CENTER FOR DETECTORS
ANNUAL REPORT
2013

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Welcome to the Center for Detectors (CfD), a cross-Institute Academic Research Center in the College of Science at the Rochester Institute of Technology. CfD continues in its fourth year of operation. In the past year, the Center has increased its performance in terms of research projects, student experiences and outcomes, and external research funding.

Of particular note, the CfD won a major new research grant from the National Aeronautics and Space Administration to develop the next generation of infrared detectors for space Astronomy. IR detectors have been key enablers for cutting-edge space-based astronomy platforms, such as the Hubble Space Telescope and the Spitzer Space Telescope. Those missions were preceeded by many years of infrared detector development and deployment on ground-based facilities. That activity was directly responsible for several new advanced instruments in space, such as the Near Infrared Camera and Multi-object Spectrograph, the Wide Field Camera 3, and the Infarered Array Camera. The Center's new research project, in collaboration with Raytheon Vision Systems, will break the current performance versus cost paradigm for IR detectors and open a much larger volume of "discovery space" for future missions.

As has been the case since the Center's inception, students are key to all of our activities. They perform original research at all levels, from early undergraduate to PhD. Over the past year, students have done independent studies, completed advanced degrees, and even contributed to the business operations of the Center. Their home academic departments include: Physics, Applied Physics, Electrical Engineering, New Media Marketing, Graphic Design, Astrophysics, Imaging Science, and Industrial Design.

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 in this report.

I welcome your interest in 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: Clumping in OB-Star Winds, Mass Loss of Red Supergiants, New VIS/IR Detectors for NASA Missions, New Infrared Detectors for Astrophysics, a Zero Read Noise Detector for Thirty Meter Telescope (TMT), a Photon-Counting Detector for Exoplanet Missions, the Nature of GLIMPSE 81: a Star Cluster to Rival Westerlund 1, and a NICMOS Survey of Newly Identified Young Massive Clusters.
- Projects completed this year are: High Mass Initial Mass Finction.

NASA Fellowship

- PhD student Kim Kolb won a NASA Earth and Space Science Fellowship (NESSF) to help develop the technology and understanding of single photon detectors. Her proposal was one of only nine out of 114 proposals in the NASA Astrophysics division selected for funding.
- PhD student Christine Trombley was selected to receive a Graduate Research Fellowship in Astrophysical Sciences and Technology sponsored by NASA and Cornell University.

Publications and Presentations

- Center for Detectors (CfD) team members published nine papers and presented two posters and several invited talks. In addition, CfD student Christine Trombley completed her PhD thesis based on research completed in the Center.

Executive Summary

This report summarizes the activities of the Center for Detectors (CfD) over the past year, spanning July, 2012 through June, 2013. The CfD was established in January, 2010. It is an Academic Research Center within the College of Science at the Rochester Institute of Technology (RIT). The purpose of the Center is to develop and implement advanced photon detectors 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.

Personnel

CfD members come from a diverse range of academic programs and professional occupations. During the 2012-2013 academic year, the staff included two Professors, four engineers, four student lab assistants, four PhD students, one MS student, and various other support staff.

Student Vignettes

Many of the Center's students do research in the Center's laboratories for their current academic programs at RIT. One student researcher, Christine Trombley, published her PhD thesis based on research completed in the center.

Publications

In the past year, nine papers have been published by CfD personnel. Two conference posters were presented at the "Massive Stars: From α to Ω!" conference in Rhodes, Greece.

Grants, Contracts, and External Funding

The Center is grant-funded, and has received more than $11 million in research funding. NASA, the Gordon and Betty Moore Foundation, and the NSF are the Center's primary supporters. In January, 2013, NASA awarded $1.1 million to the Center for Detectors to advance a new family of large format infrared detectors grown on silicon wafer substrates.

Projects

The many projects in progress at the Center combine a variety of science areas. From various branches of engineering, to imaging science, to physics, chemistry, and astronomy, the Center stands out because of its diverse applications. Projects such as

"The High Mass Initial Mass Function" use traditional techniques of observational astrophysics. Other projects, such as the NSF-funded New Infrared Detectors for Astrophysics, bring together microelectronic engineers, astronomy experts, and various other professionals in the engineering fields.

Press & Presentations

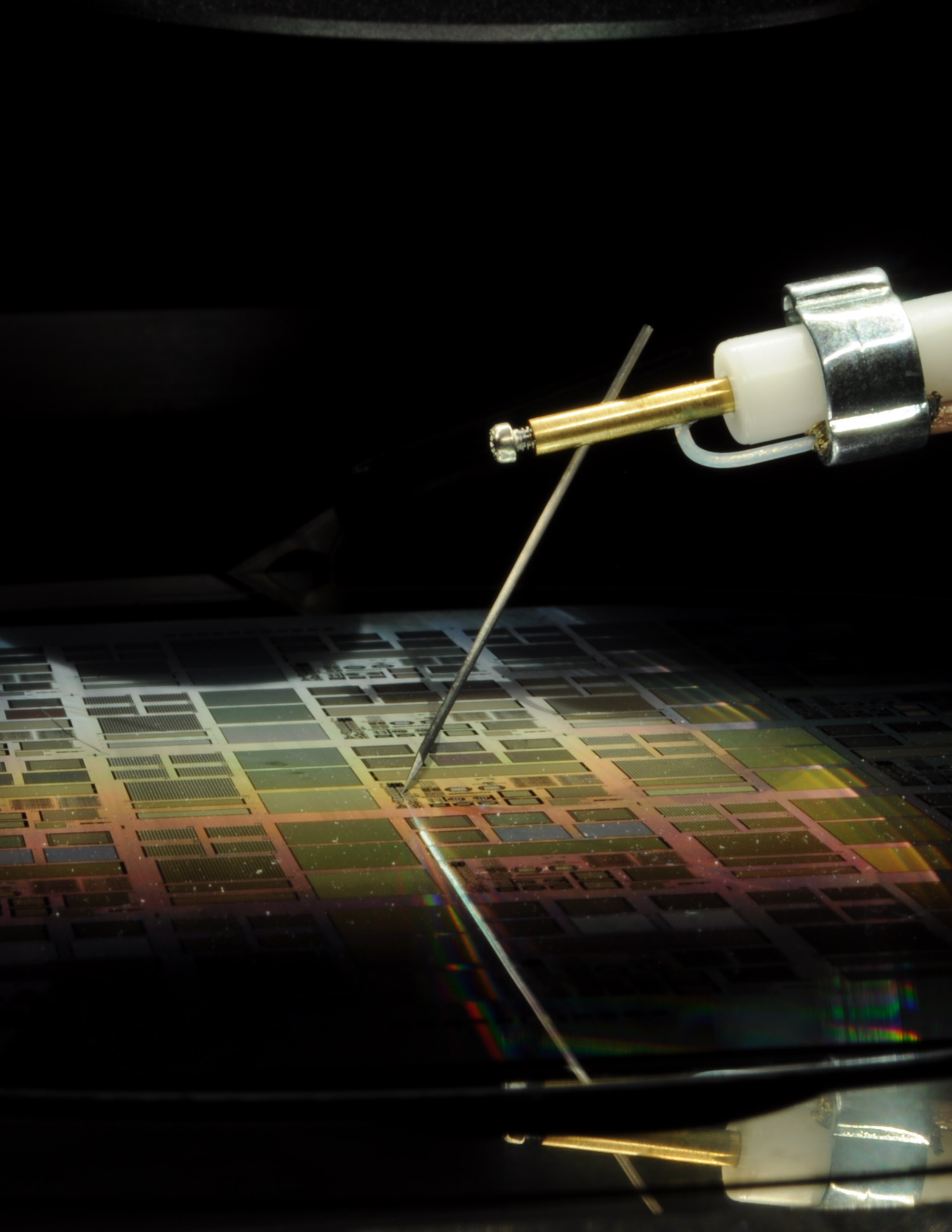
Last July, as part of the Detector Virtual Workshop, Hooman Mohseni from Northwestern University presented a talk about a new generation of Isolated Nano-injection Detectors and Imagers. This April, Christoph Baranec gave a presentation at the Rochester Institute of Technology on the subject of Rayleigh Laser Guide Stars pioneering the next decade of Astronomical Adaptive Optics. This year, Center for Detectors Director Don Figer spoke to 3rd and 5th grade students at Park Road Elementary School in Pittsford, NY.

Equipment and Facilities

The CfD is equipped with three cryogenic dewars, which were designed by the Center's lab engineers. The dewars are supported by temperature controllers, readout controllers, motion stability supports, integrating spheres, and data reduction PCs.

The Center also has a class 1000 cleanroom, where detector parts in various stages of fabrication can be tested. In addition to the Center's laboratories, the CfD staff have access to other RIT facilities such as the Center for Electronics Manufacturing and Assembly, and the Brinkman Manufacturing Lab.

Research



Research Projects

New Projects

Clumping in OB–Star Winds

NASA/Herschel

Massive stars, their nature and evolution, play an important role at all stages of the Universe. Through their radioactively driven winds they influence on the dynamics and energetics of the interstellar medium. The winds of OB stars are the most studied case. Commonly, the mass–loss rates of luminous OB stars are inferred from several types of measurements, the strengths of UV P Cygni lines, H–alpha emission and radio and FIR continuum emission. Recent evidence indicates that currently accepted mass–loss rates may need to be revised downwards when small–scale density inhomogeneities (clumping) are taken into account. Only a consistent treatment of ALL possible diagnostics, scanning different parts of the winds, and analyzed by means of state of the art model atmospheres, will permit the determination of true mass–loss rates. To this end, we have assembled a variety of multi–wavelength data, but one crucial observational set is missing: far–IR diagnostics of free–free emission, which uniquely constrain the clumping properties of the wind at intermediate heights. We are using PACS photometric mode to fill this crucial gap, studying the 70 and 110 micron fluxes of a carefully selected sample of 29 O4–B8 stars (Figure 1). These observations will provide the missing information to derive the clumping properties of the entire outflow, to understand the wind physics, and to obtain reliable mass loss rates.

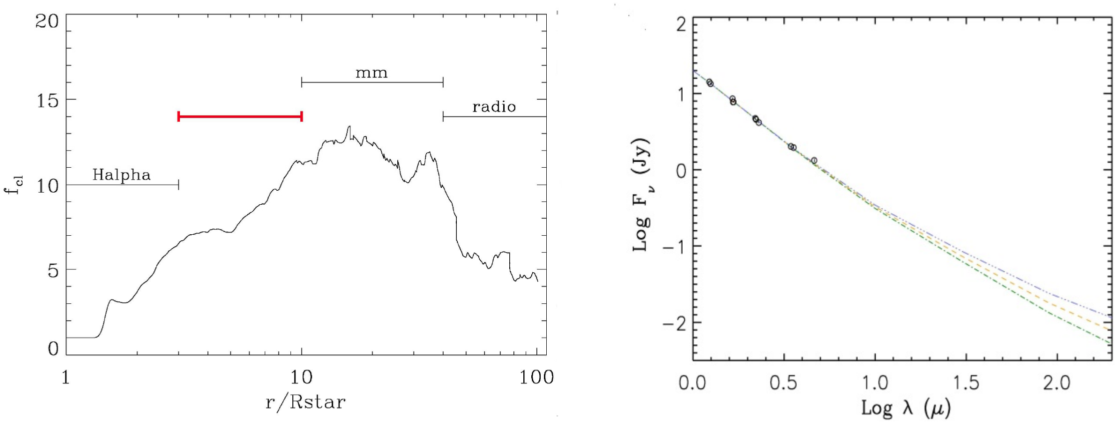


Figure 1. Radial stratification of the clumping factor, fcl(r), as predicted by hydrodynamical models, simulating the effects of the self-excited instability inherent to line-driven winds. The formation regions of different diagnostics are indicated for the case of a typical O-supergiant wind. The proposed Herschel-PACS observations at 70-130 m sample the important intermediate wind region.

The Mass Loss of Red Supergiants

NASA/Stratospheric Observatory for Infrared Astronomy (SOFIA)

The final stages of massive star evolution are key to understanding a multitude of astrophysical processes, including which stars produce neutron stars and black holes and how galaxies are seeded with heavy elements. Great progress has been made in tracing the evolutionary progressions of massive stars, but there has been no definitive measurement of the most important quantity that governs their evolution - the mass loss rate. This is the key ingredient that determines the end states of massive stars and their effect of the chemical abundance in the interstellar medium. We have been awarded time on SOFIA (Figure 2) to make the most accurate measurement of the mass loss rate of a subset of massive stars that span the mass range of red supergiants. This project is made possible by the combination of recently-discovered coeval clusters of red supergiants and the excellent performance of the Faint Object Infrared Camera for the SOFIA Telescope (FORCAST) in measuring mid-infrared photometry.

Figure 2. (left) SOFIA is an airborne observatory located in a Boeing 747 aircraft. (right) The 2.5-meter diameter reflecting telescope views the sky during flight through a door built in the fuselage of the aircraft.

New Visible/Infrared Detectors for NASA Missions

NASA/Astrophysics Research and Analysis (APRA)

The key objective of this project is to advance new large-format infrared detectors for NASA missions. We are developing new technology that provides high sensitivity, broad wavelength coverage from the optical to infrared, low noise, low dark current, very low and characterizable interpixel capacitance (IPC), low cost, and scalability to very large format sizes. The technological advances that enable these benefits include new processing for depositing HgCdTe on silicon wafers. By maturing these processes, NASA will have a powerful new tool at its disposal for fabricating extremely large infrared focal planes up to 14K×14K pixels in size. The development plan includes design and fabrication of test structures and hybridized focal planes in 1K×1K and 2K×2K pixel formats (Figure 3). All of these parts will be rigorously evaluated using test equipment and procedures that have been used in other successful detector development programs, e.g., for James Webb Space Telescope (JWST).

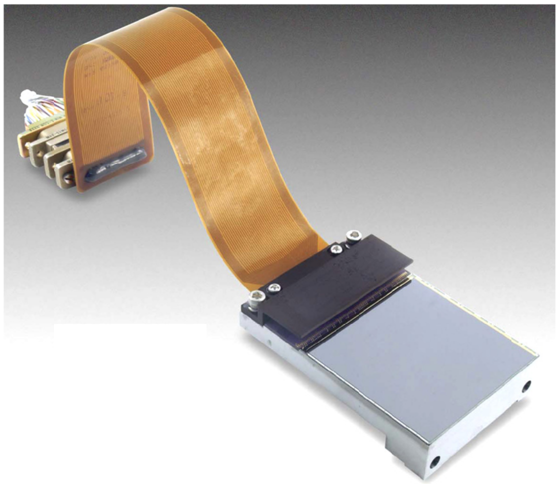


Figure 3. The picture shows a Raytheon VIRGO 2K×2K infrared detector, much like the ones that will be designed, fabricated, and tested in the newly-funded project.

These devices are ideal for missions that require large format infrared and optical detectors. NASA currently anticipates new missions that rely on the detectors like those developed in this project. These include missions to study dark energy/matter, exoplanets, and general Astrophysics. One example of a future mission that is an ideal candidate for the new detectors is the Wide Field Infrared Survey Telescope, the highest rated space Astrophysics mission to develop in the next decade. The devices will also be very valuable for Earth Science and Planetary Science missions. Missions that could have benefited from this technology include the Hubble Space Telescope and the Spitzer Space Telescope. JWST uses HgCdTe detectors, but those devices have suffered degradation, have higher inter-pixel capacitance, and use a higher-cost process as compared to the proposed technology.

The project leverages a long heritage of device design, fabrication, and testing by the team. Particularly relevant experience lies in the ~15-year development of the process to deposit HgCdTe on silicon wafers that has been matured by Raytheon. Raytheon has a record of successfully delivering advanced detectors to a broad range of customers for a diverse set of space missions. The development uses a successfully deployed readout circuit that is being used for the Visible and Infrared Survey Telescope for Astronomy (VISTA) telescope project.

Single Photon Counting Detectors for NASA Astronomy Missions

NASA/NASA Earth and Space Science Fellowship (NESSF)

This project will to characterize (theoretically and physically) three unique implementations of single photon counting detectors, benchmark their operation over a range of performance characteristics, and provide comprehensive justification for the superiority of one of the implementations for each of these NASA astronomy applications: exoplanet detection, high-contrast imaging, adaptive optics, and array-based LIDAR.

Single photon counting will be necessary for many science objectives in the near future. A good example, and one of the main goals of NASA's astrophysics research, is the discovery of exoplanets. This objective requires advancements in detector performance, especially in the case of direct imaging. A reasonable estimate for the signal in such a scenario is a 30 mag object (an Earth-like planet orbiting a Sun-like star 10 pc away, 0.1 photons/s/pixel). To reach a signal-to-noise-ratio (SNR) of 1 in this scenario, a detector with state-of-the-art read noise (3 e^-) would need an exposure time of roughly 1100 s with 70% Quantum Efficiency (QE). A photon counting detector would need only 450 s at the same QE (a 2.4x reduction). Figure 4 shows the difference in SNR between 0 e^- and 10 e^- read noise. The increase in sensitivity in the 0 e^- image allows smaller and lighter imaging systems to surpass the current state-of-the-art performance, which will lead to the discovery and study of objects that are currently undetectable.

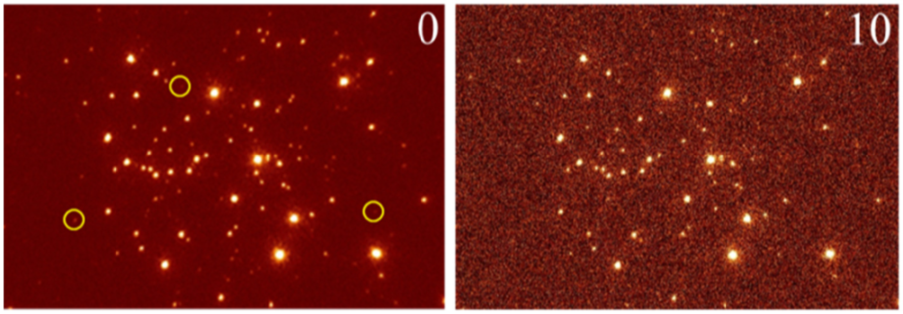


Figure 4. The above image demonstrates the benefits of zero read noise (Arches cluster) – (left) 0 electrons synthetic shot noise and (right) 10 electrons read noise. The circles show examples of faint objects that are only detectable with zero read noise.

The main goal of this project is to provide the basis of comparisons for several types of fundamentally different single photon counting detectors by producing a table of comparisons and recommendations for various applications (Table 1). All detectors must be sensitive to single photons, be scalable to large array formats, and have high QE (in the visible, UV, NIR, IR, and Far-IR wavelengths). This research will advance preliminary work by adding new characterization methods and performance benchmarks, and by comparing the different devices at predetermined milestones during the project. The recommended detector(s) should function well at high readout frequencies without significant read noise (leading to improved temporal sampling), have very low noise for increased SNR at low fluence levels, and be implemented (or able to be in the near future) on large arrays.

Table 1: NASA Astronomy Goals and Prioritized Performance Metrics

Application	Prioritized Performance Metrics
Imaging (long exposure times)	dark current, read noise, sensitivity, crosstalk
Imaging (short exposure times)	time response, read noise, dark current, sensitivity, crosstalk
Adaptive optics	time response, crosstalk, read noise, dark current, sensitivity

This project includes collaboration with Dr. Shouleh Nikzad, lead of the Advanced Detector Arrays and Imaging Systems group at NASA's Jet Propulsion Laboratory (JPL), in the detectors' simulation and testing. The research team has a long-standing, successful relationship with Dr. Nikzad, having collaborated with her on Planetary Instrument Definition and Development (PIDDP) and Astrophysical Research and Analysis (APRA) projects. The research in this project overlaps with Dr. Nikzad's interests, including the possible inclusion of delta-doped electron multiplying charge coupled devices (EMCCDs). Testing of UV-sensitive EMCCDs (and potentially other UV-sensitive detectors) at JPL is a key part of this research. The Geiger-mode avalanche photodiode (GM-APD) devices are currently in development in a collaborative effort between the CfD and MIT Lincoln Laboratory. The Gordon and Betty Moore Foundation funded the preliminary work for ground-based astronomy applications. The EMCCD is a commercially available device from E2V, and the linear-mode avalanche photodiode (LM-APD) is currently in development at the University of Hawaii with CfD collaborator Don Hall.

The project includes thorough characterization of the detectors under laboratory conditions, including single-element probe testing of GM-APD (both Si and InGaAs) and LM-APD (HgCdTe) pixels and dewar-based array testing of GM-APD (both Si and InGaAs) and EMCCD (Si) array-based detectors. Device characterization includes evaluation of the dark count rate (and the closely related metric of afterpulse generation), quantum efficiency or photon detection efficiency (PDE, which is a combination of quantum efficiency and avalanche initiation probability) in the case of the GM-APD, crosstalk (optical and electrical), and the effects of radiation damage on each of the previously listed parameters. The characterization will include laboratory testing under various operating conditions tailored to explore the operational bounds of each detector. It is important to note that signal estimate in gate-based photon counting devices is not straightforward (as in linear devices like the LM-APD). Dead-time correction is necessary to estimate the charge flux. Both GM-APD and EMCCD (photon-counting mode) devices require this correction, though the mathematical approach varies.

Ongoing Projects

New Infrared Detectors for Astrophysics

NSF/Advanced Technologies and Instrumentation (ATI)

The key objective of this project is to provide the ground-based astronomy community with a new family of detectors that have very large formats, low cost, and state-of-the-art performance. The proposed technology provides high sensitivity, broad wavelength coverage from the optical through infrared, low noise, low dark current, low and characterizable interpixel capacitance (IPC), low cost, and scalability to much larger format sizes than possible with today's technology. The key technology that enables these benefits is advanced processing for depositing HgCdTe on silicon wafers. Using the current generation of silicon wafers that are commonly-available in the semiconductor industry will directly lead to much lower cost and scalability up to 14K×14K detector arrays.

Planned project tasks during the first year include receiving HgCdTe-based detectors, designing and fabricating modifications to the testing system, writing software for the data acquisition system, and obtaining test data for the first batch of detectors. These tasks were completed. Testing indicates that one device has relatively low dark current and high noise.

Two VIRGO 2K×2K HgCdTe detectors were delivered to the Center for Detectors (CfD). One device was grown on a traditional CdZnTe wafer, whereas the second device was grown on a Silicon wafer (Figure 5). The first device has a cutoff wavelength of 1.7 µm, and the second has a cutoff wavelength of 4.9 µm.

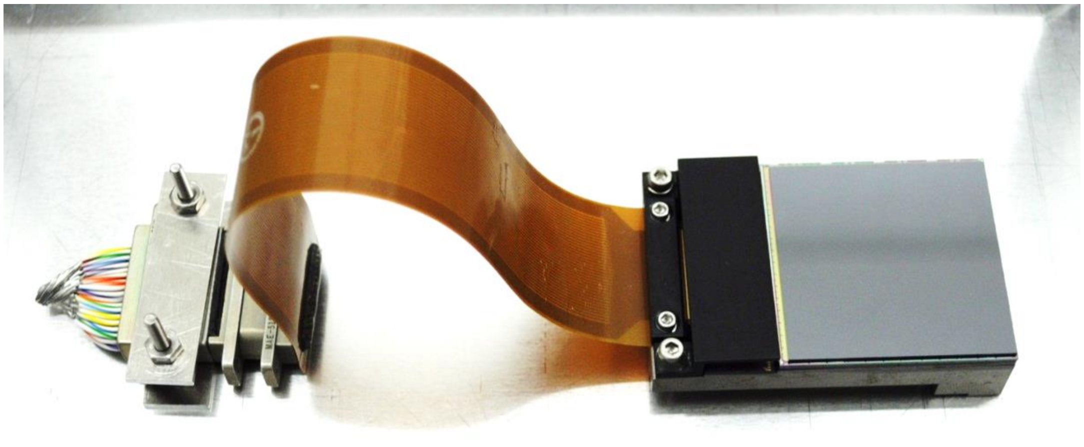
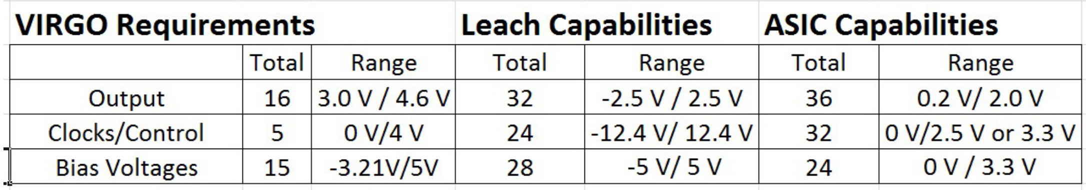


Figure 5. This is one of the VIRGO devices received by the CfD for this project.

Two electronics systems were considered for controlling the VIRGO devices: the Leach electronics system and the Teledyne Sidecar application-specific integrated circuit (ASIC). We outlined the requirements for the VIRGO and then compared them to the capabilities of the individual electronics systems (Figure 6). The ASIC system does not produce the necessary range of clocking or bias voltages, some of which are negative. Also, the video input lines on the ASIC could not handle the 3.0 V – 4.6 V range required to measure the outputs of the VIRGO. The Leach system was selected in the end since it met all the requirements, required fewer modifications to run the detector, and delivered the required low levels of system noise.



VIRGO Requirements			Leach Capabilities		ASIC Capabilities	
	Total	Range	Total	Range	Total	Range
Output	16	3.0 V / 4.6 V	32	-2.5 V / 2.5 V	36	0.2 V/ 2.0 V
Clocks/Control	5	0 V/4 V	24	-12.4 V/ 12.4 V	32	0 V/2.5 V or 3.3 V
Bias Voltages	15	-3.21V/5V	28	-5 V/ 5 V	24	0 V / 3.3 V

Figure 6. The table shows the VIRGO requirements and capabilities of the Leach and ASIC electronics.

The Leach system (Figure 7) has the added advantage of having been used for past projects, so the software infrastructure has already been established and tested. This has allowed for quick development of the system, with few modifications, and early testing within a few months of the project start date. Some of the modifications that needed to be made were custom harnesses, an application-specific current source board, and replacement of a few components to meet the specifications required to run the VIRGO device.

Figure 7. This photo shows the Leach electronics system.

A few additional cables needed to be designed to test the VIRGO with a focus on keeping the system noise as low as possible. Cables were kept short and utilized shielding that was terminated to the system ground. We designed and built a short cable (Figure 8) to allow quick warm testing of the VIRGO. With the cables attached to the electronics system, the system noise was found to be 23.8 μV CDS.

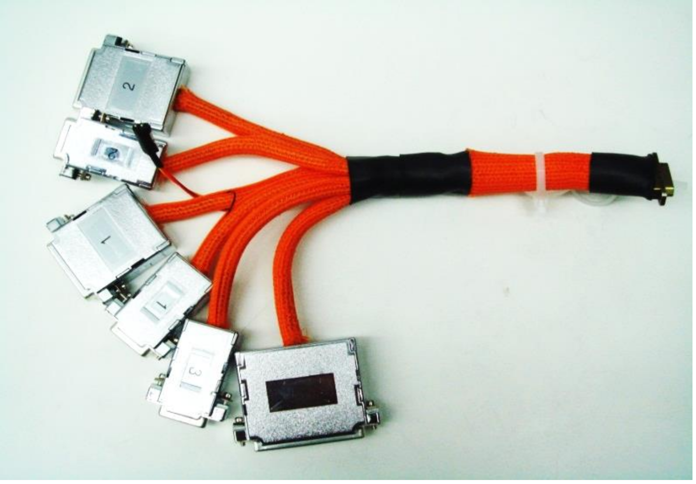


Figure 8. A test cable was built for warm testing. It connects the Leach electronics system directly to the output cable of the VIRGO device.

We procured and integrated additional test equipment to facilitate testing up to wavelengths of 5 μm. Some of this equipment included PbSe Diodes, a photometer, longwave-pass filters, PK50 filters and gratings. We also purchased two sets of J, H, K, and L band filters. Figure 9 shows the filters as installed in the filter wheel.

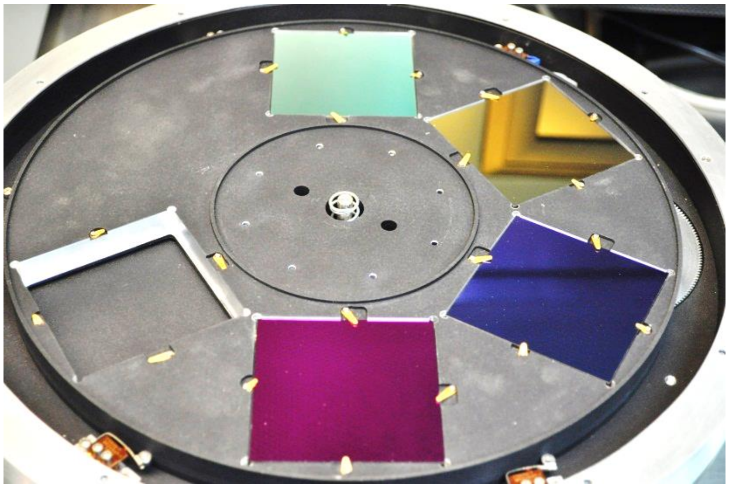


Figure 9. J, H, K, and L filters were custom-designed, fabricated, and installed in the filter wheel.

The CfD cryogenic test system, displayed in Figure 10, is modular in design to allow for different detectors to be tested with minimal modification. The primary fixture that needed to be modified for this project is the detector head. The detector head gives mechanical fixturing and thermal connection in the cryogenic test system.

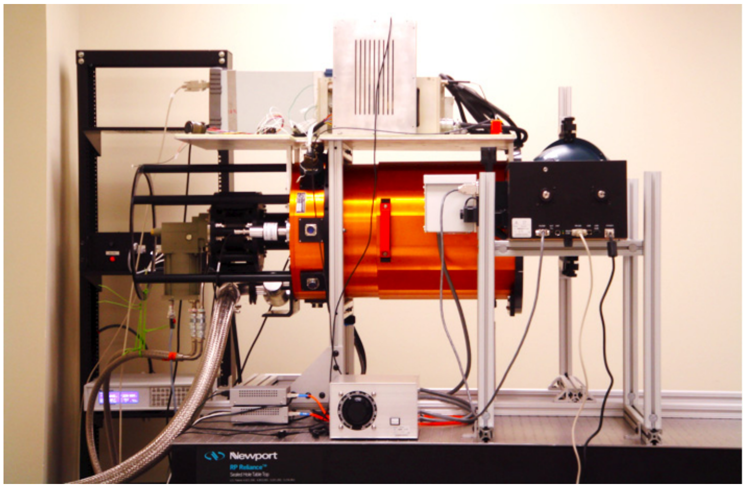


Figure 10. The CfD cryogenic test system is modular in design to allow for minimal modification to test different detectors.

Cryogenic test system components were modified to accommodate the VIRGO detectors. This included the detector head housing which mechanically and thermally connects the detector in the cryogenic test system. These components were designed, fabricated and integrated into the system (Figure 11).

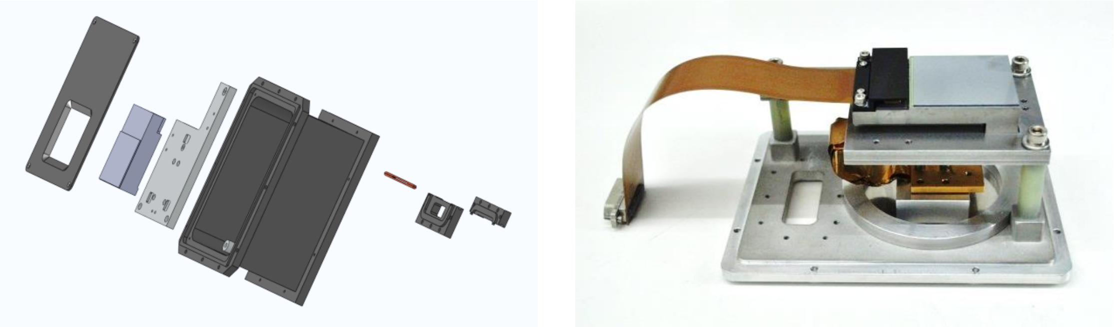


Figure 11. (left) Shown here is the design model of the detector head components with the VIRGO specific modifications. (right) This image depicts the fabricated and assembled detector head components with a VIRGO detector installed.

The read noise of a VIRGO device at 70 K was measured to be 67.5 e^- in the CDS read mode (Figure 12). This is significantly higher than expected. With continued work to isolate the source of this noise, for example; measuring the noise along various points in the cabling chain, we will continue to reduce read noise.

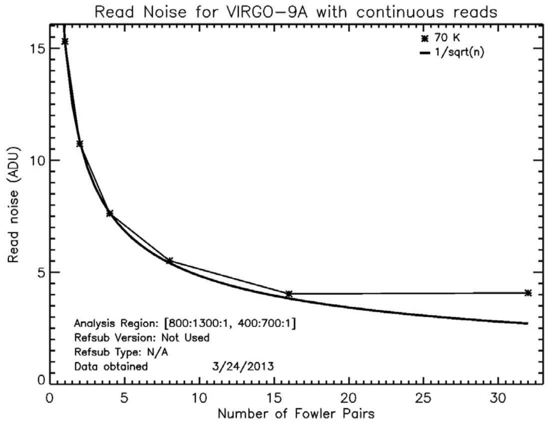


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Figure 12. Above is a plot of read noise vs fowler sample number. 67.5 e^- CDS read noise was measured at 70 K.

A Zero Read Noise Detector for Thirty Meter Telescope (TMT)

Gordon and Betty Moore Foundation

The key objective of this project is to develop a new type of imaging detector that will enable the most sensitive possible observations with the world's largest telescopes, i.e. the Thirty Meter Telescope (TMT). The detector will effectively quadruple the collecting power of the TMT, compared to detectors currently envisioned in TMT instrument studies, for the lowest light level observations. It will have fundamental importance in ground-based and space-based astrophysics, Earth and planetary remote sensing, exo-planet identification, consumer imaging applications, and homeland safety, among many others. Measurable outcomes include being able to see further back into the infancy of the Universe, and to taking a better picture (less grainy) of a smiling child blowing out the candles at her birthday party. The detector will be quantum-limited (zero read noise), be resilient against the harsh effects of radiation in space, consume low power, operate over an extremely high dynamic range, and be able to operate with exposure times over one million times faster than typical digital cameras. The CfD is teaming with MIT/Lincoln Laboratory (LL) to leverage their Geiger-mode Avalanche Photodiode technology for developing the imaging detector. The project is funded through the Gordon and Betty Moore Foundation.

In the first year of the project, the visible (Si) and infrared (InGaAs) Geiger Mode Avalanche Photodiodes (GM-APDs) were fabricated. Two types of silicon GM-APDs were fabricated and tested: low-fill-factor (LFF), and high-fill-factor (HFF) devices. The electronics and packaging needed to operate the detectors at high vacuum and cryogenic temperatures were designed and fabricated over the past academic year. A block diagram of the system is shown in Figure 13, and includes a modified version of the version-one test board along with a cold electronics board and newly-designed detector flex package. This design enables parallel testing of up to four individual detectors at once.

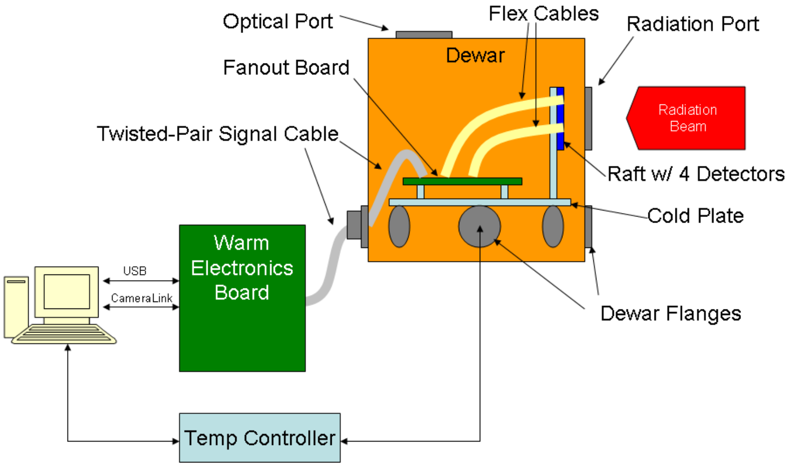


Figure 13. Pictured here is the cryogenic electronics system block diagram.

The flex package for the detector is shown in Figure 14. It consists of two rigid sections, joined in the middle by a flexible Kapton laminate.

Figure 14. Above is the detector in a flex package.

The detector and I/O connectors were mounted to the rigid sections and assembled onto a custom-machined raft designed to hold up to four detectors. The flex package was specifically designed for use at high vacuum (10 nTorr) and cryogenic temperatures; it uses the same techniques that have been used in previous Lincoln Laboratory designs (Figure 15).

Figure 15. The detectors are mounted to a raft and mount for cooling to cryogenic temperatures. Four detectors are included in this mosaic mount.

The cold fanout board is shown in Figure 16. In this image, the lower end of the 8”x8” board shows the three 100-pin micro-D connectors used for input, output and power. Near the top are four high-density connectors, which mate with the detector flex packages. In between are the LVDS receiver and driver chips, FPGA muxes, temperature sensors and test connector.

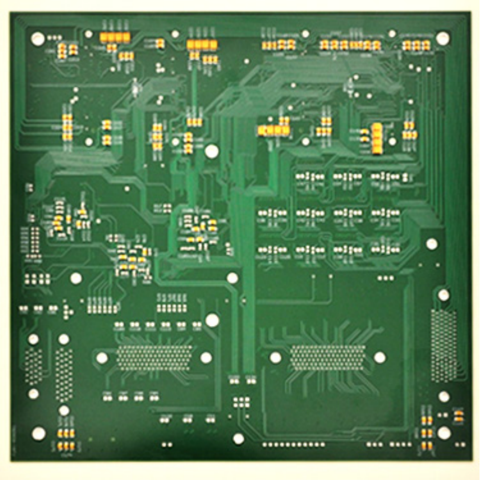


Figure 16. Above is the cold electronics fanout board.

The fully integrated detector/electronics system inside the dewar is shown in Figure 17. The system went through a thorough testing process. The system allows operation of the detector in cryogenic temperature range in a high vacuum setting and is being used extensively to characterize the detectors.

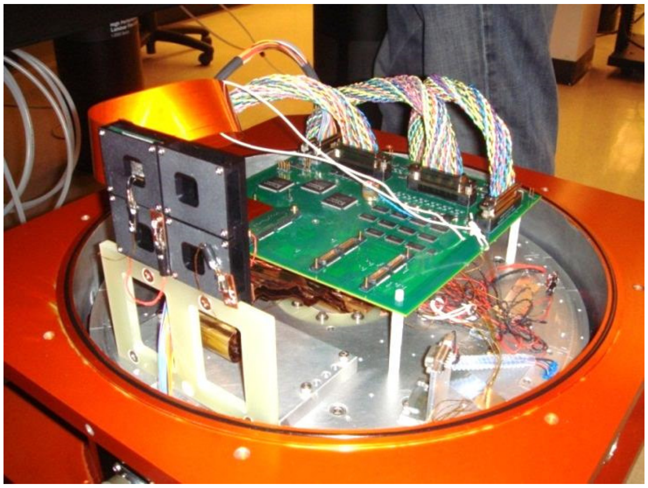


Figure 17. Shown here is the top view of fully integrated detector electronics system inside the dewar. The detector is mounted on the raft and connected to the cold fanout board.

The LFF and HFF 256×256 APD hybridized to CMOS ROICs, fabricated at MIT/LL, have been tested extensively at the CfD. The clock patterns for the APD are shown in Figure 18. In Geiger mode, the APD is biased above the breakdown voltage before the APD can detect a photon. This "arming" of the APD takes place over the duration of the arm pulse ("a" in Figure 18). Once an avalanche takes place, the APD must be refreshed and "re-armed" in order to be able to detect photons again. This can be done in the single gate mode, in which each "re-arm" takes place when desired in a single shot, or the continuous gate mode in which the "re-arm" occurs at a regular interval, τ, as in Figure 18. The APD is ready to detect a photon over the gate width of τ–a. If a photon arrives during that time, it initiates an avalanche and the flip flop on the ROIC registers an event. Other photons arriving during that time do not register an event, as the APD is already avalanching. Then, for a flux, ρ, on the APD, the trigger probability per gate is the Poisson probability of one or more photons arriving over τ, which is just 1–exp-ρτ.

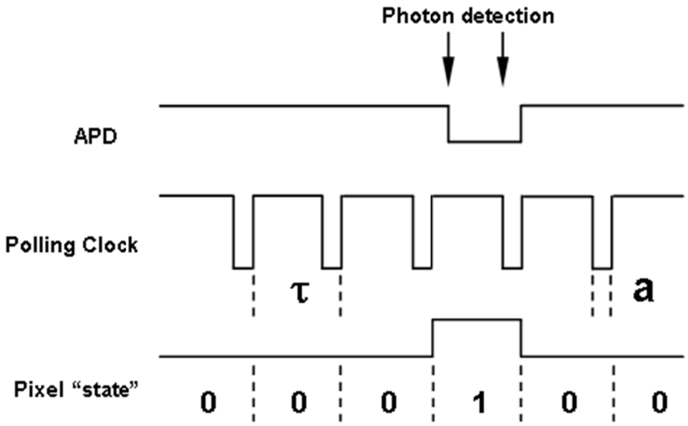


Figure 18. Depicted above are clock patterns for the APD. This picture holds for both photons and dark events.

The poissonian nature of the triggering probability can be seen in Figure 19 (left). A series of dark current exposures lasting 50,000 gates were taken in the single gate mode with a = 100 ns and τ = 0.5–4000 µsec with the LFF APD. The experimental event trigger probability, calculated by dividing the number of triggered gates by the total number of gates, closely follows the expected triggered probability of 1–exp$^{-\rho\tau}$. The event trigger probability grows linearly with the gate width for very small gate widths, and it begins to “saturate,” asymptotically reaching 1 as the gate width increases even further. The dark count rate for the pixels is calculated by fitting the data to 1–exp$^{-\rho\tau}$.

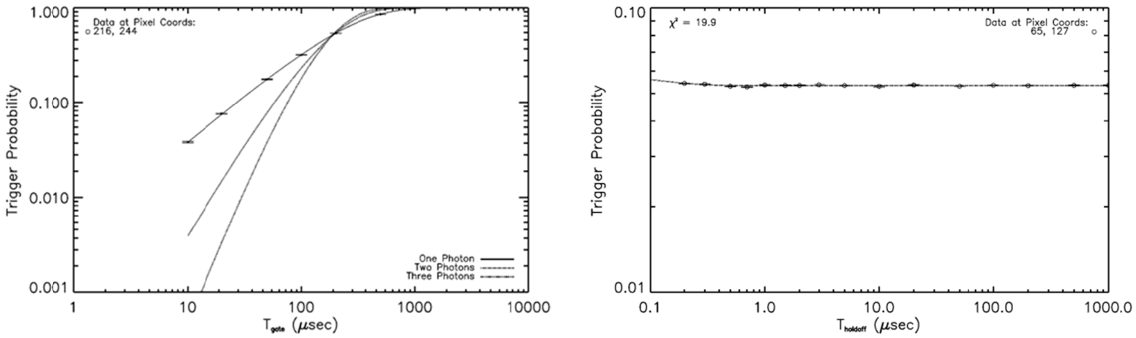
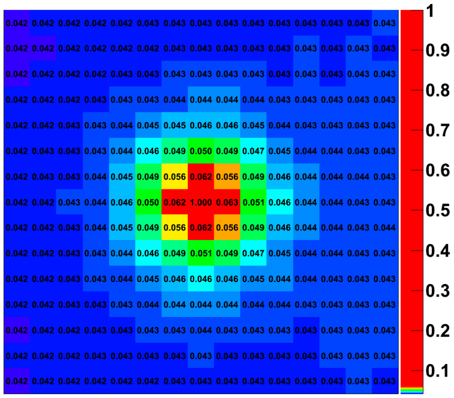


Figure 19. (left) Event trigger probability for pixels on the APD with a = 100 ns, τ = 10 to 1000 µsec. Event probability is the number of triggered gates divided by the total number of gates. Data (horizontal ticks) are fitted to 1 – exp (-ρτ), which yields a very good agreement. To illustrate the validity of the poissonian single photon trigger probability model, best fits to p = 1– exp (-ρτ) – ρτ exp (-ρτ) and p = 1 – exp (-ρτ) – ρτ exp (-ρτ) – {(ρτ) 2 exp (-ρτ)}/2 are also plotted for comparison. (right)The trigger probability changes very little as a function of hold off time, i.e. there is very little afterpulse.

An afterpulse is a false event caused by a charge carrier being trapped in a defect during an avalanche and subsequently being released after re-arming of the APD and initiating an avalanche. There is very little evidence of afterpulse in the HFF APD, as shown in Figure 19 (right).

There is, however, evidence for cross talk, i.e. a triggered pixel causes neighboring pixels to be falsely triggered, between pixels in the HFF APD. An example of this is shown in Figure 20. The nearest neighbors to the reference pixel are more likely to be triggered than the ones farther away. This behavior is seen regardless of length of the gate, bias, temperature settings, although there is less cross talk between pixels with a lower bias voltage. This behavior is problematic as this will cause pixels to be triggered by neighboring pixels and report false events. A redesign of the trenches between pixels is being undertaken at MIT/LL to mitigate cross talk.



0.042	0.042	0.042	0.042	0.042	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
0.042	0.042	0.042	0.042	0.042	0.042	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
0.042	0.042	0.042	0.042	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
0.042	0.042	0.042	0.043	0.043	0.043	0.044	0.044	0.044	0.044	0.043	0.043	0.043	0.043	0.043
0.042	0.042	0.043	0.043	0.044	0.045	0.045	0.046	0.046	0.045	0.044	0.043	0.043	0.043	0.043
0.042	0.043	0.043	0.043	0.044	0.046	0.049	0.050	0.049	0.047	0.045	0.044	0.044	0.043	0.043
0.042	0.043	0.043	0.044	0.045	0.049	0.056	0.062	0.056	0.049	0.046	0.044	0.044	0.044	0.043
0.042	0.042	0.043	0.044	0.046	0.050	0.062	1.000	0.063	0.051	0.046	0.044	0.044	0.043	0.043
0.042	0.042	0.043	0.044	0.045	0.049	0.056	0.062	0.056	0.049	0.046	0.044	0.044	0.043	0.044
0.042	0.042	0.043	0.043	0.044	0.046	0.049	0.051	0.049	0.047	0.045	0.044	0.044	0.043	0.043
0.042	0.042	0.043	0.043	0.044	0.045	0.046	0.046	0.046	0.045	0.044	0.044	0.043	0.043	0.043
0.042	0.042	0.043	0.043	0.043	0.044	0.044	0.044	0.044	0.044	0.044	0.043	0.043	0.043	0.043
0.042	0.042	0.042	0.043	0.043	0.043	0.043	0.044	0.043	0.043	0.043	0.043	0.043	0.043	0.043
0.042	0.042	0.042	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
0.042	0.042	0.042	0.042	0.042	0.042	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043

Figure 20. This image shows evidence of cross talk, i.e. a triggered pixel causes neighboring pixels to be falsely triggered. The conditional probability is averaged over a 32 x 32 pixel grid. Nearest neighbors are triggered with a higher probability than the neighbors that are far away from the reference pixel.

Figure 21 shows an image created by placing a watch on a table top, illuminating it with a light source, and focusing the light on the detector with a basic optics set up. The image was taken with the detector at 127 K and exposed to ambient light levels. It is the sum of 2000 gate exposure sequences in which only one photon is counted per gate. The event flip-flop for each pixel is read out after each gate and saved for later processing. The events generated by dark current are mitigated by setting a small gate time (30 μsec) in which the APDs are above breakdown and able to achieve a GM avalanche.

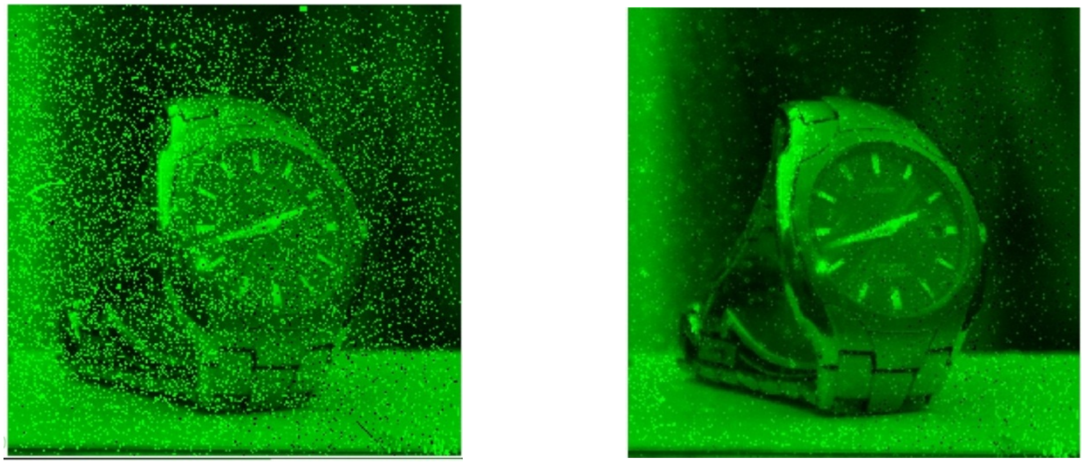


Figure 21. Above are images of a watch taken with a LFF GM-APD array biased above breakdown. (left) This is the raw image of the watch. (right) This is the same image after processing with basic filtering.

Figure 22 shows how the current-voltage (IV) characteristic of the GM-APDs changes with temperature. The breakdown voltage is estimated from this type of plot as the point on this surface plot where the anode current sharply increases.

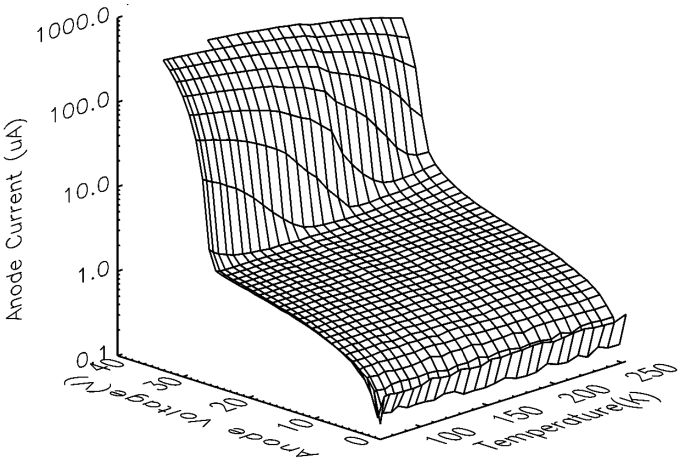


Figure 22. This is a plot of the anode current vs. voltage as functions of temperature.

A Photon-Counting Detector for Exoplanet Missions

NASA/Technology Development for Exoplanet Missions (TDEM)

The objective of this project is to advance photon-counting detectors for NASA exoplanet missions. An "exoplanet" is a planet orbiting another star outside of our solar system (Figure 23). A photon-counting detector will provide zero read noise, ultra-high dynamic range, and ideal linearity over the relevant flux range of interest. The device always operates in photon-counting mode, and therefore it is not susceptible to the excess noise factor that afflicts other technologies. Its performance is expected to be maintained at a high level throughout mission lifetime in the presence of the expected radiation dose.

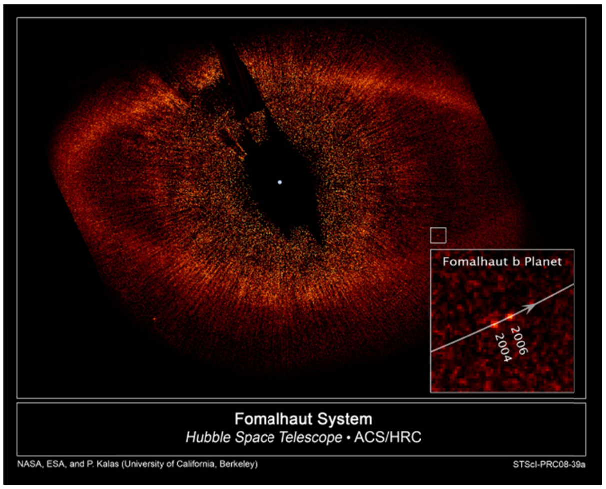


Figure 23. This image is of a stellar system with an extrasolar planet orbiting Formalhaut.

This project leverages the Moore project by using the same device design, but in higher quantities than needed for that project. By using multiple detectors, it will be possible to draw statistically significant conclusions about their performance and resilience in the presence of high energy radiation. This is important for predicting performance in a space mission.

CfD Engineer Joong Lee designed the radiation testing program, defining the relevant mission parameters, and simulating the expected on-orbit radiation dose. It was determined that the radiation dose at the L2 orbit is expected to be ~ 5 krad (Si) over 11 years. For radiation testing, the device will actually be exposed to a dose ten times higher, or ~ 50 krad (Si), with 60 MeV proton beam. It was, then, necessary to determine the impact that such a radiation environment would have on the supporting electronics, as it is imperative they remain functional during radiation testing. To determine the survivability of the supporting electronics under such radiation environment at the radiation testing facility, a detailed simulation was undertaken. Using a GEANT4-based simulation called the Simulator for the Linear Collider (SLIC) with a fully integrated 3-D geometrical model, the radiation dose seen by the electronics was mimicked. Figure 24 shows a rendering of the geometrical model of the radiation testing set up. The radiation dose seen by the electronics, estimated to be ~300 rad compared to the 50 krad exposure on the detector, is relatively benign, and the system is expected to be fully functional during radiation testing. We expect a radiation-induced dark current of ~0.5 e^{-}/pix/s/(total rad) one week after irradiation at –20 °C for a 25 μm pixel when exposed to 60 MeV protons. With cooling, the induced dark current can be reduced to acceptable levels for an exoplanet mission.

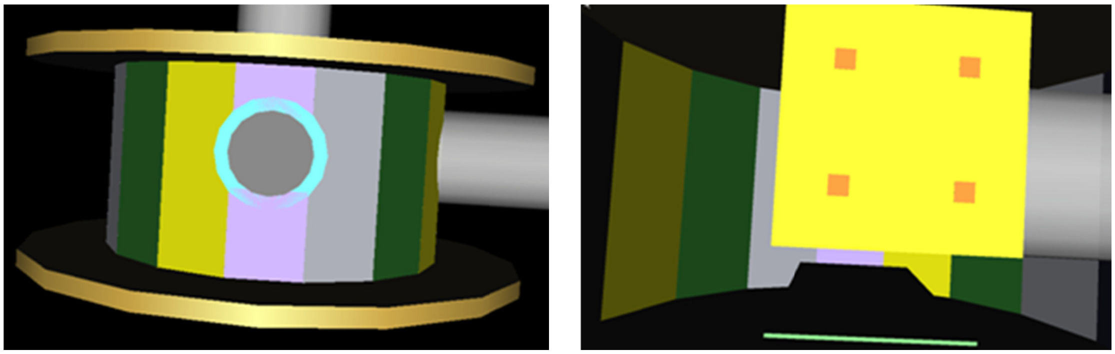


Figure 24. (left) Shown here is a rendering of the geometrical model of the dewar. (right) This image depicts the detector and electronics inside. This model is used in simulating the particle interactions as protons in the proton beam traverse the radiation port, the detector, and the inside volume.

Mechanical fixtures are being designed and fabricated to test the detectors at the radiation facility as well as optical tests in the Rochester Imaging Detector Laboratory (RIDL). The design will allow the detectors to be operated at temperatures of approximately 120 K. A thermal finite element analysis of the mounting structure reveals that the detectors can be staged at the appropriate temperature, given the radiation load on them, the power dissipation in them, and the thermal cooling power of the closed cycle refrigerators.

The Nature of GLIMPSE 81: A Star Cluster to Rival Westerlund 1

CXC/Chandra Space Telescope

This project used Chandra Space Telescope/ACIS observations of a young star cluster. The X-ray emission from this cluster, already observed in previous low-resolution observations, was resolved by Chandra into many components. Analysis included separating the diffuse X-ray emission from the point-sources, and a spectral analysis of each source. The data from this project will be combined with those from other observations in order to perform a multi-wavelength analysis.

The research team published the first paper regarding Mercer 81 in the beginning of 2012. The paper, which was published in the Monthly Notices of the Royal Astronomical Society, is entitled "A newly discovered young massive star cluster at the far end of the Galactic Bar." This paper used the HST/NICMOS data to convincingly show that the cluster is young and massive. Notably, it is one of the first such clusters to be found at the far end of the bar of the Galaxy.

Team member Diego de la Fuente obtained new spectroscopic data from ISAAC/VLT in April, 2012. These data will be analyzed and combined with the Chandra data in order to determine the physical properties of the most massive stars in the cluster. In addition, the data will be used by team member Christine Trombley to aid in determining the effect of binarity on the high end of the initial mass function for the cluster as part of her PhD thesis.

A NICMOS Survey of Newly-Identified Young Massive Clusters

NASA/Hubble Space Telescope

We are on the cusp of a revolution in massive star research triggered by modern infrared surveys such as 2MASS, Spitzer/GLIMPSE, UKIDSS, and VVV, and this undertaking capitalized on these projects by performing the first survey of massive stars in young stellar clusters throughout the Galactic plane. A search of these surveys has produced over 1000 newly-identified massive stellar cluster candidates in the Galactic plane which are hidden from our view at optical wavelengths due to extinction. In this project, CfD researchers Ben Davies and Christine Trombley used 29 HST (Hubble Space Telescope) orbits to image the most promising candidate clusters (Figure 25) in broad and narrow band filters using Near Infrared Camera and Multi-Object Spectrometer (NICMOS). The observations will be complemented with approved Spitzer and Chandra programs, numerous approved and planned ground-based spectroscopic observations, and state-of-the-art modeling. We expect to substantially increase the numbers of massive stars known in the Galaxy, including middle-aged and evolved massive stars in the Red Supergiant, Luminous Blue Variable and Wolf-Rayet stages. Ultimately, this program will address many of the fundamental topics in astrophysics: the slope to the initial mass function (IMF), an upper limit to the masses of stars, the formation and evolution of the most massive stars, gamma-ray burst (GRB) progenitors, the chemical enrichment of the interstellar medium, and the nature of the first stars in the Universe.

Most of the work in the data analysis plan has been completed. This includes manual reduction with the NICMOS pipeline and mosaicking each of the four wavebands observed. It also includes extraction of photometry using aperture photometery and

PSF-fitting, and estimates of completeness through synthetic image simulations. We have assembled color-magnitude diagrams and luminosity functions for each cluster. Both of these require accurate knowledge of the field-star contamination, which we have obtained from each cluster's control-field.

Remaining work includes determination of the extinction to each cluster from the near-IR colors. When possible, using radio data in the literature, we have obtained each cluster's radial velocity and hence kinematic distance. With the reddening and distance known, we then fit each CMD with model isochrones to get cluster ages. We then use this information, combined with the latest stellar evolutionary models, to convert each cluster's background-subtracted luminosity function into an initial mass function. At this point, we can estimate the cluster's mass, the masses of the most massive stars, and detect the presence of an upper-mass cutoff.

During the 2011-2012 academic year, the team published two papers related to this research in the Monthly Notices of the Royal Astronomical Society: “The G305 star-forming complex: the central star clusters Danks 1 and Danks 2,” and “A newly-discovered young massive star cluster at the end of the Galactic Bar.”

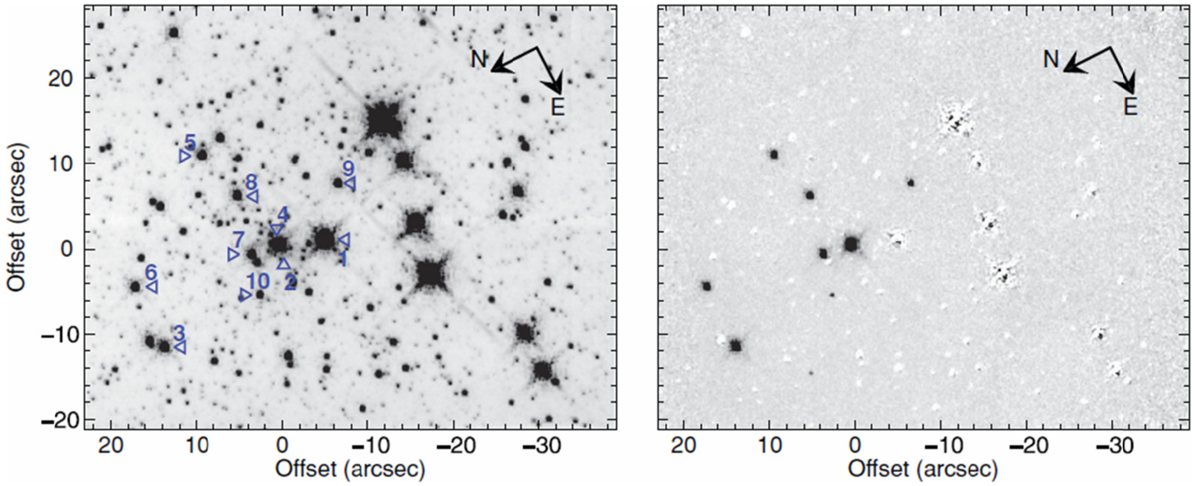


Figure 25. NICMOS images of the cluster. (left) A NICMOS image of the cluster taken through the F222M filter. The two stars for which we have spectra, as well as the other emission-line stars, are indicated by the blue triangles. (right) Shown here is the difference image (F187N − F190N), which highlights the emission-line stars. The arrows in the top right of each image indicate the orientation.

Completed this year

High Mass Initial Mass Function

NASA/Graduate Student Research Program (GSRP)

By examining a sample of young, massive stellar clusters in the galaxy, this project placed constraints on the high mass initial mass function as a function of stellar natal environment (Figure 26), lending insight into the life cycles of massive stars. We also studied evolutionary sequences of massive stars, and added new data points to help resolve the issues regarding the relationship between progenitor mass and end state of post-supernovae stellar remnants.

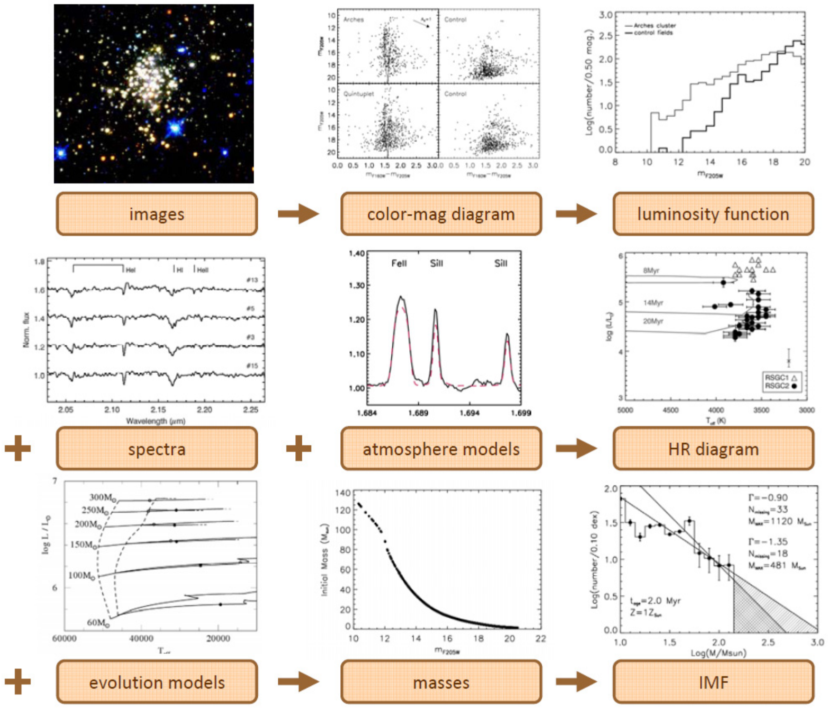


Figure 26. This flowchart shows the process used to determine the initial mass function of stellar clusters from an image.

During the past academic year, CfD Graduate Student Christine Trombley completed her analysis of data from a variety of observational facilities on Earth and in space. These data were transformed into quantitative information about massive stars, such as their birth masses, by using theoretical and empirical models of nuclear core burning and stellar winds. She then computed the slope of the initial mass function in each cluster, finding good agreement in all clusters but one. This indicates that intermediate and high mass star formation proceeds similarly in different locations. For his PhD thesis, graduate student Diego de la Fuente will use similar data to measure the chemical composition of massive stars in the Milky Way, in order to determine the chemical composition of the Galaxy.

Student Vignettes

Christine Trombley

Christine Trombley has been a graduate student member of the Center for Detectors (CfD). She recently defended her dissertation research and graduated with a PhD in the Astrophysical Sciences and Technology program in May, 2013. She completed a BS degree in Astrophysics and Physics at Michigan State University in 2007.

Her first involvement with the CfD was in 2007 when she joined the Rochester Imaging Detector Laboratory as a data analyst, reducing and analyzing Spitzer Space Telescope Infrared Array Camera observations of young, embedded stellar cluster candidates. Over her six year term with the Center, Christine has gained experience reducing and analyzing a variety of multiwavelength astrophysical observations, from radio to X-ray wavelengths.

Christine worked on investigating the slope of the high end initial mass function (IMF) in a sample of 8 young, potentially massive stellar clusters for her PhD thesis; the positions of these clusters are indicated in Figure 27. She utilized spectroscopic observations from northern and southern facilities, as well as imaging from the Hubble Space Telescope, in order to determine the masses of bright stars in each stellar cluster. Following the method outlined in the Nature article written in 2005 by Dr. Figer, she calibrated the mass-magnitude relation of stars in each cluster, and then constructed IMFs. The IMF has been shown to be nearly universal at lower mass ranges, and Christine's work investigated whether that relation holds at the high mass range.

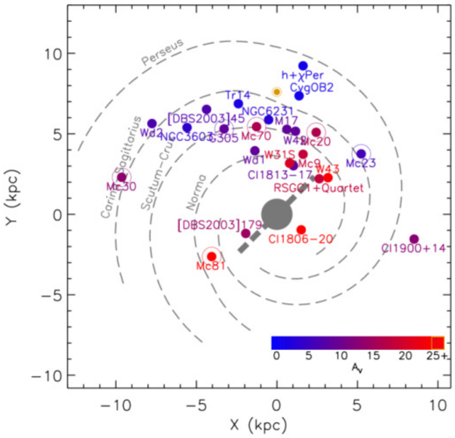


Figure 27. Christine investigated the slope of high end IMF in a sample of 8 young, potentially massive stellar clusters, whose positions are depicted above.

After winning the NASA Graduate Student Research Fellowship, Christine spent 10 weeks in Fall of 2011 at NASA's Goddard Space Flight Center in Greenbelt, MD, under the supervision of Dr Sara Heap. During this time, she examined near-IR spectra of candidate massive stars observed by colleague Diego de la Fuente, a PhD student at INTA/CSIC, comparing the spectra with atlases and models. These spectra, taken with ISAAC at the Very Large Telescope in Chile, represent the southern clusters in her sample of young, potentially massive stellar clusters. In the fall of 2012, Ms Trombley carried out her NASA Infrared Telescope Faculty near-IR spectroscopic program over 2.5 nights. This Spring, Christine won the Graduate Research Fellowship in Astrophysical Sciences and Technology, sponsored by NASA and Cornell University.

Kimberly (Manser) Kolb

Kimberly (Manser) Kolb is a graduate student member of the Center for Detectors who is pursuing a PhD in the Imaging Science program. 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-end detectors, giving her a knowledge base that encompasses detector development through fabrication, characterization, and implementation. Her PhD thesis involves the testing and comparison of a variety of photon-counting devices, including Geiger-mode APD's, EMCCD's, and linear-mode APD's, in array formats for imaging.

Her first involvement with the CfD started in 2007, when she began process development work for fabrication of silicon p-i-n diodes for hybridization (a NASA project) as a senior in the Microelectronic Engineering BS program. This work later culminated in her capstone project for that degree. After a brief stint in industry in 2008-2009, Kimberly returned to RIT and CfD to pursue her MS degree, funded by the BAE Systems Fellowship. BAE Systems is the world's second-largest defense company, and the two-year fellowship program at RIT included tuition, travel support and a stipend. She continued to participate in ongoing projects, including the hybridization portion of the NASA project to which she had previously contributed, leading to a paper published by the Society of Photo-Optical Instrumentation Engineers (SPIE) and presented at an associated conference in 2010. Kimberly also completed an internship at BAE Systems in the summer of 2010, working on infrared detector fabrication and process improvement.

Kimberly used specialized test circuitry with a customized data acquisition technique, developed a method for parameter extraction from the raw data, and examined device characteristics derived from experimental results (Figure 28). She also developed a simulation program to approximate the dark count rate (among other parameters) of a device based on semiconductor characteristics and testing conditions. Her thesis makes conclusions about the dependence of dark count rate on device architecture and how individual noise mechanisms affect device performance.

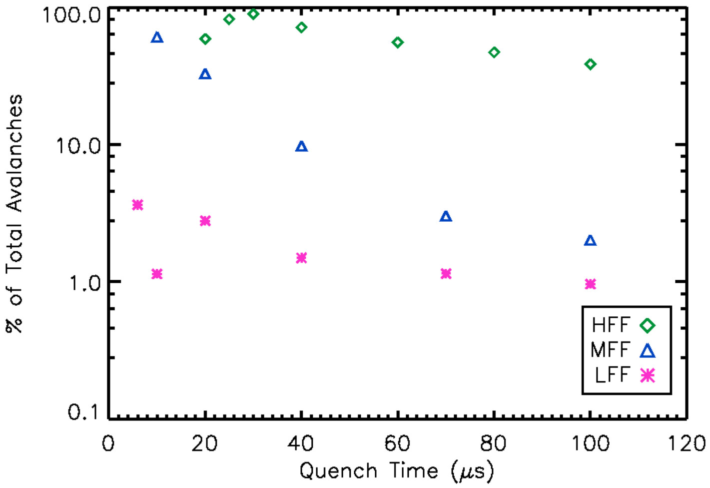


Figure 28. Above are the results for self-retriggering noise contributions; where LFF, MFF, and HFF represent different device types.

Kimberly investigated the dark count rate of these detectors and reported the results in her thesis. There are a number of mechanisms that produce dark counts, the most prominent being thermal excitation of carriers. Thermal carrier generation rates are generally only dependent on the temperature of the diode and may be constant under certain controlled conditions. Afterpulsing results from the release of carriers trapped in intermediate energy states (states with energy less than the band gap of the material). Unlike thermal carrier generation, afterpulsing is dependent on the dead time of the device (the time during which the device is unable to detect a carrier). Another mechanism, called self re-triggering, occurs when relaxing carriers emit photons during an avalanche. These photons can be absorbed in the substrate and generate dark carriers. Self-retriggering is also dependent on the dead time of the device.

Now working on her PhD research, Kimberly is building on her masters work to fully characterize array-based GM-APDs. Based on this work and proposed testing of two other types of single-photon counting devices (linear-mode APDs and electron-multiplying CCDs, Figure 29), she won a prestigious NESSF fellowship. The fellowship funds research that will ensure continued training of a highly qualified workforce in disciplines needed to achieve NASA's scientific goals.

Kimberly's proposal was one of only 9 selected for funding out of 114 in the Astrophysics division. This fellowship will allow her to collaborate with forerunners in her field. Single-photon counting detectors have the potential to be the next big advancement for NASA astronomy missions. The ability to count single photons facilitates science goals that are impossible even with current state-of-the-art detectors. Single photon counting detectors are the future, and many different implementations are in development.

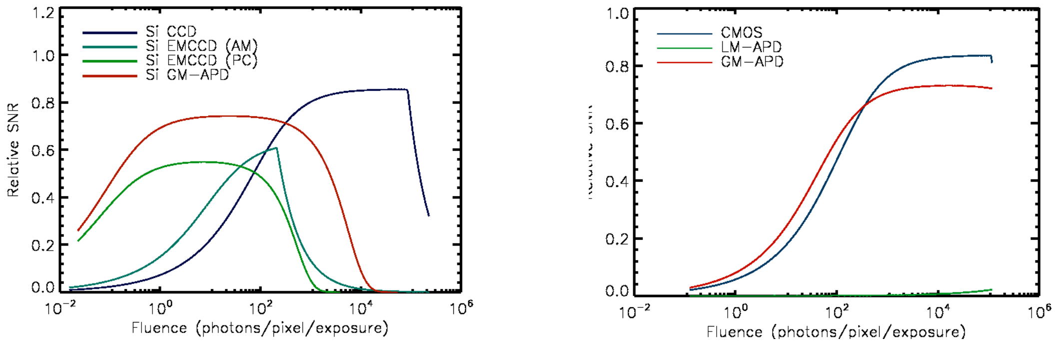


Figure 29. (left) SNR per 0.1 s of exposure time for a variety of detector technologies – visible spectrum. (right) SNR per 10^3 s of exposure time – IR spectrum. CCD (HST WFC3), GM-APD, LM-APD, CMOS, and EMCCD (E2V) detectors are modeled using Kimberly's theoretical derivations for SNR as well as standard equations.

Michael Every

Michael Every is an undergraduate student working on his Bachelor of Science degree in Physics, which he is anticipating in May 2014.

Mike's career at the Center for Detectors started in April of 2013. He has always been passionate about optics and astronomical instrumentation, and was involved in an outside project for which he studied UV signatures of AGN of the 2 Jy Sample.

In addition, Mike has been working on his own project, investigating the development of lightweight, high accuracy telescope mirrors for use in visible wavelength regime which has led him to various conference invitations and talks.

Michael hopes that if the opportunity arises, he could either develop, or be part of the developing team for an instrumentation project that involves both detectors and other imaging devices.

At the Center for Detectors, Michael will be working on the Infrared Detectors (NSF/ATI) project as a laboratory assistant (Figure 30), hoping to learn more about imaging devices and contribute some novel ideas to the Center.

Figure 30. Michael will be working with the Center for Detectors' cryogenic test systems as part of his involvement in the Infrared Detectors projects.

Jonathan Zimmermann

Jonathan Zimmermann is an undergraduate student who is working on his Bachelor of Science degree in Electrical Engineering, and plans on getting his Master's in Electrical Engineering as well.

As an electrical engineering student, Jonathan has been involved in a wide variety of research projects since coming to RIT. In his freshman year Jonathan conducted flow cytometry experiments with the RIT honors program to determine the significance of specific proteins in HL-60 cell adhesion using Matlab for video data processing. In his sophomore year Jonathan was a Resident Advisor and that summer had his first cooperative experience at General Motors Hydrogen Fuel Cell Research Facility. At GM Jonathan developed a model to classify the properties of the carbon anode in lithium ion batteries using electrochemical impedance spectroscopy. Currently Jonathan has begun to work in the CfD on the Zero Read Noise Detector and the Infrared Detectors projects. Recently, Jonathan designed a light tight fixture (Figure 31) for the Center's dewars which decreases error in measurements. His hope is to help the CfD complete these projects and perhaps in the future gain further insight into digital and analog signal circuitry and processing.

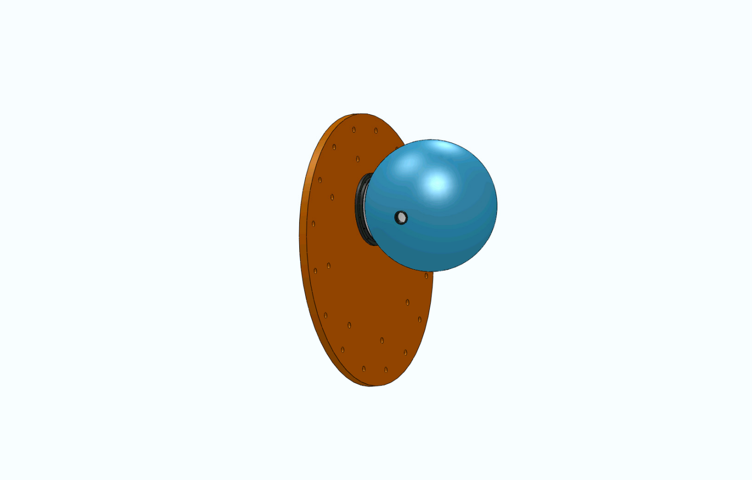


Figure 31. The image above displays a custom designed light tight fixture between the blue integrating sphere and the orange Dewar plate. The light tight fixture was designed to decrease error in measurements due to external light sources and to allow for easy experimental setup.

Yuanhao “Harry” Zhang

Yuanhao “Harry” Zhang graduated from the East China University of Science and Technology in 2012 with a Bachelor’s of Science in Engineering in Applied Physics. During his undergraduate years, Harry did research in condensed matter physics.

Here at the Center for Detectors, Harry is working on the Mass Loss of Red Supergiant project in the Summer of 2013 (Figure 32). Up until recently, studies of this quantity have been problematic due to the low numbers of Red Supergiants and the difficulty of observing in mid-IR. The recent discoveries of two Galactic clusters with an unprecedented number of Red Supergiants allow the Center to undertake a comprehensive and unique study of the pre-SN mass-loss of massive stars. Harry and the rest of the team will be using Spitzer Space Telescope observations in conjunction with state-of-the-art dust models to provide the first quantitative investigation in this field. Harry has been doing some preliminary work related to this project since Fall 2012.

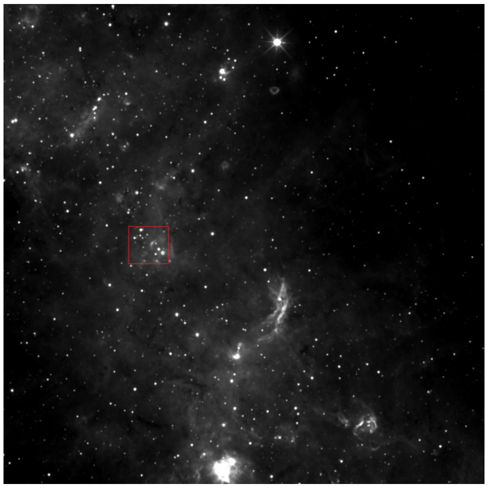


Figure 32. Above is the Wide-Field Infrared Survey Explorer data for Red Supergiant Cluster #2. The cluster is marked with a red rectangle.

He also carefully set the chop nod angle for observations using the FORCAST camera on the NASA SOFIA mission. This angle is crucial for ensuring that the signal from the red supergiants that will be observed for the program will be uncontaminated by nearby background sources.

Kenny Fourspring

Kenny Fourspring is a graduate student who is working towards his PhD in the Imaging Science program.

In 2011, he was awarded a NASA Graduate Student Research Fellowship. He spent part of that year at NASA's Goddard Space Flight Center, involved in low temperature testing of Digital Micromirror Devices (DMDs, Figure 33) for the W-FIRST space telescope program. W-FIRST (Wide-Field IR Space Telescope) is planned to advance the ability to find earth sized planets, and also investigate dark matter.

The focus of Kenny's work was in three areas that addressed the suitability of proposing DMDs for future space missions. Kenny ensured that the DMDs were optically characterized to assess their utility in a spectrograph and that they were also cooled in a liquid nitrogen dewar to determine their minimum operating temperature. The low temperature tests indicated that the DMD can operate to temperatures as low as 130 K. In addition, several DMDs were irradiated with high-energy protons at the LBNL 88" Cyclotron to determine how robust the devices are to ionizing radiation (protons). The radiation testing results indicate that DMDs would survive medium to long duration space missions with full operability. Based on preliminary tests in these three areas, Kenny believes the DMD should be considered as an excellent candidate for deployment in future space missions.

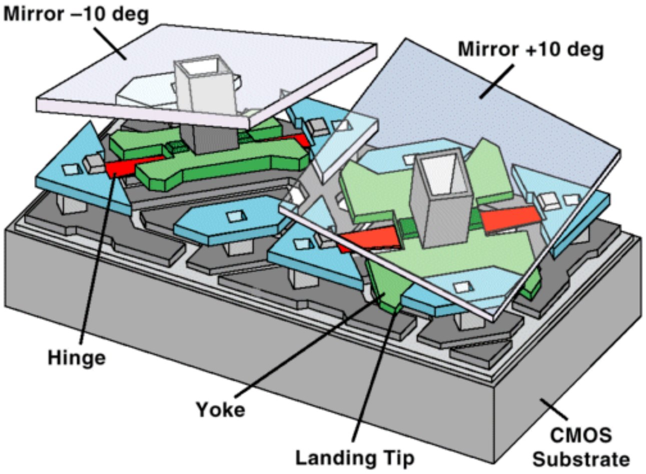


Figure 33. Above is a representation of a Texas Instruments' Digital Micromirror Device, similar to those that Kenny Fourspring focused on for his research.

Evan Jorgensen

Evan Jorgensen completed his fifth year as Microelectronic Engineering student in May 2013. He plans on going to graduate school for a Master of Science in Electrical Engineering starting this fall at either RIT or Carnegie Mellon University (still pending decision).

He began working at the CfD in late September 2012. He mostly concentrated on the ATI and Moore projects during his time here. Work he has done for these projects ranges from the acceptance testing of system components to actually taking the dewars apart to debug problems or install new components. These tasks have required use of electrical engineering, programming and some mechanical skills. Evan feels that working at the CfD has broadened his range of engineering skills in a very constructive way. His academic interests are in nanoscale electronic devices, photonic devices, microlenses, integrated circuit design and fabrication, and RF/microwave devices. His personal interests include downhill mountain biking, freestyle snowboarding and golf.

Matt Davis

Matt Davis is a graduate student who is pursuing a Master of Science in the Electrical Engineering and is expected to graduate in May 2015. He started working at the CfD in the summer of 2012 as a lab assistant.

Since then Matt has worked on a variety of projects in the lab which encompass a wide assortment of disciplines. He designed and implemented a voltage protection circuit for the VIRGO infrared detector (Figure 34) as well as performed extensive temperature testing on one of the cryogenic test chambers.

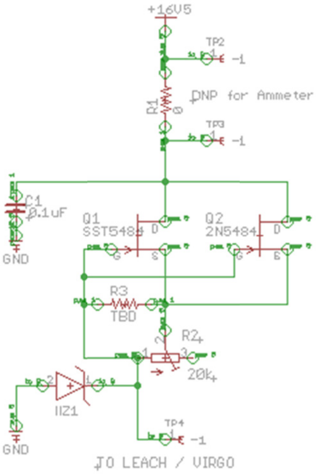


Figure 34. Above is a schematic Matt designed for a current source circuit with a Zener diode to protect the sensitive infrared detector from voltage surges.

Dmitry Vorobiev

Dmitry Vorobiev received a Bachelor of Science in Astrophysics from the University of New Mexico and joined the CfD in the Fall of 2011. Before arriving at RIT, Dmitry worked with the Measurement Astrophysics (MAP) group at UNM on a NIST-funded project, developing extremely accurate techniques for ground-based photometry aimed at developing a catalog of photometric standard stars. Dmitry used real-time direct measurements of atmospheric transmission using an atmospheric LIDAR and demonstrated that these new techniques are an improvement to conventional methods, such as differential photometry.

As part of the CfD, Dmitry has been working with advisor Zoran Ninkov to develop polarization-sensitive focal plane arrays for use in a wide range of applications in astronomy, remote sensing and machine vision. This work is done in close collaboration with MOXTEK, Inc. – a world leader in the fabrication of optical components. Dmitry is involved with the characterization of microgrid polarizer arrays (MGPAs), fabrication of the polarization-sensitive FPAs and FDTD modeling of these systems (Figure 35).

Recently, Dmitry was awarded computing time by the National Nanotechnology Infrastructure Network, to perform detailed simulations of these devices on a supercomputing cluster at Harvard University.

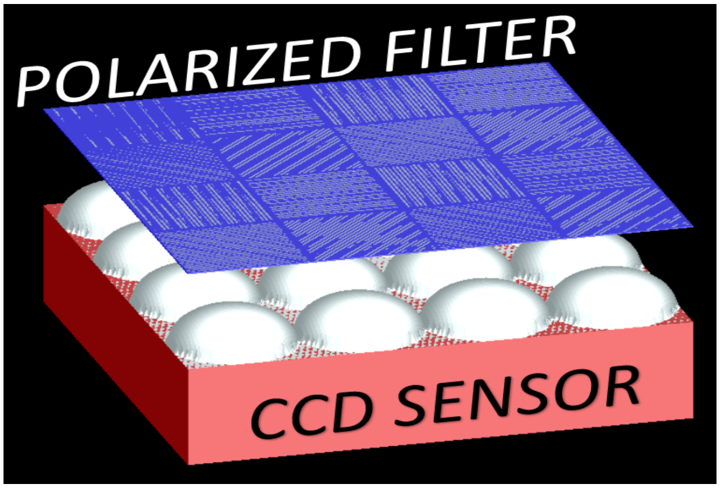


Figure 35. A 3D simulation of a CCD sensor with microlenses and a micrograd polarizer array.

External Funding and Collaborating Partners

Figure 36 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.

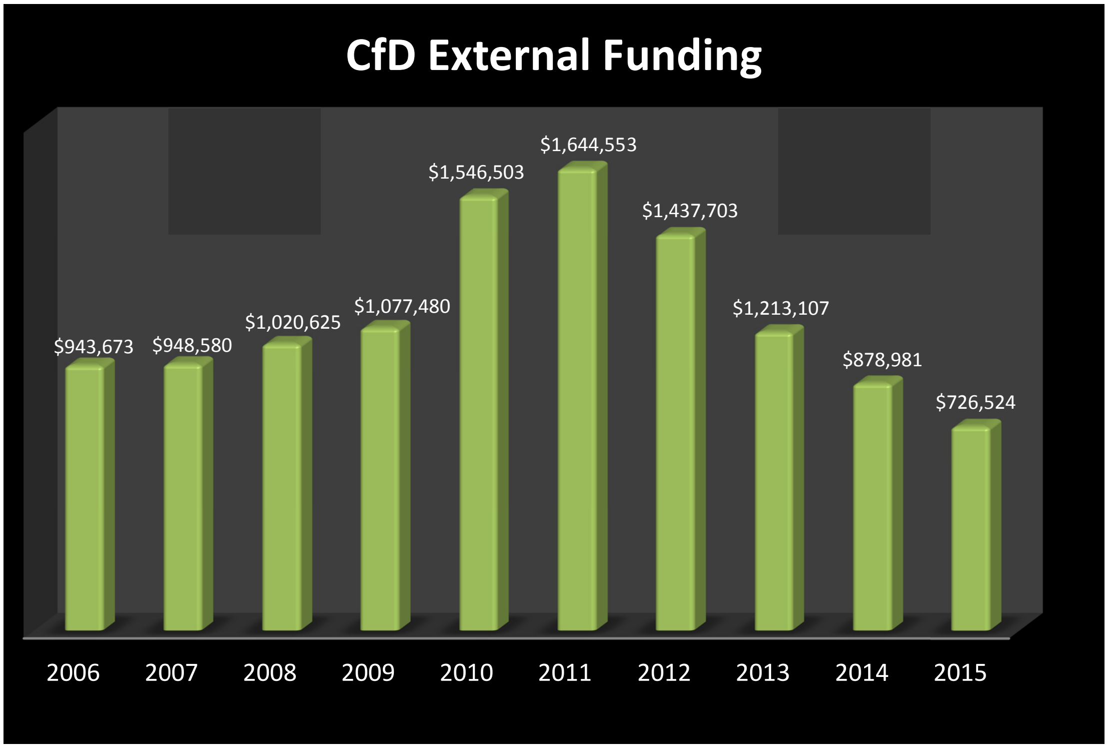


Figure 36. Since its inception in 2006, the CfD has received $11 million in research funding. The largest contributions are from the Moore Foundation and NASA. The Moore Foundation has awarded $2.8 million to support the development of a zero noise detector, while NASA awarded over $6 million in research 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 to advance a new family of large format infrared detectors.

Grants and Contracts- New

Title	Funding Source	Dates	Amount
New Infrared Detectors for Astrophysics	NSF	6/01/12-5/31/15	$1,246,799
Fabrication of a Polarization Sensitive Imaging Sensor	STAR	12/01/12 - 02/28/13	$10,000
Imaging Reflectometer	NYSTAR/ UofR/ Johnson & Johnson Ortho-Clinical Diagnostics	10/01/12 - 06/30/13	$16,700
Imaging Polrimetry with Microgrid Polarizers	Moxtek	09/01/12 - 08/31/13	$35,750
Enhancing Focal Plane Array Quantum Efficiency with Quantum Dots	NYSTAR/ UofR/ Thermo Fisher	07/01/12 - 06/30/13	$27,000
THz Virtual Scene General and Microgrid Polarizer Development	NYSTAR/ UofR/ ITT Exelis	07/01/12 - 06/30/13	$90,000
The Clumping in OB-Star Winds	NASA	12/27/2012-6/30/2015	$11,453
The Mass Loss of Red Supergiants	NASA	1/16/2013-1/15/2015	$8,000
A New VIS/IR Detector for NASA Missions	NASA	3/1/2013-2/29/2016	$1,115,107
Single Photon Counting Detectors for NASA Missions	NESSF	9/1/2013-8/31/2016	$90,000

Grants and Contracts - Ongoing

Title	Funding Source	Dates	Amount
Next Generation Imaging Detectors for Near- and Mid- IR Wavelength Telescopes	Gordon and Betty Moore Foundation	10/01/08-9/30/13	$2,839,191
A Photon-Counting Dectector for Exoplanet Missions	NASA/TDEM	2/19/10-2/18/13	$783,981

The nature of GLIMPSE 81: a star cluster to rival Westerlund1	CXC/Chandra	6/21/10-6/20/13	$35,768

Grants and Contracts - Completed within the Past Year

Title	Funding Source	Dates	Amount
Detector Virtual Workshop	NSF	7/01/11-6/30/13	$19,999
A NICMOS Survey of Newly Identified Young Massive Clusters	NASA- STcl/HST	1/01/09-12/31/12	$180,449
Advanced Imaging Arrays for Multi-Object Spectrometers Utilizing Digital Micromirror Devices	NASA	09/15/10 - 09/14/12	$60,000
NASA GSRP	NASA/GSRP	9/15/11-9/14/12	$30,000
A LIDAR Imaging Detector for NASA Planetary Missions	NASA/MIT	08/01/08 - 07/31/12	$241,798

Collaborating Partners

The CfD is consistently in collaboration with organizations outside of RIT. These include partners in academia, such as the University of Rochester, at national laboratories, such as NASA, and in industry, such as ITT and Raytheon Vision Systems. The vision of the CfD is to be a global leader in realizing and deploying ideal detectors and associated systems. This vision is bold and requires the support of brilliant engineers, passionate philanthropists, and truly inspired industrial partners. We believe in collaborating with partners such as these because no single organization could accomplish all the goals of our projects. It takes a team effort, distributed across several organizations, each with its own world-class expertise and often significant infrastructure developed over decades of past projects.

Because of this collaborative approach, CfD students are exposed to a wide range of research and development environments. Student involvement is central to all CfD projects. A major goal is training students through deeply immersive work with authentic externally funded research that defines the cutting edge of what is possible. In some cases, they visit partner organizations for extended periods of time. Students also sometimes decide to start a career at these sites after their graduation.

In Spring 2013, the CfD was awarded a $1.1 million grant from NASA to advance a new family of large format infrared detectors grown on silicon wafer substrates, Raytheon Vision System's breakthrough technology in detector development. The RIT-Raytheon detectors could someday support future NASA missions to understand the nature of dark matter and dark energy, and to find Earth-like exoplanets. The CfD will collaborate with Raytheon to design, fabricate and test the hybrid detectors grown on silicon wafer substrates. We are very excited to be partnering with RVS to develop, fabricate, and test infrared detectors under this new award.

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

National Research Laboratories

MARSHALL SPACE FLIGHT CENTER

NSF

NASA

LSST

MIT Lincoln Laboratory

Office of Science U.S. DEPARTMENT OF ENERGY

National Optical Astronomy Observatory

SLAC

JPL

SPITZER SPACE TELESCOPE

CSIC

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

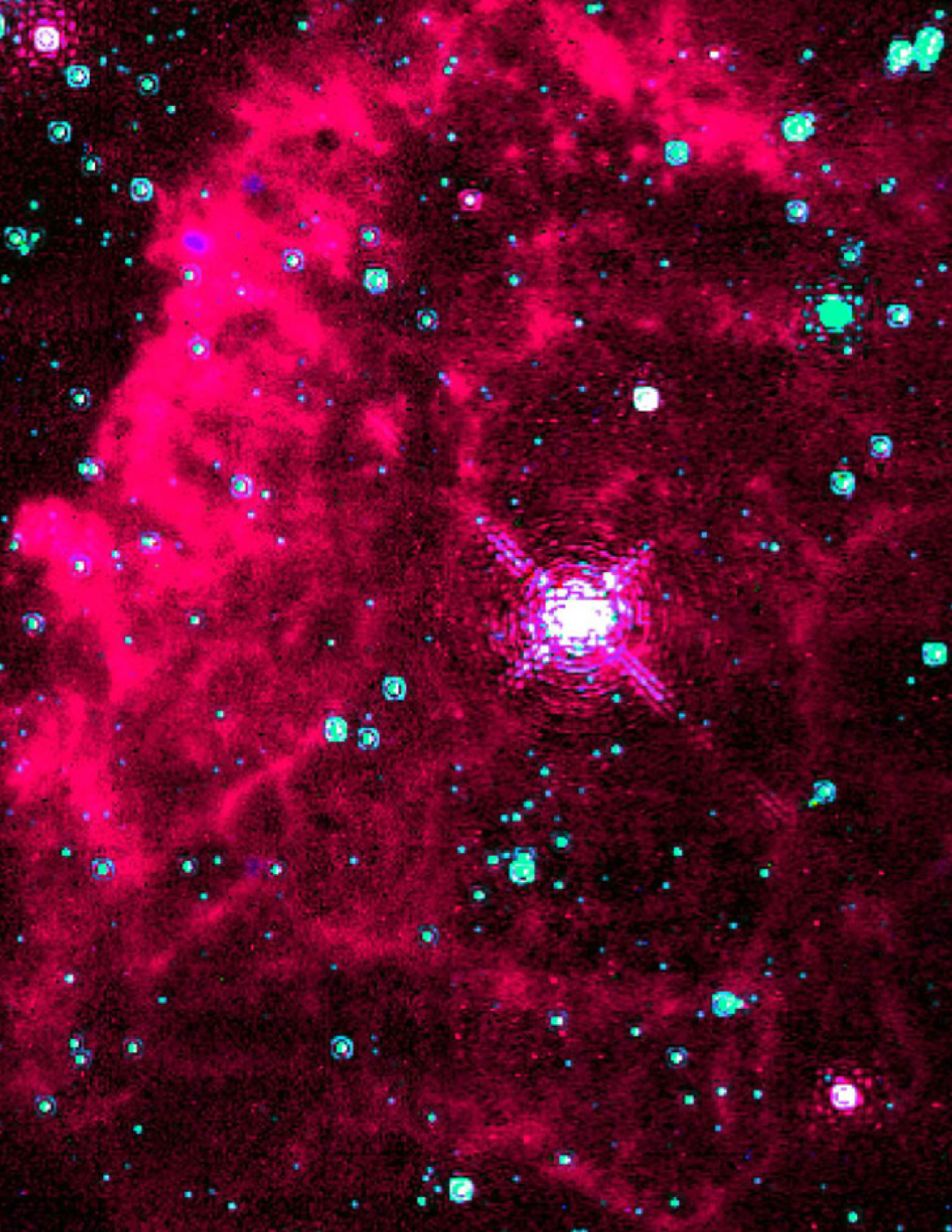
Thermo SCIENTIFIC

Ball

ITT Engineered for life

Kodak

Communication



In the News

NASA Awards RIT $1.1 Million to Develop Infrared Detectors for Space Missions

In April of 2013, the Center for Detectors was featured in an RIT News release, *NASA Awards RIT $1.1 Million to Develop Infrared Detectors for Space Missions*. The article describes RIT's Center for Detectors' collaboration with Raytheon to, "advance a new family of large format infrared detectors grown on silicon wafer substrates." The future developments could aid future NASA missions to further comprehend the nature of dark matter and dark energy, and to discover Earth-like exoplanets.

Together, the CfD and Raytheon will design, engineer and test the hybrid detectors which are grown on silicon wafer substrates. Raytheon's process for depositing light sensitive material on silicon wafers departs from standard technology. Since the 1980s we've relied upon small, seldom produced and extremely expensive Cadmium Zinc Telluride wafers, this has all changed thanks to the company's innovative ideas and productions.

Previously, RIT received a $1.2 million grant from the National Science Foundation for similar research conducted with Raytheon. Now, NASA has extended this research to space applications requiring radiation-hardy instruments. Astronomical discoveries of dark energy, dark matter and Earth-like exoplanets have become more attainable, they also hope to enhance NASA's missions involving characterization of weather, climate, and air pollution.

"Raytheon has come up with an innovation to combine the silicon wafer with the mercury cadmium telluride light-sensitive layer in a way that could end up dominating the field of infrared detectors for the next twenty years," Figer says.

Student-Designed Signs Give Center for Detectors a Welcoming Look

One of the employees at the Center for Detectors was recognized in an RIT News release, *Student-Designed Signs Give Center for Detectors a Welcoming Look*. The article describes how CfD employee Allison Conte, undergraduate Graphic Design major, helped brand the research center. Conte recently designed the glass and metal signage displayed at the entrance of the CfD, located on the third floor of Engineering Hall at RIT (Figure 37).

Conte, one of the administrative assistants at the center, was caught off guard when the director, Don Figer, asked her to design the welcoming visitor signs.

"Don wanted me to direct the project," says Conte. "I think he wanted to see how far I could take it by myself."

Figure 37. (left) This is a photo of the CfD welcome display designed by Allison Conte. (right) Ms. Conte also designed an information display using the same style and materials as the welcome display.

Figer envisioned a grouping of professional signs promoting the center's role in advancing photon detectors and related technologies. Conte and Figer joined forces to create the signs' content and worked directly with Signs Now Rochester Inc. to produce the final product.

The layouts and photographs of the final signs are now a part of Conte's portfolio (Figure 38). She acknowledges her design experience here at the Center for helping her obtain a summer internship with Procter & Gamble.

Figure 38. Allison Conte proudly poses in front of her finished project, which is placed in the hallway of the CfD.

"I've had a lot of responsibility with this project," Conte says. "It shows that I am able to handle the process all the way from the beginning to the end, and that I can produce professional designs."

Education and Public Outreach

Students Explore Virtual Planetary Surfaces

For the Student Explorations on Virtual Planetary Surfaces project, several RIT undergraduate students collaborated with 15-20 high school students from the Rush-Henrietta school district in order to design and develop a “3D Planeterrainium.” The Planeterrainium is an immersive tool that projects 3-dimensional red/cyan anaglyph images of the surfaces of various planets, as observed by NASA SMD missions. The Planeterrainium was designed to project those images directly onto the floor, creating an illusion of walking on the surface of a different planet (Figure 39).

Figure 39. K-12 students are using 3D glasses to observe the Planeterrainium’s various 3-dimensional planetary surfaces.

The team found data primarily from the Mars Reconnaissance Orbiter HiRISE camera as the present best source of 3D data – but with the appreciation that future Light Detection and Ranging (LIDAR) imagers (the focus of the parent science proposal) would also produce data sets ideal for this system.

In addition to projecting Mars’ surface, the Planeterranium also featured high-resolution anaglyphs of the Moon’s surface. Currently, the project is working towards expanding its library of anaglyphs and adding more planetary surfaces, for example, an anaglyph of Mercury’s surface may soon be available.

The system is powered by software that uses a “Google Mars” backbone, and is controlled by a hand held Nintendo WiiMote device. The specific choices of these systems were in order to maintain the low cost and friendly nature of the project, while using red/cyan anaglyph images allows for low cost projections systems and 3D glasses to replicate this concept very easily in classrooms or small science centers across the nation.

The team designed the "tripod" structure of the Planeterrainium (Figure 40) with the idea that it should be simple and inexpensive enough to reproduce. The structure is made out of PVC pipe, a modified garbage container, and rope.

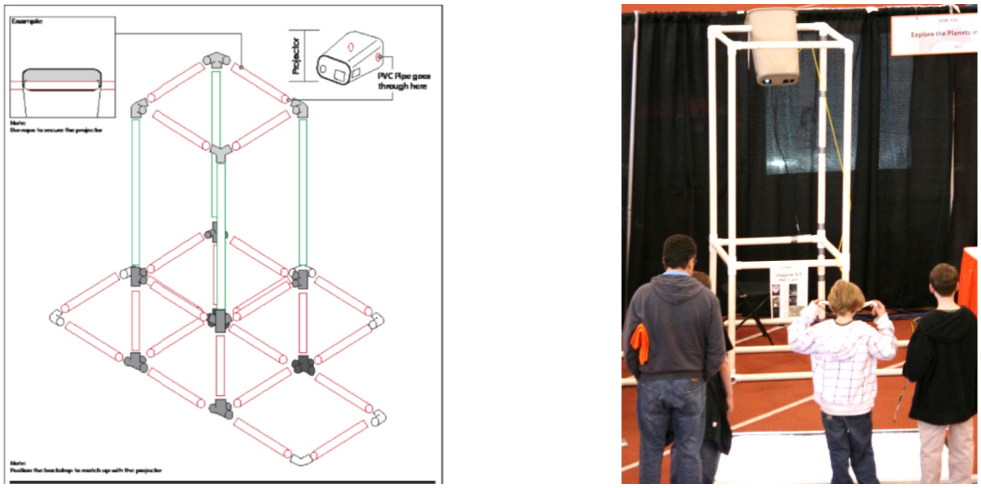


Figure 40. (left) What started out as a structural design became a (right) successfully functioning Planeterrainium.

After the Planeterrainium was developed, the team presented it to K-12 audiences at different venues throughout the country: Imagine RIT Festival; Astrozone at the Boston Museum of Science; the USA Science and Engineering Festival in Washington, DC; Rochester Museum and Science Center; and the Wegman's LPGA Golf Tournament.

In addition to being demonstrated to students at museums and events, this project has also been shared with the astronomy education community at conferences and in publications all around the country: Meeting of the American Astronomical Society, Meeting of the National Afterschool Association, and in the proceedings of the Astronomical Society of the Pacific.

Elementary School Students Learn About the Pistol Star

In June 2013, CfD Director Dr. Donald Figer was invited to Park Road Elementary School in Pittsford, NY to give two presentations about the Pistol Star, one of the most massive and luminous stars known today. Over thirty 3rd and 5th grade students attended the presentation.

Part of Dr. Figer's presentation consisted of imagery that explained relative sizes for planets and stars to give the students an idea of how massive the Pistol Star really is (Figure 41).

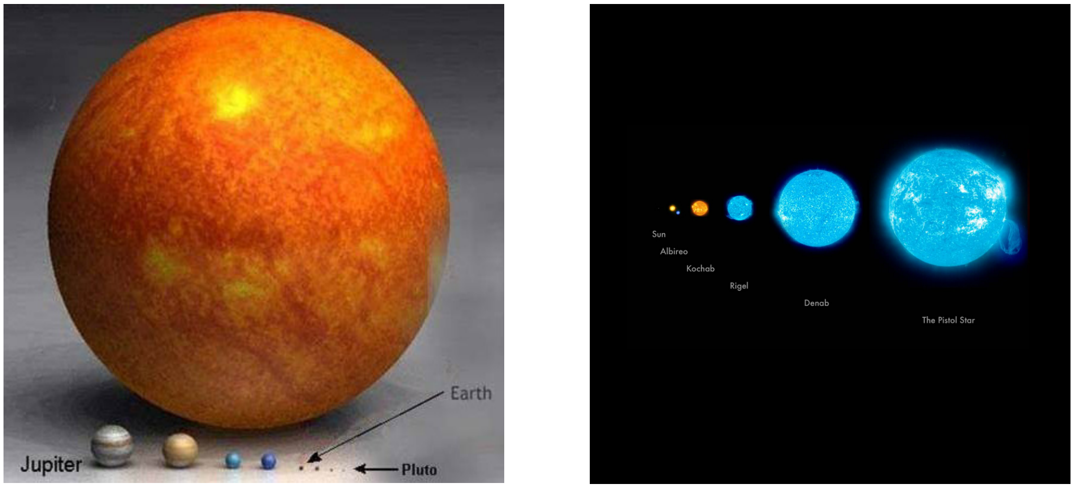
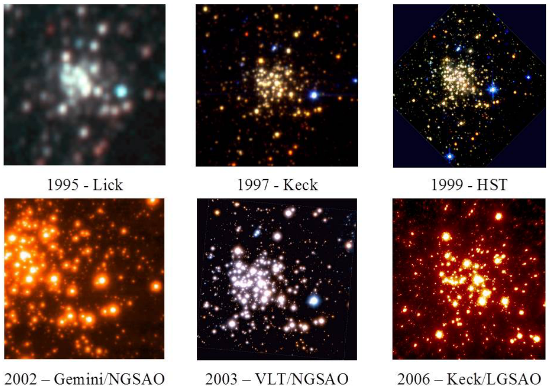


Figure 41. The images above were included in Dr. Figer's presentation at the elementary school. (left) This image shows the relative sizes of the planets within the Solar System. (right) The Sun appears much smaller in this image, where its size is compared to other stars, such as the Pistol Star, which is the most massive star depicted here.

Dr. Figer also described the process of searching for the Pistol Star, including the technology that was used and the research methods conducted. He demonstrated how fast astrophysical imaging technology is evolving by placing the original images of the Pistol Star from 1994 side-by-side with images made through 2006. Students also learned about detectors that are used in telescopes, star clusters, various types of telescopes, and the influence of space discoveries on pop culture.


1995 - Lick
1997 - Keck
1999 - HST
2002 – Gemini/NGSAO
2003 – VLT/NGSAO
2006 – Keck/LGSAO


From:

- thank you for coming ♥ I loved your presentation -

Valia

-Iain Howard

Chiara

-Robbie Smith

Thx for coming to our class this was really —! -Rachel Rennie

JAKE

-Karthik

-Eliza Ryan ☺

Thank you so much for coming

-Chloe Lang ★ Thank you!

Jordan Moran Daniel

Sweet Dog

-Joey B.

-ASHley Sampone ☺ It was really fun

-Bryan Ball

It was awesome -Sebastian, Afford

SARAH O'HARA ♡

Olivia Bernick ☺

It was very fun and interesting -Andrew Deming

thank you!

Thank you! It was really fun/intresting!

Abby

(are you making more waves?)

AM 8:45 JUN/12

Figure 42. (left) This series of Arches Cluster images demonstrates how much imaging technology has evolved and improved since the the 1990's. (right) The Park Road Elementary students collaborated and handmade a card thanking Dr. Figer for his presentation.

Publications

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- Najarro, F.; de la Fuente, D.; Davies, B.; Trombley, C.; Figer, D.; Herrero, A. 2013. *Hot stars in young massive clusters: Mapping the current Galactic metallicity.* Massive Stars Conference, 10-14 June, 2013, Rhodes, Greece

Organization


17-3179

Personnel

Don Figer

Director

Degree(s): PhD in Astronomy, 1995, UCLA; M.S. in Astronomy, 1992, U. Chicago; B.A. in Physics, Math, Astronomy, 1989, Northwestern U.

Website: http://www.cis.rit.edu/~dffpci/

Email: figer@cfd.rit.edu

Phone: 585-475-6005 (office), 585-747-6020 (cell)

Zoran Ninkov

Professor

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

Email: ninkov@cis.rit.edu

Phone: 585-475-7195 (office)

Joong Lee

Engineer

Degree(s): Ph.D. Physics, Dec 2007, UCLA; B.S. Physics, 1998, UC Berkeley

Email: jylpci@rit.edu

Phone: 585-475-5779 (office)

Brandon Hanold

Engineer

Degree(s): B.S. in Astrophysics, 2006, Michigan State University

Email: hanold@cfd.rit.edu

Phone: 585-475-4104 (office)

Tom Montagliano

Engineer

Degree(s): B.S. Electrical Engineering Technology, 2004, Rochester Institute of Technology

Email: tjmpci@cfd.rit.edu

Phone: 585-475-4107 (office)

Daniel Grant

Engineer

Degree(s): B.S. in Computer Engineering Technology, 2008, Rochester Institute of Technology

Email: dagpci@rit.edu

Phone: 585-475-4104 (office)

Christine Trombley

PhD Student

Degree(s): B.S. in Astrophysics and Physics, 2007, Michigan State University; PhD in Astrophysics, 2013, Rochester Institue of Technology

Email: cmt2410@rit.edu

Phone: 585-475-7131 (office)

Kim Kolb

PhD Student

Degree(s): B.S. in Microelectronic Engineering, 2008, Rochester Institute of Technology; expected PhD in Imaging Science, 2015, Rochester Institute of Technology

Email: kem2691@rit.edu

Phone: 585-475-4102 (office)

Matt Davis

Lab Assistant

Degree(s): M.S. Electrical Engineering, 2015, RIT; J.D., 2009, Albany Law School; B.S. Biochemistry, 2006, University of Wisconsin - Madison.

Email: msd8744@rit.edu

Phone: 585-475-2338 (office)

Kenny Fourspring

PhD Student

Degree(s): PhD Imaging Science, May 2013, Rochester Institute of Technology

Email: kdf5036@cis.rit.edu

Ross Robinson

PhD Student

Degree(s): PhD Imaging Science, Rochester Institute of Technology

Email: rer5221@cis.rit.edu

Dmitry Vorobiev

PhD Student

Degree(s): B.S. in Astrophysics, 2011, University of New Mexico; expected PhD in Astrophysics, Rochester Institute of Technology

Email: dxv2686@rit.edu

Yuanhao Zhang

MS Student

Degree(s): B.E. in Applied Physics, 2012, East China University of Science and Technology

Email: yxz5461@rit.edu

Allison Conte

Administrative Assistant

Degree(s): B.F.A. in Graphic Design, 2014, Rochester Institute of Technology

Email: arc7384@rit.edu

Phone: 585-475-4106 (office)

Caitlin Mucenski

Administrative Assistant

Degree(s): B.F.A. Medical Illustration, May 2013, Rochester Institute of Technology

Email: cem8191@rit.edu

Phone: 585-475-4106 (office)

John Leavitt

Administrative Assistant

Degree(s): B.F.A. in Industrial Design, May 2014, Rochester Institute of Technology

Email: jpl6704@rit.edu

Anastasia Rzhevskaya

Administrative Assistant

Degree(s): B.S. in New Media Marketing, May 2014, Rochester Institute of Technology

Email: axr7516@rit.edu

Phone: 585-475-4106 (office)

Evan Jorgensen

Lab Assistant

Degree(s): B.S. in Microelectronic Engineering, May 2013, Rochester Institute of Technology

Email: ekj9409@rit.edu

Michael Every

Lab Assistant

Degree(s): B.S. in Physics, May 2014, Rochester Institute of Technology

Email: mje1450@rit.edu

Jonathan Zimmermann

Lab Assistant

Degree(s): B.S. in Electrical Engineering, May 2015, Rochester Institute of Technology

Email: jtz7449@rit.edu

Phone: 585-475-4218 (office)

Charter

About the Center for Detectors

The Center for Detectors (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 applies 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

Since its inception in 2006, the Center for Detectors has received $11 million in research funding. The largest contributions are from the Moore Foundation and NASA. The Moore Foundation has granted $2.8 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 wafter substrates.

Capabilities, Equipment, and Facilities

The Center for Detectors (CfD) 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 43), the Quantum Dot Detector Laboratory, the Imaging LIDAR laboratory, and the Wafer Probe Station laboratory. The laboratories contain special facilities and equipment dedicated to the development of detectors.

Figure 43. Above is a lab area in 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 PCs. 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 40) use three 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, and custom FPGA systems based on Altera and Xilinx parts. 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 a large integrating sphere that provides uniform and calibrated illumination from the ultraviolet to through the infrared, and it can be mounted to the dewars. The dewars are stationed on large optical tables that have vibration-isolation legs.


Figure 44. Detectors are evaluated in three custom dewar test systems.

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 – 1100 nm) provide for absolute flux measurements. RIDL also has a spot projector to characterize the inter-pixel response of the detectors, including optical and electrical crosstalk. Figure 45 shows a laser spot projection system on a 3D motorized stage that produces a small (~few microns) point source for measurements of intrapixel sensitivity.

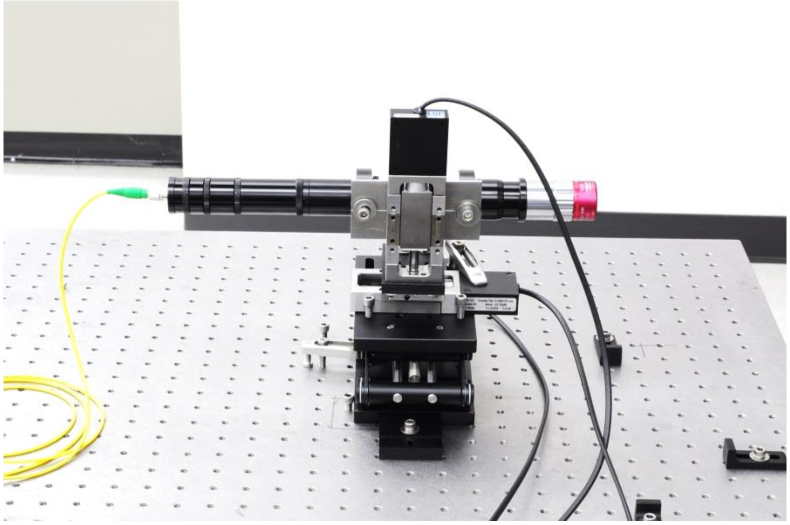
Figure 45. Shown here is a laser spot projector with three axis motion control system.

The lab contains eight data reduction PCs, 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 a dedicated class 1000 cleanroom (by FED Standard 209E), located in the SMFL. The SMFL has 10,000 ft^2 of additional 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 cleanroom and probe stations offer wafer-level testing, even during the fabrication process, allowing mid-process design changes (Figure 46). The probe station accommodates electrical and circuit analysis of both wafers and packaged parts, including low current and radio frequency (RF) probing. Also available for CfD use are the Amray 1830 Scanning Electron Microscope (SEM; see Figure 47), 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.

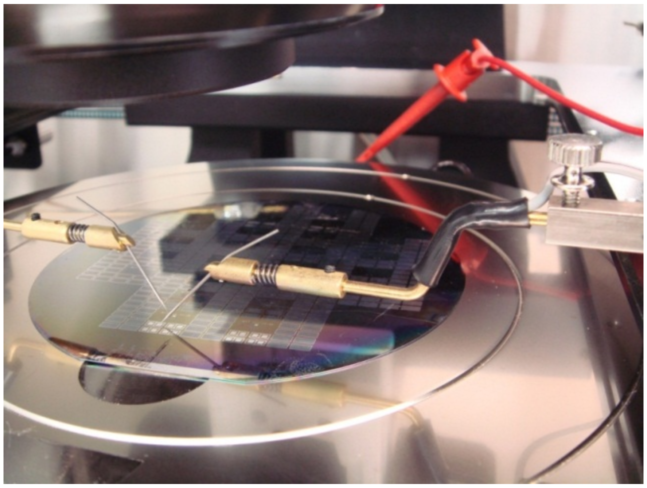

Figure 46. Device wafers are tested in the clean room lab probe station.

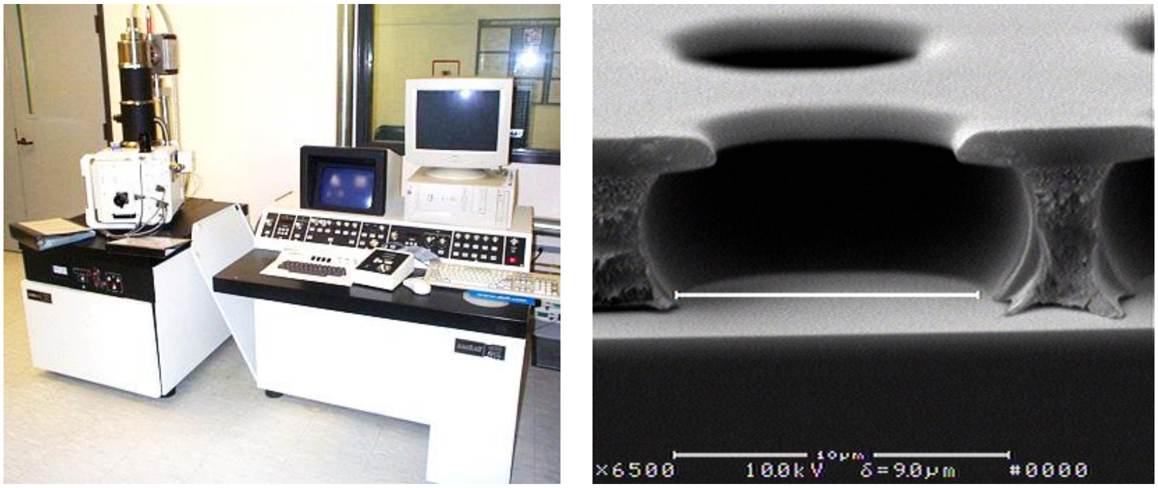

Figure 47. (left) The Amray 1830 Scanning Electron Microscope (SEM) is used to image devices. (right) SEM image of a device that has been prepared for indium bump deposition.

Figure 48 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.

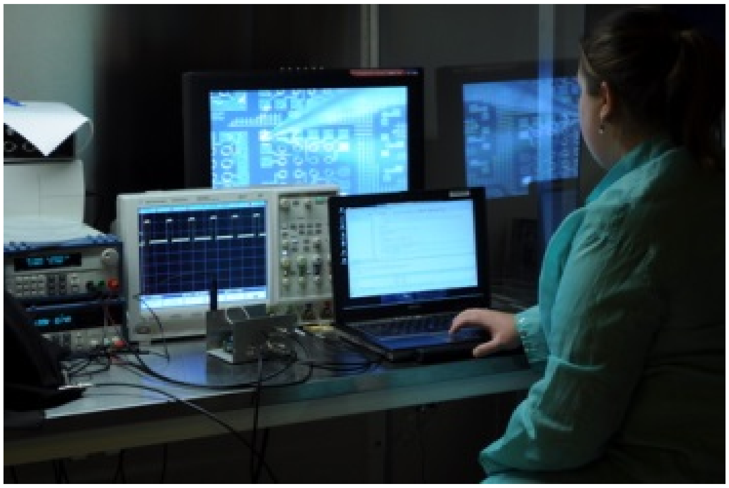

Figure 48. PhD student Kimberly Kolb conducts electrical experiments on one of the cutting edge devices being characterized at the Center for Detectors.

The entire probe station (Figure 49) 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 0.0049 mm^2).

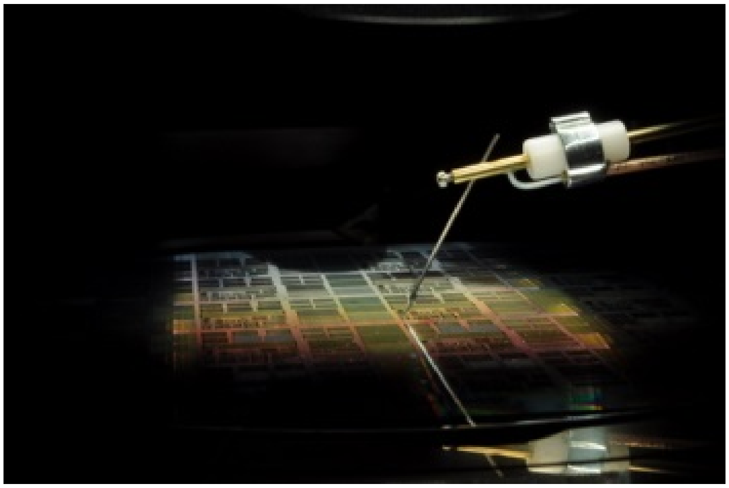

Figure 49. This image is a close-up of a device wafer being tested on the probe station under dark conditions.

In addition to fabrication and testing capabilities, the Center 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 50).

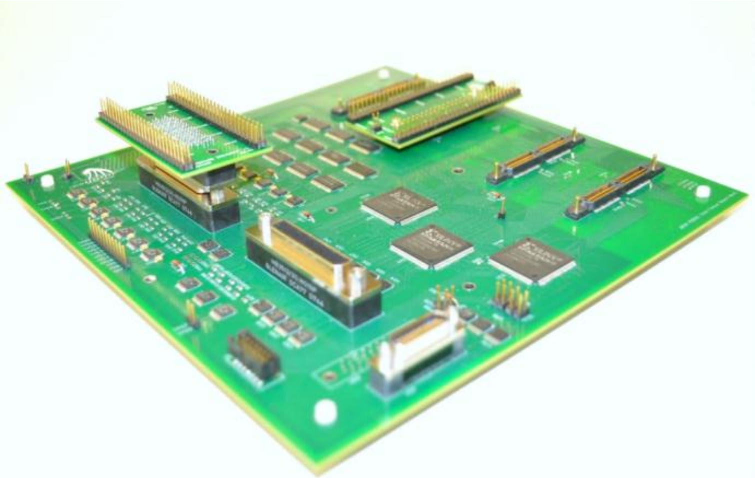

Figure 50. This image shows a cryogenic multi-layer circuit board designed in the CfD and populated in CEMA. All of the components on this board will be exposed to temperatures as low as 40 K, nanoTorr pressure levels, and high energy particle radiation.