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The Center for Detectors (CfD) is motivated by "big" questions: Are we alone in the Universe? What is the nature of dark energy and dark matter? How does the human brain develop? Can we improve outcomes for breast cancer survivors? Is it possible to build ultra-high speed fully secure global computer networks? Can we "see in the dark" and through obstructions to ensure national security? While seemingly unrelated, the answers to these questions will come through new photon detection and transmission technology. Our goal is to be a driving force behind the development of that technology.

The CfD is a Research Center within the RIT College of Science. In our fifth year, we have increased in size and continued to involve many students from a variety of majors in our research to develop new detectors. CfD student researchers are eager to participate in center research because their experiences are authentically connected to world class research and development. Students take on responsibility to push the essential research forward in order to advance our projects, and they are integral players in an interdisciplinary research team.

The following Annual Report describes the new and exciting activities of the Center of the past year. In it, you will find descriptions of CfD research, education, and outreach programs.

I welcome your interest in the CfD and look forward to your support and feedback.

Donald Figer

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

Highlights

Research

- Current projects are: New Visible/IR Detectors for NASA Missions, A Zero Read Noise Detector for the Thirty Meter Telescope (TMT), and Single Photon Counting Detectors for NASA Astronomy Missions.
- Projects completed this year are: Clumping in OB-Star Winds

New Members

- The Center added three new faculty members: Michael Zemcov (School of Physics and Astronomy), Stefan Preble (Microsystems), and Jing Zhang (Electrical Engineering).

NASA Fellowship

- PhD student Kimberly Kolb completed her research of single photon counting imaging detectors through support from a NASA Earth and Space Science Fellowship (NESSF). She will continue her post-doctorate career at the U.S. Army Night Vision and Electronic Sensors Directorate (NVESD).

Publications and Presentations

- Center for Detectors (CfD) team members published ten papers.
- Three talks and three posters were presented.

Visits

- NASA Administrator Charles Bolden toured the CfD.
- NASA Astronaut Donald Pettit met with CfD personnel and discussed a new project to enhance images taken from the International Space Station.

Executive Summary

This report summarizes activities in the Center for Detectors (CfD) over the past year, spanning July, 2014 through July, 2015. The purpose of the Center is to develop and implement advanced photon devices to enable scientific discovery, national security, and better living. These objectives are met through leveraging multi-disciplinary and symbiotic relationships between its students, staff, faculty, and external partners, and by pursuing projects with personnel from multiple colleges, departments, companies, and national laboratories. The vision, mission, and goals are described in the Center Charter Document. The CfD was established in January, 2010. It is an Academic Research Center within the College of Science at the Rochester Institute of Technology.

Personnel

CfD members come from a diverse range of academic programs and professional occupations. Personnel last year included two Professors, three engineers, four student laboratory assistants, one student laboratory programing researcher, four PhD students, and other support staff. Near the end of the reporting period, three Professors were added, along with roughly ten students and staff.

Student Vignettes

Many of the Center's students do research in the Center's laboratories for their academic programs at RIT. CfD student, Kimberly Kolb completed her PhD research, and she will be moving on to the U.S. Army's Night Vision and Electronic Sensors Directorate, located at Fort Belvoir, VA. The Center welcomed new graduate students, Katie Seery and Jam Sadiq, both in the Astrophysical Sciences and Technology PhD program.

Publications

In the past year, CfD researchers submitted ten papers for publication. Five were in refereed astrophysics journals. Four were in proceedings of conferences, including one in Spain and another in Montana. Center Director Figer wrote an invited review article of research on a massive star that was published in Nature Magazine.

Grants, Contracts, and External Funding

The Center is grant-funded, and has been awarded more than $15M in research funding. Near the end of the reporting period, NSF chose the CfD to receive an additional $2M to further develop infrared detectors for future astronomy projects.

Projects

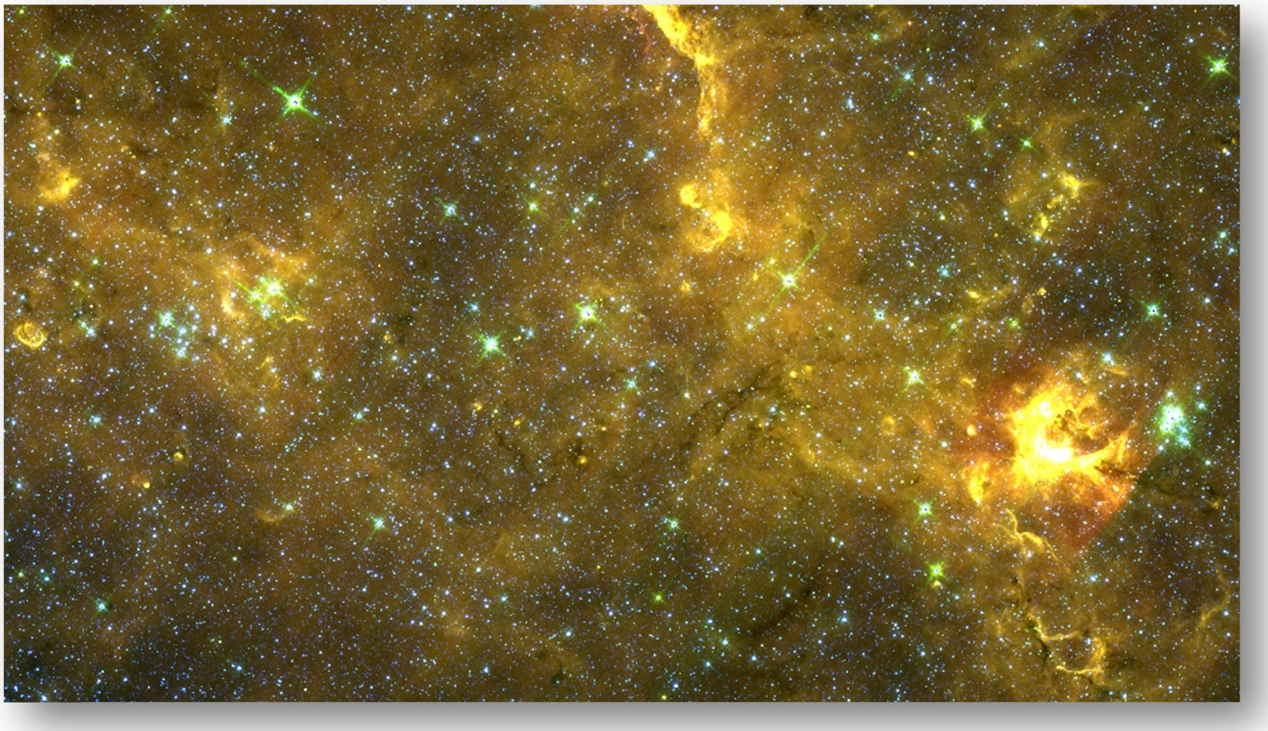
The Center primarily executed three main projects during this year. One is the single photon imaging detector development project, funded by the Gordon and Betty Moore Foundation and done in collaboration with MIT Lincoln Laboratory. The second project is the development of HgCdTe infrared-sensitive detectors using silicon wafer substrates. The third is the integration and validation of a new set of detector acquisition and control electronics.

Press & Presentations

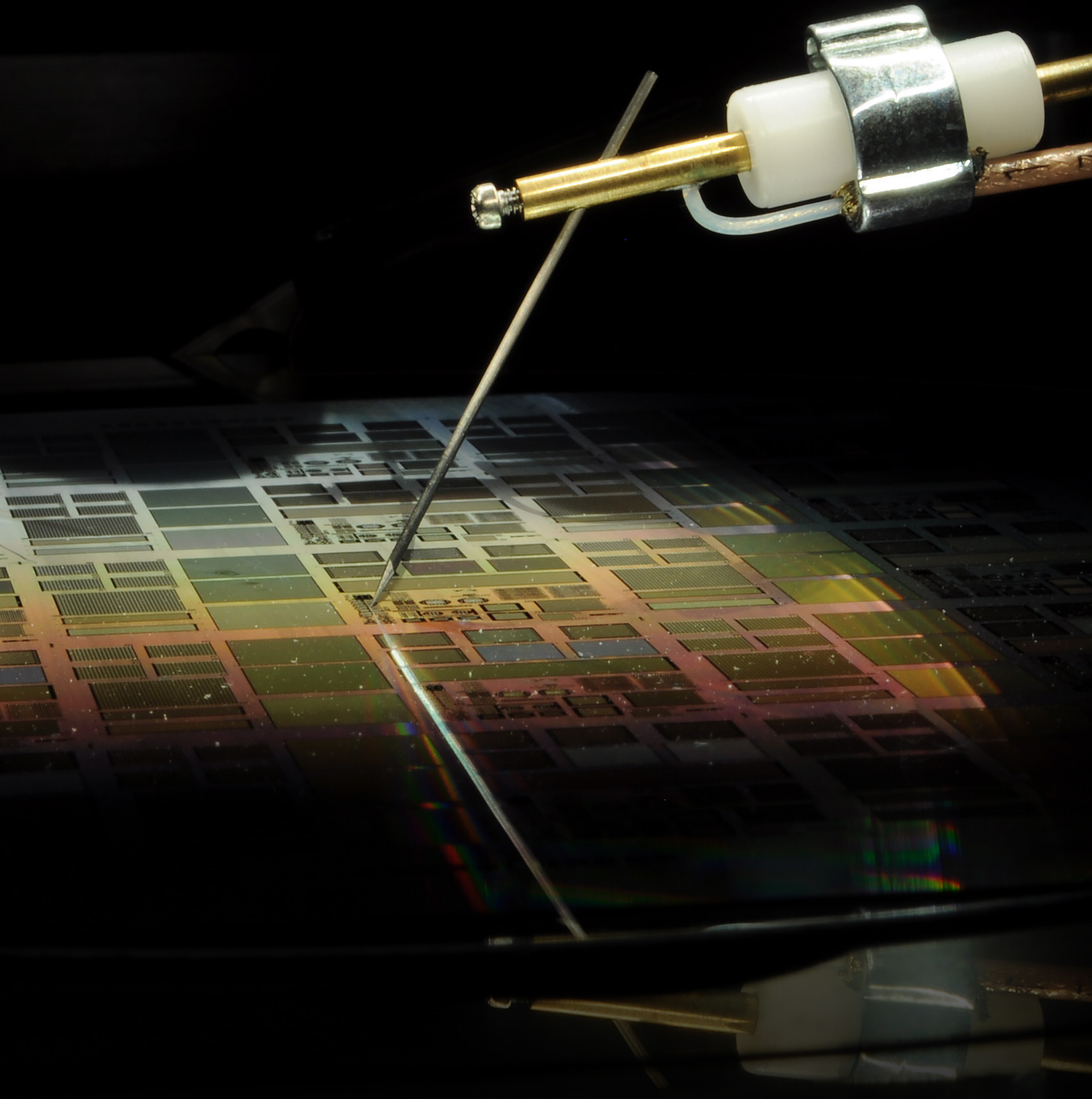
Last year, CfD Director Figer appeared on the radio show, “Connections: Science Roundtable” with Evan Dawson on WXXI AM 1370 News, where he spoke about massive stars and the modern trends of technology-driven science. The CfD hosted visits by NASA Administrator Charles Bolden and NASA Astronaut Donald Pettit. The Center hosted talks by Michael Zemcov, Sloane Wiktorowicz, and Roger O’Brient. Finally, CfD Director Figer’s image of the Pistol Star that he obtained using the Hubble Space Telescope was featured on a new postage stamp made by the country of Jersey.

Equipment and Facilities

The CfD facilities have expanded to accommodate new faculty. The Quantum Dot Imaging Detector Laboratory (QDIDL) has been retired in order to make room for a new sub-orbital rocket laboratory to be directed by new faculty member Michael Zemcov. In addition, the center has expanded to include the already-existing nanophotonics laboratory that is located on the same floor as the CfD and that is directed by new CfD member Stefan Preble. The CfD acquired a fourth dewar system for detector characterization and funded by an NSF supplemental award. This new system is now fully operational.



Research



New Visible/Infrared Detectors

NASA/Astrophysics Research and Analysis Program
NSF/Advanced Technologies and Instrumentation Program

The Center for Detectors continued to advance large-format infrared detector technology, in collaboration with Raytheon Vision Systems (RVS), so that future NASA and NSF astronomy projects can have higher performance, more reliable, and less expensive detectors. During the past year, the research primarily included the fabrication and characterization of 2.5μm cutoff MBE HgCdTe/Si detectors including pre- and post-thinning performance.

Infrared HgCdTe (MCT) detector(s) grown on Si cost less than using CdZnTe (CZT). Larger wafer size allows for larger die and more die per wafer which in turn reduces cost. The goal of the current effort is to produce a 2K×2K MBE MCT/Si detector with competitive performance, and the longer-term goal is to produce an 8K×8K version of this device.

Today, a typical state-of-the-art device has 2K×2K pixels and costs ~$350-500K, and 4K×4K devices cost >$750K. Infrared detectors are expensive, and this is the primary constraint that prevents their use in greater numbers. Small telescopes (D~1 m) rarely have infrared instruments, and even moderately-sized telescopes (D~3 m) often have only one infrared instrument that is usually an imager. While large telescopes (D~8-10 m) now typically have multiple infrared instruments, their focal planes are sparsely populated, again often due to the cost of infrared detectors. Even plans for instruments on the next generation of extremely large telescopes (ELTs, D~20-40 m) have extremely small focal planes. The infrared discovery space for all of these facilities is primarily constrained by the cost of large format infrared detectors.

Past experiences have shown that investment in detector technology results in high return for astronomy. In today's tight budget environment, technologies that can reduce detector development cost and increase large format detector array yield will be critical to making future observatories more affordable and leverage investments in existing observatories. The astronomy community will commit a significant amount of money to detectors in the next 10 years, and affordable large-format infrared detectors will be crucial.

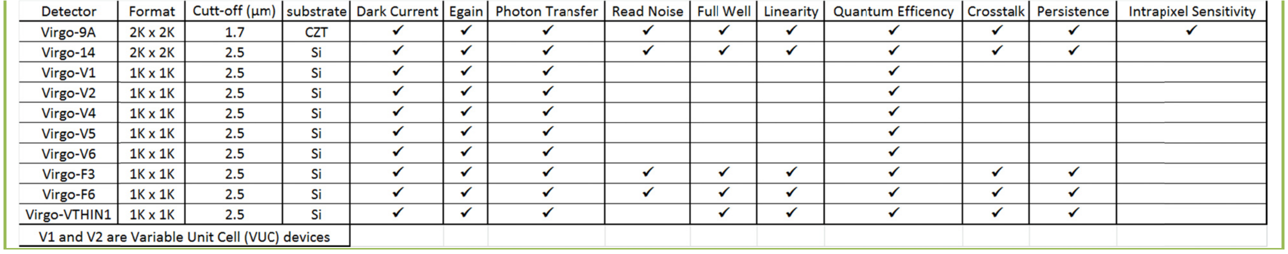
Si wafers are the primary material for semiconductor circuit substrates and are thus pervasive in the semiconductor industry. Given their daily use in very high volume, and general availability, they are inexpensive, on the order of zero cost in the context of scientific detectors. They are also readily available in large sizes. This is unlike substrates of more exotic materials, e.g., CZT, which have very limited commercial use, are produced in low volumes, are available through a small set of vendors, and come in very small sizes. Commonly-available Si wafers have sizes of 8-12 inches (and increasing) which would accommodate 8K×8K (64 Mpixel) or 14K×14K (200 Mpixel) arrays with 15 μm pixels. This development has ancillary benefits for NASA Astrophysics, Earth Science, and Planetary Science missions. Note that large format VIS/IR detectors are one of four key enabling technologies for future Earth Science space missions for characterization of weather, climate, and air pollution.

In Phase I of the project, CfD and RVS designed, fabricated, and tested new infrared detectors based on HgCdTe (MCT) light-sensing material deposited on Si wafers. The effort validated key principles of the technology and demonstrated that it will be successful for astronomy.

RIT received a total of nine devices, including the two benchmark devices that were fabricated prior to this project. VIRGO-9A is a MCT/CZT device and VIRGO-14 is a MCT/Si device. Having one device from each substrate material gave a comprehensive data set for comparison. Seven devices were tested from four wafers across two fabrication runs. Five of the tested devices had a design variation in each quadrant and are referred to as variable unit cell (VUC) devices. Results from the VUC devices gave feedback to the fabrication process which corrected the issues observed. A second fabrication run produced parts, labelled “F” parts, made with the best design and growth process. All devices for this project have a 20 µm pixel pitch.

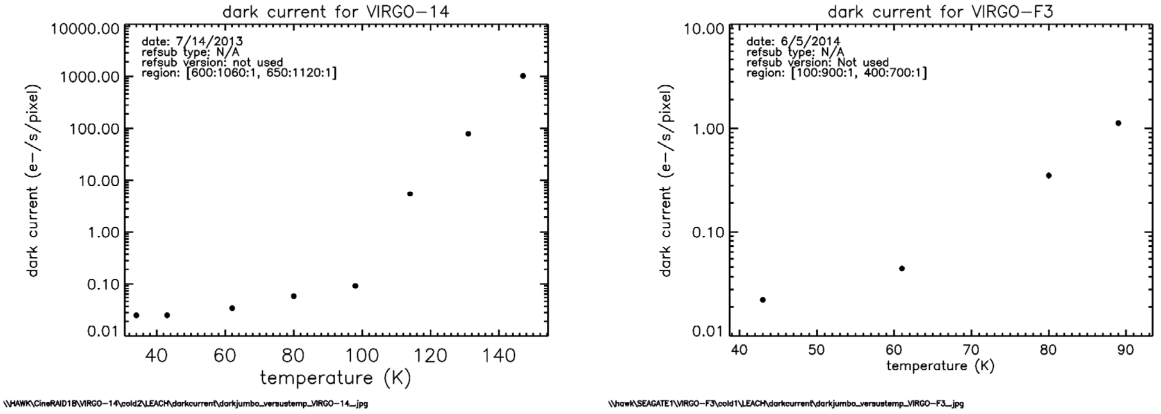
Table 1 shows a summary of parts tested in this project. Not all tests have been done for every part. Rather, specific tests were selected for certain parts in order to diagnose changes in the design and fabrication recipes. For instance, the “V” parts have a range of parameter variations in the design of their unit cells. Given these variations, the most interesting performance characteristic to test is quantum efficiency (QE) and dark current.

Table 1 - This table shows the devices that were delivered for this project along with a list of performance metrics that were measured. The top two are heritage devices for benchmark testing. The “V” parts have a four variable unit cell (VUC) designs. The “F” parts were designed and fabricated from a second fabrication run after testing the VUC parts. ✓ status is successfully met.



Detector	Format	Cutt-off (µm)	substrate	Dark Current	Egain	Photon Transfer	Read Noise	Full Well	Linearity	Quantum Efficency	Crosstalk	Persistence	Intrapixel Sensitivity
Virgo-9A	2K x 2K	1.7	CZT	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Virgo-14	2K x 2K	2.5	Si	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Virgo-V1	1K x 1K	2.5	Si	✓	✓	✓				✓			
Virgo-V2	1K x 1K	2.5	Si	✓	✓	✓				✓			
Virgo-V4	1K x 1K	2.5	Si	✓	✓	✓				✓			
Virgo-V5	1K x 1K	2.5	Si	✓	✓	✓				✓			
Virgo-V6	1K x 1K	2.5	Si	✓	✓	✓				✓			
Virgo-F3	1K x 1K	2.5	Si	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Virgo-F6	1K x 1K	2.5	Si	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Virgo-VTHIN1	1K x 1K	2.5	Si	✓	✓	✓		✓	✓	✓	✓	✓	
V1 and V2 are Variable Unit Cell (VUC) devices													

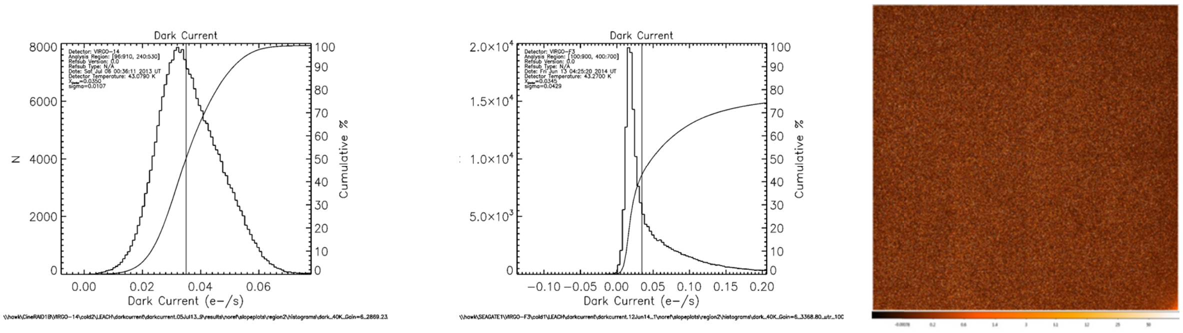
A key performance metric for these detectors is dark current. This is the intrinsic signal that the detector itself produces, even in the absence of light. Given that the detectors are meant to be used to observe the faintest objects in the Universe, it is desirable to have minimal dark current. Figure 1 shows a comparison of the dark current behavior as a function of temperature between VIRGO-14 and VIRGO-F3. VIRGO-14 has a distinct “knee” at 100 K, below which the rise in dark current is very slow, 0.0005 e^-/second/K and above which the rise is very steep, 30 fold increase every ~15 K. VIRGO-F3 has a much less distinguishable knee. VIRGO-F3 has about an order of magnitude higher dark current, than VIRGO-14 starting at ~80 K. The encouraging part is that F3 does, however, perform on par or better below 60 K.



(a) (b)

Figure 1. These plots show the dark current as a function of temperature for the heritage device, 14 (a), and the new device, F3 (b).

Figure 2 shows the contrast in dark current histograms for parts 14 and F3. For many of the pixels, the performance is similar, the peaks being 0.04 e⁻/pixel/s and 0.02 e⁻/pixel/s, respectively. Where they differ is at the high end of the tail where part 14 has a symmetric distribution. Part F3, on the other hand, has a significant tail at the high end with 25% of the pixels having dark current above 0.2 e⁻/pixel/s. What is encouraging is that, except for the tail end of F3 pixels, the performance of F3 is on par with 14. Figure 2 (c) shows that the spatial distribution of the high dark current pixels in part F3 is random. The extended dark current tail in part F3 is believed to be due to an insufficiently thick MBE buffer layer, as will be discussed in the next section.

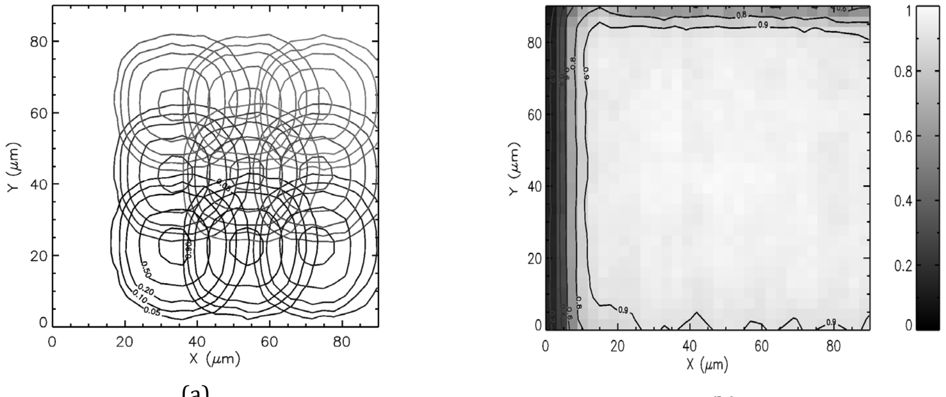


(a) (b) (c)

Figure 2. Dark current histograms for VIRGO-14 (a) and VIRGO-F3 (b). The distribution of the high dark current pixels for the latter is random (c). The dark current at the peak of the distributions is actually less for VIRGO-F3, being 0.02 e⁻/pixel/s, as compared to 0.04 e⁻/pixel/s for VIRGO-14.

Intra-pixel sensitivity measures the variations in sensitivity to photons within a single pixel. To map out intra-pixel sensitivity, a raster scan was performed using a spot projector mounted on a three dimensional scanning mount. The spot projector was used to scan a 3x3 pixel region at 2 μm spacing in which an exposure is taken with the beam at each location. The beam used in the measurement has a wavelength of 1.1 μm with a spot profile of 7 μm (FWHM). Intra-pixel sensitivity measurements were conducted on 9A, as the long wave cutoff of F6 and F3 allows for a significant background signal. The difference in the pixel structure between 9A and F6 is minimal and a significant difference in performance is not expected.

When the response of the 3×3 pixels for each location of the beam is overlaid on the same plot, there are nine distinct contours 20 μm apart, as expected (see Figure 3 (a)). The 50th percentile contours overlap at the borders between nearest neighbors, indicating that when the beam is straddling the border between two pixels, a photon from the beam is equally likely to be detected by either pixel. Even when the beam is centered over a pixel, there is a finite probability of a photon being detected by a neighboring pixel. The extended sensitivity of a pixel well beyond the borders, and soft transition in sensitivity between neighboring pixels, are likely due to the finite spot size of the beam. Lateral charge diffusion prior to charge collection could be contributing to this result as well. The raster scan does reveal, however, that the pixel structure is symmetric in x and y directions. When the pixel responses are summed over the entire raster scanned region the summed responses are uniform across the entire region (Figure 3 (b)), proving that there are no dead regions within the pixels.



(a)

(b)

Figure 3. These plots show the intrapixel sensitivity of the 9A. A raster scan with 2 μm spacing was done on a region covering 3x3 pixels using a circular beam (7 μm FWHM). The contour plots show the responses of the nine pixels overlaid on the same plot (a). The signal from each pixel is summed at each location of the beam and plotted, showing the summed response is uniform throughout the entire 3x3 pixel region (b).

As discussed in the previous section, the new detectors exhibited relatively high dark current. It was hypothesized that this may be due to high defect density stemming from lattice dislocations in the detector material. This could be caused by insufficient buffering with the intermediate layers between the Si substrate and the HgCdTe detector material. In order to test this hypothesis, imaging of the lattice structure was required. Imaging of the buffer and detector material layers is best done with high-resolution transmission electron microscopy (TEM). TEM imaging can resolve individual lattice sites to detect lattice dislocations and defects.

Witness parts from the same lot that produced the “F” detectors were prepared and TEM imaging was performed at Cornell University’s Center for Material Research (CCMR). Cross-sectional images of the parts through epitaxial layers, including buffer layers, (see Figure 4) were obtained. The figure shows how lattice defects are minimized, by use of the buffer layers, before propagating through to the HgCdTe (off to the right of the figure).

Figure 4 show the buffer layers exhibited a high concentration of lattice mismatch and defects, which is expected as these layers absorb stress from the epitaxial layers. The defects are also visible well into the second buffer layer. Higher resolution imaging of the interface between the buffer layers and the HgCdTe layer will be obtained in order to quantitatively describe the epitaxial material quality in the HgCdTe absorber. The data strongly suggests a significant concentration of defects is present in the HgCdTe layer.

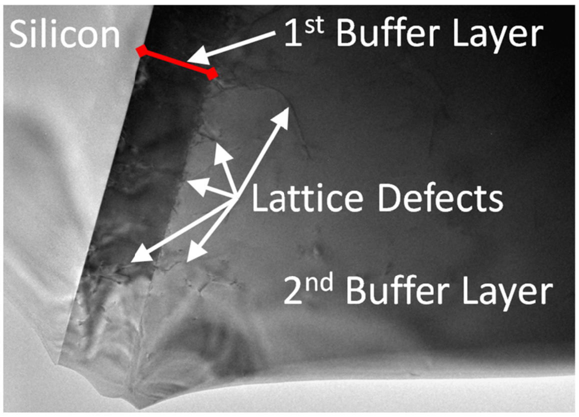


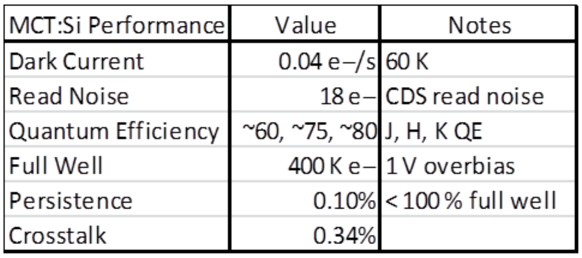
Figure 4. High resolution TEM image of a die sample. Shown are two buffer layers and the Si substrate. Lattice defects can be seen in higher density in the first layer and diminishing in the second buffer layer.

In order to mitigate this problem in future process designs, the buffer layers should be made thicker to more fully absorb the stress of the mismatched epitaxial layers. This will result in less stress on the device layer and fewer dislocations and defects. In turn, this lower defect density should lead to decreased dark current. The dark current tail observed for F3 and F6 indicates that the thin buffer is inadequately thin for short-wavelength cutoff HgCdTe (which has a higher Cd fraction than more commonly grown mid-wavelength cutoff HgCdTe). The benchmark MCT/Si detector, VIRGO-14, was designed with thicker buffer layers and the dark current tail is absent (Figure 2). While thick buffers significantly reduce the dark current tail, they would cause detector damage if not removed before cryogenic testing. However, substrate removal process allows selective etch removal of these buffers, and the visible/NIR-band response specs for this project already require it.

The initial project to develop the devices described in this paper is drawing to a close and a new phase of the project is beginning. Good progress was made in Phase I, but the final designs do not satisfy science grade requirements. The performance can meet requirements with a manageable improvement in the dark current and minor design change. In Phase II, improvements to the performance will be made to develop final devices and designs that will be ready for implementation in a 4K×4K format. The most important area to improve in Phase II is the relatively large distribution of pixels with high dark current. While the median dark current may be acceptable for some applications, it is clear that the performance would not be suitable for most astronomy applications and certainly not for low-background applications, e.g., for spectroscopy or in space. This problem is expected to be relatively straight-forward to fix by using an iterative design-build-test approach.

The high dark current tail, and high persistence after full-well fluence, seen in some devices are likely due to the relatively thin buffer layer and a processing issue respectively. Both are being addressed by redesigning the buffer layer to be thicker and then by thinning the devices in order to achieve high quantum efficiency at shorter wavelengths. This new design combines properties from the design of the heritage device and the devices developed earlier in this project.

The current state-of-the-art MCT/Si technology is close to meeting the SATIN project goals, as summarized in Figure 5. Median dark current is as low as 0.04 e^-/sec/pixel at 60 K. The SATIN goal of 0.05 e^-/sec/pixel is specified at 80 K, at which the best measurements are ~0.10 e^-/sec/pixel (Figure 1). The CDS read noise of 18 e^-, or equivalently 5~6 e^- for Fowler-16, previously demonstrated by VIRGO-14 is on the cusp of meeting the SATIN goal. Except for the depressed QE in the J band, the QE meets the SATIN goal of 70% minimum. Persistence below 100% fluence levels is about 0.1%. If the persistence above the 100% fluence level can be reduced to this level of performance, then that would meet the SATIN goal. Note that the SATIN goal is 0.1% after 100% fluence. It doesn't actually specify over 100% fluence. The devices already meet the goal as strictly interpreted. Crosstalk is very small at 0.3% and the well depth is rather large, in excess of 400,000 e^-.



MCT:Si Performance	Value	Notes
Dark Current	0.04 e–/s	60 K
Read Noise	18 e–	CDS read noise
Quantum Efficiency	~60, ~75, ~80	J, H, K QE
Full Well	400 K e–	1 V overbias
Persistence	0.10%	< 100 % full well
Crosstalk	0.34%	

Figure 5. This table gives the summary of the current state of MCT/Si. Some performance metrics have already met the SATIN goals, while others are close to meeting the SATIN goals.

Single Photon Counting Detectors

A Zero Read Noise Detector for the Thirty Meter Telescope

Gordon and Betty Moore Foundation

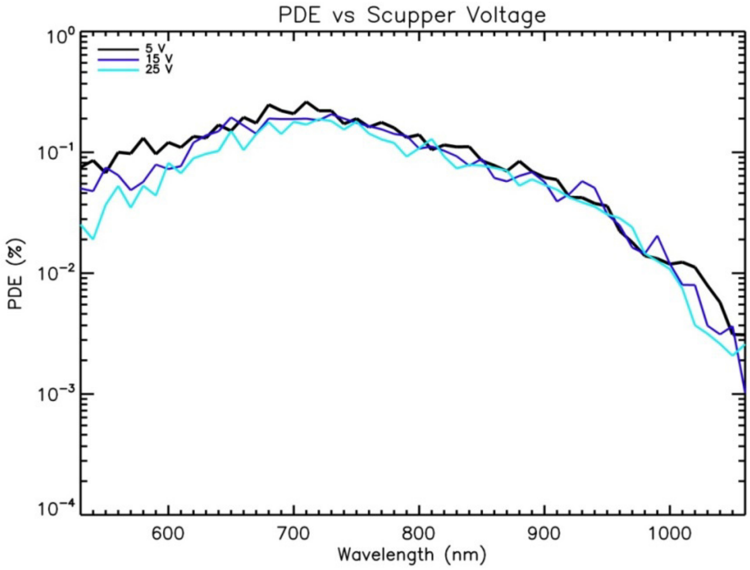
The Center for Detectors, in collaboration with Lincoln Laboratory, has pursued the development of detectors that can detect a single photon. The advantage of such devices is that they are much more sensitive than current detectors that require the presence of multiple photons in order to register a detectable signal beyond the noise that the detector and electronics inject into then measurement. Single photon counting detectors have the potential to deliver a big advancement for astronomy, as well as other fields, such as biophotonics.

The CfD is currently testing Geiger-mode avalanche photodiode (GM-APD) imaging detector arrays with zero read noise for a number of research projects. The performance of devices are also being compared to other single photon counting detectors, such as electron-multiplying charge-coupled devices (EMCCDs) and linear-mode avalanche photodiodes (LM-APDs).

The most recent revision of the imaging detector array implemented elements to improve the imaging quality and reduce the amount of false events. Testing at CfD showed that the revision accomplished this goal. Figure 6 shows the images taken with a previous version of the imaging detector (*left*) and the current version of the imaging detector (*right*). The images were taken under similar conditions. The images have had minimal processing performed on them and the image quality is significantly improved with the newest device. The recent testing shows the technology is progressing towards being effective for astronomy and other applications.

Figure 6. The picture on the left was taken with a previous version of the photon counting imaging detector, whereas the one on the right was taken with the most recent version of the detector. The images were taken under similar conditions. The images have had minimal processing performed on them and the image quality is significantly improved with the newest device.

Characterization of the newest revision of the imaging detector suggests improvement in performance areas such as dark count rate, afterpulsing, and crosstalk. Initial measurements of photon detection efficiency (PDE) using flood illumination show that the device is either less sensitive than expected, or that the sensitivity within each pixel is unevenly distributed. Figure 7 shows the result of this measurement for the newest device and it reveals a peak value of ~0.2%. The two curves represent different bias voltages applied to the scupper circuit that sweeps leftover charge to ground.



\\tiger2\SEAGATE1\PCROIC\cold1\PCROIC\PDE\PDE.01May15\PDE vs Scupper Voltage.jpg

Figure 7. The plot of the photon detection efficiency shows a peak response of ~0.2 % at ~700 nm.

Future revisions of the imaging detector will be focused on improving the PDE. Measurements of the intrapixel sensitivity (Figure 8) show that the low PDE is primarily due to depressed sensitivity in the perimeter of each pixel. The response shown in Figure 8 is normalized to the peak response of the pixel. This measurement shows that the pixel response drops sharply away from the pixel center. The responsivity of a pixel is about half at 5 µm radially from the pixel center. The PDE can be increased significantly if the pixel's response can be increased at the pixel periphery.

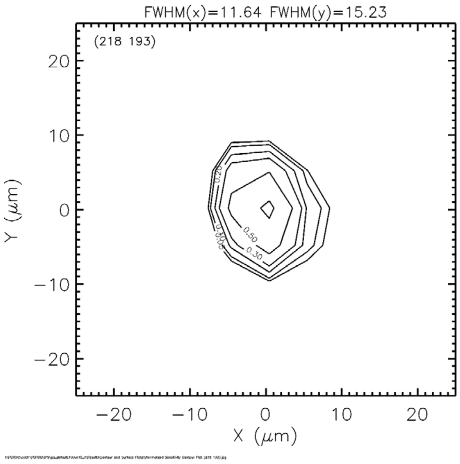


Figure 8. This plot shows the intra-pixel sensitivity of a single pixel. The response is normalized to the peak response of the pixel. This measurement shows that the pixel response drops sharply away from the pixel center.

The project was completed last year, and the results were reported in Kim Kolb's PhD thesis. In addition, the results have been presented in number of conference proceedings and journal articles.

Student Vignettes

Kimberly Kolb

Kimberly Kolb is a graduate student member of the Center for Detectors (CfD) who completed her PhD in the Imaging Science program in May 2015. She completed her MS degree in the same program during the summer of 2011. She completed a BS degree in Microelectronic Engineering in 2008. Her combination of degrees and experience is useful in the field of high-performance detectors, giving her a knowledge base that encompasses detector development through fabrication, characterization, and implementation. As an undergraduate student in 2007, Kimberly worked for the CfD to develop a fabrication process for the fabrication of silicon p-i-n diodes for hybridization. This work culminated in her capstone project for her BS degree.

After working for Fairchild Semiconductor (2008-2009), Kimberly returned to RIT and the CfD to pursue an MS in Imaging Science, funded by the BAE Systems Fellowship. This fellowship included a three-month co-op experience at BAE systems in Lexington, MA, working on infrared detector fabrication and process improvement. The topic of her MS thesis was the characterization of single-element, on-wafer Geiger-mode avalanche photodiode (GM-APD) devices. She tested structures to determine their noise characteristics and developed a new model for determining the contribution of optical self-retriggering to the dark count rate.

After completing her MS degree in 2011, Kimberly decided to stay with the CfD and complete a PhD. In 2013, she won a prestigious NASA Earth and Space Science Fellowship (NESSF) for her thesis proposal. The fellowship funding ensures continued training of a highly qualified workforce in disciplines needed to achieve NASA's scientific goals. Kimberly's proposal was one of only nine selected for funding out of 114 in the Astrophysics division that year. This fellowship will allow her to collaborate with leaders in the field, including Dr. Shouleh Nikzad of NASA's Jet Propulsion Laboratory. Kimberly's PhD thesis involved the testing and comparison of a variety of photon-counting devices, including GM-APDs, electron-multiplying charge-coupled devices (EMCCDs), and linear-mode APDs (LM-APDs), in array formats for imaging. Her research plan included the full characterization of GM-APDs in the CfD, as well as the effects of radiation on the devices, and the testing of a UV-enhanced EMCCD at NASA's JPL. A theoretical model of LM-APDs for comparison to the other devices is based on the work of Dr. Don Hall at the University of Hawaii.

In the past year, Kimberly's NESSF ended with the publication of her dissertation and completion of her degree. She presented a theoretical comparison of GM-APD and EMCCD performance in a the proposed WFIRST-AFTA mission concept at the IEEE Aerospace Conference in Big Sky, MT, and gave an invited talk at the University of Oxford on Photon Counting Detectors for Scientific Imaging. Figure 9 shows the final comparison of Kolb's dissertation, showing the relative SNR (normalized to the shot noise limit) of a state-of-the-art EMCCD and GM-APDs with various dark count rates (including the current state-of-the-art).

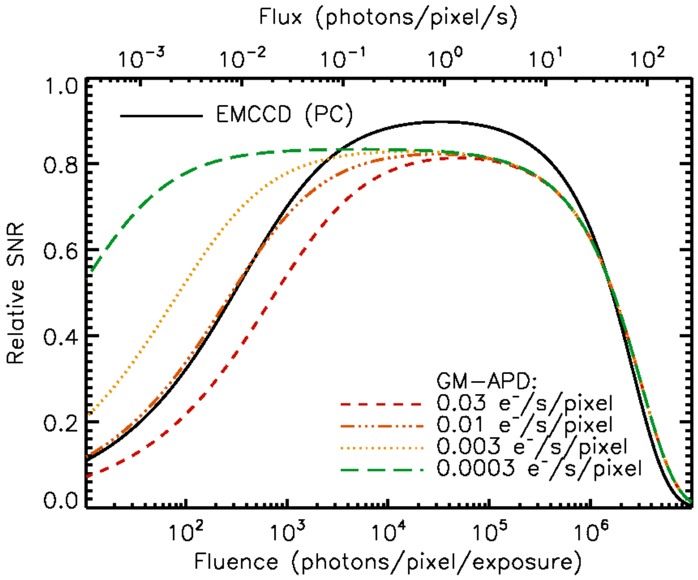


Figure 9. This plot shows relative SNR (normalized to $\sqrt{Fluence}$) for a state-of-the-art EMCCD and GM-APDs with various values for dark count rate. The current state-of-the-art DCR for the GM-APD is shown, as well as 1/3, 1/10, and 1/100 reduction in DCR. For even the 1/3 reduction in DCR, the GM-APD is comparable to EMCCD performance due to the clock-induced-charge that plagues the EMCCD.

Kenneth Bean

Kenneth Bean is a CfD lab assistant who recently received his Bachelor of Science, Cum Laude in Mechanical Engineering from RIT. He spends much of his free time participating in Recreational and RIT Intramural sports including volleyball, soccer, football, broomball, and running.

Since being hired in 2013, Kenny has worked to perform constant lab upkeep and equipment repairs. He has conceived, designed, machined, assembled, and produced documentation of a large variety of hardware mounts and integrating systems so that experiments could be performed faster and more repeatable. Several of these mounting systems have needed to be light tight, air tight, or have free rotation on one or more axes, all while being inexpensive and easy to make/assemble using limited equipment.

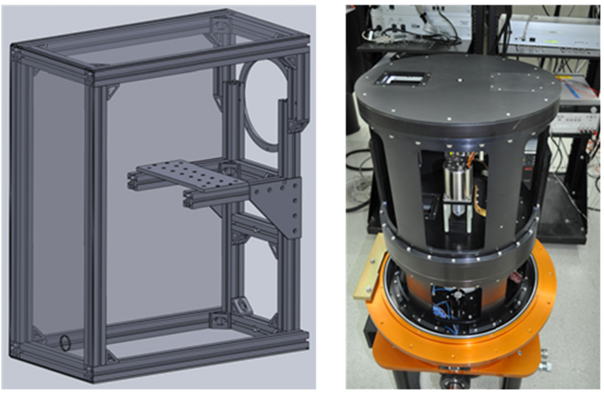


Figure 10. The rendering on the left shows a Solidworks model of a light-tight, adjustable mount for the IPS projector. The photo on the right shows a partially disassembled new dewar.

Kenneth has also worked to support the development of a new dewar system, which was purchased with a supplemental NSF/ATI grant. The purpose of this project is to expand the Center's capabilities to evaluate detectors provided by its industrial partner, Raytheon. Each dewar requires intensive design and planning, due to both its internal complexity and number of external systems. Peripheral systems that needed to be designed or purchased included a rotatable dewar stand, isolated electronics plate, temperature control system, cryogenic cooling system, vacuum pressure gauge, monochromator, and motor controller for the two rotating filter wheels. Each of these components, along with all of the dewar's internal subsystems, require individual testing and troubleshooting as well as integration into the system as a whole. All issues must be flushed out during testing because it is critical for the system to maintain the proper environment once a detector is installed inside.

John Hatakeyama

John Hatakeyama is a CfD lab assistant with a degree in Electrical Engineering, Cum Laude, from RIT. He was a student member of the RIT Amateur Radio Club, and participates in autocross with the local branch of the Sports Car Club of America.

John joined CfD in the winter of 2015 to work on interfacing and characterizing a new set of test electronics from JMClarke Engineering for CfD's Raytheon Vision Systems infrared detectors. The new set of electronics required a wrapper plugin to be created to interface with test software written in IDL. Careful consideration and testing was done to emulate the operation of other control electronic used by CfD. A battery of tests was performed to both confirm the specifications and optimize the performance of the electronics. One of the tests involved Fowler sampling, which is the averaging of multiple images, on the input channels of the electronics to determine the system noise characteristics. The results from this test are presented in Figure 11.

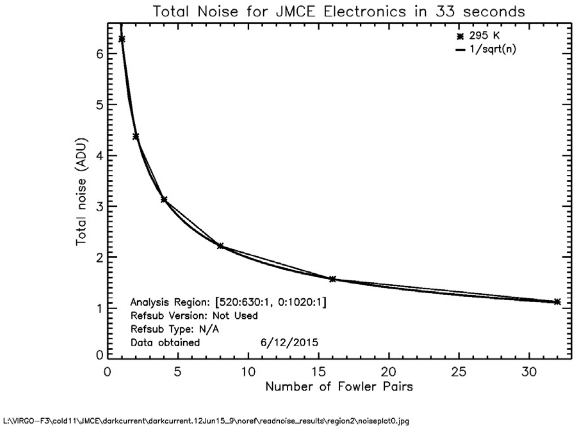


Figure 11. The figure shows total measured noise as a function of number of reads for a new set of electronics developed by JMClarke Engineering and characterized in an NSF-funded project. One can see that the noise decreases as more reads are averaged together, and the level of reduction matches the expected trend of decreasing by one over the square root of the number of reads.

In addition to working on new electronics, John has also run several of CfD's experiments and provides general lab support.

Joseph DiPassio

Joseph DiPassio is a student Co-op and Laboratory Research Assistant at the Center for Detectors. He is pursuing a dual Bachelor/Master of Science degree in Electrical Engineering, focusing on Digital Signal Processing for his graduate studies. At RIT, Joseph is involved in the music community, as a member of the RIT Concert Band, Jazz Lab Band, and the Brick City Singers a cappella group, where he serves as music director.

Joseph began working at the Center for Detectors in May 2015. Since joining the center, his work has focused on computational problem solving and data analysis. He spearheaded a project brought to the center by NASA astronauts to remove cosmic rays from images of the International Space Station. As part of a team with fellow CfD staff, Joseph co-wrote functional prototype software that has been proven to remove the unwanted pixels from these images using an algorithm based on Gaussian statistics.

Joseph has also written acquisition and reduction software for several projects since joining the Center. Most recently, he and fellow CfD student employee Neil Guertin authored an automated experiment by which the glow of a detector could be measured and represented graphically. It was realized that, after running an experiment in which the number of times the detector was read out in a certain time period was varied, the amount of 'read frames' in an exposure had an influence over the measured signal in that exposure time. Because of this result, shown graphically in Figure 12 below, a glow experiment became necessary to examine the accuracy of dark current measurements using different electronics sets. Joseph played a key role in writing the analysis software, which determines from the experimental data the magnitude of the glow seen on the detector during the exposure time. Joseph also tested and improved the acquisition code used to acquire data from the detector.

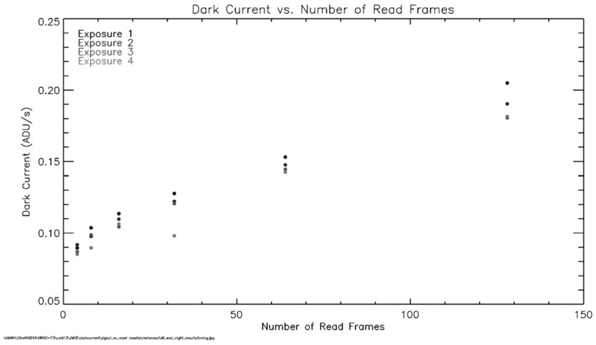


Figure 12. This figure shows the measured dark current of a detector, measured using the JMCE control electronics, in an experiment run by Joseph to examine dark current versus the number of read frames over a constant exposure time. The results of this experiment proved the need to test for detector glow, since read frames appeared to have an influence on the total accumulated charge measured over the exposure.

Neil Guertin

Neil Guertin joined the CfD as a Lab Programming Researcher in June 2015. He is a double major currently pursuing a Bachelor of Science in Computational Mathematics and Computer Science. In his free time he sings bass in his a cappella group Surround Sound, is a member and past president of the RIT Pep Band, and helps run the mathematical problem solving club which helps prepare students for a variety of math competitions.

Neil's work at the center has primarily involved writing code for various applications, including writing data acquisition experiments, improving logging capabilities, and searching for and correcting bugs in old code. He also runs experiments and analyzes the results. One of the experiments he wrote measures glow, the extra signal produced by reading out the detector (Figure 13).

Neil played a key role in a project to remove unsightly hot pixels from images taken on the International Space Station. Working with Joseph DiPassio, he created an algorithm to isolate and correct these pixels, which are thought to be caused by cosmic rays. He then packaged up this algorithm into an application and sent it to astronaut Don Pettit, who originally took the images.

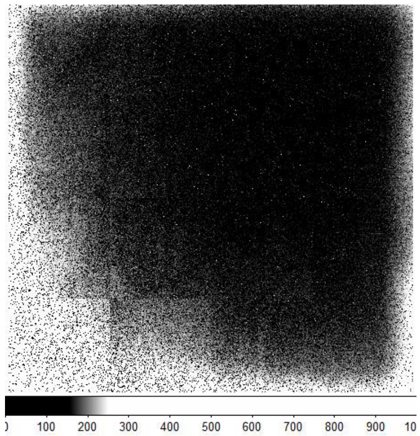
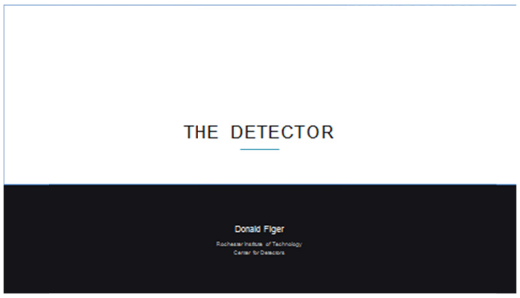


Figure 13. An image showing glow around the edges and bottom left corner of a detector. Neil wrote the data acquisition and reduction code for this experiment.

Alexa and Jamie Martinez

Alexa and Jamie Martinez, both recent RIT graduates with B.F.A. degrees in New Media Design, developed graphics for presentation materials that were shown at the Hartford Club in Connecticut, by Director Figer. The design was developed by first interviewing the Director and then creating a set of design elements for inclusion in the PowerPoint presentation. Two of the slides from the presentation are shown below.



THE DETECTOR

Donald Figer

Rochester Institute of Technology
Center for Detectors

27

MILLION DEATHS

New cases are expected to increase by 70% within the next 20 years, leading to 27 million deaths from breast cancer.

Statistic according to World Health Organization

Aye Yi Chan

Aye Yi Chan received an Associate of Science Degree in Business Administration from Monroe Community College before joining the Center for Detectors in the summer of 2015. Prior to beginning her academic career at RIT, she worked with the Paradigm Environmental Services, located in Rochester, as an Administrative Assistant.

At CfD, Aye is an Executive Assistant to the Director and is responsible for performing accounting reconciliations, utilizing Excel and Oracle applications for purchasing essential lab equipment, overseeing Oracle grant statements, and sending monthly standardized correspondence to key financial departments within RIT.

In addition to administrative tasks, Aye also prepares reports, develops marketing and communications plans, designs graphics for external and internal publication, handles information requests from CfD personnel, performs a wide variety of clerical functions, maintains the Center for Detectors web site, and is responsible for CfD mail.

Beginning her studies in Accounting at RIT in the upcoming Fall Semester, Aye looks forward to year of both academics and working at CfD.

Kirk M. Winans

Kirk M. Winans received a Master's of Science Degree in Science, Technology and Public Policy while working for the Center for Detectors in 2015. For his thesis, Kirk analyzed the interactive features of political party websites in the United States and Sweden.

Kirk joined CfD in July 2014 as an Executive Assistant. While at CfD, Kirk was responsible for performing accounting reconciliations, utilizing Excel and Oracle applications for purchasing essential lab equipment, overseeing Oracle grant statements, and various onboarding tasks for new employees. Kirk also aided in overseeing the recent successful faculty search chaired by Dr. Figer which culminated in the selection of Dr. Michael Zemcov as an addition to CfD beginning August 2015.

In addition to administrative tasks, Kirk also prepared reports, developed marketing and communications plans, designed graphics for external and internal publication, handled information requests from CfD personnel, and maintained the Center for Detectors web site.

Kirk will begin a Master's of Communication and Media Technologies and an Advanced Certificate in Applied Statistics in the upcoming Fall Semester.

External Funding and Collaborating Partners

Figure 14 shows funding per year since the inception of the Rochester Imaging Detector Laboratory in 2006, and continuing through the period after the Center for Detectors (CfD) was established. A breakdown of current individual grants and contracts is given in the following pages. In the past year, the CfD won ~$2M in external grant research funding, primarily through NSF.

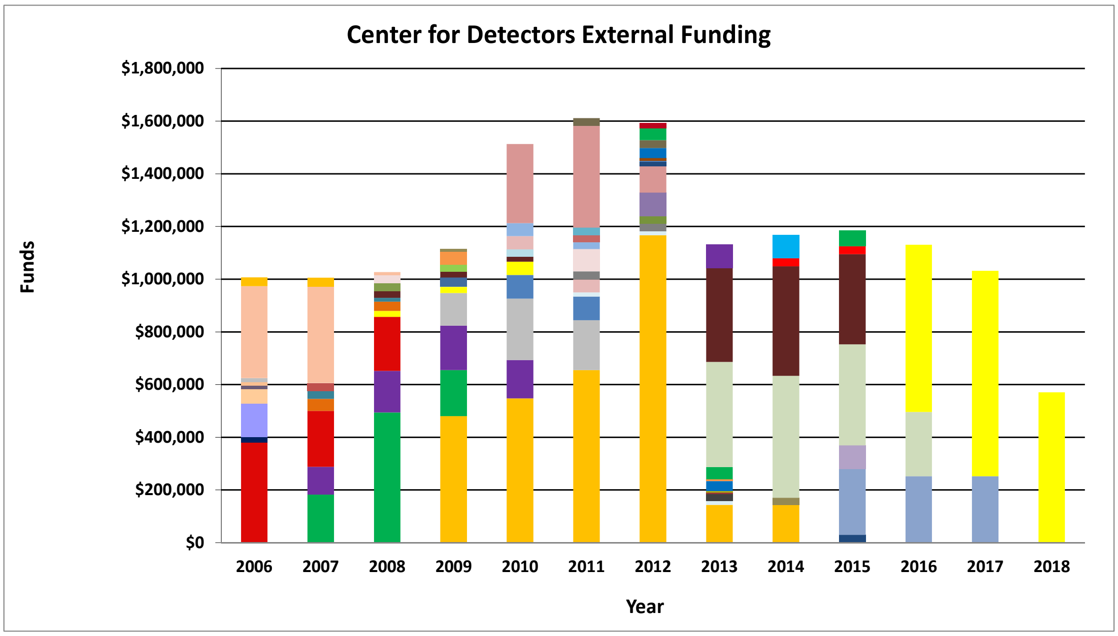


Figure 14. Since its inception in 2006, the CfD has been awarded over $15M in research funding. The largest contributions are from the Moore Foundation and NASA. The Moore Foundation has awarded $3M to support the development of a zero noise detector, while NASA awarded over $7M in research grants. At the end of the year, NSF signaled that it would award nearly $2M for the further development and testing of infrared detectors grown on silicon wafers.

Grants and Contracts- New

Title	Funding Source	Dates	Amount
Phase II: New Infrared Detectors for Astrophysics	NSF/ATI	TBD	$1,983,212
Procurement of Cinema DMDs	NASA/STScI	03/25/2015-11/30/2015	$60,100

Grants and Contracts - Ongoing

Title	Funding Source	Dates	Amount
The Development of Digital Micromirror Devices for use in Space	NASA/SAT	01/01/2014-12/31/2015	$749,281
New Infrared Detectors for Astrophysics	NSF	06/01/2012-04/30/2016	$1,115,106
A New VIS/IR Detector for NASA Missions	NASA	03/01/2013-02/29/2016	$1369,418
Next Generation Imaging Detectors for Near- and Mid-IR Wavelength Telescopes	Gordon and Betty Moore Foundation	10/01/2008-12/15/2015	$3,122,191

Grants and Contracts - Completed within the Past Year

Title	Funding Source	Dates	Amount
THz Modeling and Testing	ITT Exelis NYSTAR UofR/CEIS	07/01/2014-06/30/2015	$90,000
Single Photon Counting Detectors	NASA/NESSF	09/01/2013-06/30/2015	$60,000
The Mass Loss of Red Supergiants	SOFIA	01/16/2013-01/15/2015	$8,000
Enhancing the UV/VUV Sensitivity of CMOS Image Sensors	Thermo Fisher Scientific NYSTAR UofR/CEIS	07/01/2010-06/30/2014	$134,550
THz Virtual Scene Generation and Microgrid Polarizer Development/THz Antenna Modeling	ITT Exelis NYSTAR UofR/CEIS	07/01/2012-06/30/2014	$178,500

Collaborating Partners

The CfD collaborates extensively with a broad range of organizations, including other academic institutions, government agencies, and industry leaders. Some examples are, the University of Rochester, NASA, ITT Exelis, and Raytheon Vision Systems. The vision of the CfD is to be a global leader in realizing and deploying ideal detectors and associated systems, which requires the support of brilliant engineers, passionate philanthropists, and truly inspired industrial partners. Our mission requires a team effort, distributed across several organizations, each with its own world-class expertise and often significant facilities developed over decades of past projects. With appropriate teaming arrangements, this capability can be leveraged in ways that would be impossible if it were necessary to rebuild this infrastructure.

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

Universities

UC DAVIS

UC IRVINE | UNIVERSITY of CALIFORNIA

UNIVERSITY of ROCHESTER

THE UNIVERSITY of NEW MEXICO

NYSTAR®

University of Hawaii Institute for Astronomy

Gordon and Betty MOORE FOUNDATION

R·I·T

LELAND STANFORD JUNIOR UNIVERSITY

UNIVERSITY OF PITTSBURGH

National Research Laboratories

MARSHALL SPACE FLIGHT CENTER

NSF

NASA

DEPARTMENT OF ENERGY • UNITED STATES OF AMERICA

LSST

MIT Lincoln Laboratory

Office of Science U.S. DEPARTMENT OF ENERGY

National Optical Astronomy Observatory

CSIC

SLAC

JPL

SPITZER SPACE TELESCOPE

SNAP

Sandia National Laboratories

BERKELEY LAB

SPACE TELESCOPE SCIENCE INSTITUTE

Industry

Rochester General Health System

Carestream HEALTH

BAE SYSTEMS

TELEDYNE SCIENTIFIC & IMAGING, LLC
A Teledyne Technologies Company

INFOTONICS technology center inc

Raytheon

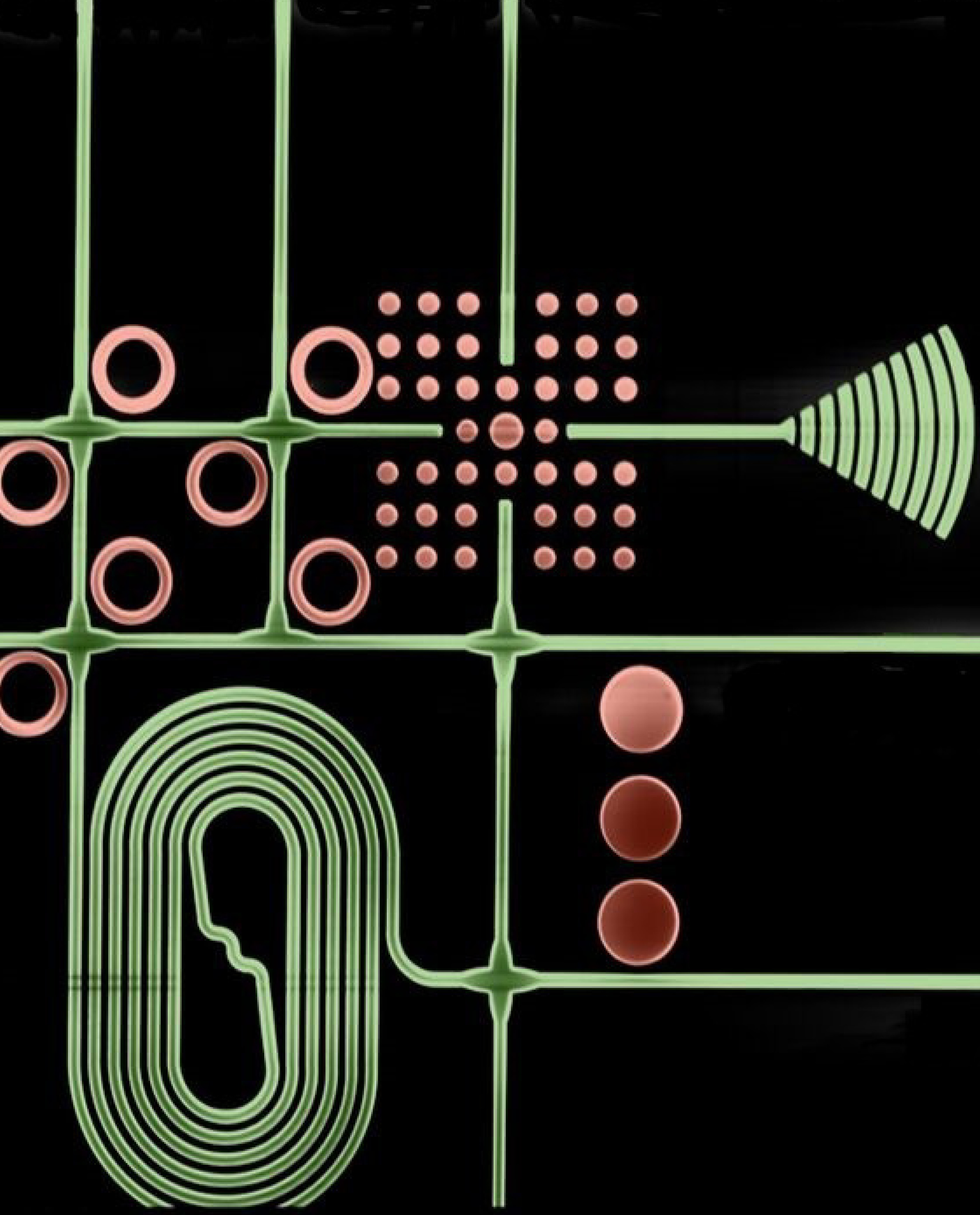
Thermo SCIENTIFIC

Ball

ITT Engineered for life

Kodak

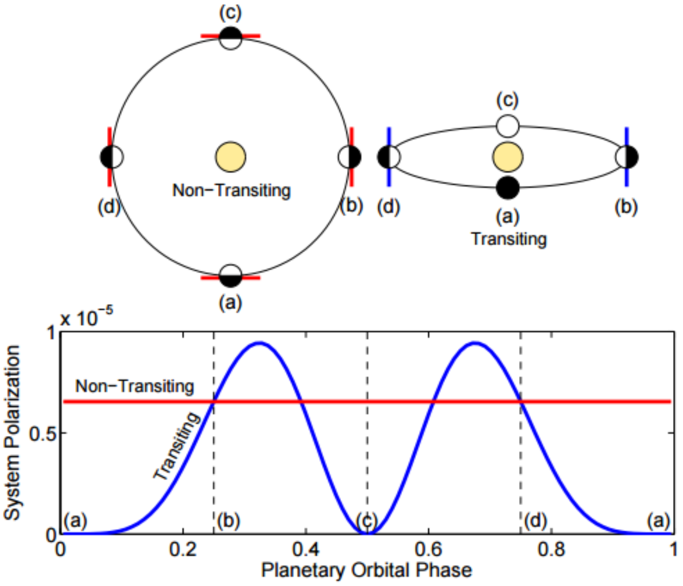
Communication



Distinguished Speaker Series

Characterizing Exoplanet Atmospheres through Our Own – Dr. Sloane Wiktorowicz

Abstract



Transformative science is achieved through an understanding of the limitations of current instrumentation and by the construction, commissioning, and calibration of new instruments. Each instrument utilizes the photon properties most conducive toward the science goal (amplitude, phase, wavelength, and polarization). My main focus is ground-based, direct detection of scattered light from short-period exoplanets, which requires Hubble-like nightly accuracy. This prompted the development of the POLISH and POLISH2 polarimeters at Palomar and Lick Observatories, the latter of which achieves the requisite accuracy from a site overlooking the tenth largest city in the US. This technique enables a broad range of exoplanet science, such as the study of clouds, atmospheric diversity from Jovians to super-Earths, planetary asphericity, and mass measurement for non-transiting exoplanets. In addition, POLISH2 contributes to many fields of time-domain astronomy on various timescales: the Crab pulsar (milliseconds), asteroids (hours), Cygnus X-1 (days to months), and SN 2014J (weeks), for example. I propose three instruments, involving RIT students, for exoplanet science at Lick and Keck to pave the way to TMT: a Keck scattered-light polarimeter (with unprecedented gamma-ray burst and supernova time domain capability with the Keck I Deployable Tertiary Mirror), a 0.1 milli-mag Lick APF differential photometer, and a Lick ShaneAO upgrade (for rotation periods and fractional cloud cover on imaged exoplanets). The differential photometer targets super-Earth transits and hot Jupiter occultations, which enables a study of transit timing variations for low-mass planets soon to be discovered by the space-based K2 and TESS Missions. These observations will provide sorely needed mass and bulk density constraints for planet formation theories. Therefore, through diligent minimization of systematic effects, transformative exoplanet science may be achieved even from the ground.

About the speaker

Dr. Wiktorowicz is fascinated by transformative science, generally involving ground-based exoplanet characterization, and the instrumentation necessary to enable it. As a NASA Sagan Fellow at the University of California, Santa Cruz, Dr. Wiktorowicz constructed a large POLISH2 program to study exoplanets and other observable phenomena, and he led laboratory testing and on-sky calibration of the Gemini Planet Imager polarimetry mode.

Mapping the Large Scale Structure of the Cosmos from the Big Bang to the Present – Michael Zemcov

Abstract

Understanding the structure of the universe on the largest and most distant scales is one of the central topics in observational astrophysics. Successful measurements of cosmological structures require precise and sensitive instruments both on the ground and in space. Enabled by modern detector technologies and carefully designed experiments, exciting new observational and data analysis techniques are beginning to yield dramatic new results at a variety of wavelengths. In particular, results using Intensity Mapping methods from optical to radio wavelengths are in the process of revolutionizing our understanding of the large scale structure of the cosmos. I will review Intensity Mapping (and related) methods to show that they provide a holistic view of cosmic structure, and highlight recent results emerging from a variety of experiments which highlight the need for specialized instruments deploying cutting-edge detectors to help build an overall picture of the evolution of the universe on the largest scales.

About the speaker

Michael Zemcov earned his PhD at Cardiff University in the UK studying the polarization of the cosmic microwave background radiation. Following this, he was a NASA Postdoctoral Fellow at the NASA Jet Propulsion Laboratory working on a variety of infra-red, sub-mm, and mm instruments. He is currently a Senior Postdoctoral Fellow in Physics at the California Institute of Technology, and leads experimental programs focused on applying innovative detector technology and data analysis methods to perform precision cosmological observations.

Moore's law and astrophysics: detectors that teach us about physics beyond the standard model– Roger O'Brient

Abstract

Data from modern submillimeter telescopes and in particular, their detectors, are teaching us about the history of our universe over the longest and shortest time-scales, and informing us of the laws of physics beyond the standard model. These detectors share the common feature of integrating quasi-optical components such as antennas, power dividers and hybrids, filters, and even spectrometers "on chip" with the detectors into monolithic packages. In this talk, I will discuss several examples of this technology including ones that let us test models of inflation by searching for inflationary gravitational waves (via the BICEP and Keck Array telescopes) and others that let us test the neutrino mass hierarchy (via Polarbear and South Pole Telescope). While these specific telescopes use the microwave background as their basic data set, the technology is more broadly applicable to submillimeter emissions from regions other than the last scattering surface. I will discuss how future extensions of this technology may let us learn the detailed history of reionization as well as deepening our constraints on Dark Energy.

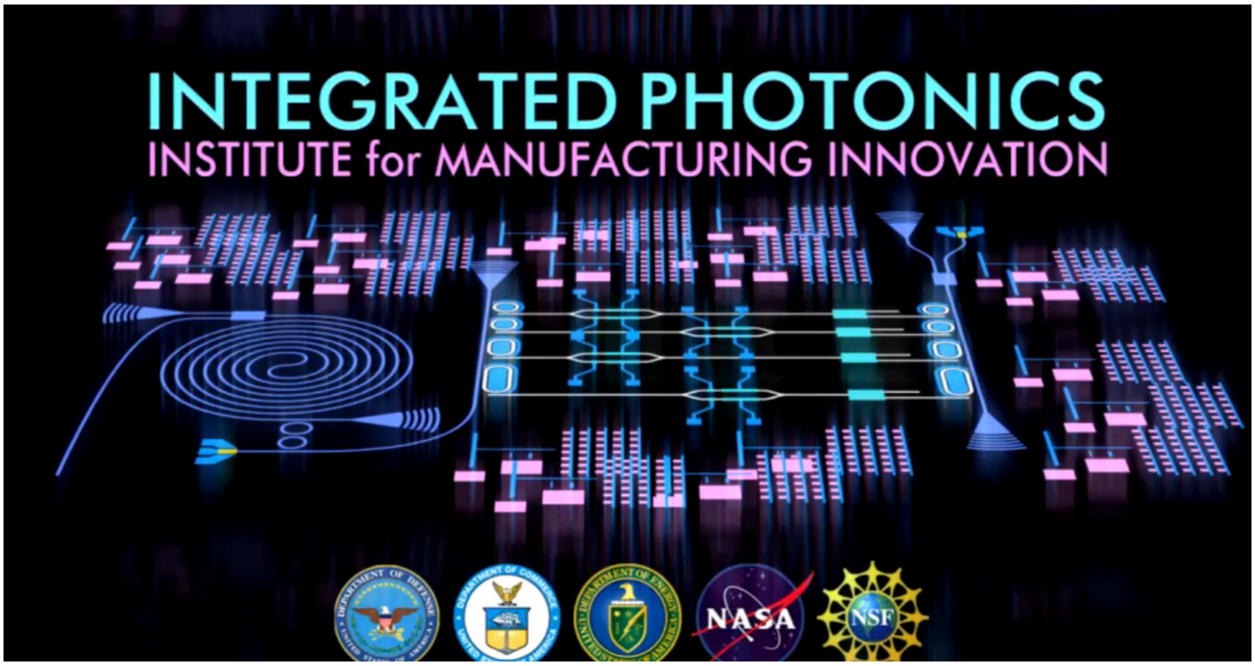
About the speaker

Roger O'Brient received his BS from Caltech and PhD from UC Berkeley, with a focus on astrophysics instrumentation. The detectors from his doctoral thesis are "mult-chroic" antenna-coupled TES bolometers that are being used by Polarbear, SPT, the EBEX balloon, and JAXA's Lightburd satellite. He is currently a NASA postdoctoral scholar at NASA's Jet Propulsion Laboratory at Caltech where he manages the CMB detectors program that has provided detectors for BICEP2, Keck Array, BICEP3, and SPIDER. Currently, he is exploring how these detectors can be used to implement intensity mapping to explore a variety of cosmological experiments.

In the News

CfD Part of New American Institute for Manufacturing Integrated Photonics

RIT was chosen as part of a large consortium to create the new American Institute for Manufacturing Integrated Photonics (AIM Photonics). The goal of AIM is to build the manufacturing infrastructure that will ensure a world-leading role for the United States in the area of integrated photonics. CfD Professors represent the strongest concentration of photon-related research at RIT, giving the center a strong role in AIM. The initiative will be led in Rochester, with University of Rochester and RIT as academic partners. The full membership includes over 20 universities, 30 community collegs, and 50 companies, spread over multiple states. AIM Photonics will be funded through $110M of federal funding and over $500M of consortium-supported and state funding.



CfD Faculty Member Michael Zemcov Part of Team Chosen to Develop Space Mission to Study Neutron Stars, Black Holes and More

In a major piece of news, new CfD professor Michael Zemcov was part of the team chosen to study a new proposed space mission. Details of the announcement are below.

RIT's Center for Detectors adds scientist on NASA-selected SPHEREx program

by Susan Gawlowicz

Rochester Institute of Technology has hired scientist Michael Zemcov as an assistant professor in the Center for Detectors and the School of Physics and Astronomy.

Zemcov will join RIT this fall from the California Institute of Technology, where he held a senior postdoctoral fellowship and served as an affiliate scientist at NASA's Jet Propulsion Laboratory. He is an astrophysicist with specialization in the measurement of the cosmic microwave and infrared background radiation.

A major focus of Zemcov's research is intensity mapping measurement of cosmological structure formation and studies of the epoch of reionization that ended the opaque "Dark Age" of the early universe. This is when scattering electrons and protons began to form neutral hydrogen atoms and the cosmos grew increasingly transparent.

In addition to astronomical observation, Zemcov also develops enabling technologies for astrophysics and leads team projects on platforms ranging from ground-based to sub-orbital and space observatories. He is a co-investigator and the lead instrument scientist of the recently selected NASA Explorers Program, Spectro-Photometer for the Extragalactic structure, Reionization and Ices eXplorer (SPHEREx) awarded to the California Institute of Technology. SPHEREx will conduct an all-sky near infrared survey that will probe the origin of the universe, search for ice on planets that could harbor life outside our solar system, and explore the evolution of galaxies.

"By accessing large spatial scale information, SPHEREx is capable of extracting a huge amount of information about even the most faint and distant galaxies in the universe," Zemcov said. "This project promises to revolutionize our understanding of the physics of the cosmos. I am thrilled to bring involvement in this and other projects to RIT, where the Center for Detectors will allow me to purse a world-class astrophysical research program at a leading institution."

Zemcov's expertise will expand the Center for Detectors' ability to develop and conduct experimental science on advanced astronomical instrumentation in new application areas.

"Professor Zemcov's research leads the world in important applications for technology developed in the Center for Detectors," said Don Figer, center director and professor in RIT's astronomical sciences and technology. "We look forward to increasing opportunities and collaborations that his research brings to RIT and the center."

RIT's Don Figer imaged star with Hubble as a young astronomer at UCLA

CfD Director Don Figer received an odd phone call during the past year from someone on the island of Jersey, located in the English Channel between England and France. He was asked if he would consent to Jersey using the image of the Pistol Star that he took using the Hubble Space Telescope. The following story, written by Susan Gawlowicz, and appearing in RIT University News, describes what happened next.

Pistol Star gets a stamp of approval

May 26, 2015
by Susan Gawlowicz

A set of British postal stamps commemorating the 25th anniversary of NASA's Hubble Space Telescope includes a star detected by a Rochester Institute of Technology professor nearly 20 years ago.

The Pistol Star made international news in 1997 and continues to shape Don Figer's career in unexpected ways. Most recently, an employee at the Jersey Post in the United Kingdom called Figer seeking permission to put the Pistol Star on a stamp.

"The call took me by surprise," said Figer, professor of physics and director of the Center for Detectors at RIT. "It was a nice courtesy, but the Hubble pictures aren't mine."

Figer doesn’t own copyright to the image he helped make famous. Hubble’s pictures are in the public domain and are free to use.

The Pistol Star is considered to be one of the most luminous, massive young stars in the Milky Way. It is part of the Quintuplet Cluster near the galactic center and takes its name from the Pistol Nebula, a dying star, whose gas was ejected from and now surrounds the star. Figer had recently earned his Ph.D. in astronomy at the University of California at Los Angeles when he released the Hubble image of this bright, young star on Oct. 8, 1997.

News of the massive young star with the evocative name went viral, 1990s style. It landed Figer on the front page of the New York Times, above the fold, and on the ABC Nightly News.

The Pistol Star quickly found a place in pop culture. Figer remembers a Los Angeles-based band, Mary’s Danish, whose lead singer went on to form a new band named Pistol Star. The name caught on in other circles and has resurfaced on T-shirts, tattoos and Twitter. Pistol Star is also the name of clothing line and a thoroughbred racehorse in Australia.

Figer never anticipated the Pistol Star’s broad appeal.

“Sometimes, you do something in science and it becomes a popular cult thing,” he said.

Since the Pistol Star, Figer has balanced his research between observing massive star clusters and other astronomical objects, and advancing imaging detectors for industry and astronomy. But the Pistol Star keeps popping up in unusual places—this time in the mail.

Figure 15: The image shows the full eight-stamp commemorative set of images taken by the Hubble Space Telescope, printed on the 25th anniversary of the observing facility.

NASA Astronauts Visit RIT and the Center for Detectors

The CfD was twice-blessed by visits from NASA astronauts. First, International Space Station (ISS) astronaut Donald Pettit visited RIT, in part to discuss the possibility that the CfD could help him by repairing pictures of the Earth and space taken from the ISS. The visit was arranged by RIT Alumnus, Peter A. Blacksberg (’75). CfD personnel and Dr. Pettit discussed a potential student pilot project to remove artifacts of cosmic ray damage in the pictures. Subsequent to the visit, the CfD students completed the initial stages of the project.

Second, NASA Administrator Major General Charles Bolden visited RIT to give the commencement address and accept an honorary degree. During his visit, he also met with CfD personnel.

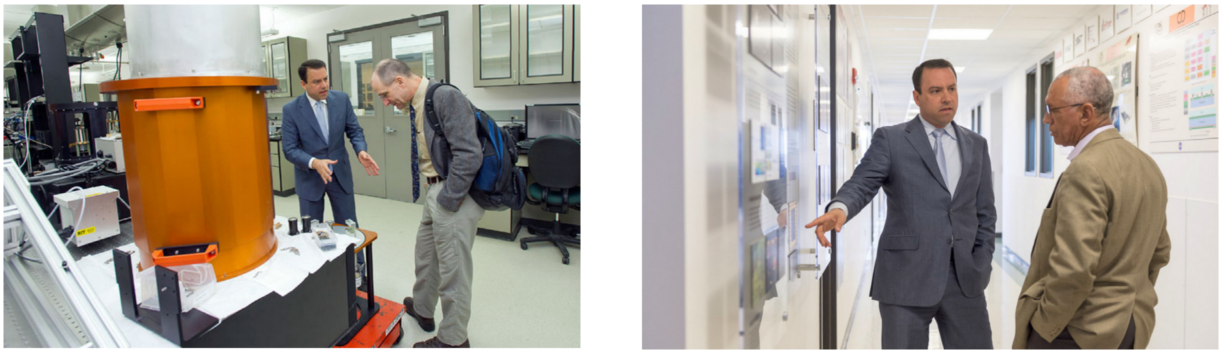


Figure 16: NASA astronauts Donald Pettit (left) and Charlie Bolden (right) visited the CfD.

An abbreviated version of an associated article describing Administrator Bolden's visit from RIT University News is given below.

NASA head to RIT graduates: 'Answer Earth's big help wanted ad'

May 22, 2015

by Greg Livadas

RIT President Bill Destler awarded NASA Administrator Maj. Gen. Charles F. Bolden Jr. an honorary doctorate of science for his distinguished service to our country, his many accomplishments as an astronaut and administrator of NASA, and for championing the spirit of innovation, creativity and exploration. Bolden, center, is hooded by Provost Jeremy Haefner and Christine Whitman, chair-elect of the Board of Trustees.

None of us knows what the future holds, which makes it all the more important to consider all possibilities—even reaching for the stars.

That was the message NASA Administrator Maj. Gen. Charles F. Bolden Jr. gave to the graduates at Rochester Institute of Technology's 130th Academic Convocation on Friday.

"Growing up, I never conceived that someday I'd become a Marine Corps jet pilot, let alone pilot the space shuttle," said Bolden, a decorated Marine Corps veteran and astronaut who orbited the Earth on four space shuttle missions—two as pilot, two as commander.

Bolden cited the long-time ties between NASA and RIT: More than 25 RIT students have completed co-ops at NASA in the past three years, and at least 190 RIT graduates have worked for the agency.

"We collaborate on cutting-edge technologies like large format infrared detectors that can teach us more about dark matter and energy, 3D super roadmaps of planets and moons and smart dust technology that can help unlock the mysteries of the universe," he said.

He likened NASA, which has been ranked as the best federal agency to work for in the past three years, to RIT, which also has been ranked a top university to work for in the United States. He noted RIT is a leader in aerospace education and as one of the greenest universities, according to the Sierra Club.

"Do not let the fears, insecurities and beliefs of others limit what is possible for you," she said. "You have everything you need to change the world, but you have to be willing to put in the work. Nothing worth attaining in life comes easy. It takes passion, drive and choosing to achieve greatness. … The power of choice is in our hands. It is our time to make our mark on the world."

*To read the full text of Bolden's remarks, go to*http://www.rit.edu/news/story.php?id=52370.

CfD Student Kim Kolb Defends Her PhD Thesis

CfD student, Kim Kolb, successfully defended her Imaging Science PhD thesis at the end of the academic year. After considering several options, Dr. Kolb chose to take a position with the U.S. Army's Night Vision and Electronic Sensors Directorate, located at Fort Belvoir, VA. In her new role, Dr. Kolb will assess the suitability of sensor technology for tasks related to protecting American soldiers, especially in low-light level situations. The CfD hope to stay in touch with Kim and wish her the best of luck in the future.

Education and Public Outreach

Connections: Science Roundtable with Evan Dawson

On August 4, 2014, CfD Director Figer was a guest on "Connections: Science Roundtable," hosted by Evan Dawson on WXXI AM 1370 in Rochester, NY. Along with another RIT guest, Professor David Merritt, the host guided the discussion from dark matter to dwarf galaxies, massive stars, and the ways that technology is at the heart of scientific discovery. In particular, Dr. Figer explained that most advances in observational astrophysics have historically come from advances in technology, either through bigger telescopes, more sensitive instrumentation, or more capable detectors.

Presentation at the Hartford Club

In April of 2015, CfD Director Figer gave a public lecture at the Hartford Club, in Hartford, CT, by invitation of RIT Board of Trustees member David Smith. The event was arranged by RIT Associate Vice President for Development, Craig Smith. The talk consisted of two separate presentations, one about an hour long and summarizing research in the Center for Detectors, and another that was ten minutes long and presented an exciting possibility that the kinds of detectors being developed by the Center for Detectors could be used in the fight against breast cancer, especially through early detection and therapeutic monitoring. Student Designers, Alexa Martinez and Jamie Martinez, assisted Dr. Figer in giving this presentation by designing the slide graphics and honing the message. Approximately 40 people attended the talk, including RIT alumni and families of prospective and incoming students. The invitation to the event is shown below.

WE ARE ON THE CUSP OF A REVOLUTION in light detection technology that will allow us to address foundational problems in the human experience. The Center for Detectors at the Rochester Institute of Technology is leading an effort to perfect this new technology in a pursuit to answer the following questions: Can we improve outcomes for breast cancer survivors? Are we alone in the Universe? How does the human brain develop? Is it possible to build ultra-high speed fully secure global computer networks? Can we "see in the dark" to ensure national security? How can space-borne threats be identified quickly to allow countermeasures?

ALUMNI
ASSOCIATION
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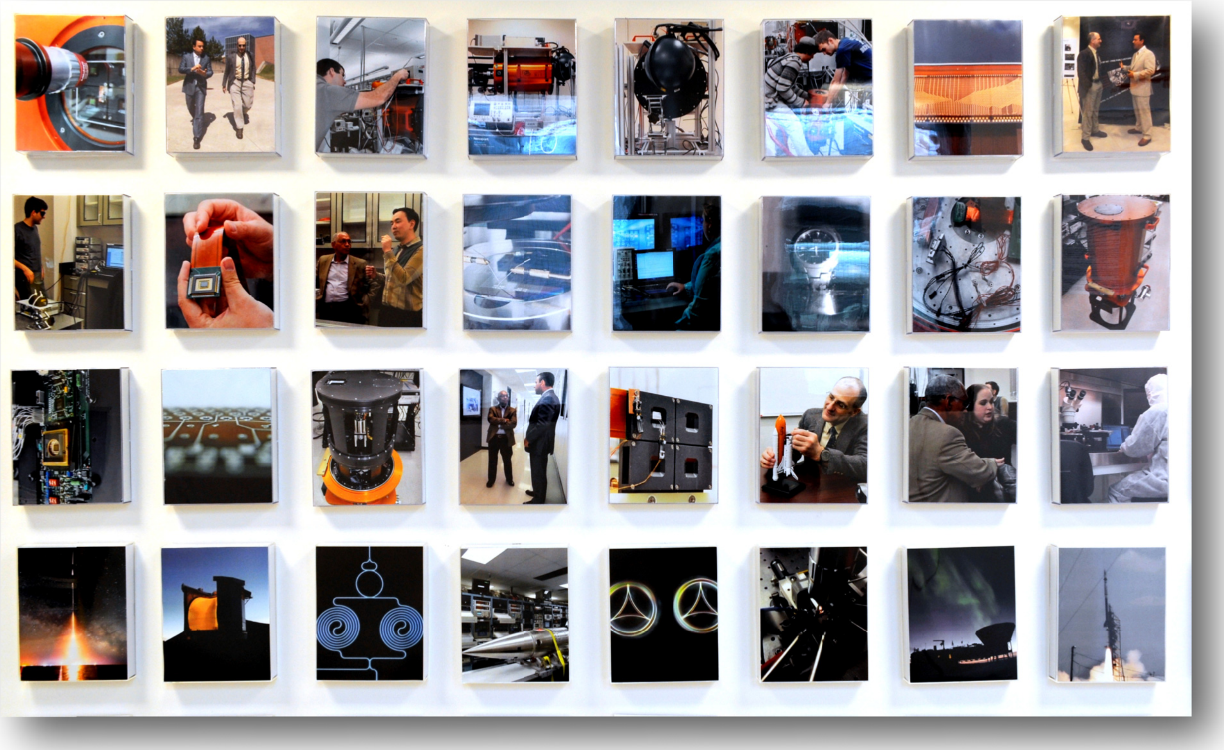
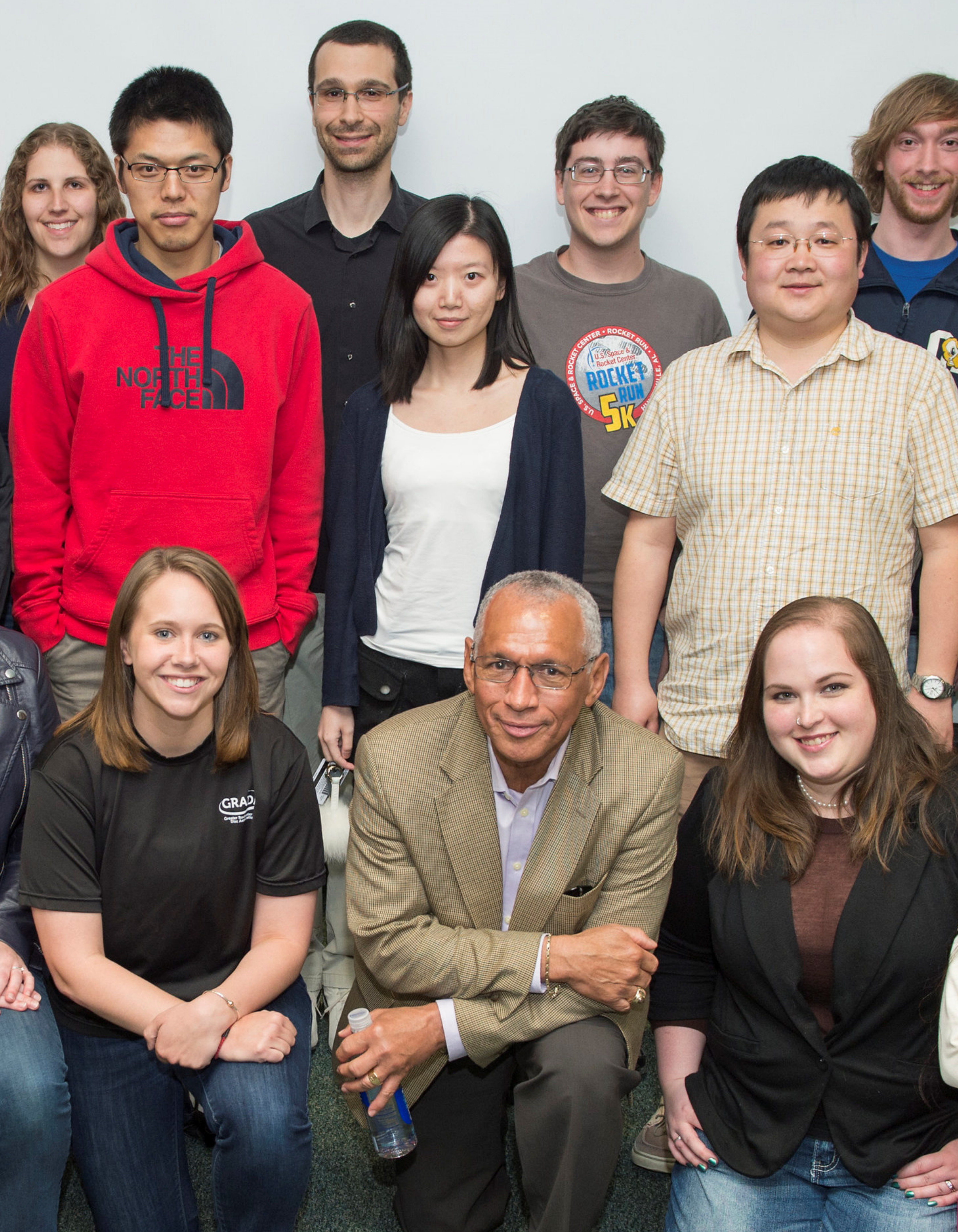
Publications

- Messineo, M., Menten, K., Figer, D., Ivanov, V., Zhu, Q., Kudritzki, R., Davies, Ben., Clark, J., Rich, M., Chen, R., Trombley, C., MacKenty, J., Habing, H., Churchwell, E. 2015, *Hunting for exploding red supergiant stars,* IAU XIX General Assembly
- Messineo, M., Clark, J., Figer, D., Kudritzki, R. P., Najarro, F., Rich, R., Menten, K., Ivanov, V., Valenti, E., Trombley, C., Chen, C.-H., & Davies, B. 2015, *Massive stars in the W33 giant molecular complex,* The Astrophysical Journal, 805, 110
- Kolb, K., Figer, D. 2015, *GM-APD Imaging Arrays for Direct Imaging of Exoplanets*, Proceedings of the IEEE Aerospace Conference, Big Sky, USA
- Trombley, C., Figer, D., & Davies, B. 2015, *Investigation of infrared-selected candidate star clusters: [BDS2003] 52,* The Astrophysical Journal, submitted
- de la Fuente, D., Najarro, F., Trombley, C., Davies, B., & Figer, D. F. 2015, *FS CMa stars in clusters. Evolutionary state as constrained by coeval massive stars,* Astronomy & Astrophysics, 575, A10
- Vorobiev, Dmitry; Ninkov, Zoran 2014, *Compact polarimeters based on polarization-sensitive focal plane arrays,* SPIE, 91435F
- de la Fuente, D., Najarro, F., Trombley, C., Davies, B., & Figer, D. F. 2014, *The nature of FS CMa stars as revealed by host young clusters,* Highlights of Spanish Astrophysics VIII, Proceedings of the XI Scientific Meeting of the Spanish Astronomical Society held on September 8 – 12, 2014, in Teruel, Spain
- Figer, D. F. 2014, *Astrophysics: Monster star found hiding in plain sight,* Nature, 515, 42
- Messineo, M., Qingfeng, Z., Ivanov, V. D., Figer, D. F., Davies, B., Menten, K. M., Kudritzki, R. P., & Chen, R. C.-H. 2014, *Near-infrared spectroscopy of candidate red supergiant stars in clusters,* Astronomy & Astrophysics, 571, A43
- Messineo, M., Menten, K. M., Figer, D. F., Davies, B., Clark, J. S., Ivanov, V. D., Kudritzki, R. P., Rich, R. M., MacKenty, J. W., & Trombley, C. 2014, *Massive stars in the giant molecular cloud G23.3-0.3 and W41,* Astronomy & Astrophysics, 569, A20



Organization


THE NORTH FACE
U.S. Space & Rocket Center
ROCKET RUN 5K
GRAD

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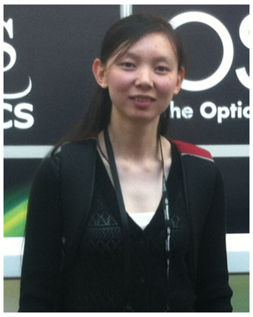

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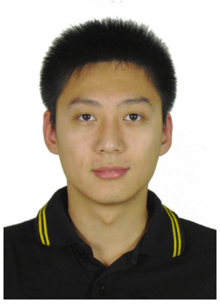

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Charter

About the Center for Detectors

The CfD designs, develops, and implements new advanced sensor technologies through collaboration with academic researchers, industry engineers, government scientists, and students. The CfD enables scientific discovery, national security, better living, and commercial innovation through the design and development of advanced photon detectors and associated technology in a broad array of applications such as astrophysics, biomedical imaging, Earth system science, and inter-planetary travel.

Vision and Mission

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

Goals

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

Focus Areas

The Center seeks to apply its technologies to many different scientific areas including Astrophysics, Biomedical Imaging, Defense, Earth Systems Science, Energy, Homeland Security, and Quantum Information. These focus areas are mainly what brings together the great variety of individuals from diverse areas of expertise.

Astrophysics – A zero read noise detector will enable the discovery of Earth-like planets around nearby stars, life on other planets, the nature of dark energy and dark matter, and the origins of stars and galaxies.

Biomedical Imaging – The Biophotonic Experiment Sensor Testbed will enable safe detection and monitoring of breast cancer and cognitive functioning with unprecedented sensitivity.

Defense – Space-based cameras will be equipped with the most sensitive detectors that provide rapid delivery of the most sensitive information.

Earth Systems Science – The Center's detectors will be exploited to address fundamental Earth system science questions, such as sensing of photosynthesis or the creation of atmospheric pollutants, detection of atmospheric or ocean temperature gradients, or the timely viewing of extreme events.

Energy – New high photon-efficiency solar cells will be developed to ensure sustainable energy generation for economic competitiveness and national security.

Homeland Security – Advanced imaging detectors will be able to reveal potential airborne biochemical hazards through high-resolution three-dimensional ranging, spectral discrimination, and motion pattern recognition.

Quantum Information – High-speed single photon receivers will be deployed to support future technologies in photonics, communication, quantum computing, and quantum cryptography.

Governance

The Center is supervised and operated by its founding Director, Dr. Donald Figer. A committee of experts, from RIT and elsewhere, advise the Director to ensure successful definition and execution of the Center's vision and goals. The committee meets once per year after the completion of the CfD Annual Report. Center members include academic researchers, industry engineers, government scientists, and university/college students.

Funding

5Since its inception in 2006, the Center for Detectors has received $13 million in research funding. The largest contributions are from the Moore Foundation and NASA. The Moore Foundation has granted $3.0 million to support the development of a zero noise detector, while NASA awarded over $6 million in research grants. In 2012, NSF also became a major sponsor with a research grant of $1.2 million for the development and testing of infrared detectors grown on silicon wafers. In 2013, NASA granted $1.1 million to the Center for a related project to advance a new family of large format infrared detectors grown on silicon wafer substrates. In October, 2013, the Gordon and Betty Moore Foundation award $283,000 to the Center for Detectors. Most recently, the CfD received $2M from NSF.

Capabilities, Equipment, and Facilities

The Center for Detectors is located in the Engineering building (Building 17) at the Rochester Institute of Technology. It has 5,000 square feet of space for offices and labs, including offices for 17 people, and four research laboratories: the Rochester Imaging Detector Laboratory (see Figure 17), a newly-renovated laboratory for suborbital rocket missions, the Imaging LIDAR laboratory, and the Wafer Probe Station laboratory. The laboratories contain special facilities and equipment dedicated to the development of detectors.

Figure 17. Above is the main CfD lab, the Rochester Imaging Detector Laboratory.

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

The RIDL detector testing systems (Figure 19) use four cylindrical vacuum cryogenic dewars. Each individual system uses a cryo-cooler 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 Model 340 temperature controllers to sense temperatures at 10 locations within the dewars and control a heater in the detector thermal path. This thermal control system stabilizes the detector thermal block to 400 μK RMS over timescales greater than 24 hours. The detector readout systems include an Astronomical Research Camera controller having 32 digitizing channels with 1 MHz readout speed and 16-bit readout capability, two Teledyne SIDECAR ASICs having 36 channels and readout speeds up to 5 MHz at 12-bits and 500 kHz at 16-bits, custom FPGA systems based on Altera and Xilinx parts, and a JMClarke Engineering controller with 16 readout channels and 16-bit readout designed specifically for Raytheon Vision System detectors. The electronics packages are shown in Figure 18.

Figure 18. The three electronics packages used to test detectors. Electronics from left to right: Astronomical Research Camera Controller; JMClarke Engineering, Teledyne SIDECAR ASIC.

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

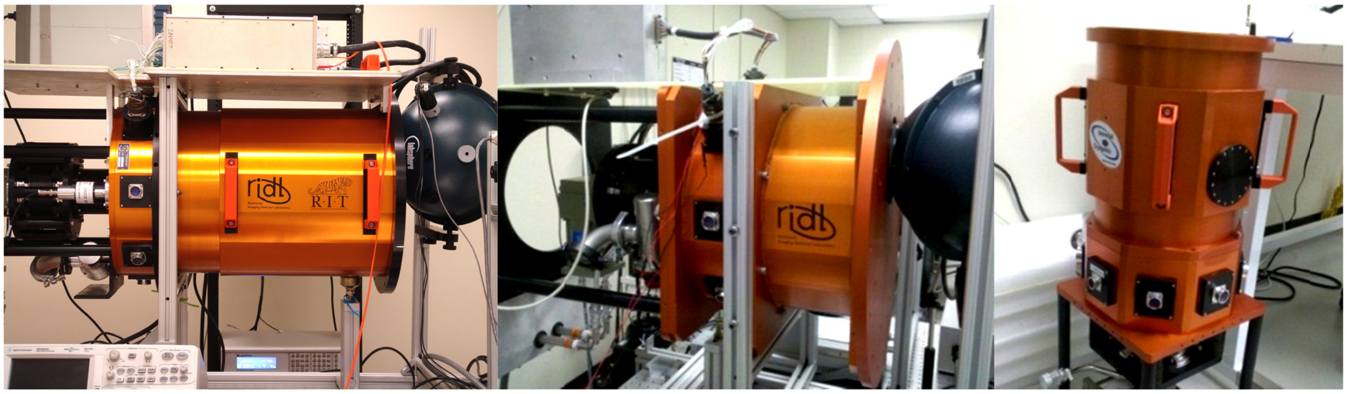

Figure 19. Detectors are evaluated in four custom dewar test systems. The fourth dewar is a duplicate of the one picture on the left.

The lab equipment also includes a Pico Quant 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 an approximate wavelength range of 250 nm – 2500 nm. NIST-traceable calibrated photodiodes (with a wavelength range of 300 nm – 5000 nm) provide for absolute flux measurements. CfD also has a spot projector to characterize the inter-pixel response of the detectors, including optical and electrical crosstalk. Figure 20 shows a laser spot projection system on a 3D motorized stage that produces a small (~few microns) point source for measurements of intrapixel sensitivity.

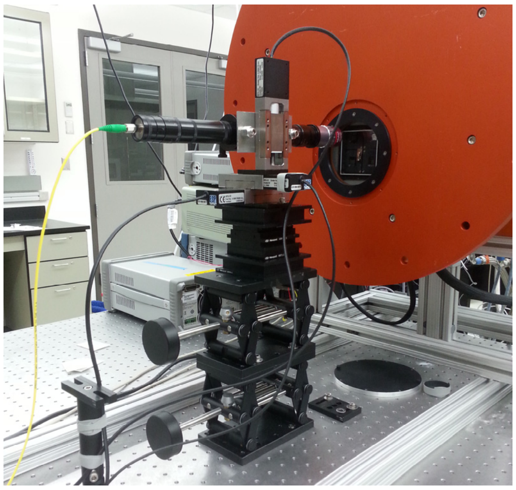

Figure 20. Shown here is a laser spot projector with three axis motion control system.

The lab contains eight data reduction computers, each with eight processors and up to 16 GB of memory for data acquisition, reduction, analysis and simulations, and 25 TB of data storage. Custom software runs an automated detector test suite of experiments. The test suite accommodates a wide variety of testing parameters through the use of parameter files. A complete test suite takes a few weeks to execute and produces ~0.5 TB of data. The data reduction computers reduce and analyze the data using custom automated code, producing publication-quality plots in near-real time as the data are taken.

CfD has the capability to design system components needed for detector testing using CAD programs, *e.g.* SolidWorks. This thermal finite element analysis software is also used to simulate thermal cooling of system components and detectors. Eagle and PCB Express are used to design layouts for readout circuits that interface with the detectors. System-based software tasks also include data processing with IDL, C and C++, HDL programming on Xilinx and Altera chips, as well as the SIDECAR ASIC.

CfD has access to facilities in the SMFL. The SMFL has 10,000 ft^2 of cleanroom space in class 1000, 100, and 10. Using the SMFL's resources, the Center can fabricate detectors with custom process flows, and has the freedom to use multiple process variations.

The Center's flow-bench and probe stations offer wafer-level testing, even during the fabrication process, allowing mid-process design changes (Figure 21). The probe station accommodates electrical and circuit analysis of both wafers and packaged parts, including low current and radio frequency (RF) probing.

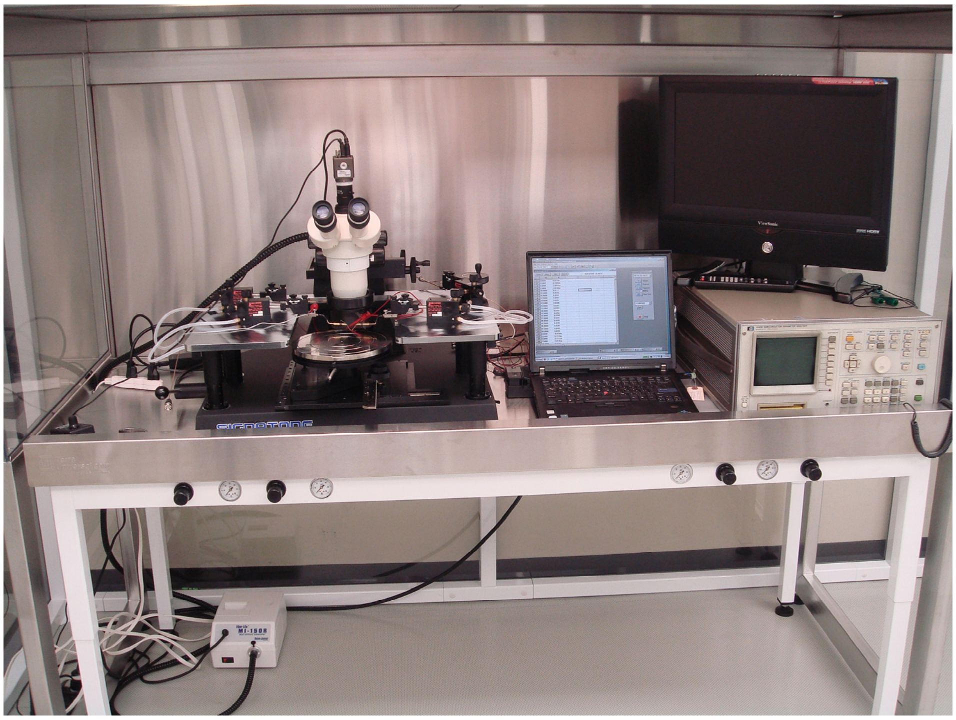

Figure 21. Device wafers are tested in the flow-bench lab probe station.

Also available for CfD use are the Amray 1830 Scanning Electron Microscope (SEM; see Figure 22), used for high-magnification imaging of devices, and the WYKO white light interferometer, used for surface topography measurements. The SMFL also has other in-line fabrication metrology capabilities, including material layer thickness, refractive index, and wafer stress characterization tools.

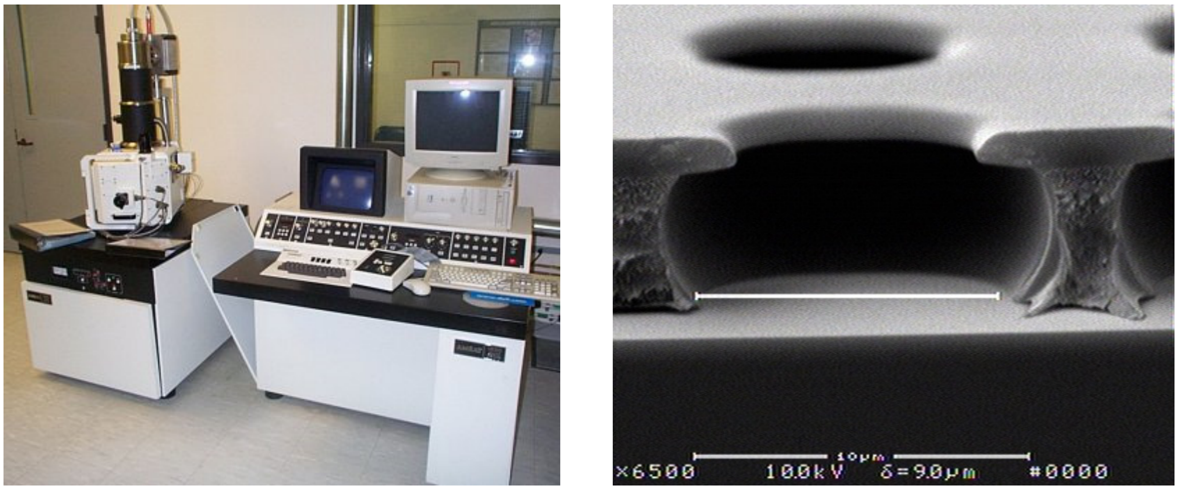

Figure 22. (left) The Amray 1830 Scanning Electron Microscope is used to image devices. (right) SEM image of a device that has been prepared for indium bump deposition.

Figure 23 shows a customized setup consisting of two voltage power supplies, an Agilent oscilloscope, an LCD screen for viewing devices through the microscope probe station, and a custom circuit board for specific device diagnostics. The dedicated lab computer also runs a specially-designed data acquisition program to collect and analyze data from the device.

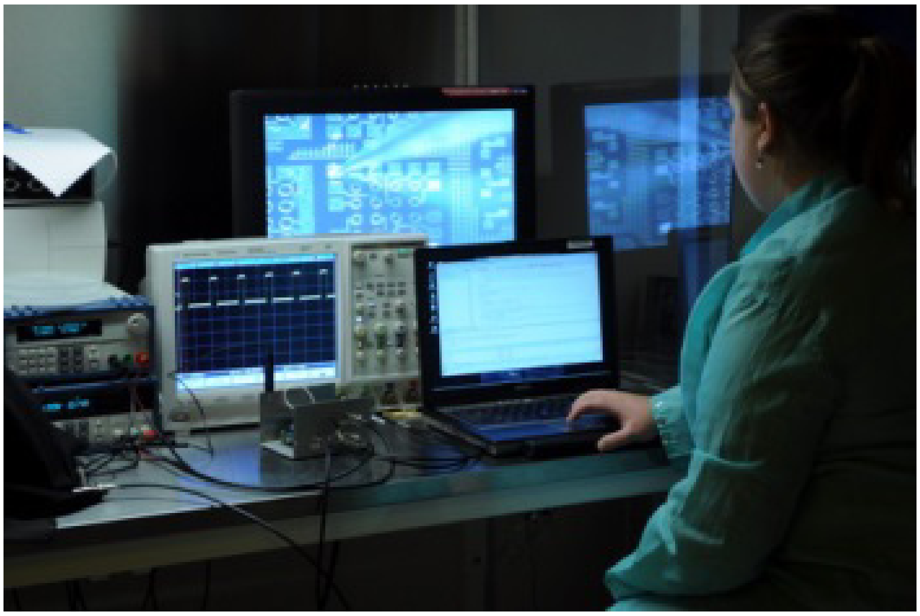

Figure 23. PhD student Kimberly Kolb conducts electrical experiments on one of the cutting edge devices being characterized at the Center for Detectors.

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

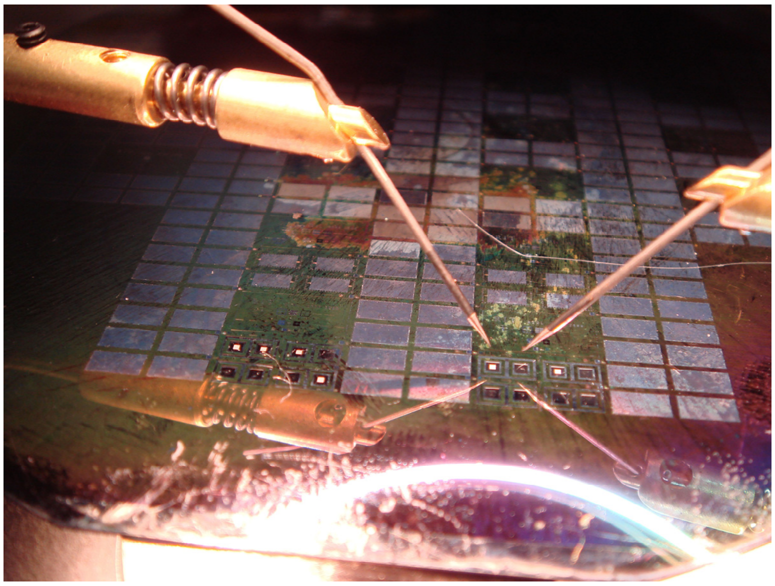

Figure 24. This image is a close-up of a device wafer being tested on the probe station.

In addition to fabrication and testing capabilities, the Center for Detectors 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 RIT SMFL, building a physics-based model in 3D space of a device from initial substrate to completed device.

The Center for Detectors uses many other RIT facilities, *e.g.*, 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 25).

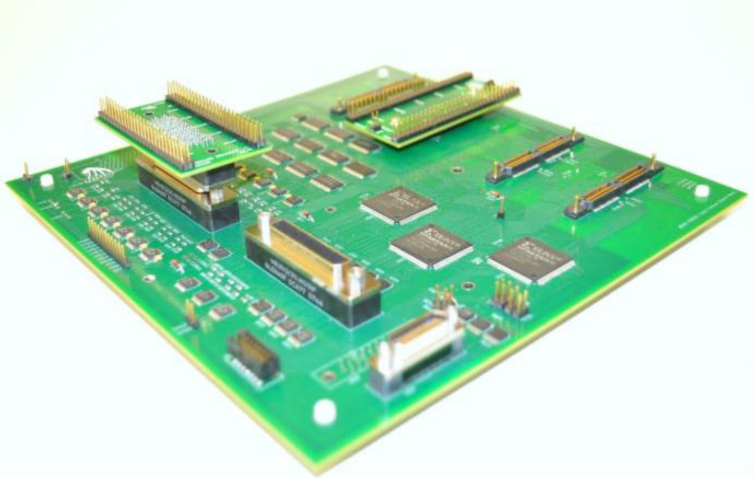

Figure 25. This image shows a cryogenic multi-layer circuit board designed in the CfD and populated in CEMA. All of the components on this board will be exposed to temperatures as low as 40 K, nanoTorr pressure levels, and high energy particle radiation.

The Center for Detectors has two integrating spheres. One is gold and is optimized for infrared light (Figure 26). The other has a white coating that is ideal for UV and optical light. The spheres allow researchers to uniformly scatter and diffuse incident light, with entrance and exit ports. They also measure the diffuse reflectance of surfaces, providing an average over all angles of illumination and observation. The integrating sphere is currently being used to create a light source with apparent intensity uniform over all positions within its circular aperture.

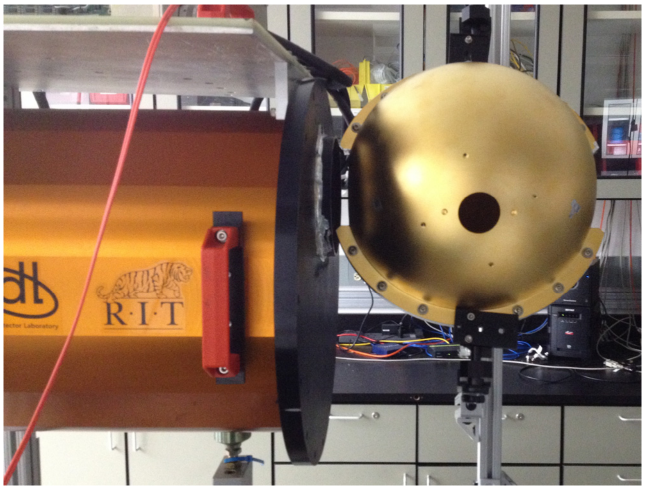

Figure 26. This image shows a gold-coated integrating sphere attached to one of the dewars. The gold coating is more reflective in the infrared than the more commonly-used integrating sphere that is coated with white paint that is highly reflective at optical wavelengths.