of the optics, using a collimator (center foreground). The photo is provided by the Wallops Flight Facility.

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

National Science Foundation
Parsian Katal Mohseni

Escalating trends in global energy consumption mandates like 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 and 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 contain radially segmented p-i-n junctions 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.

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 due 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.

Diagnosing, Addressing, and Forecasting CIB Contamination in Spectral Measurements of the Sunyaev Zel'dovich Effect

NASA
Michael Zemcov

We have measured the ICM properties for a single cluster, RX J1347.5-1145, and have initial estimates of the temperature of the gas. This was made possible through collaboration with Caltech, who developed a routine known as PCAT that identifies and models individual CIB point sources, removing them from the SPIRE data, as shown in Figure 14.

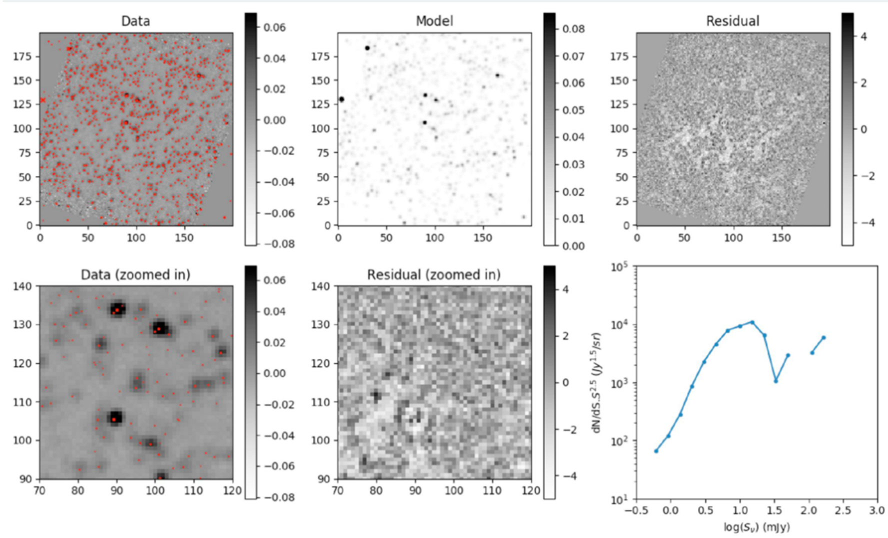


Figure 14. The figures show the identification and modeling of CIB point sources from SPIRE maps inside of PCAT. The challenge in this dataset is to prevent removing the extended emission from the SZ effect along with the flux from point sources. Ideally, the identified and removed point sources match the known source flux distribution from mock realizations of the same patch of sky.

This was integrated into a custom pipeline developed at RIT, which uses Bolocam data from the same cluster to create an SZ template, which is fit to the residual map from PCAT. The fitting procedure creates a grid of possible cluster gas temperatures and densities which are fed to the software SZPack. This generates the expected SZ intensity given these parameters for SPIRE frequencies. An outline of this full pipeline procedure is given in Figure 15.

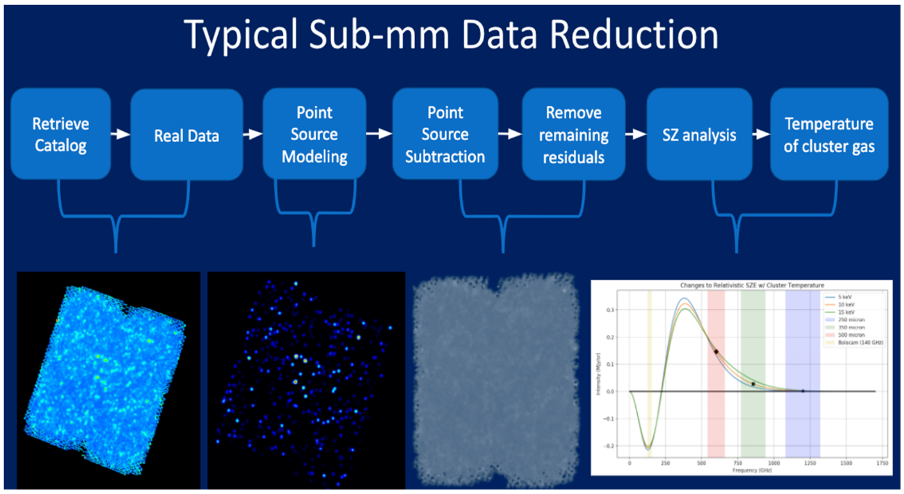


Figure 15. This schematic of the SPIRE data analysis pipeline was used to calculate the temperature of the gas in our cluster sample. PCAT is responsible for the middle three sections by modeling and removing CIB point sources, and fitting templates for galactic dust and the background flux offset. The residual contains the SZ effect, instrument noise, and confusion noise. The remaining signal is fit using an SZ template created by Bolocam; a ground based, bolometric SZ instrument.

We are currently working to finish a simulation pipeline to complement this analysis, which generates mock SPIRE observations of the cluster, and includes a generated SZ signal. These simulated maps are used to estimate the bias in our temperature measurement due to our analysis methods. We are also creating more realistic templates for the dust component, as seen by the *Planck* satellite, and are considered a contaminant to be modelled and removed within PCAT. Once these tasks are completed, we will apply our analysis techniques to the remaining 23 clusters in our sample.

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

NASA
Michael Zemcov

In 2017, the CfD received a NASA Earth and Space Science Fellowship (NESSF), which supports the research of a student, Chi Nguyen (AST PhD 2021), 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 summer 2019 and early spring 2020, Nguyen played a major role in two field campaigns at the Wallops Flight Facility (WFF) to ready CIBER-2 payload for launch. After the CIBER-2 launch was delayed by the COVID-19 shutdown, she is currently designing a survey strategy to accommodate a new launch date in late 2020/early 2021. She is also revising the data analysis of the previous experiment, CIBER, to prepare for adaptation to CIBER-2 data.

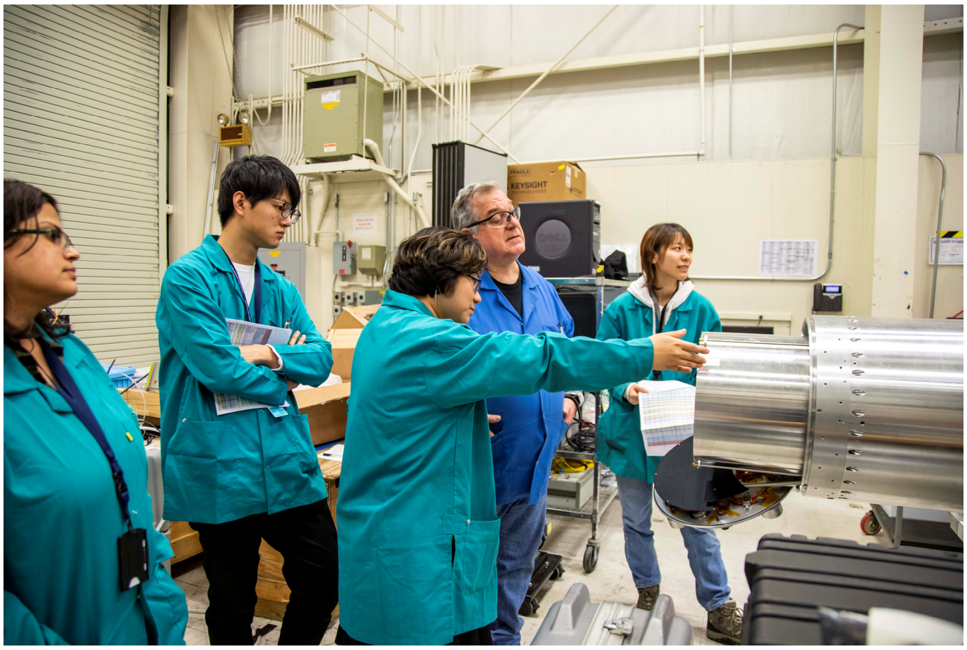


Figure 16. Nguyen (center) verified the performance of CIBER-2 deployable baffle during a flight sequence rehearsal. This photo is provided by the Wallops Flight Facility.

Measuring Reionization and the Growth of Molecular Gas with TIME

NSF/Caltech
Michael Zemcov

After the engineering run in March 2019, several improvements were made to the software. New methods for scanning the telescope were added, along with additional on-screen information on current atmospheric conditions. On-site conditions and observer logs were also added to data storage files, coupled to the scientific data.

Since then, work has focused on creating a quick-look data analysis pipeline. This involved converting lab data to the same file format as the observational data, and creating a system for extracting specific datasets. The Data Retrieval System (DRS) was created to accomplish this second task. It allows the user to perform a file search based on date, time, or observer name and access data from the instrument, telescope or other system.

We have also been working to improve our control over the instrument. Each of the 2000 detectors is electrically biased to operate under specific environmental conditions (Figure 17.) Previous techniques sacrificed the operation of 60% of the detector array for speed. This routine has been improved using archival lab data to calculate the optimal bias configuration for multiple environments, as well as adapting to new conditions in the field.

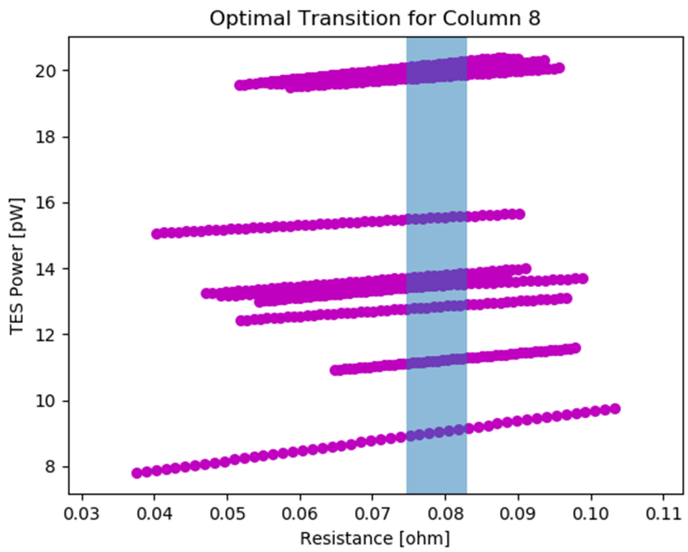


Figure 17. This figure shows the testing of advanced detector biasing technique. The shaded region shows the optimal electrical resistance needed to keep the most detectors operating. This is done per column since detectors are electrically coupled in this configuration. These values are from static lab data taken at room temperature, and will change due to change in atmospheric conditions and the source being observed.

Work has also progressed for the Kmirror System (KMS), which underwent testing in the fall of 2019 at the Kitt Peak site. The system was put through several tests to determine how closely the rotation of the mirror arm tracked with the movement of the telescope. These involved varying the gravitational load on the arm, tracking speed, and the shape of the telescope scan. Figure 18 shows one such test. The majority of the time, the KMS was within acceptable positional errors, but suffered some communication issues. The residual error will be minimized in future by work on the PID control software that manages the response of the motor to updated position commands. The communication issues will be resolved during the next installation of the system, or during the future instrument deployment.

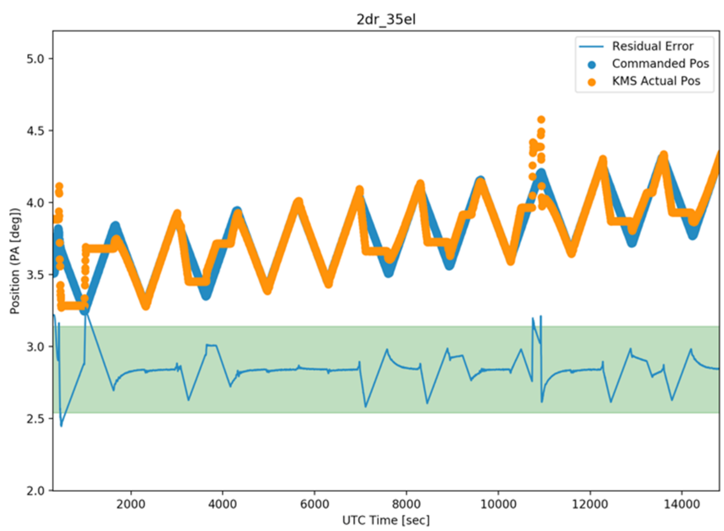


Figure 18. This graph shows the rotational test of the KMS system at a 65° angle through a 2D raster scan of the telescope. The errors are nominally within the calculated tolerance of ± 1.5°.

The Development of Digital Micromirror Devices for use in Space

NASA
Zoran Ninkov

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

The team assembled an optical test set up to assess the light scattering and reflectance properties of DMDs in a spectrograph configuration. The test set-up simulates the performance of the DMD in a typical multi-object spectrograph (MOS) configuration. In a MOS, individual micromirrors are selected and turned to the on-state to reflect light to a spectrograph. All other micromirrors are turned to the off-state, away from the spectrograph. Light scattered from DMD mirrors in the off-state can contaminate the measured spectra.

For use in the infrared, it is required that DMDs operate at cooled temperatures. The testing established that normal operation of these devices was able to be carried out to a temperature of near 77K. This was the limit of how cold the DMD could be cooled by the test configuration and did not reflect a failure of the DMD.

Heavy ion and high energy proton testing of DMDs has been previously performed. Dr. Ninkov's team preformed gamma radiation testing of DMDs to determine the viability of the devices in the space radiation environment at the NASA Goddard Space Flight Center's Radiation Effects Facility (Figure 19). The testing found that the devices tolerated the total-ionizing dose expected for a typical 4-year mission at an L2 orbit.

Figure 19. The picture shows (from left to right and top to bottom): Marty Carts (NASA), Lexi Irwin (PhD student), Kate Oram (PhD student), Zoran Ninkov (RIT), Tony Chapman (Thermo Scientific), Dmitry Vorobiev (CU/RIT), Eugene Gerashchenko (NASA) at the Gamma Testing facility at NASA Goddard Space Flight Center.

Texas Instruments supplied the DMDs with a protective borosilicate glass window. This glass limits the range of wavelengths that the device can be used for. We have developed a technique for removing these windows and repacking the devices with windows that are transmissive in the ultraviolet and infrared. Initially we have used magnesium fluoride and HEM Sapphire as the replacement window material. These devices have been successfully shake/shock/vibration tested at the NASA GSFC facility for verification of ability to survive a launch.

Developing THz Detector Technology for Inspection Applications

RIT
Zoran Ninkov

A silicon CMOS based array purposed for the terahertz regime has promising applications for many fields including security screening, manufacturing process monitoring, communications, and medicine. Current systems mainly consist of bulky technology, including large pulsed laser systems, and are primarily laboratory-based setups. In this research, we chose a silicon CMOS based technology in order to eventually develop a compact, portable, practical imaging system. A large amount of recent research has been conducted regarding the detection of terahertz using silicon MOSFETs. The THz focal plane technology being tested is uncooled and employs direct overdamped, plasmonic detection with silicon CMOS MOSFETs that are each coupled to individual micro-antennae (Figure 20).

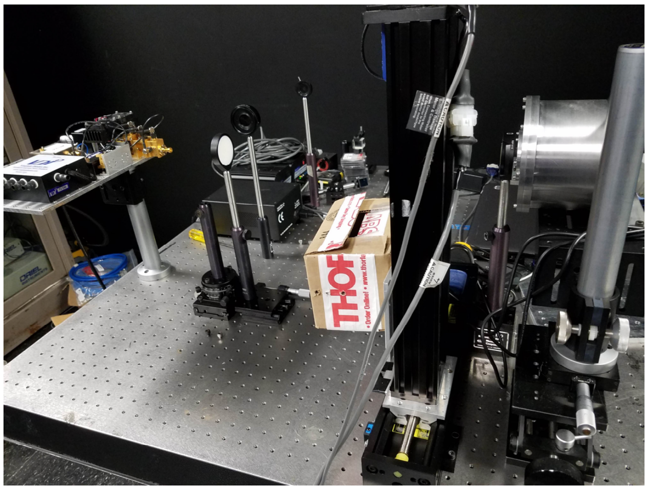


Figure 20. The photo above shows the experimental THz scanner setup. The source is on the left, followed by the Teflon lens, and the test dewar enclosure on the right. The Thorlabs box contains various targets. It is mounted on XYZ and rotation stages for scanning.

The chip used in these experiments was custom designed and fabricated in a 0.35 μm silicon CMOS process using the MOSIS facility. On the chip is a test imaging array and fifteen test transistors. These 'test' transistors can be connected directly to outputs for characterization without clocking electronics. Our work has focused on characterizing the response from these five test transistors. Figure 21 shows a micrograph of the test chip with the test transistors located on the bottom edge.

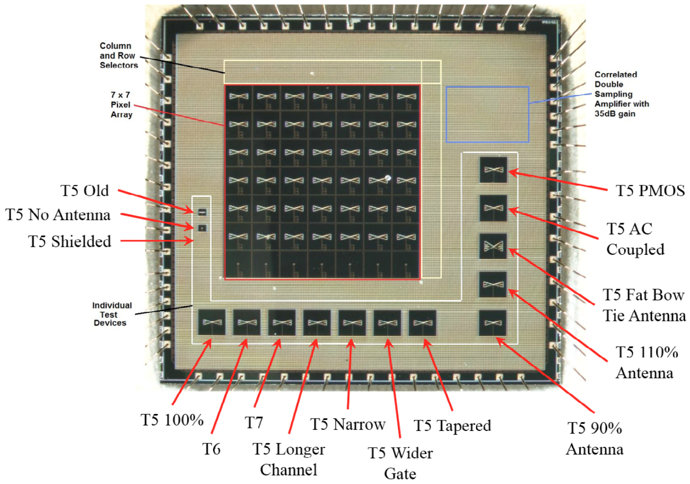


Figure 21. Above is a photo of the generation II MOSIS THz device. Fifteen test structures are along the edges.

The transistors were biased using SRS power supplies that connect to the test enclosure via low noise shielded twisted pair cables. The enclosure creates a Faraday cage around the fan-out board and test chip, and the connections are fed through the box with feed-through capacitors to reduce as much RF noise as possible. A removable high resistivity silicon window on the front of the enclosure precedes a high-speed shutter which is controlled via digital I/O. The enclosure is mounted on XYZ and rotation stages for alignment purposes. A SRS 560 current preamplifier is commanded via a MATLAB serial interface for applying bias sweeps and relaying data. The radiation source is a 200 -300 GHz tunable source from Virginia Diodes.

Development of Quantum Dot Coated Detector Arrays

NYSTAR/University of Rochester
Zoran Ninkov

There are many interesting things to see in the ultraviolet (UV). Lithography for integrated circuit production is exposed with 193 nm light with future, analytical instruments use UV emissions to identify materials, and honeybees' view of flowers include the UV region. Current silicon CMOS or CCD based detectors used in standard digital cameras do a poor job of recording UV images. Switching to exotic materials or polishing the detector until it is so thin that it is flexible and almost transparent may improve the ability to detect UV light. Both of those options are very expensive to fabricate. A different approach is to apply a coating of nanometer-scale materials to the surface of a detector chip to convert the incoming UV light to visible light. Standard detector chips more readily record visible light. We use an inkjet printer to deposit the quantum dots. This research has developed a method of coating detector arrays with nanomaterials and applied it to improve the ability of detectors to record UV and blue light (Figure 22).

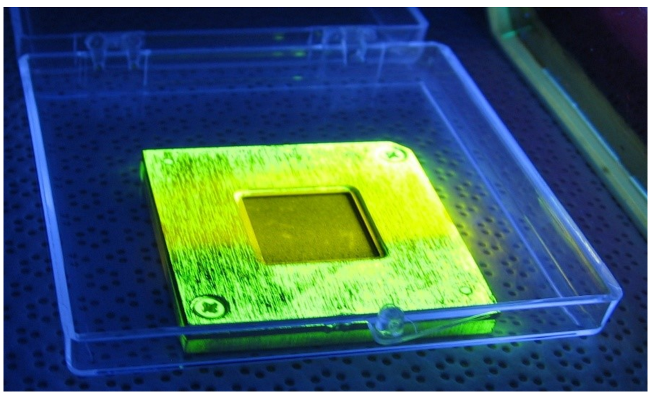


Figure 22. The yellow/green device above is a Quantum Dot coated detector in an aluminum mask under UV illumination. The active area is 15 mm×15 mm.

Analysis of the optical properties of digital micromirror devices in the ultraviolet wavelength regime

Space Telescope Science Institute
Zoran Ninkov

RIT proposes to support the efforts "The Space Telescope Ultraviolet Facility (The STUF)" project led by STScl PI Mario Gennaro. RIT will provide digital micromirror devices (DMDs) with standard protective windows replaced by ultraviolet transparent windows appropriate for studies of DMDs optical properties in the ultraviolet regime. Our proposal includes also a request to support a student from RIT for a two-year period.

Imaging Polarimetry

Zoran Ninkov

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

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

We had the opportunity to deploy one of these polarization cameras to the CTIO 1 meter telescope in Chile, South America. Figure 23 shows an image of Jupiter obtained from that data, revealing the polarization signature.

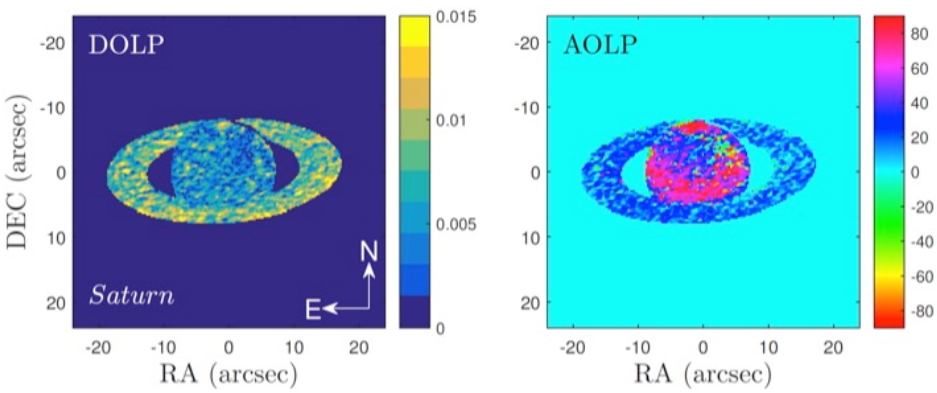


Figure 23. The figure shows two images of Jupiter in degree of linear polarization and angle of polarization.

Student Vignettes

Lucas Berens

Undergraduate Researcher

Lucas Berens is a 4th-year physics major and Undergraduate Researcher currently working in Professor Stephan Preble's photonics laboratory. Lucas is originally from Los Angeles, CA, and still has not adjusted to the cold. His work mainly focuses on characterizing photonic chips by controlling waveguide heating profiles, thereby changing wavelengths of light that are allowed through the chip. One of his main projects has been to write an efficient sweeping program to allow for fast Power vs. Wavelength data collections. Lucas started working in the CfD after interning for Dr. Michael Fanto's group at AFRL. There, he worked on using on-chip ring resonators to test the Hon-Ou-Mandel effect with a single-photon source.

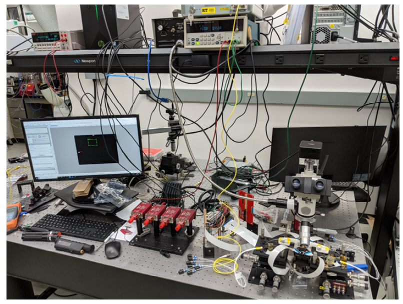


Figure 24. An example of the output of a photonic chip. Because only certain wavelengths of light can easily pass through waveguides of a given dimension, changing the wavelength of light changes the amount (power) of light seen at the output. Doing this sweep quickly can often be a challenge.

Teresa Symons

PhD Student Researcher

Teresa Symons is a third-year graduate student pursuing her PhD in the Astrophysical Sciences and Technology program. She previously received her MS in Computational Physics and Astronomy from the University of Kansas and her BS in Space Physics from Embry-Riddle Aeronautical University. Over the past year, she has contributed to the point spread function (PSF) estimation component of the data analysis pipeline for the upcoming NASA medium explorer mission SPHEREx, work that she presented at the 235th American Astronomical Society Meeting in January 2020 and will soon be published. She also analyzes images taken by the Long Range Reconnaissance Imager (LORRI) on NASA's New Horizons spacecraft in order to measure the cosmic optical background (COB), which is the faint background of light in the universe from all sources outside the Milky Way at optical wavelengths. Measuring the COB allows for a comparison with all expected sources of emission such as galaxies, and potential identification of the source of any excess component of diffuse emission. Her PSF estimation algorithm is also being used to measure the PSF of LORRI from the New Horizons images, which will allow for better characterization of star light in those images.

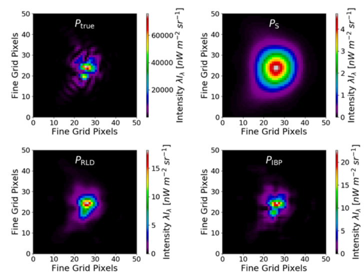


Figure 25. A demonstration of Symons' PSF estimation algorithm. P_S is the point spread function (PSF) of a stack of many undersampled stars in a simulated SPHEREx image, P_{RLD} is an intermediate deconvolution step that partially recovers the underlying PSF, P_{true}, and P_{IBP} is a final deconvolution that represents an excellent reconstruction of P_{true} in the presence of noise and other complicating factors.

Benjamin Vaughan

Undergraduate Researcher

He is a senior in the School of Physics and Astronomy and currently pursuing his Bachelors of Science in Physics. As an Undergraduate Researcher he works Dr. Michael Zemcov on a project to measure the Relativistic Sunyaev-Zeldovich effect in galaxy clusters. These galaxy clusters have an atmosphere made of hot diffuse gas fueled by galactic processes. The Sunyaev-Zeldovich effect (SZe) is due to photons from the Cosmic Microwave Background scattering with this hot atmosphere in a process called Inverse-Compton Scattering. This creates a spectrum that we can then measure to determine properties of cluster thermodynamics and give us insight into the evolution of these galaxy clusters. His research is carried out through data analysis of Herschel-SPIRE data, a photometer on the Herschel Space Observatory

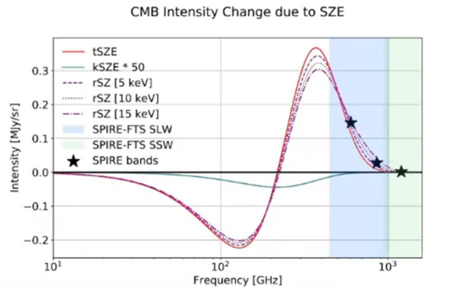


Figure 26. Here is a plot of the SZe spectrum with various relativistic corrections. The starred points represent the observed frequencies of the SPIRE photometer..

Margaret Cruz

Lab Assistant

Margaret Cruz is a first year masters student in Mechanical Engineering. She received her BS in Psychology with a Biological concentration at University of California, Davis in 2011. Prior to joining CfD, she has worked as a laboratory technician for several academic research facilities including Crocker Nuclear Laboratory in Davis, CA, Lawrence Berkeley National Laboratory in Berkeley, CA and Koch Institute for Integrative Cancer Research in Cambridge, MA with diverse projects in the fields of spectrometry, optics, photolithography, nanofabrication and biotechnology. Within CfD, she has assisted in developing a preliminary protocol for the radiation testing of the Quanta Image Sensor (QIS) detector. Using Space ENVironment Information System (SPENVIS), an orbit trajectory can be defined in order to simulate a radiation environment (Figure 27). Radiation dose for certain geometries can then be interpolated, which can provide useful information towards the performance of the QIS device in space. A thorough background on the simulation platform and a review of previous radiation testing protocols conducted for similar image sensing technologies will aid scientists and engineers to accurately characterize the sensor in a radiation environment with specific orbit parameters fitting the LuVOIR and HabEx missions where the QIS is most strategic.

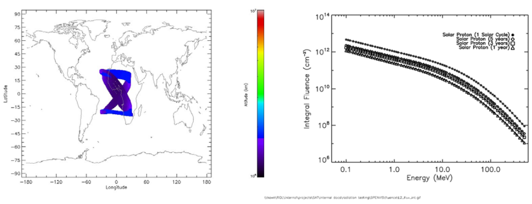


Figure 27. An orbiting satellite 1.5 million kilometers above earth (left) absorbs relative amounts of fluence based on the length of a mission (right). Source: SPENVIS

Long Nguyen

Undergraduate Researcher

Long Nguyen is a third-year undergraduate student pursuing a BS/MS Dual Degree in Electrical Engineering. Long is an undergraduate research student at CfD working in the characterization of the Quanta Image Sensor (QIS) (Figure 28), a single-photon resolving camera which has huge potential application for astrophysics and military. In this research, he has worked on analyzing .fits files from the QIS to compute important characterization parameters such as conversion gain, quantum efficiency, dark current. Nguyen also investigated and simulated readout electronics, cable connections of the QIS to understand how to operate the device (Figure 28). With that understanding, he has helped to outline the requirements to design a new readout electronics based on CfD's future applications. The next step that he is contributing is to ensure new design satisfies all the requirements through circuit simulation, RTL simulation, and ultimately develop the complete design for manufacturing.

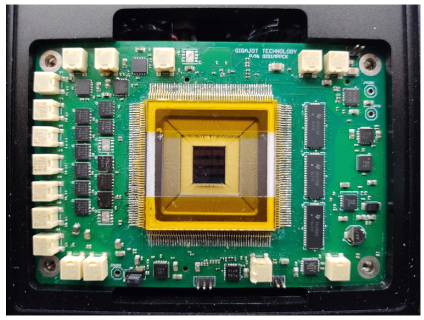


Figure 28. Above is the QIS commercial product from Gigajot.

Mark Nash

Student Software Engineer

Mark Nash is a researcher on the Engineering Verification Test (EVT) team in the CfD. He is a fourth-year BS/MS student in computer science. Prior to joining the CfD, he completed a co-op at Rheonix, a biomedical device company where he worked with software to control device functionality. Within the CfD, along with other computer science students, he is building a software application written in Python that interacts with various lab measurement instruments in order to remotely control and receive data from them (Figure 29, left). This will be able to efficiently test the validity of the outputs of a Photonic Integrated Circuit (PIC) without being in the lab. His contributions to the software have been writing drivers for many instruments and creating a command interpreter for a microprocessor using GNU Bison written in C. The microprocessor interacts with other printed circuit boards that read and output data from measurement instruments and photonic circuitry. An instrument setup is shown in Figure 29 (right). Upon the EVT project's completion, Precision Optical Transceivers will sell this test suite service to other companies for them to test their PICs.

Figure 29. The left image shows the eye scan software that interacts with various measurement instruments, such as the set up shown on the right.

Chi Nguyen

PhD Student Researcher

Chi H. Nguyen is a graduate student in the Astrophysical Sciences and Technology (AST) Ph.D program and a member of the Center for Detectors working under the guidance of Dr. Michael Zemcov. Before coming to Rochester, she received a BS degree in Astronomy 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 work to directly image supermassive black holes in nearby galaxies. Her instrument was verified and implemented successfully in Antarctica in 2015. In April 2019, the Event Horizon Telescope collaboration made history with the first direct image of the supermassive black hole M87*. Her Ph.D 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, in which a group of RIT undergraduate students verify the feasibility of flying a scientific CMOS detector on a sounding rocket at cryogenic temperature. The technology of CSTARS is currently being implemented into the CIBER-2 star tracker. In 2019 summer, CIBER-2 first integration campaign at Wallops Flight Facility (WFF) concluded and the experiment was relocated to RIT for further calibration and improvement. In early 2020, CIBER-2 returned to WFF for vibration test and was qualified for flight in early March 2020. The payload is currently awaiting a launch opportunity in late 2020 - early 2021. In addition to lab work, Nguyen is currently developing a data analysis pipeline for CIBER-2 detectors, building on the knowledge from the previous experiment CIBER-1.

Scott Mann

Lab Assistant

Scott Mann is a fifth year undergraduate student completing his BS in Electrical Engineering with a minor in Imaging Science in 2020. His undergraduate education was focused in image processing and machine vision for armed robots. His industry experience includes circuit design for optical devices. Scott's work at the Center for Detectors has been centered on the characterization of a single-photon resolving detector with potential use for discovering habitable exoplanets. Due to his knowledge of printed circuit board design and electrical hardware integration, his contributions have included the designing of two circuit boards for detector testing. The first will contain the electronics necessary for converting the detector output into a usable electrical signal, while the second will house the detector and must contain components capable of surviving within cryogenic temperatures. If successful, this detector could be used for NASA's replacement for the James Webb Space Telescope.

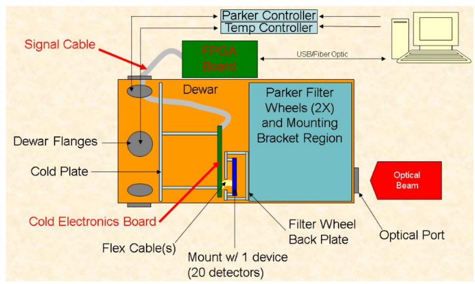


Figure 30. An upper level cryogenic environment testing diagram for characterizing the detector.

Irfran Punekar

Undergraduate Researcher

Irfan Punekar is a fourth year student pursuing his Bachelors and Masters in Science in the Computer Engineering program. His current research is on the NASA SAT project, where he is working to develop a testing system for the Quanta Image Sensor (QIS), a single photon sensing and photon number resolving megapixel CMOS imager. The QIS is a 3D stacked CMOS Megapixel imager proposed, created, and developed by Eric Fossum, and is able to achieve photon number resolution at room temperature. Irfan focuses primarily on field-programmable gate array (FPGA) system design as well as embedded software and systems integration.

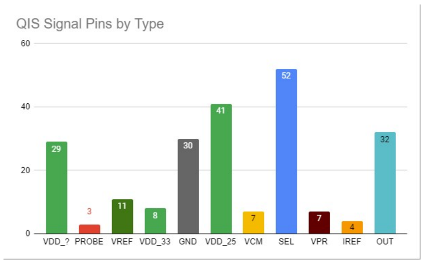


Figure 31. Above is a visual representation of the signals used to operate the Quanta Image Sensor (QIS).

Michael Fanto

PhD Student Researcher

Michael Fanto is a graduate student member of the Future Photon Institute (FPI) 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 a tremendous experience with nonlinear interactions with aterials. 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, he was awarded an Air Force Development Opportunity package and accepted the admission to RIT to start his Ph.D. in microsystems engineering in the integrated photonics group of 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. The characterization and generation of photons with aluminum nitride has been the majority of his research conducted over the past year. Michael successfully defended his thesis entitled, "Nonlinear Optics in Photonics Ultrawide-bandgap Circuits," on April 1, 2020.

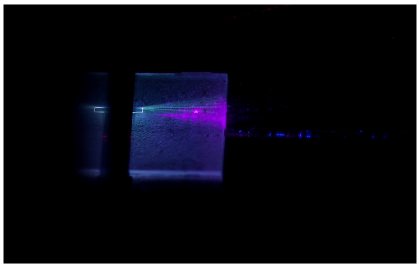


Figure 32. Aluminum nitride photonic integrated circuit with incident light from a femtosecond Ti:Sapphire laser coupled into the waveguide undergoing second harmonic generation to produce violet light from an infrared input beam.

Justin Gallagher

Graduate Research Assistant

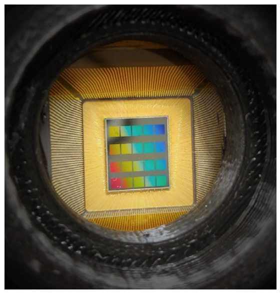


Figure 33 The QIS chip with twenty integrated 1Mpixel QIS detectors integrated on the QISPF electronics (not shown) residing in a 3D printed camera housing.

Justin Gallagher is a fifth year BS/MS student at Rochester Institute of Technology (RIT) pursuing a Master of Science in Astrophysical Sciences and Technology in conjunction with a Bachelor of Science in Physics. Justin is a graduate assistant researcher at RIT's Center for Detectors (CfD) under the guidance of Dr. Donald F. Figer, and will be completing his master defense at the end of the summer 2020 term. Within the CfD, Justin's research primarily focuses on the Quanta Image Sensor (QIS), a single photon sensing and photon-number-resolving CMOS megapixel detector that is being characterized for NASA space missions. Justin is the assigned manager for the NASA PCOS/COR funded project at RIT. Over the past few months, Justin has managed a team of up to five students working diligently to design and produce an electronic system that can operate the QIS chip under a cryogenic vacuum and while being irradiated via a proton beam. The QIS combines a small capacitance sense node, low power usage, and on-chip correlated double sampling to achieve single photon sensing photon-number-resolution. Photon resolution allows the QIS to thrive in ultra-low-light applications where the average photon per pixel is less than one, such as astrophysical imaging, LIDAR imaging, neuromorphic computing, biophotonics, as well as bi-photon quantum entanglement experiments. Justin's past research includes work on the evolution of High-redshift galaxies and galaxy clusters with a focus on the relationship between a galaxy's Star Formation Rate (SFR) and its local environment during the epoch of peak star formation. Using data from the Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (CANDELS), the SFR of more than 40,000 galaxies was calculated using MAGPHYS, a program that fits a model to the Spectral Energy Distribution (SED) measured from a galaxy. A galaxies local environment was determined via measuring the average distance between neighboring galaxies at a redshift of Z = 1 and up to Z = 3. Galaxies are superimposed onto a 2D map, and using Delaunay triangulation, the local environment of a galaxy is characterized by its Voronoi tessellation.

James Parkus

Undergraduate Student Researcher

James Parkus was an undergraduate student researcher at the Center for Detectors completing his BS in Mechanical Engineering in 2020. Throughout his undergraduate education, his work was focused on the fluid loop system in CSTARS, the electronics box for CIBER 2, and the pop-up baffle assembly for CIBER 2. He was responsible for integration and testing of the CSTARS fluid loop which is flight-ready, this work was completed in 2018. After that, he worked on CIBER 2, for which he completed the design of a new electronics box to house the large PCBs that controlled the system. Lastly, he worked on the pop-up baffle assembly for CIBER 2. The pop-up baffle assembly work included fixing the last few issues and preparing it for flight. This work was completed in Winter 2019 when he brought the flight-ready baffle assembly down to Wallops Flight Facility and qualified it for flight through the necessary vibration testing.

Figure 34 Chris Pape (right) and James (left) stand with the baffle for CIBER2 at the Wallops Flight Facility. .

Alexander Zades

Undergraduate Student Researcher

Alexander Zades is a second-year Undergraduate Researcher at the Center for Detectors student working towards a BS in Physics in 2022. He contributes toward Dr. Howlands research on single photon emission from room temperature gallium nitride quantum dots. The GaN quantum dots, when excited, should emit single photons, and when using two detectors, should exhibit antibunching. The experiment Alexander has contributed to seeks to demonstrate this antibunching behavior. Alexander's work has focused on improving the optics in the antibunching experimental setup and creating an automated system to locate and reliably stimulate GaN quantum dots on a given sample. The automated system Alexander has been developing aims to compensate for temperature drift, which has caused the quantum dots to become misaligned during longer experiments. The system also aims to create maps of the quantum dots on the sample since the manufacturing process makes their position and size somewhat unknown. This software will significantly improve the experiment's reliability when completed.

External Funding

NSF, NASA, United States Air Force, and several other organizations provided CfD over $2.5M for projects this past fiscal year. Figure 35 illustrates the estimated funding provided to CfD per year since the inception of the Rochester Imaging Detector Laboratory (RIDL) in 2006, and continuing through the establishment of the CfD. The following pages show a breakdown of current grants and contracts.

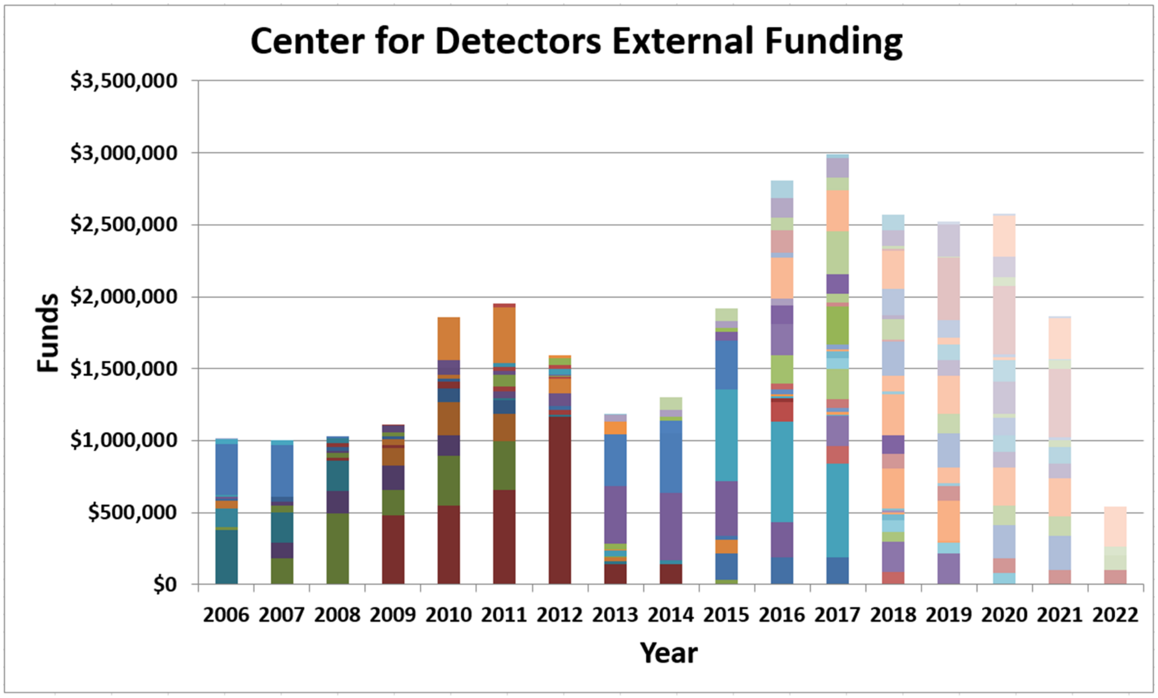


Figure 35. This chart shows historical and anticipated funding levels for CfD projects. Each color in the chart represents a unique research program and budget. Most projects have budgets that span multiple years. Federal agencies, national labs, and research foundations awarded CfD a total of $27M in research funding since the inception of the RIDL in 2006. NASA, NSF, United States Air Force, NYSTAR, and the Moore Foundation provided the most funding.

Grants and Contracts - New

Title	Funding Source	Dates	Amount
PIC: Hybrid Silicon Electronic-Photonic Integrated Neuromorphic Networks	NSF	9/1/2018 - 8/31/2021	$7,000
Diagnosing, Addressing, and Forecasting CIB Contamination in Spectral Measurements of the Sunyaev Zel'dovich Effect	NASA	5/13/2019 - 5/12/2022	$445,481
SPHEREx: An All-Sky Spectral Survey, Phase B	NASA/CALTECH	5/20/2019 - 7/31/2020	$30,911
Development of Quantum Dot Coated Detector Arrays	NYSDED/UofR	7/1/2019 - 6/30/2020	$9,000
Development of Quantum Dot Coated Detector Arrays	ThermoFisher	7/1/2019 - 6/30/2021	$48,000

Measuring Reionization and the Growth of Molecular Gas with TIME	NSF/CALTECH	9/1/2019 - 8/30/2022	$192,389
QLCI - CG: Quantum Photonic Institute	NSF	9/1/2019 - 8/31/2020	$149,215
On-chip quantum photonic sensors using entangled photons and squeezed states	FFRDC-ORNL	10/1/2019 - 9/30/2021	$51,000
A Single Photon Sensing and Photon Number Resolving Detector for NASA Missions	NASA	11/25/2019 - 11/24/2021	$945,228
Program Officer at NSF	NSF	1/21/2020 - 1/20/2021	$236,143
Multi-Color Anisotropy Measurements of Cosmic Near-Infrared Extragalactic Background Light with CIBER-2	NASA	3/3/2020 - 3/2/2022	$844,112
Analysis of the optical properties of digital micromirror devices in the ultraviolet wavelength regime	NASA/STScI	4/17/2020 - 12/31/2020	$142,007
Navy SITR 2020.A - Topic N20A-T005 (Quantum Optical Semiconductor Chip and its Application to Quantum Communication)	ONR/AdvR, Inc.	5/4/2020 - 10/30/2020	$120,725
		Total	$3,221,211

Grants and Contracts - Ongoing

Title	Funding Source	Dates	Amount
Navy SITR 2020.A - Topic N20A-T005 (Quantum Optical Semiconductor Chip and its Application to Quantum Communication)	ONR/AdvR, Inc.	5/4/2020 - 10/30/2020	$66,810
Analysis of the optical properties of digital micromirror devices in the ultraviolet wavelength regime	STScI	4/17/2020 - 12/31/2020	$75,870
Program Officer at NSF	NSF	1/21/2020 - 1/20/2021	$236,143
On-chip quantum photonic sensors using entangled photons and squeezed states	IC-USG/FFRDC-ORNL	10/1/2019 - 9/30/2021	$7,000
Measuring Reionization and the Growth of Molecular Gas with TIME	NSF/CALTECH	9/1/2019 - 8/30/2022	$192,389
Multi-Color Anisotropy Measurements of Cosmic Near-Infrared Extragalactic Background Light with CIBER-2	NASA	3/3/2020 - 3/2/2022	$293,682

A Single Photon Sensing and Photon Number Resolving Detector for NASA Missions	NASA	11/25/2019 - 11/24/2021	$445,065
SPHEREx: An All-Sky Spectral Survey, Phase B	NASA/CALTECH	5/20/2019 - 7/31/2020	$29,288
QLCI - CG: Quantum Photonic Institute	NSF	9/1/2019 - 8/31/2020	$149,214
Development of Quantum Dot Coated Detector Arrays	ThermoFisher	7/1/2019 - 6/30/2021	$48,000
Development of Quantum Dot Coated Detector Arrays	NYSDED/UR	7/1/2019 - 6/30/2020	$9,000
Diagnosing, Addressing, and Forecasting CIB Contamination in Spectral Measurements of the Sunyaev Zel'dovich Effect	NASA	5/13/2019 - 5/12/2022	$243,139
Precision - RIT Fiber Attach	Precision Optical Transceivers	1/15/2019 - 8/31/2019	$45,000
Air Force STTR Phase II AF16-AT01: "Wafer-Level Electronic-Photonic Co-Packaging"	USAF/Phase Sensitive Innovations Inc.	9/6/2018 - 8/31/2020	$250,257
Studies of the Diffuse Optical Background with New Horizons	NASA	9/4/2018 - 9/3/2021	$456,000
PIC: Hybrid Silicon ElectronicPhotonic Integrated Neuromorphic Networks	NSF	9/1/2018 - 8/31/2021	$523,053
CAREER: Development of HighEfficiency Ultraviolet Optoelectronics: Physics and Novel Device Concepts	NSF	3/15/2018 - 2/28/2023	$500,145
Development of Digital Micromirror Devices for Far-UV Applications	NASA	1/1/2018 - 12/31/2020	$536,981
Probing the History of Structure Formation through Intensity Mapping of the Near-Infrared Extragalactic Background Light	NASA	9/20/2017 - 9/19/2020	$122,697
Collaborative Research: SOAR/SAM Multi Object Spectrograph (SAMOS)	NSF/JHU	9/1/2016 - 8/31/2020	$92,925
EAGER: TDM solar cells: Bifacial III-V nanowire array on Si tandem junctions solar cells	NSF	5/1/2017 - 10/31/2020	$299,808
Multi-Color Anisotropy Measurements of Cosmic Near-Infrared Extragalactic Background Light with CIBER2	NASA/CALTECH	5/2/2016 - 7/31/2019	$280,552
TAP Hub 2019 Development TAP Hub 2019 Developmet	NYSESD/SUNYRF	1/1/2019 - 6/30/2020	$450,586

AIM Academy Photonic Integrated Circuit Design and Test Education Curricula	USAF/SUNYRF	1/1/2018 - 4/1/2020	$122,012
TAP Process Development 2018 (Rochester Hub)	USAF/SUNYRF	1/1/2018 - 12/31/2019	$498,489
Understanding and Engineering Valence Band Structures of III-Nitride Semiconductors for High-Efficiency Ultraviolet Lasers and Emitters	ONR	6/1/2016 - 5/31/2020	$325,100
Integrated Quantum Photonics for Photon-Ion Entaglement	USAF	3/14/2016 - 9/30/2021	$1,436,625
Phase II: New Infrared Detectors for Astrophysics	NSF	9/15/2015 - 8/31/2020	$1,983,212
		Total	$9,719,042

Grants and Contracts - Completed within the Past Year

Title	Funding Source	Dates	Amount
Development of Quantum Dot Coated Detector Arrays	NYSDED/UR	7/1/2017-6/30/2018	$9,000
Development of Quantum Dot Coated Detector Arrays	Thermo Fisher	7/1/2017-6/30/2018	$18,000
Developing the THz detector technology for inspection applications	NYSDED/UR	7/1/2017-6/30/2018	$30,000
The Development of Digital Micromirror Devices for use in Space	NASA	5/19/2014-5/18/2018	$565,275
Quantum Silicon Photonics Measurement System	USAF	9/15/2016-9/14/2017	$276,475
MRI: Acquisition of an Inductively Coupled Plasma Reactive Ion Etching System for Research and Education in Nanophotonics, Nanoelectronics and Nano Bio Devices	NSF	9/1/2016-8/31/2017	$305,000
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
OVPR (GWBC 2016) - A Data Analysis Pipeline Simulator for a Millimeter-Wavelength Imaging Spectrometer	RIT	5/1/2016-8/31/2017	$5,000
Air Force STTR Phase 1 AF16-AT01: Wafer-Level Electronic-Photonic Co-Packaging	USAF/Phase Sensitive Innovations Inc.	11/15/2016-8/14/2017	$49,030
		Total	$1,262,780

Collaborating Partners

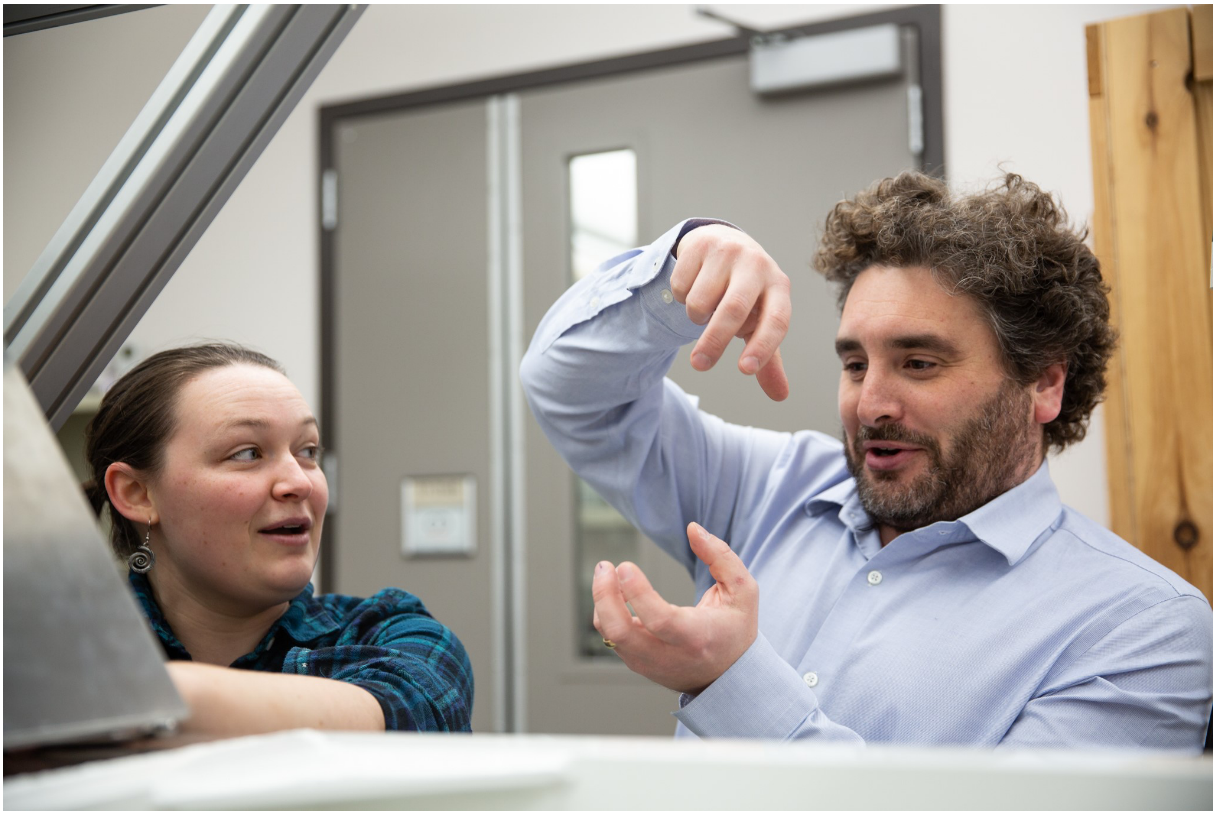
The CfD collaborates extensively with a broad range of organizations, including other academic institutions, government agencies, and industry leaders. Some examples are Caltech, Cornell University, University of Rochester, NASA, NSF, Thermo Fisher Scientific, Raytheon Vision Systems, Gigajot Technology, TOPTICA Photonics, and Precision Optical Transceivers.

Because of our collaborative approach, and the centrality of student involvement in all of our projects, CfD students benefit from exposure to a wide range of research and development environments. This is consistent with a key objective 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

Laboratories, Federal Agencies, and Foundations

Industry



Communication

COMMUNICATIONS

In the News

RIT Awarded NSF Funding to Conceptualize Quantum Photonic Institute

Figure 36. Don Figer, director of RIT's Future Photon Initiative, led leaders in quantum science and technology on a tour of RIT's photonics research facilities during the Photonics for Quantum Workshop.

RIT will develop plan for open access Quantum Foundry for quantum photonic Circuits

Luke Auburn
August 7, 2019

The National Science Foundation awarded Rochester Institute of Technology a grant to conceptualize a new institute that would be at the forefront of quantum science and technology. RIT received $150,000 in funding from the NSF's Quantum Leap Challenge Institutes program to create a plan for an institute that would expand quantum science and technology capabilities through quantum photonic integrated circuits.

"Quantum technologies are on the verge of transitioning from fundamental research to applied technology, forming a quantum industry," said Don Figer, director of RIT's Future Photon Initiative. "This field will have broad impact on computing, artificial intelligence, biosensors, positioning systems, navigation, machine learning and cryptography. The new funding will help us develop a proposal for a Quantum Photonic Institute that would create and use the only U.S.-based open-access Quantum Foundry for quantum photonic circuits, positioning RIT at the forefront of this emerging industry."

The U.S. government boosted efforts to accelerate quantum technology in December when it signed the National Quantum Initiative Act into law, providing $1.2 billion in funding for quantum technology research over five years. The act will create new multidisciplinary research centers aimed at transitioning quantum technologies form laboratory experiment to deployable technologies. These centers and their partners will train the future quantum workforce.

"RIT has always been a leader in innovative technologies, and I am pleased that this grant will allow them to continue that legacy by solidifying their position in the quantum science field," said U.S. Congressman Joe Morelle. "Quantum-photonic technologies have broad applications that will strengthen our economy and create new job opportunities. I am grateful to NSF for this investment and look forward to RIT's growth and success in this important industry."

Earlier this year, RIT brought hundreds of leaders in quantum science and technology to campus for the Photonics for Quantum Workshop.

RIT's Future Photon Initiative develops photonic devices in pursuit of answers to grand questions, leveraging efforts of existing RIT research groups who develop technology for the generation, transmission, manipulation, absorption, and detection of photons. For more information, go to https://www.rit.edu/fpi/

Morelle Announces $150k in Funding for RIT Quantum Photonics

Figure 37. Pictured above is Congressman Joe Morelle.

Gino Fanelli

August 7, 2019

U.S. Rep. Joe Morelle, D-N.Y. has announced a $150,000 grant for the Rochester Institute of Technology toward the development of a quantum photonics institute.

Awarded through the National Science Foundation, the funding will help support the development of a quantum photonics ecosystem at RIT, with a goal of making the school a leader in the field. Quantum photonics focuses on developing photonic-based tools and circuits for use in the quantum space. In other words, light-based circuits used in extremely small and precise technology.

"Quantum technologies are on the verge of transitioning from fundamental research to applied technology, forming a quantum industry," said Don Figer, director of RIT's Future Photon Initiative, the core photonics program at RIT, in a statement. "This field will have broad impact on computing, artificial intelligence, biosensors, positioning systems, navigation, machine learning and cryptography."

With the funding, Figer hopes to develop the United States's first open-access "quantum foundry" for quantum photonic circuits.

"RIT has always been a leader in innovative technologies and I am pleased that this grant will allow them to continue that legacy by solidifying their position in the quantum science field," Morelle said. "Quantum-photonic technologies have broad applications that will strengthen our economy and create new job opportunities."

RIT Researchers Help Develop Practical New Method for Measuring Quantum Entanglement

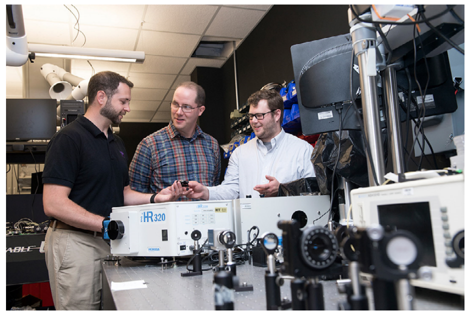


Figure 38. Michael Fanto (left), an RIT microsystems engineering Ph.D. student and the experimental lead for the Air Force Research Laboratory Quantum Information Science group; James Schneeloch (center), a postdoctoral researcher with the Air Force Research Laboratory U.S. Air Force; and Gregory Howland (right), RIT assistant professor, were among the researchers to develop a new technique to measure quantum entanglement.

Luke Auburn
August 23, 2019

Rochester Institute of Technology researchers have helped develop a new technique for quantifying entanglement that has major implications for developing the next generation of technology in computing, simulation, secure communication and other fields. The researchers outlined their new method for measuring entanglement in a recent Nature Communications article.

When two quantum particles—such as photons, electrons or atoms—become entangled, they have special correlations that show up in their measurements even when the particles are separated by an enormous distance. This unique property, which can only be explained through quantum mechanics, is at the heart of many of the technologies as part of the National Quantum Initiative.

"Quantum entanglement is a resource that can be used to do important tasks such as quantum computing or secure communication," said Assistant Professor Gregory Howland, a member of RIT's Future Photon Initiative. "Two people that have entangled quantum particles can generate an unbreakable key for sending messages back and forth to one another in such a way that if some third party intercepts the message, by the laws of physics it's impossible for them to decode the message."

As quantum technologies become more complex, users will need a way to calculate how much quantum entanglement exists within a given system. For the system in this study—involving spatially entangled photon pairs—the new technique needed a million-times fewer measurements than previous methods. And because the technique is based on information theory, the measurement technique has the added benefit of never overestimating how much entanglement is in a system.

"This turns out to be critical because it means we never accidentally tell you that you have more of the resource than you really have," Howland said. "It's especially important for something like secure communication, where you're trying to avoid an adversary intercepting a message."

Scientists Developing Single Photon Detector to Search for Habitable Exoplanets

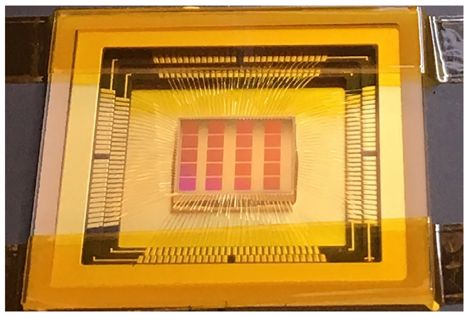


Figure 39. The single photon detector being developed leverages the Quanta Image Sensor (QIS) semiconductor chip shown above

NASA to award RIT and Dartmouth grant to develop highly sensitive detector for future missions

Luke Auburn, RIT University News

September 12, 2019

NASA announced it is awarding a team of researchers from Rochester Institute of Technology and Dartmouth College a grant to develop a detector capable of sensing and counting single photons that could be crucial to future NASA astrophysics missions. The extremely sensitive detector would allow scientists to see the faintest observable objects in space, such as Earth-like planets around other stars.

The detector leverages Quanta Image Sensor (QIS) technology, which represents a new way to collect images in a camera. The QIS measures every photon, or individual particle of light, that strikes the image sensor. While other sensors have been developed to see single photons, the QIS has several advantages including the ability to operate at room temperature, resistance to radiation and the ability to run on low power.

“This will deliver critical technology to NASA, its partners and future instrument principal investigators,” said Don Figer, director of RIT’s Center for Detectors, the Future Photon Initiative and principal investigator for the grant. “The technology will have a significant impact for NASA space missions and ground-based facilities. Our detectors will provide several important benefits, including photon counting capability, large formats, relative immunity to radiation, low power dissipation, low noise radiation and pickup, lower mass and more robust electronics.”

The project’s co-investigators include RIT Assistant Professor Michael Zemcov and Dartmouth Professor Eric R. Fossum, the primary inventor of the modern CMOS image sensor “camera-on-a-chip” technology used in over a billion cameras each year, including in all smartphones. Fossum has focused on inventing the QIS technology while RIT is leading application-specific development that leverages their expertise in astrophysics.

"We’re excited for this collaboration with RIT to build upon Dartmouth’s proof-of-concept QIS technology to research and develop instrument-grade sensors that can detect single photons in the dimmest possible light,” Fossum said. “This has tremendous implications for astrophysics and enables NASA scientists to collect light from extremely distance objects.”

The detector could help with several NASA missions over the next decade including the Large UV/Optical/IR (LUVOIR) Surveyor and A Habitable-Expolanet (HabEx) Imaging Mission. It could also be used in many other technologies that use detectors, such as cell phones, biomedical imaging devices, self-driving cars and more.

The researchers will develop the technology over the next two years. The Center for Detectors will publish results, reports and data processing and analysis software on their website.

New Tech at RIT May Help Find Other Planets

Figure 40. Above, Justin Gallagher adjusts the QIS camera in the RIDL to use it for testing.

WROC Staff

October 4, 2019

ROCHESTER, N.Y. (WROC) — A breakthrough in sensor technology at the Rochester Institute of Technology may contribute to finding other planets like ours.

A camera with a specific sensor is used to detect light or photons from distant planets.

Fifth year astrophysics student Justin Gallagher interprets the data captured by the camera.

“We have zero photons, pixels that exhibited one photon, pixels that might have had two photons captured,” Gallagher said.

“We’d like to know how those pixels behave, how efficient are those pixels, are there any errors with those pixels that might in fabrication you’d like to go back and redesign.”

Dr. Don Figer of RIT has worked closely with sensors for years.

“With this new grant we’re going to be able to characterize it in every conceivable way that’s relevant for a space mission that NASA wants to do.”

After measuring photons, the next step may be detecting certain gases like oxygen or methane.

“Those are biomarkers,” said Figer. “So now this becomes a life finder, so it’s not just a planet finder, it’s a life finder.”

Researchers Prepare Rocket for Launch

Figure 41. In the photo, Assistant Professor Michael Zemcov and Chi Nguyen, Ph.D. student, are preparing CIBER-2 to fly on a Black Brant IX sounding rocket, left.

Luke Auburn, RIT University News

November 21, 2019

A team of RIT researchers is helping launch an experiment above the atmosphere to better understand extragalactic background light, which traces the history of galaxies back to the formation of the first stars in the universe.

"We're trying to understand the fluctuations in the background light at infrared wavelengths," said Michael Zemcov, assistant professor of physics and a member of RIT's Future Photon Initiative and Center for Detectors. "We want to know if there is matter or sources of light in between galaxies that we can't find in the ways we've been using up to now."

The experiment leverages an observational technique called intensity mapping used to study the structure of the universe.

Zemcov is the principal investigator of the observational cosmology project, dubbed the Cosmic Infrared Background ExpeRiment-2 (CIBER-2).

Chi Nguyen, an astrophysical sciences and technology Ph.D. student from Vietnam, is one of the researchers critical to the project. She received a NASA Earth and Space Science Fellowship in astrophysics research that funds her contribution to the project's data analysis and instrumentation.

The experiment section of the rocket—the compartment that holds the telescope and detectors—arrived at the RIT campus in August so that Zemcov and Nguyen could assemble and calibrate the equipment, along with support from collaborators from Japan, California Institute of Technology, and University of California, Irvine.

At the end of November, it ships to the Wallops Flight Facility in Virginia to be integrated with the rocket.

It then heads to the New Mexico desert in January where the rocket will ultimately launch.

CIBER-2 will fly on a Black Brant IX sounding rocket from the White Sands Missile Range in February. The short flight will last for about 15 minutes and CIBER-2 will collect data for about half that time before the rocket returns to Earth.

Once the launch is complete, researchers will begin analyzing the data and preparing for subsequent launches over the next five years that will collect additional data at different wavelengths.

Zemcov said that if the experiment uncovers new sources of light in between galaxies that couldn't be found through other means, it would raise additional important questions.

"If we find such light, how bright is it, where is it coming from, and what's responsible? It could be things as simple as stars outside of galaxies or it could be even more exotic things like dark matter that's decaying into photons."

RIT to Host Workshop Exploring the Intersection of Photonics and Quantum Technology

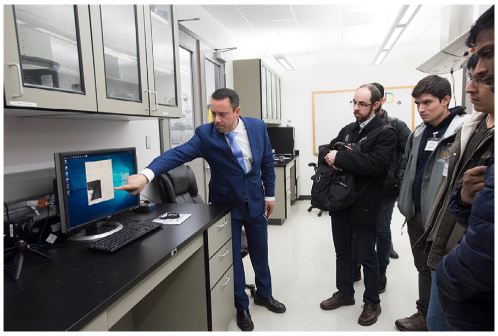


Figure 42. During RIT's first Photonics for Quantum workshop in 2019, Don Figer led attendees on a tour of RIT's photonics research facilities. Photonics for Quantum 2 will take place June 23-25.

Photonics for Quantum 2 to take place June 23-25

Luke Auburn
January 24, 2020

Rochester Institute of Technology will bring international pioneers in the advancement of photonics for quantum devices to campus this summer for a special workshop. The Photonics for Quantum Workshop 2 takes place June 23-25 at the RIT campus.

The workshop aims to explore how photonic devices may impact quantum science, technology and applications. Topics will focus on quantum technology development in five main applications—computing, communication, imaging, sensing and clocks.

"This is an exciting time to be working in the field of quantum science and technology," said Don Figer, director of RIT's Future Photon Initiative and the Center for Detectors. "The federal government invested heavily in the field when it passed the National Quantum Initiative Act in 2018, and late last year, we saw a major breakthrough in quantum supremacy. Photonic devices will be key to unlocking the potential of quantum technology, and we look forward to exploring that in detail at the workshop."

Speakers will include academic and industry experts from MIT, Dartmouth College, University of Wisconsin, University of Arizona, RMIT University, University of Vienna, Purdue University, Xanadu and more. The workshop will include special events such as Quantum Careers and Education as well as the Women in Quantum: Increasing Diversity in Industry and Academia breakfast panel. It also comes on the heels of the AIM Photonics Members Meeting to be held at RIT on June 22.

This year the workshop is offering a new program to assist undergraduate and graduate students with travel costs through $200 stipends per student. Students can apply for the travel stipends through the registration form. Stipends are available on a first-come, first-served basis for students traveling more than 50 miles to Rochester.

RIT held the first Photonics for Quantum Workshop in January 2019. In addition to RIT, this year's workshop is sponsored by L3Harris, TOPTICA Photonics, Teledyne Princeton Instruments, ID Quantique, Photonics Media, Single Quantum and Quantum Design. It is also partially funded by a National Science Foundation grant that supports an RIT-led team to propose an NSF Quantum Leap Challenge Institute.

Additional speakers and the full program will be announced later this spring. For further information about the workshop, including registration, visit the Future Photon Initiative website or contact Robyn Rosechandler.

Making a Quantum Leap

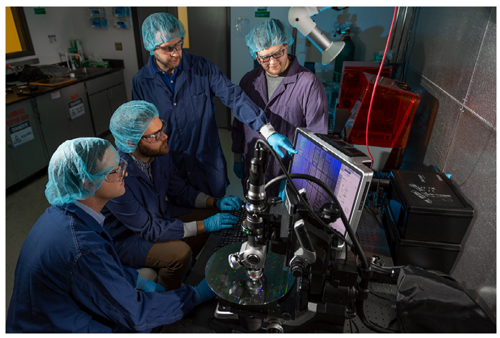


Figure 43. RIT researchers inspect the quantum photonics wafer under a microscope. From left to right, Professor Stefan Preble; microsystems engineering Ph.D. student Matthew van Niekerk; microsystems engineering Ph.D. student Michael Fanto; and assistant Professor Gregory Howland.

Luke Auburn
January 24, 2020

Researchers from RIT's Future Photon Initiative, in collaboration with the Air Force Research Laboratory, have produced the Department of Defense's first-ever fully integrated quantum photonics wafer.

Wafers are used to mass produce integrated circuits or microchips. The microchips produced by this wafer will help to explore how photonics can be used to develop quantum computers.

Quantum technology leverages the effects of quantum physics at the atomic level, where different rules govern matter and classical physics is defied. Quantum phenomena such as entanglement—when particles

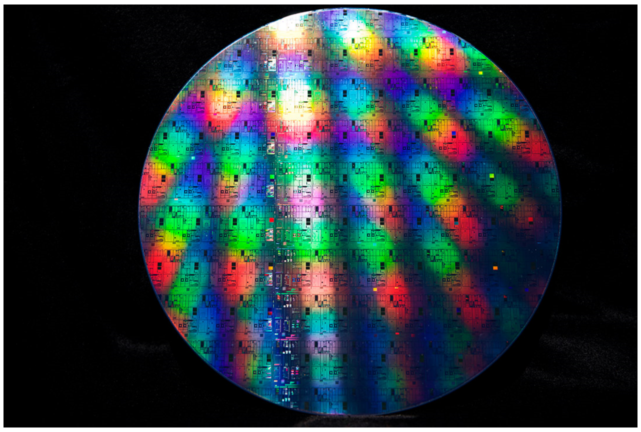


Figure 44. Air Force Research Laboratory: Michael Fanto and Christopher Tison RIT researchers produced the Department of Defense's first-ever fully integrated quantum photonics wafer, shown here. The wafer was broken into microchips to be used in quantum computing tasks.

share certain properties even when separated by an enormous distance—and superposition—when objects can be at two different states at the same time—promise to make the seemingly impossible possible.

The first wave of quantum technology included lasers, the transistor, and GPS, helping usher in the information age. Scientists have since developed a deeper understanding of the underlying quantum physics, and are now racing to develop quantum technology that would bring about a quantum 2.0 revolution and supercharge capabilities in computing, communication, imaging, and sensing.

The quantum photonics wafer project is led by the Air Force Research Laboratory and RIT. The wafer includes chip designs from both RIT and Air Force Research Laboratory, along with designs by collaborators at MIT, Purdue University, Oak Ridge National Laboratory, Army Research Laboratory, and Rensselaer Polytechnic Institute.

The wafer was fabricated by SUNY Polytechnic Institute, which leads the American Institute for Manufacturing Integrated Photonics (AIM Photonics).

"The traditional quantum optics experiments done with single photons up until a few years ago were all realized on giant optical tables with lots of mirrors, lenses, lasers, and other bulk optics equipment," said Stefan Preble, RIT's lead on the project and a professor in microsystems engineering. "That's not very scalable because it obviously takes up a lot of space," he said. "Through this project, we are taking that giant optical table that proves these quantum concepts and miniaturizing it down onto a microchip."

Once the 300mm wafer was created, it was divided into individual chips and the chips were distributed to the collaborators so they can begin using them in experiments to develop quantum photonics devices and circuits.

By scaling these experiments down to chips that are about one square centimeter, they can explore bigger and more complex systems.

In October 2019, Google announced it had achieved quantum supremacy, claiming it developed a quantum computer using superconducting circuits that could perform a calculation in 200 seconds that would have taken the most advanced supercomputer 10,000 years. Scientists still have a way to go before producing practical quantum computers, and photonics could be a key to achieving that.

There are several approaches to creating quantum computing devices, including using photons, trapped ions, or superconductors. But photons have an advantage over other methods because they don't have to be cooled to extreme temperatures like superconductors or be used in a vacuum like trapped ions.

RIT researchers have been working at the intersection of photonics and quantum technology for years and last year the university brought international pioneers in the field to its first Photonics for Quantum Workshop. RIT is planning the second international Photonics for Quantum Workshop June 23-25.

Other RIT collaborators working on the quantum photonics wafer project include Gregory Howland, an assistant professor in the School of Physics and Astronomy, and microsystems engineering Ph.D. students Matthew van Niekerk and Michael Fanto, who is also a research physicist at the Air Force Research Laboratory.

"There are a lot of important building block experiments on the wafer," said Howland. "We're working on making good sources of photons, circuits for manipulating them, and calibration circuits. We're refining these individual devices and, in the future, they will be combined together to make a quantum computing device."

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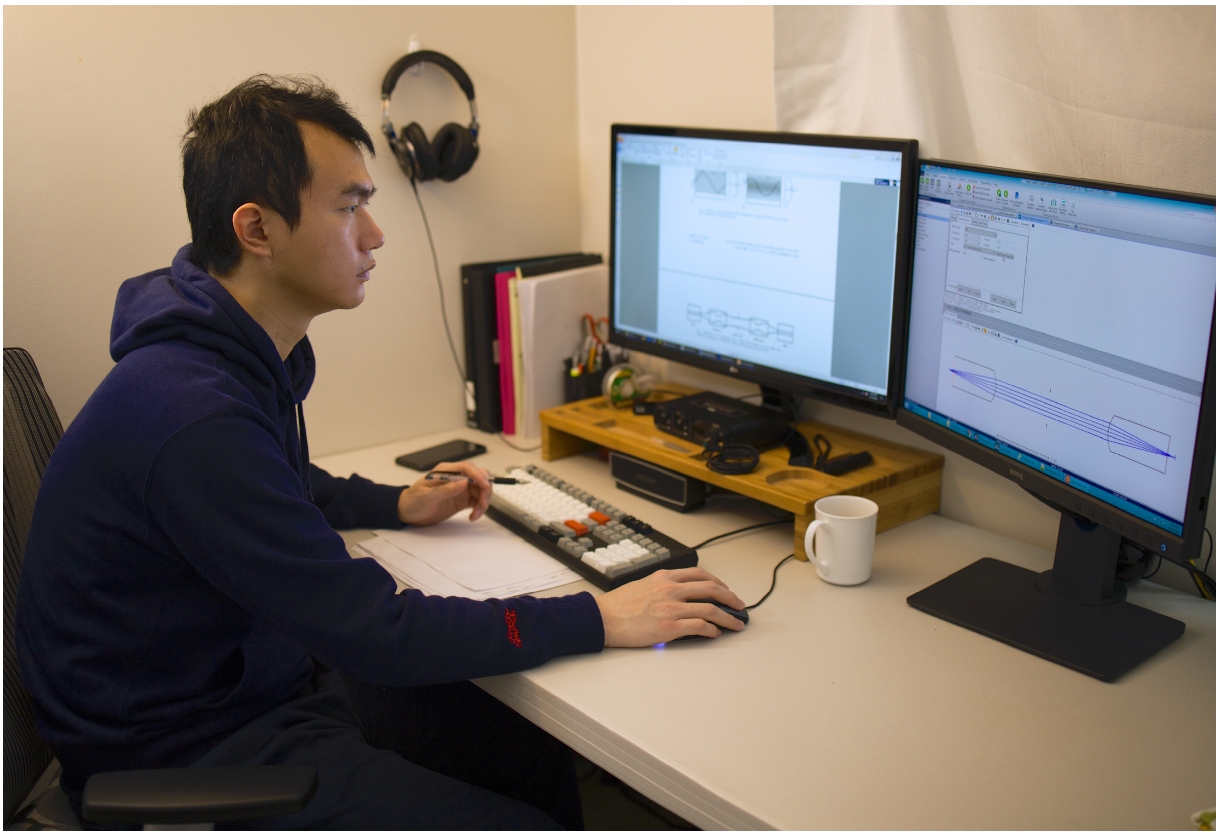


Organization

ORGANIZATION

Personnel

Don Figer

Director, Professor

PhD Astronomy, 1995, University of California, Los Angeles; MS Astronomy, 1992, University of Chicago; BA Physics, Math, Astronomy, 1989, Northwestern University

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 researches massive stars and develops advanced imaging detectors for cross-disciplinary applications. Other research interests of Dr. Figer are developing integrated sensor systems on a wafer and development of a single-photon-sensing and photon-number-resolving detector.

Projects led by Dr. Figer over the fiscal year are, A Single Photon Sensing and Photon Number Resolving Detector for NASA Missions, New Infrared Detectors for Astrophysics, and the QLCI – CG: Quantum Photonic Institute.

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.

Gregory Howland

Assistant Professor

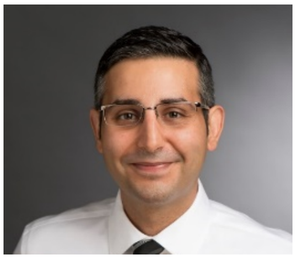
PhD Physics, 2014, University of Rochester; BA Physics, 2007, Oberlin College

Dr. Howland joined RIT as an assistant professor in 2019 after working in Stefan Preble's Integrated Photonics Group as a postdoctoral associate.

His research focuses on high-dimensional quantum information science in photonic systems, with a current emphasis on quantum integrated photonic circuits.

Dr. Howland played a major role in the CfD and FPI quantum project proposals over this fiscal year.

His publications have appeared in Nature Communications, Physical Review X, Physical Review Letters, Physical Review A, Optics Express, and Applied Optics.



Parsian K Mohseni

Assistant Professor

PhD Engineering Physics, 2011, McMaster University, Canada; BS Engineering Physics, 2005, McMaster University, Canada

Dr. Mohseni is an assistant professor in the College of Engineering. Dr. Mohseni's research interests are cross-disciplinary, spanning the fields of solid state physics, optoelectronics, materials characterization, nanoengineering, 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 major research during the fiscal year involves exploration of 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 to enable cost-effective manufacturing of high-efficiency TDM solar cells.

Dr. Mohseni has received research awards from the Canadian Institute for Photonic Innovations and the Ontario Centres of Excellence, and won an NSF EAGER award.

Zoran Ninkov

Professor

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

Dr. Ninkov's 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. 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 temporarily joined the NSF as a program manager through the Intergovernmental Personnel Act (IPA) program this year.

Dr. Ninkov 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

Professor

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

Dr. Preble is professor in the College of Engineering and the lead of the Integrated Photonics Group. Dr. Preble's research concentrations are quantum computing, communication and sensing, photonics packaging, and integrated photonics education. His research focuses 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.

Projects led by Dr. Preble during the fiscal year are integrated quantum photonics for photon-ion entanglement sponsored by the USAF, and the process development of the AIM Photonics' Testing Assembly and Packaging (TAP) Hub.

Dr. Preble has received numerous awards recognizing his work, including the 2019 RIT Trustee Scholarship Award, a DARPA (Defense Advanced Research Projects Agency) Young Faculty Award, and an AFOSR (Air Force Office of Scientific Research) Young Investigator Award.

Michael Zemcov

Assistant Professor

PhD Physics, 2006, Cardiff University; BS Physics, 2003, University of British Columbia

Dr. Zemcov is an assistant professor in the College of Science. His scientific background and interests are 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 is a principle or senior co-investigator on several large programs, including the SPHEREx All-Sky Spectral Survey, the Cosmic Infrared Background Experiment, the Line Intensity Mapping Experiment, and the Tomographic Ionized-carbon Mapping Experiment.

Dr. Zemcov received the NASA Achievement Award twice. He is a member of the American Astronomical Society and a fellow of the Royal Astronomical Society.

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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's major project during the fiscal year was the development of 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. This project 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.

Dr. Zhang has published more than 30 refereed journal papers and 65 conference publications, including invited talks. Dr. Zhang won the NSF Career Award in 2018.

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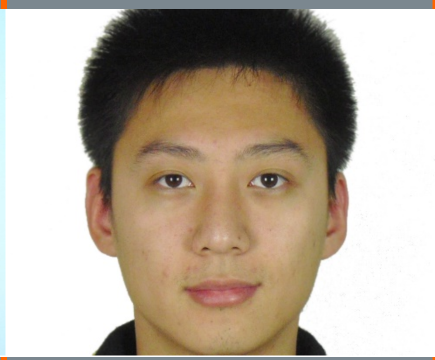

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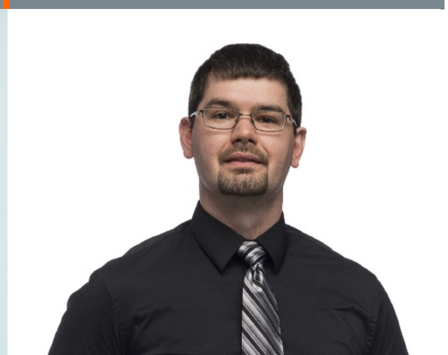

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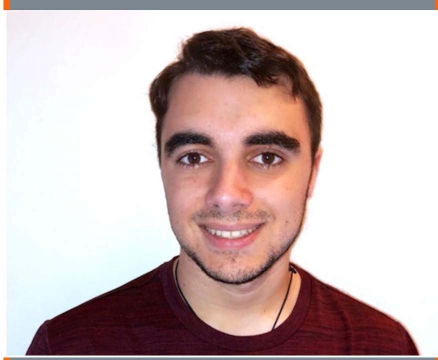

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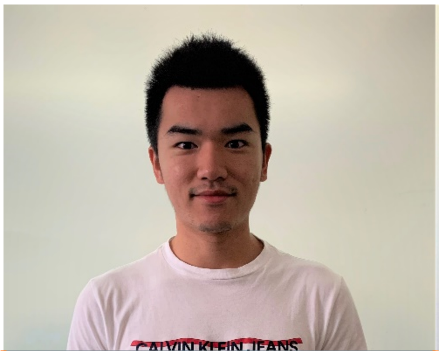

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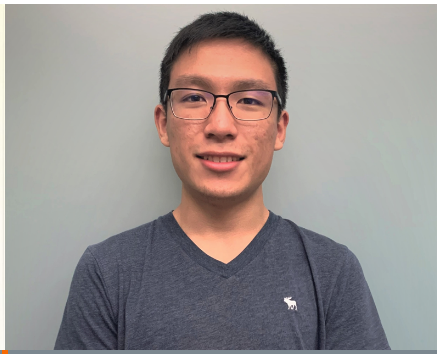

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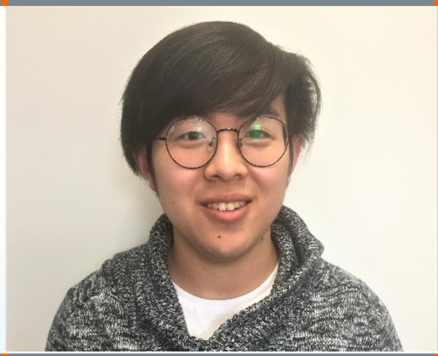

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Facilities and Equipment

The Center for Detectors (CfD) is located in Engineering Hall (Building 17). The CfD headquarters consists of approximately 7,000 square feet of office and research laboratory space. CfD lab space includes the Rochester Imaging Detector Laboratory (RIDL), the Lobozzo Photonics and Optical Characterization Laboratory, the Integrated Photonics Laboratory, the Experimental Cosmology Laboratory, the Laboratory for Advanced Instrumentation Research (LAIR), the Quantum Imaging and Information Laboratory, the Suborbital Astrophysics Laboratory, and the Electrical and Optical Characterization Lab for LED devices.

Facilities within CfD include a permanent clean room, ESD stations, vacuum pumping systems, liquid and closed-cycle cryogenic dewars, optical benches, flow tables, light sources, UV-IR monochromators, thermal control systems, cryogenic motion control systems, single-photon detector systems, a cryogenic optoelectronic probe station, vibration testing stations, a suborbital rocket payload assembly area, power supplies, general lab electronics, and data reduction computers. 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.

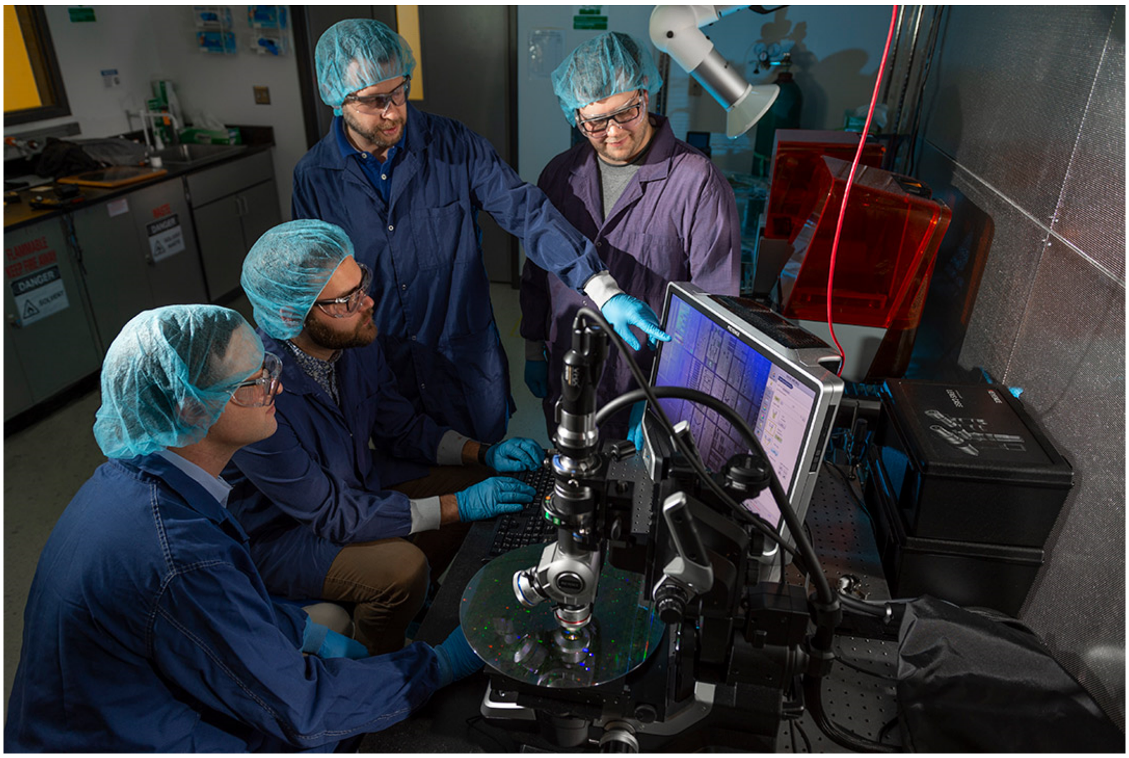


Figure 45. Stefan Preble, Matthew van Niekerk, Michael Fanto, and Gregory Howland inspect the quantum photonics wafer under a microscope in one of the SMFL labs.

Rochester Imaging Detector Lab

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 two Astronomical Research

Camera controllers with 32 digitizing channels, a 1 MHz readout speed, and 16-bit readout capability. The readout systems also contain one Teledyne SIDECAR ASICs with 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 46 shows the electronics packages.

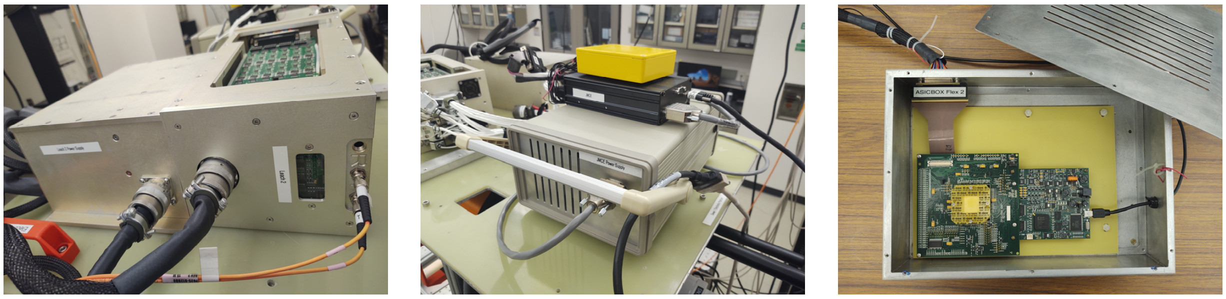


Figure 46. The Astronomical Research Camera Controller (left), the JMClarke Engineering (middle), and the Teledyne SIDECAR ASIC (right) are electronic packages used by CfD to test detectors in RIDL.

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 connector, 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 47).

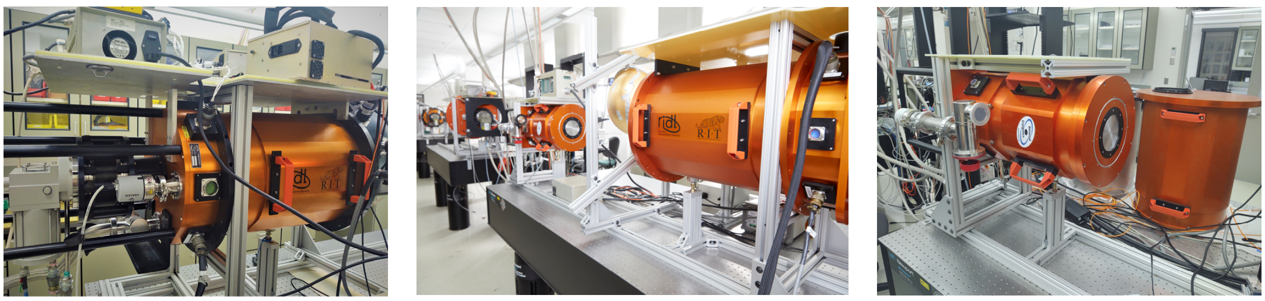


Figure 47. The four custom dewar test systems evaluate detectors in RIDL.

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 absolute flux measurements. RIDL also has a spot projector to characterize the interpixel response of the detectors, including optical and electrical crosstalk. Figure 48 shows a laser spot projection system on a 3D motorized stage that produces a small (~few µm) point source for measurements of intrapixel sensitivity.

RIDL has many data acquisition and reduction computers, each with 8 to 24 threads and up to 256 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 60 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 using parameter files. A complete test suite takes a few weeks to execute and produces ~1 TB of data. The data reduction computers reduce and analyze the data using custom automated code, producing publication-quality plots in near-real time.

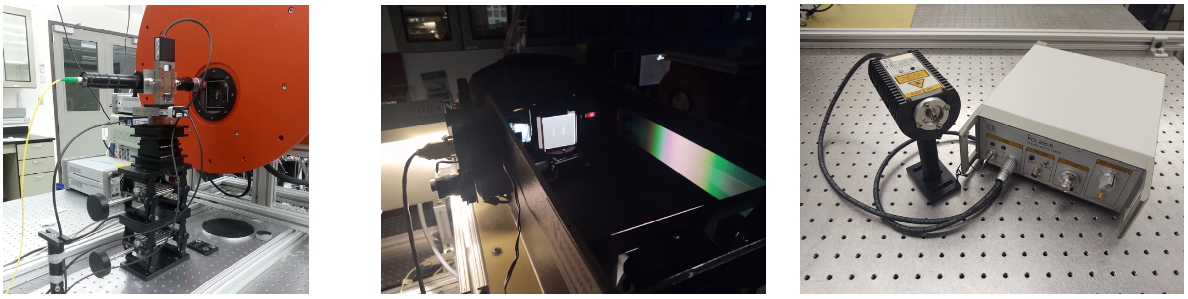


Figure 48. (left)A laser spot projector with a three-axis motion control system projects a small spot of light within individual pixels of detectors in order to measure the response in all regions of a pixel. (middle) A photo of a monochromator with light sources. (right) The PicoQuant laser is used for LIDAR system characterization and testing that requires pulsed illumination.

Lobozzo Photonics and Optical Characterization Lab

The RIT Integrated Photonics Group conducts research in the Lobozzo Photonics and Optical Characterization lab (Figure 49). Dr. Preble and his team develop high performance nanophotonic devices and systems using complementary metal–oxide–semiconductor compatible materials and processes. Their work enables unique 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.

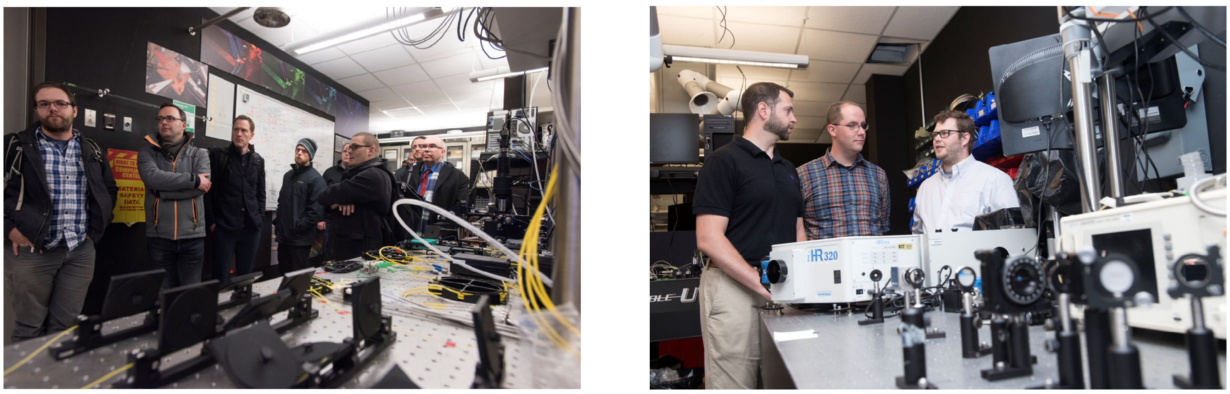


Figure 49. (left) Participants from Photonics for Quantum 1 take a tour of the Photonics and Optical Characterization Lab. (right) Michael Fanto (AFRL), James Schneeloch (AFRL), and Gregory Howland in the lab.

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 50, including an iHR320 spectrometer, a Syncerity CCD Array detector, a liquid helium cryostat, 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.

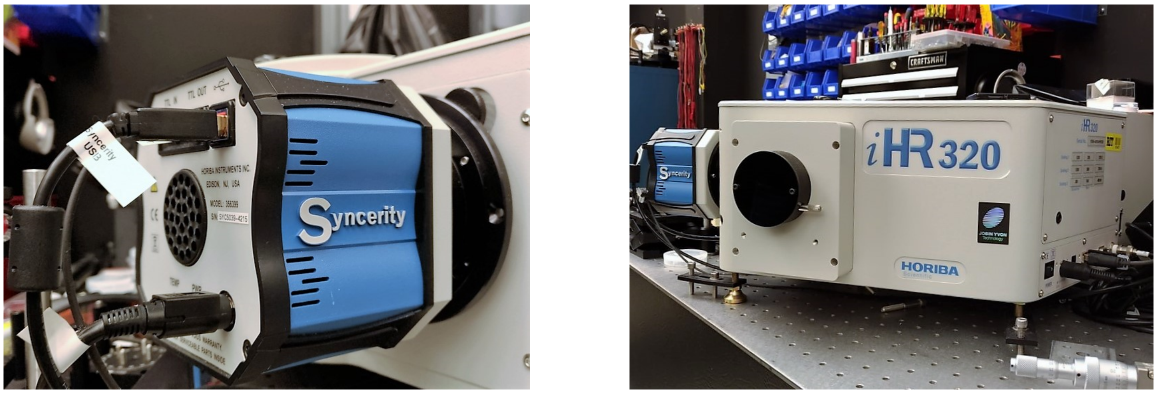


Figure 50. The Syncerity CCD Array detector (left) and the iHR320 spectrometer (right) are part of the photoluminescence system.

Integrated Photonics Lab

The Integrated Photonics Group has added space for quantum integrated photonic experiments, called the Integrated Photonics Lab. Researchers use this lab to design and develop 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 Air Force Office of Scientific Research (AFOSR) provided funding through the Defense University Research Instrumentation Program for a Photon Spot single-photon detector system (Figure 51, *right*), which has high detection efficiencies (>85%) and very low dark counts (<200Hz). The system has detectors for both short-wave infrared and UV wavelengths. The National Science Foundation, Air Force Research Laboratory, and the Gordon and Betty Moore Foundation fund the laboratories' research projects.

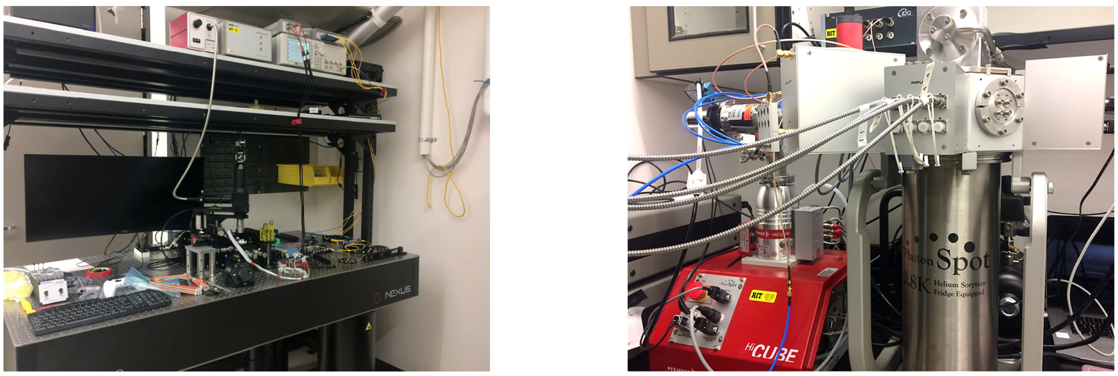


Figure 51. (left) The photo above shows the optical table used to run quantum integrated photonic experiments in the Integrated Photonics Lab. (right) This photo shows the Photon Spot single-photon detector system funded by AFOSR.

Experimental Cosmology Lab

CfD Professor Dr. Michael Zemcov directs the Experimental Cosmology Laboratory. This 375 square foot 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 52). Inside the lab are two Oerlikon Leybold Turbolab turbo-molecular pump systems, optical benches, lifting equipment, and tooling and component fabrication equipment. Multiple computers within the lab run 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 vibration test system and rapid-prototyping PCB mill adds to the capabilities for cosmology instrumentation and testing in this lab.

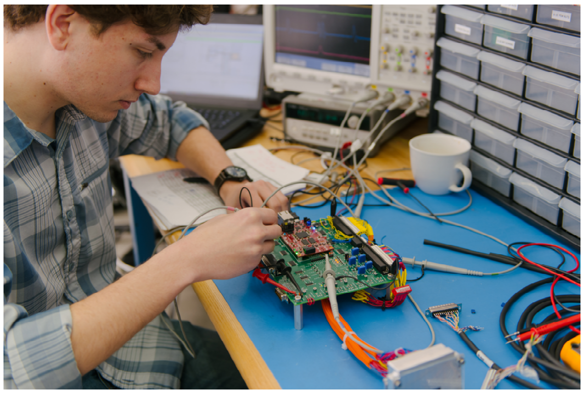
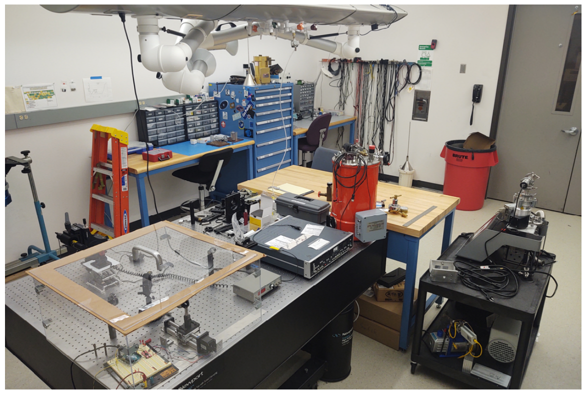



Figure 52. (left) Former CfD student, Ben Stewart, is working with the FPGA-based control board, function generators, and oscilloscopes used to develop CSTARS. (right) The picture shows an overview of the lab.

Suborbital Astrophysics Lab

The Suborbital Astrophysics Laboratory provides RIT with capabilities to design, integrate, and calibrate sounding rocket payloads for astrophysical science. It includes clean facilities to allow disassembly and assembly of rocket instruments, optical and electronic development and validation instruments, and cryogenic and vacuum capabilities. In this lab, Dr. Zemcov and his team prepared the CSTARS and CIBER-2 payloads for flight at White Sands Missile Range, NM (Figure 53) scheduled to take place in Fall 2020.

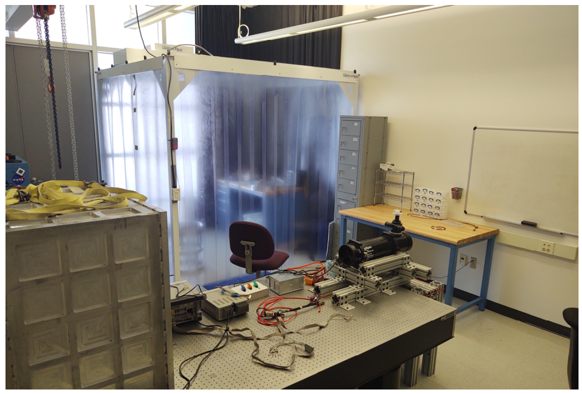
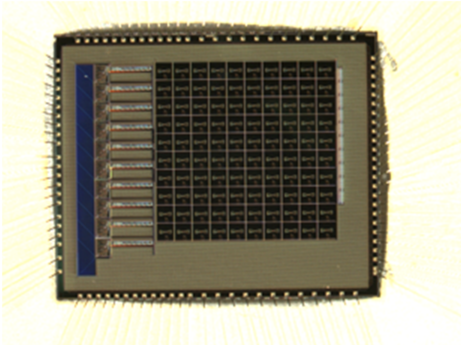



Figure 53. (left) Michael Zemcov and Chi Nguyen inspect the CIBER-2 payload in the clean room area of Suborbital Astrophysics Laboratory (right) before shipping to NASA Wallops flight facility.

Laboratory for Advanced Instrumentation Research

The Laboratory for Advanced Instrumentation Research (LAIR), led by CfD Professor Dr. Zoran Ninkov, is in the Chester F. Carlson Center for Imaging Science, a short distance from the CfD Headquarters. The LAIR develops novel and innovative instruments for gathering data from a wide variety of physical phenomena and trains the next generation of instrument scientists who will occupy positions in government, industry, and academia. It includes hardware and software for developing terahertz (THz) imaging detectors using Si-MOSFET CMOS technology (Figure 54). Over the years, Dr. Ninkov and his team developed a wide variety of instruments at LAIR, including digital radiography systems, liquid crystal filter based imaging systems for airborne (UAV) mine detection, a speckle imaging camera for the WIYN 3.6 meter telescope, a MEMS digital micromirror based multi-object spectrometer, and an X-ray imaging system for laser fusion research. NASA, the NSF, NYSTAR and a variety of corporations such as Exelis, ITT, Kodak, Harris, Moxtek, and Thermo Fisher Scientific, have funded this research.



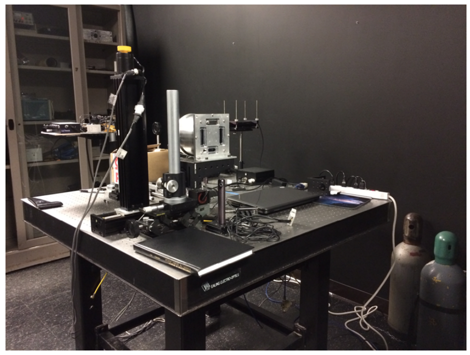


Figure 54. Student researchers in the LAIR developed a terahertz detector (left) and characterized it in the laboratory (right).

Epitaxially-Integrated Nanoscale Systems Lab

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. Dr. Mohseni's group is interested in exploring the fabrication of III-V semiconductor nanostructures using non-conventional metallic catalysts composed of carbon-nanotubes and graphene.

Researchers in the EINSL have access to the wide range of capabilities provided by the NPRL, seen in Figure 55, 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 55. (left) PhD student Mohad Baboli loads a sample in the AIXTRON 3×2 Close Coupled Showerhead metal-organic chemical vapor deposition reactor, which is a part of the MOVPE. (right) PhD student Alireza Abrand is processing samples in the fume hood.

Quantum Imaging and Information Lab

In the new Quantum Imaging and Information laboratory, Assistant Professor Gregory Howland studies how to create, manipulate, and detect quantum mechanical phenomena in the spatial degrees-of-freedom of quantum light. These "Quantum Images" encode large amounts of quantum information of single or entangled photons and serve as a platform for quantum sensing, quantum communication, and quantum computing. Specific research topics range from the applied – such as extreme low-light imaging – to the fundamental – such as quantifying large dimensional quantum entanglement. The 700 square foot laboratory will provide optical benches, laser sources, and single-photon detectors for quantum-optical experiments using bulk, fiber, and integrated optics.

Figure 56. During the COVID-19 shutdown, the Quantum Imaging and Information Lab installed optical benches after completing a full renovation.

Electrical and Optical Characterization Lab for LED devices

The Electrical and Optical Characterization Lab for LED devices, used by Jing Zhang's research group, makes use of advanced tools and techniques to characterize fabricated devices. These devices include advanced LEDs for applications such as home lighting, display, and quantum computing. The lab includes equipment such as a semiconductor parameter analyzer, electrical probe station, an electroluminescence (EL) measurement setup (Figure 57), and a polarization-dependent setup. These tools help describe the power efficiency and optical pattern of the emitted light from these advanced LEDs.

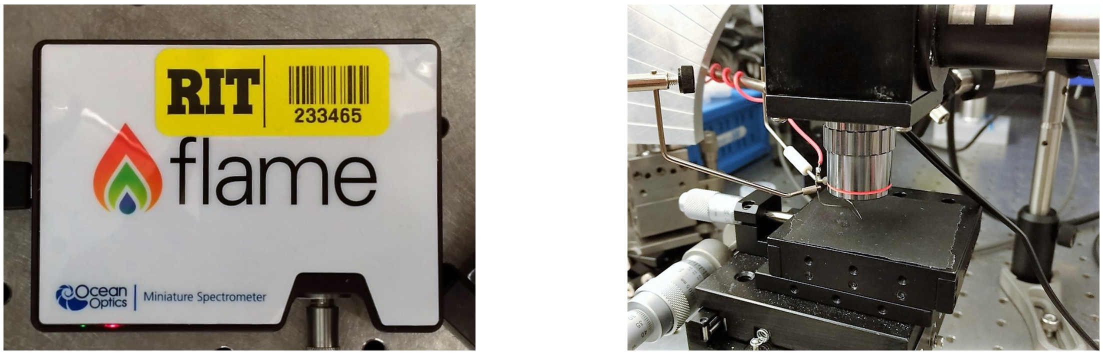


Figure 57. The electroluminescence measurement setup includes a rotating testing stage (right) and a Flame 200 nm – 850 nm spectrometer (left).

Semiconductor & Microsystems Fabrication Lab (SMFL)

The SMFL is equipped with micro-fabrication and metrology equipment to support research programs in photonic devices, nanomaterials, semiconductor materials and devices, nano-electronics, MEMS devices and sensors. These systems are utilized as part of RIT's role in AIM Photonics, to advance integrated photonics. Using the SMFL's resources, CfD can fabricate detectors with custom process flows and multiple process variations. The lab's flow bench and probe stations offer wafer-level testing, even during the fabrication process, allowing mid-process design changes (Figure 58). The probe station accommodates electrical and circuit analysis of both wafers and packaged parts, including low current and radio frequency (RF) probing.

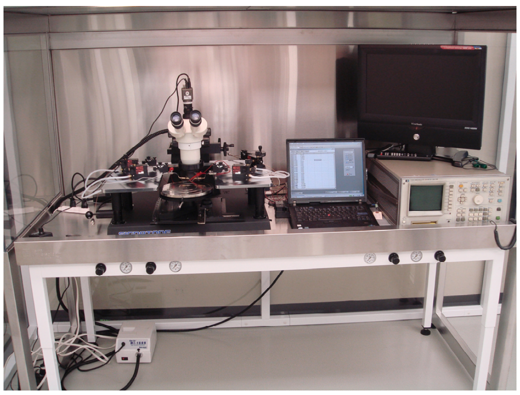


Figure 58. Shown above is the flow-bench lab probe station CfD researchers use to test device wafers.

CfD members use the metal organic vapor-phase epitaxy system (MOVPE) for or growth of III-V thin film crystals and nanostructures, and III-V lasers which Dr. Preble then integrates onto silicon photonic wafers (Figure 59.)


Figure 59. (left) Seth Hubbard tests a wafer load. (right) Karl Hirschman, Stefan Preble, and Seth Hubbard work in the SMFL developing and fabricating integrated circuits.

Figure 60 shows the TS Space Systems two-zone close match solar simulator testing photovoltaic solar cells under simulated sunlight conditions. The solar simulator is a dual source 18 kW system, custom built by TS Space Systems. The ultraviolet and visible (UV-VIS) portion of the spectrum are created using a 6 kW mercury halide arc lamp (also known as a hydrargyrum medium-arc iodide lamp, or HMI), while infrared (IR) was produced from a 12 kW quartz tungsten halogen (QTH) lamp. The output from these lamps were individually filtered to produce either AM0 or, with the insertion of an additional filter set, AM1.5G. The system was designed to produce a 300mm diameter beam. Additional characterization of nanomaterials electronic properties can be performed in the materials and device characterization space using the spectroradiometer, probe stations and IR cameras.

Figure 60. Parsian Mohseni is using the TS Space Systems two-zone close match solar simulator.

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.

Additional Labs

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 61).

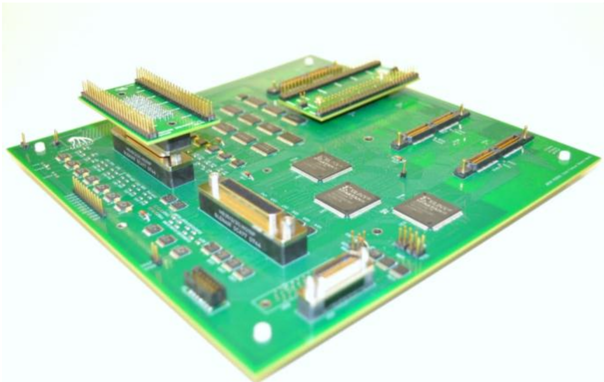


Figure 61. This image shows a cryogenic multi-layer circuit board designed in the CfD and populated in CEMA. All of the components on this board work at temperatures as low as 40 K, nanoTorr pressure levels, and in the presence of high energy particle radiation.

Center for Detectors