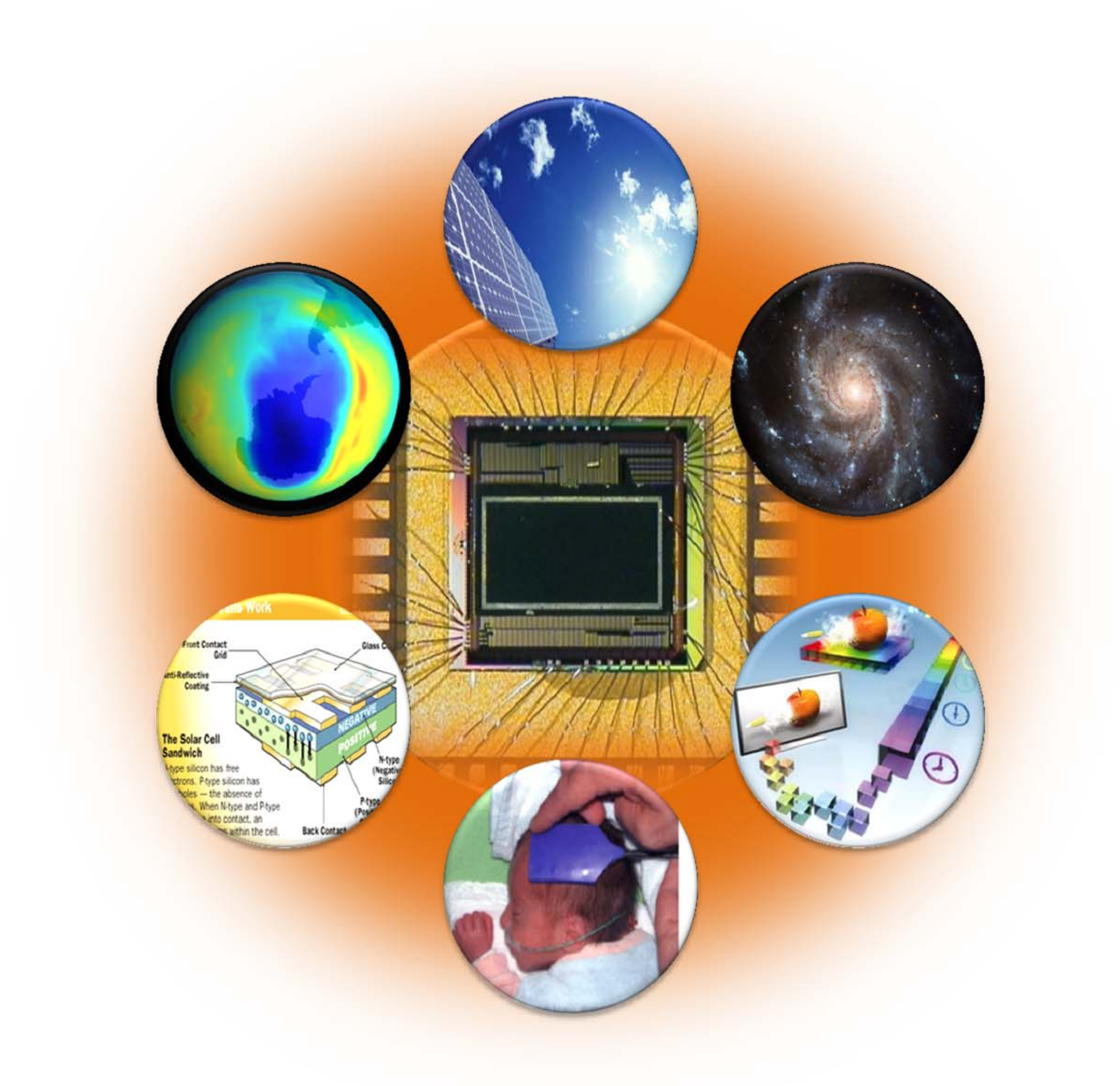

Center for Detectors Annual Report 2011

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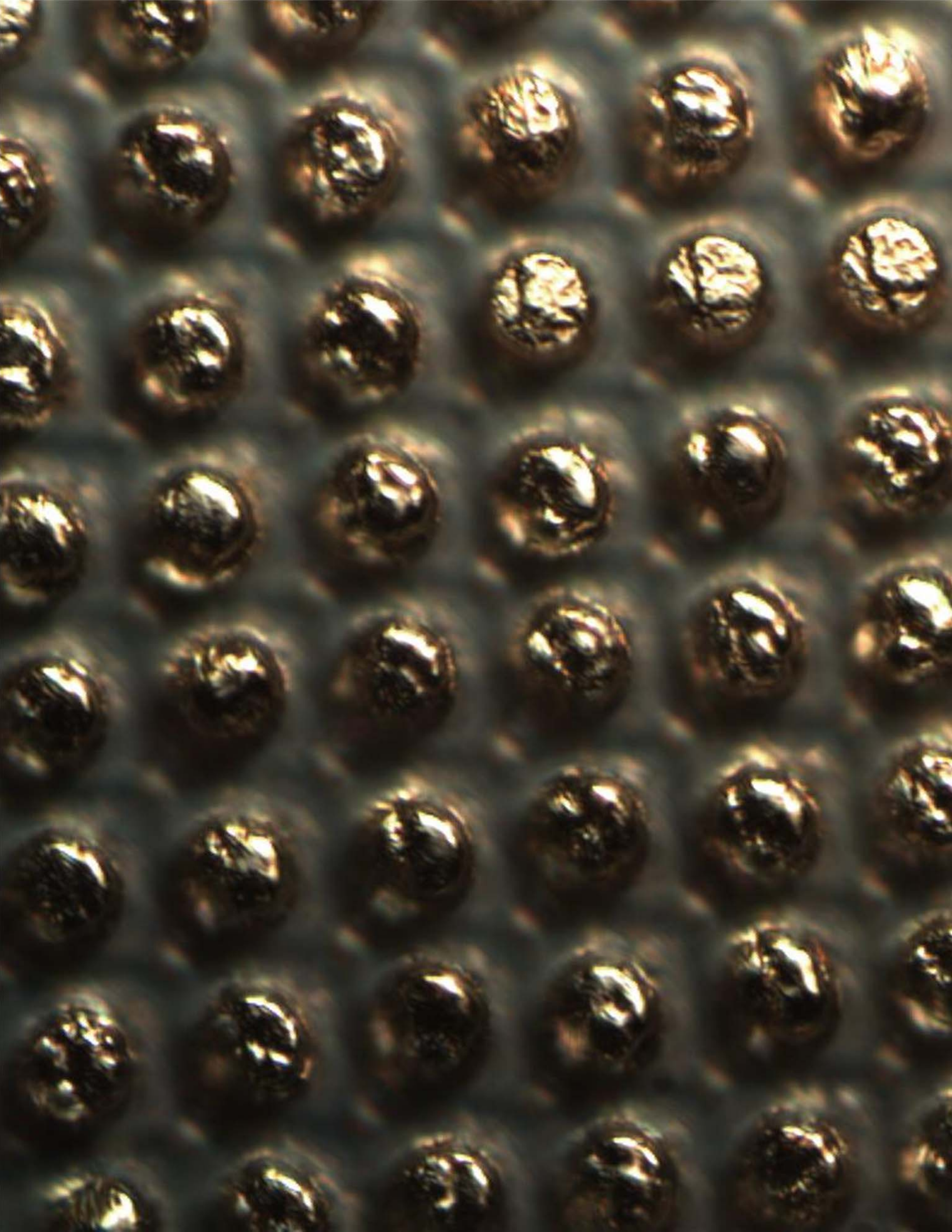


Director's Comments

Welcome to the inaugural Annual Report of the Center for Detectors (CfD) in the College of Science at the Rochester Institute of Technology. Formed two years ago as a cross-Institute Academic Research Center, CfD is off to an excellent start. The Center has emerged as an international leader in developing and deploying advanced detectors. Over a dozen conferences around the world have hosted invited talks by CfD researchers in the past few years.

"Our vision is bold, and it requires the support of brilliant engineers, passionate philanthropists, and inspired industrial partners. CfD is the first center of its kind to bring together imaging detector expertise in an academic, government, and industrial partnership."

The Center's educational mission is paramount. Students at all levels, from beginning undergraduate to PhD level, are deeply embedded in authentic world-class research in the Center. Student Researchers work with other students and professionals in over seven different academic departments and multiple colleges at RIT, in government institutions, and in industry. Their extraordinarily deep and broad interdisciplinary experiences make CfD students valuable in a wide range of fields for further education and in professional careers.

This report documents progress in the Center over the past year. It also includes highlights from the past five years during which the Center's precursor entity, the Rochester Imaging Detector Laboratory, was operating. You will find exciting 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.

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

Highlights

Research

- continued three projects: A Zero Read Noise Detector for Thirty Meter Telescope (TMT), LIDAR Imaging Detector for NASA Planetary Missions, and A Photon Counting Detector for Exoplanet Missions
- completed six projects within the last year: A Very Low Noise CMOS Detector Design for NASA, A Radiation Tolerant Detector for NASA Planetary Missions, The Journey of a Photon, A NICMOS survey of newly-identified young massive clusters, The nature of GLIMPSE 81: a star cluster to rival Westerlund 1, Characterization of Silicon Geiger-Mode Avalanche Photodiodes with Novel Device Architecture
- awarded NSF funding for the Detector Virtual Workshop
- submitted a $50M proposal to the NSF Science and Technology Center program to establish “The Future Photon Initiative”
- received NASA fellowships for two CfD Student Researchers
- mentored two undergraduate and seven graduate students in a multi-disciplinary, team-based, project-driven environment

Communications

- published nine papers and presented seven invited talks
- engaged high school students in Explorations of Planetary Surfaces

Cross-RIT Collaborations

- completed benchmark analysis with RIT College of Business
- re-imagined our space with RIT School of Design

Organization

- moved into excellent new lab and office areas

Executive Summary

This report summarizes the activities of the Center for Detectors (CfD) over the past year, spanning July, 2010, through June, 2011. As the inaugural report for the Center, it also includes activities from the previous four years of the precursor entity, the Rochester Imaging Detector Laboratory. CfD was established in January, 2010. It is an Academic Research Center within the College of Science at the Rochester Institute of Technology. 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 by leveraging multi-disciplinary and symbiotic relationships between its students, staff, faculty, and external partners. The vision, mission, and goals are described in the Center Charter Document.

Research

Projects in the Center span a variety of topics. From the many branches of engineering, to imaging science, to physics, to chemistry and to astronomy, the Center stands out for its multi-disciplinarity that is required for its success. New projects, such as the "High Mass Initial Mass Function" project, incorporate astronomy and imaging science. While ongoing projects, such as the NASA funded LIDAR Imaging Detector project, unite microelectronic engineers, astronomy experts, imaging scientists, and various other professionals in science fields. The Center for Detectors benefits from employees that come from a diverse range of academic programs and professional occupations. The current make-up includes two professors, four engineers, one student programmer, two PhD students, one Master's student, and various other support staff. In the previous year, the Center published nine papers that described scientific advances in astrophysics and technical progress in detector technology.

Many of the Center's Student Researchers apply CfD research to their current academic programs at RIT. There are currently two students pursuing their PhD's at the Center. Others include those earning Bachelor and Master degrees in Computer Engineering, Bachelor and Master degrees in Microelectronic Engineering, Master degrees in Electrical Engineering, and degrees in various other majors. Many of the undergraduate Student Researchers choose to pursue Master degrees based on research in the Center.

The Center is grant-funded and has received more than $8.1 million in sponsorship. NASA and the Gordon and Betty Moore Foundation are the Center's primary supporters. Other sources of funding include the National Science Foundation, BAE Systems, the Spitzer Science Center, the Herschel Science Center, and the Smithsonian Astrophysical Observatory.

Outreach and Communications

Education supplements to two of our grants have funded exciting projects involving students from local high schools. Students mapped the “Journey of a Photon,” and presented their work at venues nationwide. A second group of high school students is currently engaged in “Exploring Planetary Surfaces in 3D,” incorporating the use of an RIT-developed 3D projection system dubbed the “Planeterrainium.”

The Center has been featured in many conferences and press venues during the previous year. Student Researcher Kim Kolb presented her MS thesis at SPIE Optics and Photonics Conferences. The Rochester Business Journal published an article, “New center at RIT finds novel ways to use photo sensors,” summarizing the foundations of the Center to the public. The RIT University News published the article, “RIT Center for Detectors Advance Detector Technology,” informing the RIT community about the purpose of the new Center’s lab facilities.

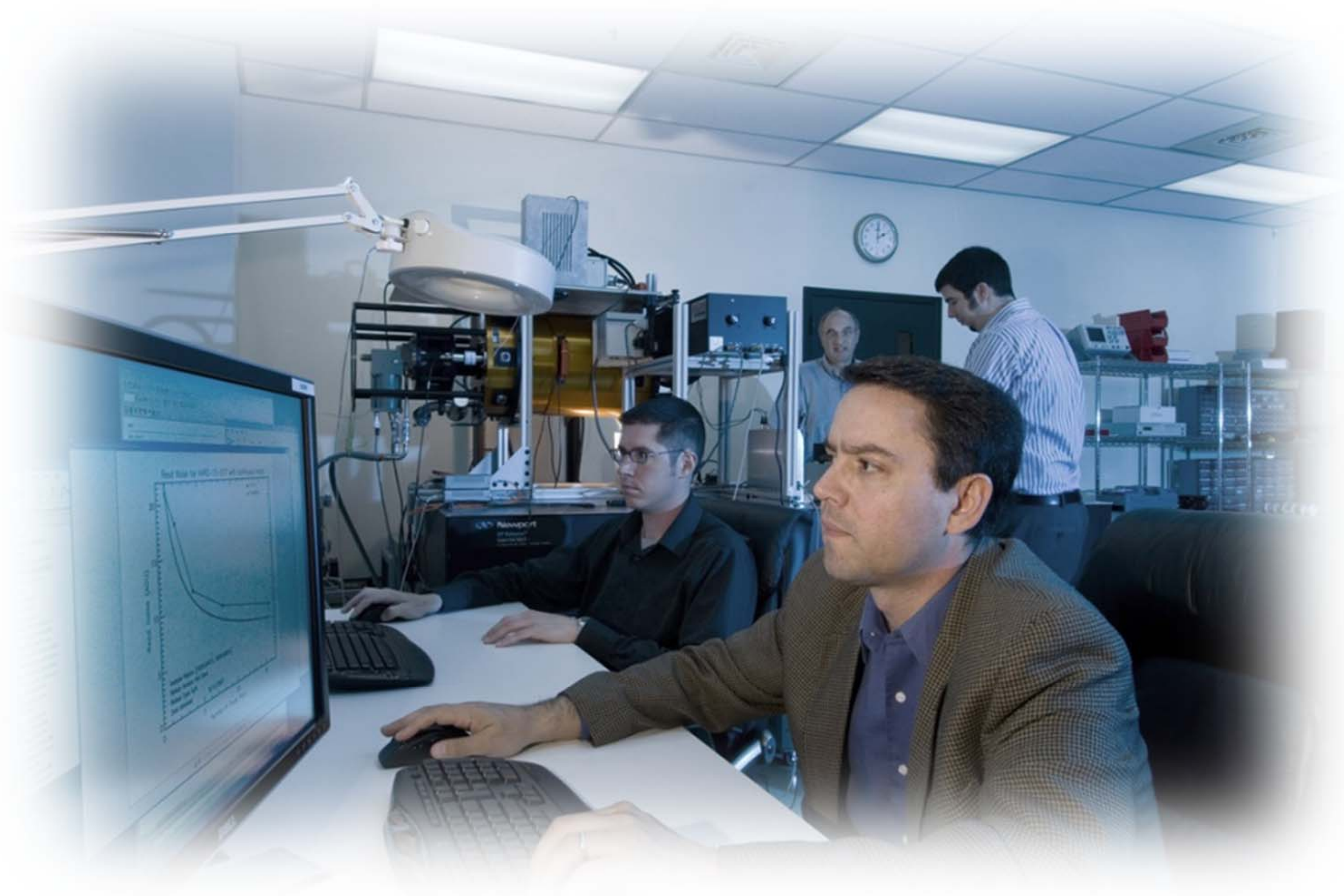
CfD hosted a variety of distinguished speakers. Presenters include Dr. Donald Hall of the University of Hawaii, Dr. Chris Packham of the University of Florida, Dr. Joss Bland-Hawthorn of the University of Sydney, Bruce Tromberg, of the University of California, Irvine, and Dr. Shouleh Nikzad, Dr. Michael Hoenk, and Bedabrata Pain of the California Institute of Technology’s Jet Propulsion Laboratory.

Cross-Institute Collaboration

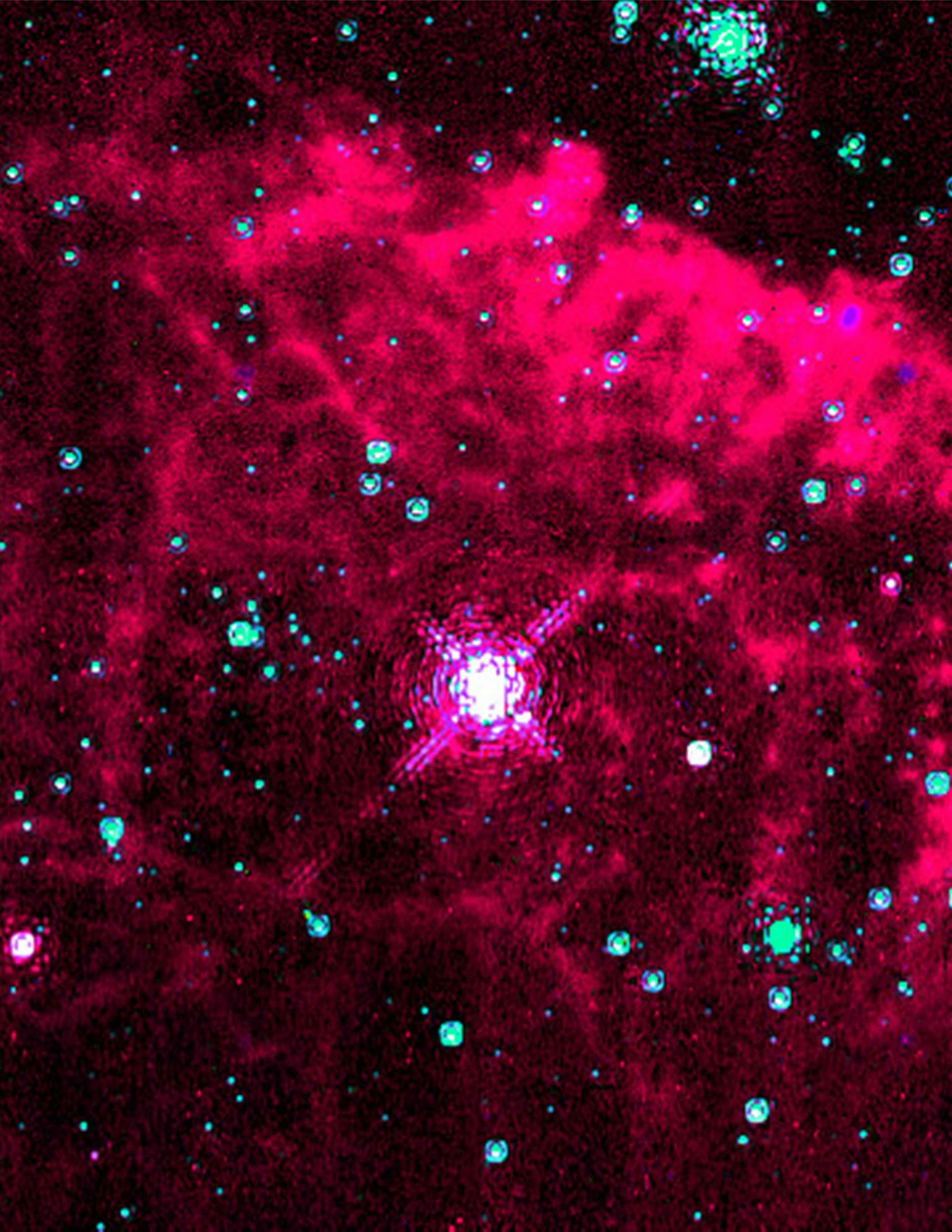
In the spring of 2011, seniors from RIT’s School of Design collaborated with the CfD for their senior design projects. The students toured the Center’s existing facilities, and proposed creative ideas to redesign lab and office spaces. College of Business student Shivam Bansal and professor Richard Notargiacomo worked with the CfD this year as well. The team developed a report benchmarking the CfD against similar research centers across various dimensions such as vision and mission, industrial relationships, online presence, brand image, organizational structure, overhead costs, and funding.

Equipment and Facilities

Essential to Center for Detector’s detector testing capabilities are our three test systems that were designed in the Center. The Center also has a class 1000 cleanroom, allowing for testing of detectors in various stages of fabrication. The Center’s access to other Rochester Institute of Technology facilities further enhances our capabilities. Such facilities include the Center for Electronics Manufacturing and Assembly, which specializes in semiconductor chip packaging, printed circuit board assemblies and electronics/optoelectronics systems, and the Brinkman Manufacturing Lab, which provides machining support for our in-house fabrications.



Research



Research Projects

New Projects

Clumping in OB-star winds

NASA/Herschel

Massive stars, their nature and evolution, play important roles at all evolutionary stages of the Universe. Through their radiatively driven winds they influence the dynamics and energetics of the interstellar medium. Commonly, the mass-loss rates of luminous stars are inferred from several types of measurements, the strengths of ultraviolet lines, hydrogen emission lines and radio and far infrared 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. This project uses Herschel Space Telescope data to consistently treat *all* possible diagnostics, scanning different parts of the winds (Figure 1). We will analyze the data using state of the art model atmospheres to determine more accurate mass-loss rates.

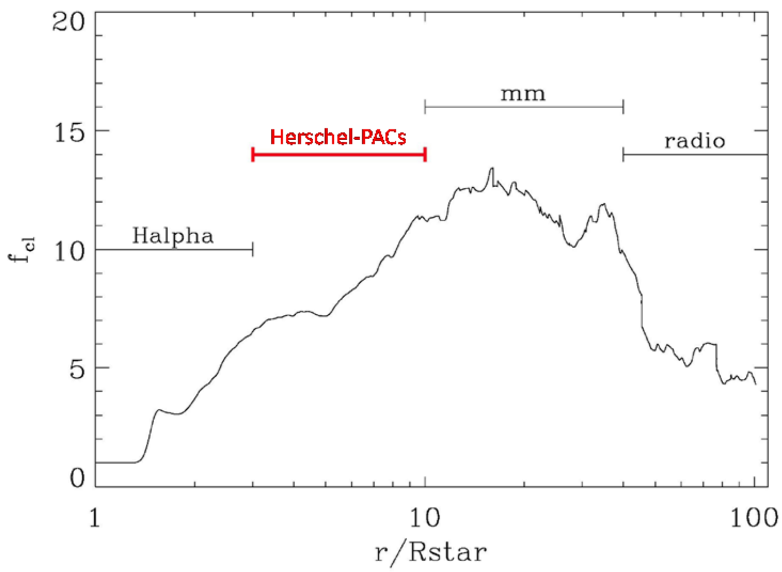


Figure 1. The plot shows the clumpiness of material, f_{cl}, in stellar winds as a function of the distance from the center of the star, based on hydrodynamical models. The Herschel-observations at wavelengths of 70-130 μm sample the important intermediate region.

High Mass Initial Mass Function

NASA/GSRP

By examining a sample of young, massive stellar clusters in the galaxy, this project will place constraints on the high mass initial mass function as a function of stellar natal environment, lending insight into the life cycles of massive stars (see Figure 2). We will also study evolutionary sequences of massive stars, and add new data points to help resolve the issues regarding the relationship between progenitor mass and end state of post-supernovae stellar remnants.

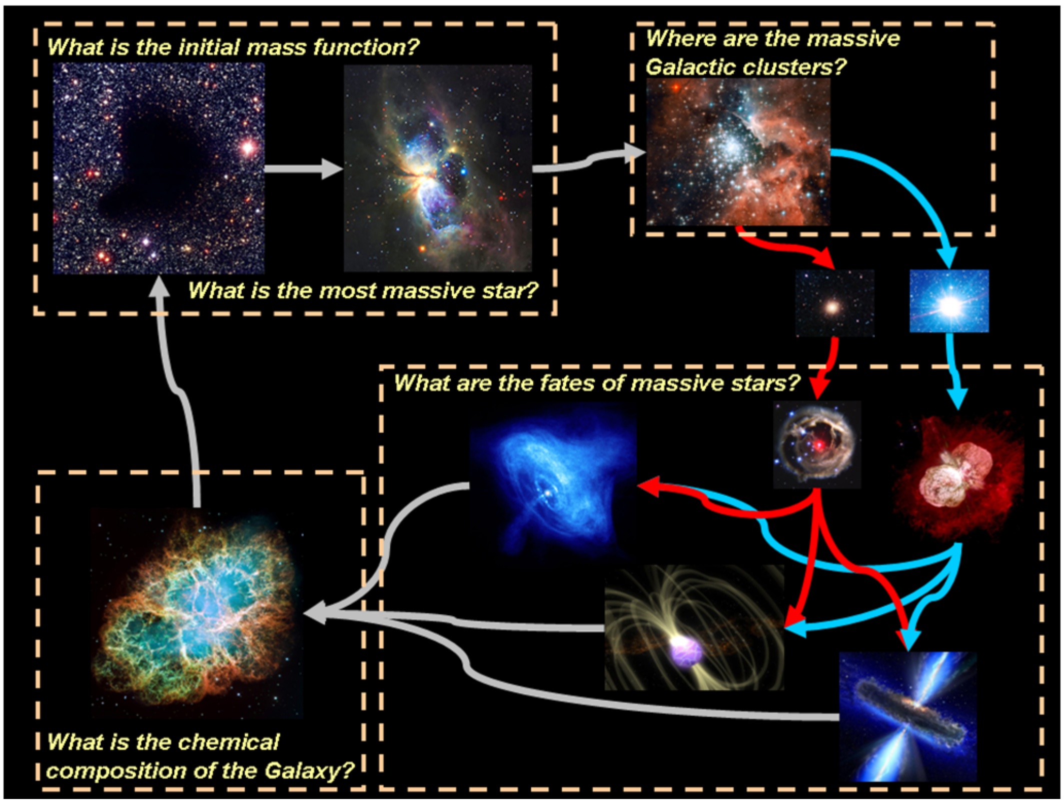


Figure 2. The life cycles of massive stars. Some of the questions in yellow will be addressed in the proposed activity. Note the uncertainty between progenitor mass and end state, as demonstrated by the overlapping lines connecting neutron stars, magnetars, and black holes to intermediate mass stars that become red supergiants (red lines) and more massive stars that only become blue supergiants (blue lines); it is not clear which of these lines are accurate.

This project requires many steps, as shown in Figure 3. CfD Graduate Student Christine Trombley will obtain and analyze data from a variety of observational facilities on Earth and in space. These data will be 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.

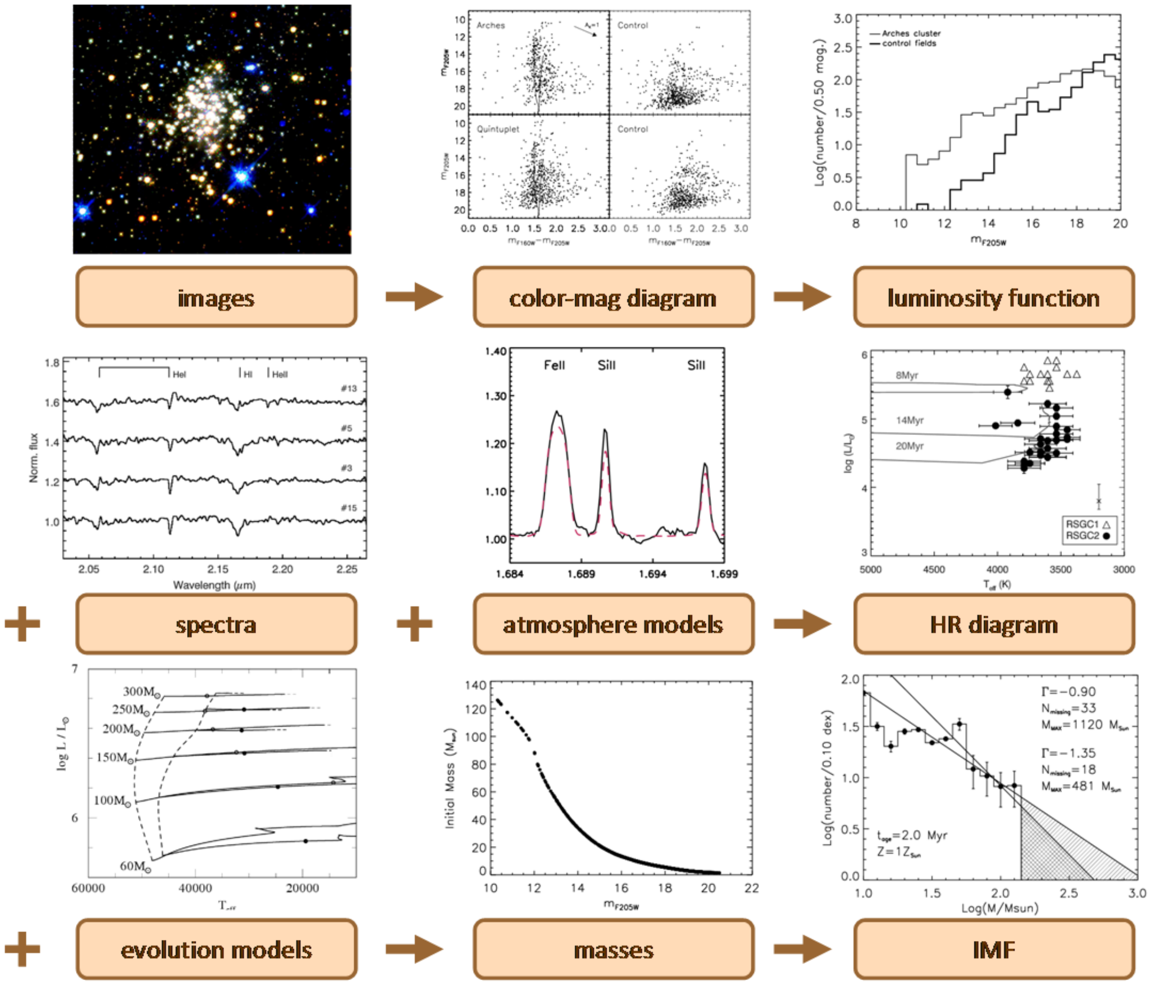


Figure 3. Flowchart illustrating the steps from observation to initial mass function.

Ongoing Projects

A LIDAR Imaging Detector for NASA Planetary Missions

NASA/Planetary Instrument Definition and Development Program

In collaboration with MIT/Lincoln Laboratory, CfD is developing an imaging Light Detection and Ranging (LIDAR) detector for NASA planetary space missions. The device has a pixelated array of independent Geiger-mode Avalanche Photodiodes that can asynchronously measure laser light time of flight. The output is a three-dimensional image, providing distance measurements for each pixel. When used in an oversampling mode, the data will have timing accuracy of ~100 picoseconds, thus enabling a ranging accuracy ~1 cm, or roughly two orders of magnitude better than existing LIDAR instruments.

MIT/Lincoln Laboratory delivered a 32×32 pixel hybridized, bump-bonded LIDAR detector testing in the Rochester Imaging Detector Laboratory (see Figure 4). We assembled the test system for the detector and are currently characterizing the device. The test system consists of readout and control electronics, a camera enclosure, a power supply system, a PicoQuant laser, and focusing optics. The Field Programmable Gate Array (FPGA) firmware, written to run functionality tests on the ROIC, is being expanded for characterization of the final detector. In addition, automated test suites for carrying out the characterization tests in accordance with the performance test plans are being iteratively developed.

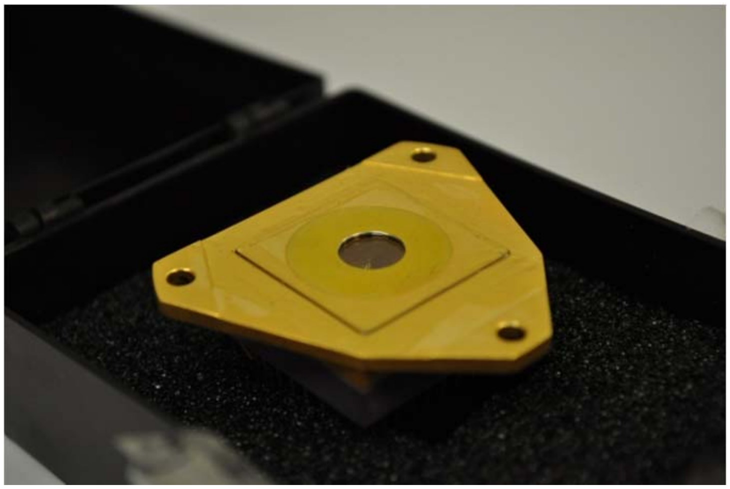


Figure 4. Photograph of the packaged 32×32 pixel hybridized LIDAR detector.

We assembled the LIDAR test system (Figure 5), composed of a host PC to coordinate all the elements, the hybridized detector, a supporting readout board (ROB), a custom PCI acquisition board, a PicoQuant laser, a camera enclosure, and a power supply unit. The acquisition board communicates with the host computer via a PLX 9656 PCI bridge chip and interfaces with the ROB via fiber optic link. The readout board utilizes Altera FLEX 10KE and Cyclone devices with supporting components. The FLEX 10KE device supplies the 32×32 pixel ROIC with the control/multiplexing signals for proper readout, and the Cyclone FPGA converts linear feedback shift register timestamps into a binary count.

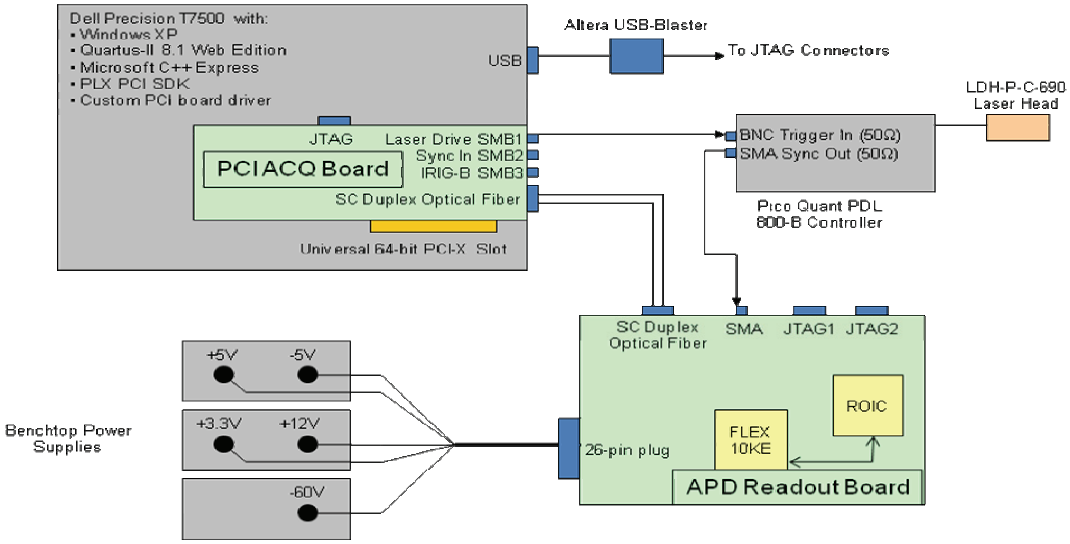


Figure 5. Block diagram of the electronics utilized to characterize the 32×32 pixel test readout integrated circuit.

CfD Student Researchers, Chris Maloney and Andrew Komendat, designed a camera enclosure for the detector and supporting readout board (Figure 6) in order to facilitate imaging and characterization experiments. The enclosure was designed to be light-tight, providing a simple and effective means of achieving a dark environment for the detector. The mounted lens adds focus capability, a requirement for the completion of the timing jitter, photon detection efficiency, and crosstalk tests. The enclosure also adds mobility to the system. This optical system uses a beam collimator which expands and collimates the laser output of the PicoQuant laser head.

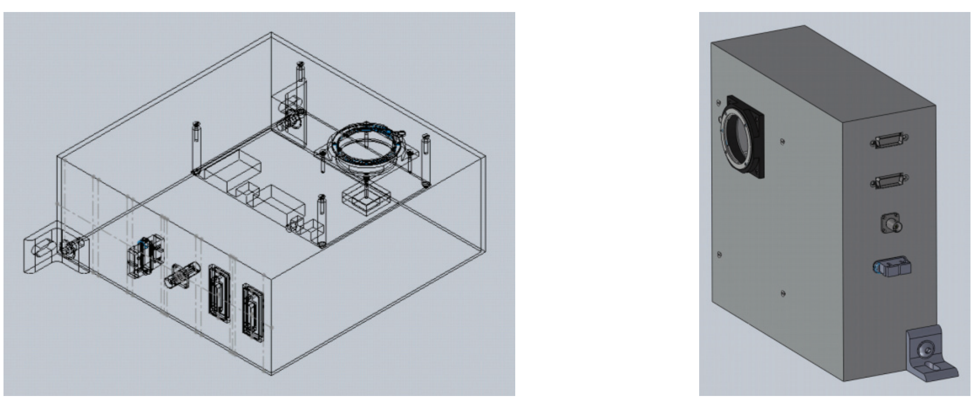


Figure 6. CAD models of the LIDAR detector camera enclosure.

We are currently evaluating the properties of a LIDAR detector. One of the most important parameters of its performance is the dark count rate (DCR), or how often the detector erroneously records an event in total darkness. To measure DCR, many dark frames (images read out in the absence of light) are acquired, and the number of dark events is recorded. Using this number and the effective exposure time, we infer the DCR as follows:

$$DCR = -\frac{\ln\left(1 - N_C/N_G\right)}{\tau} \qquad (1)$$

where N_C is the number of dark events, N_G is the total number of gates (how many times the pixels were reset during the exposure time), and τ is the range gate duration in seconds. Figure 7 is a preliminary plot of the measured DCR versus the reverse bias applied on each pixel. Examination of the plot indicates that the dark count rate grows with reverse bias, as expected as the bias exceeds the breakdown voltage and the avalanche initiation probability dramatically increases.

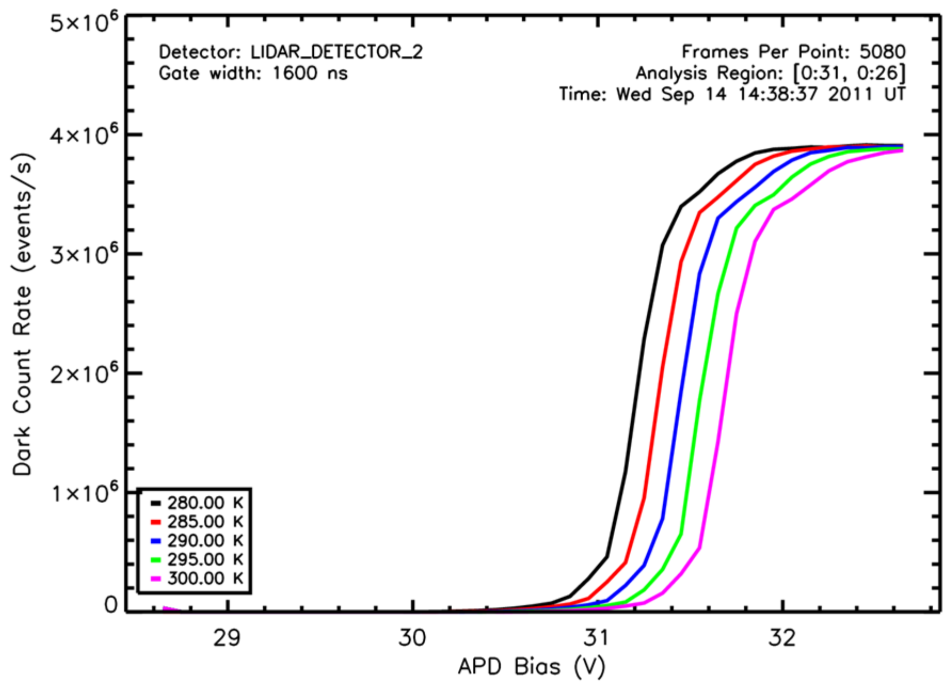


Figure 7. Plot of dark count rate versus diode reverse bias for the first 32×32 pixel bump-bonded LIDAR detector.

In preparation for characterization of the hybridized detector, MIT/Lincoln Laboratory provided a wafer of LIDAR-style Geiger-Mode Avalanche Photodiodes (GM-APDs) for preliminary testing at a probe station (Figure 8). This wafer contains a variety of test structures with a range of size and geometry. CfD Student Researcher Kim Kolb characterized the electrical properties of these test structures. She also visited MIT/Lincoln Laboratory for on-site device testing.

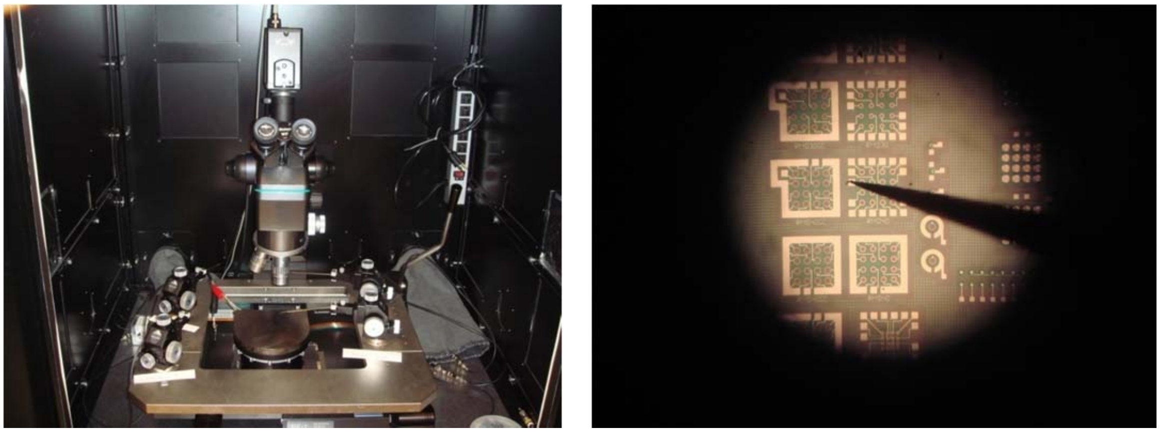


Figure 8. (left) The Rochester Imaging Detector Laboratory cleanroom probe-testing station. (right) a LIDAR-style GM-APD wafer with a probe applied to a pad of a device.

The current through the diodes was measured as a function of voltage, a common way to ascertain certain performance characteristics for a diode. These current-voltage (I-V) curves were plotted (Figure 9). The lack of a recombination and generation (R/G) region in small forward-bias region indicates a minimal number of traps (impurities) within the GM-APDs.

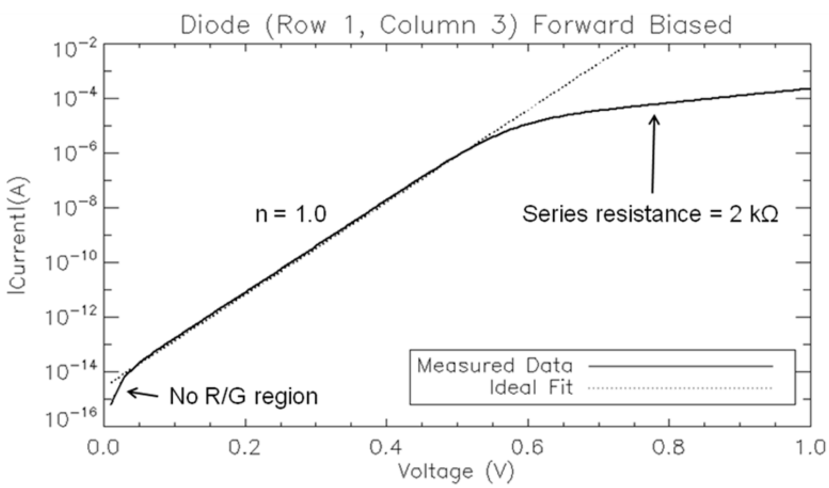


Figure 9. Forward-bias IV curves for LIDAR-style GM-APDs on preliminary testing wafer.

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; see Figure 10). 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 would 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 taking a better picture (less grainy) of a smiling child blowing out the candles at her birthday party. The detector will be quantum-limited (have 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 Center for Detectors is teaming with MIT/Lincoln Laboratory to leverage their Geiger-mode Avalanche Photodiode technology for developing the imaging detector. The project is funded through the Gordon and Betty Moore Foundation.

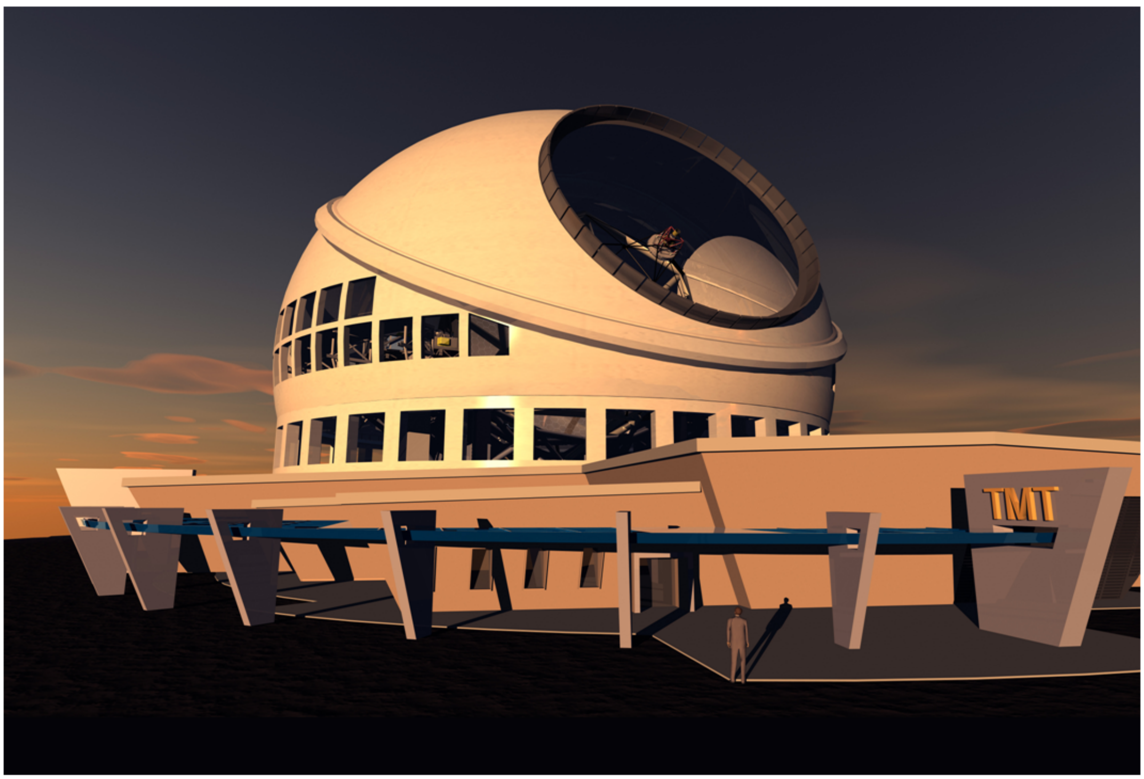


Figure 10. The TMT is expected to be among the first extremely large telescopes to be built over the next 10 years. The noiseless detector being developed is expected to effectively quadruple the collecting power of the TMT for the faintest of objects in the Universe.

Lincoln Laboratory submitted the first-version CMOS ROIC design to the MOSIS foundry service, which sent the design to IBM for fabrication in a 0.18 μm process. MIT/Lincoln Laboratory then packaged and shipped the device to RIT for testing. Functional testing uncovered an error in the design of the device, and as a result, a second version of the ROIC was designed, reviewed, and fabricated (Figure 11). This second design was found to be free of error.

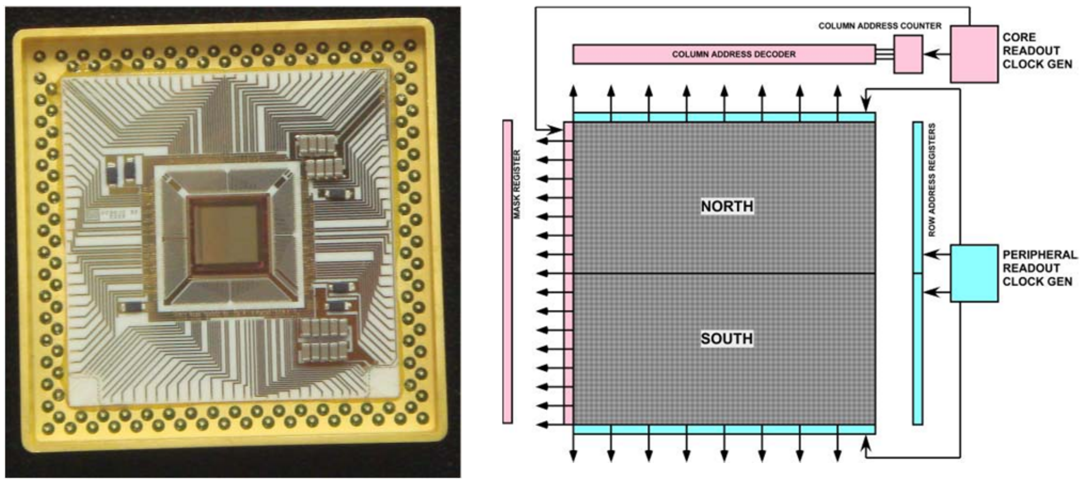


Figure 11. (left) the 256×256 CMOS readout integrated circuit. The chip was fabricated in an IBM 0.18 µm process. (right) a block diagram of the pixel architecture.

The visible (Si) and infrared (InGaAs) Geiger Mode Avalanche Photodiodes (GM-APDs) arrays have been fabricated. Two types of silicon GM-APDs have been fabricated and tested: low-fill-factor (LFF), and high-fill-factor (HFF) devices. Each of these types of APDs have been hybridized via bump-bonds to the second version of the CMOS ROIC, then packaged and shipped to RIT for testing in late January 2011. First-generation InGaAs GM-APDs have been fabricated and tested at Lincoln Laboratory. A second-generation 32×32 pixel InGaAs GM-APDs array that has been hybridized to a ROIC will be tested.

In order to test the first generation diodes at cold operating temperatures, we designed, purchased, and received a custom dewar in which the detectors will be mounted for cryogenic operation. The electronics and detector packaging to operate the detectors at cryogenic temperatures have been designed, integrated, and tested. For testing the detectors at room temperature, we have designed warm electronics. These warm electronics were used to validate the functionality of the CMOS ROIC while the phase one detectors were being fabricated.

A block diagram of the cryogenic system is shown in Figure 12 and includes a modified version of the test board along with a cold electronics board and newly-designed detector flex package. This packaging will enable parallel testing of up to four individual detectors at once.

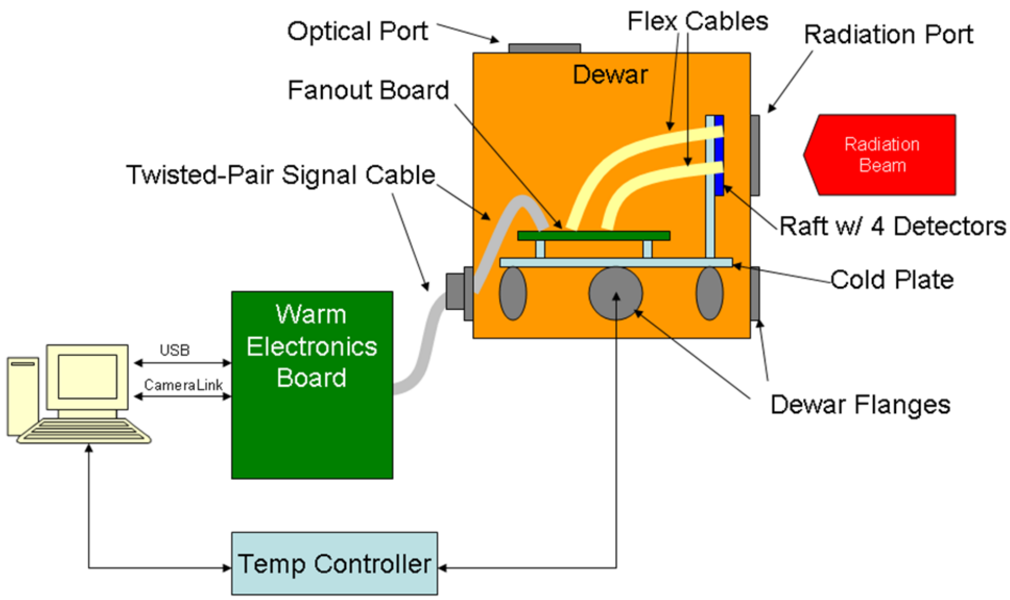


Figure 12. Cryogenic electronics system block diagram.

The flex package for the detector is shown in Figure 13. It consists of two rigid sections, joined in the middle by a flexible Kapton laminate. The materials in this design are compatible with cryogenic and vacuum operation. They also present relatively low cross-sectional area, and will therefore be resilient in a high energy radiation beam. The connectors and sockets have been used successfully in multiple programs in the past.

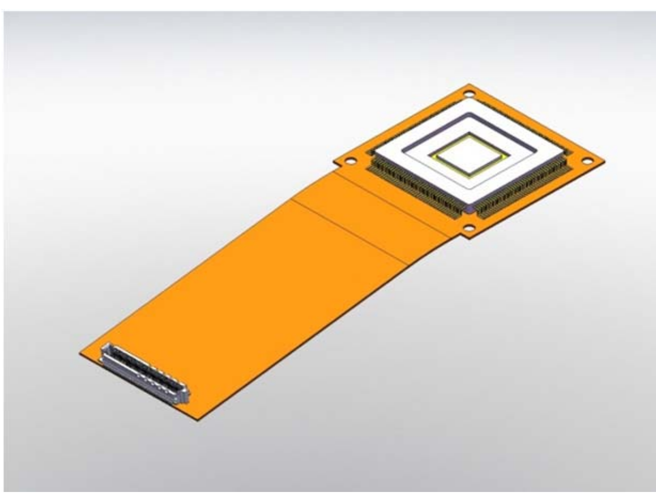


Figure 13. Detector in flex package.

The detector and input/output (I/O) connectors will be mounted to the rigid sections and assembled onto a custom-machined raft designed to hold up to four detectors, shown in Figure 14. The flex package is being specifically designed for use at high vacuum (10 nTorr) and cryogenic temperatures and will use the same techniques that have been used in previous Lincoln Laboratory designs.

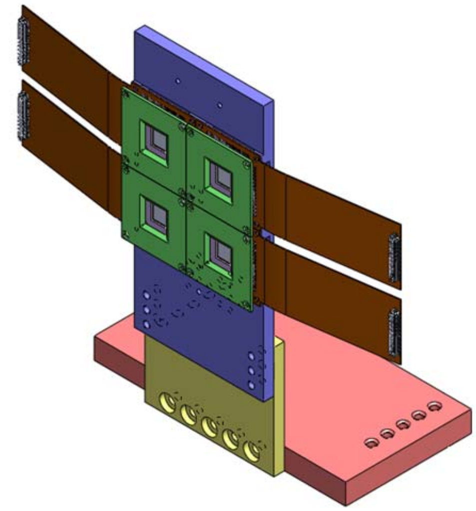


Figure 14. Example schematic of the packaged detectors. The detectors are mounted to a raft and mount for cooling to cryogenic temperatures.

Inside the dewar, the detector flex packages will mate to a signal fanout board, a block diagram of which is shown in Figure 15. The board will be thermally connected to the cold plate, which is also affixed to the bottom of the mounting bracket shown in Figure 14.

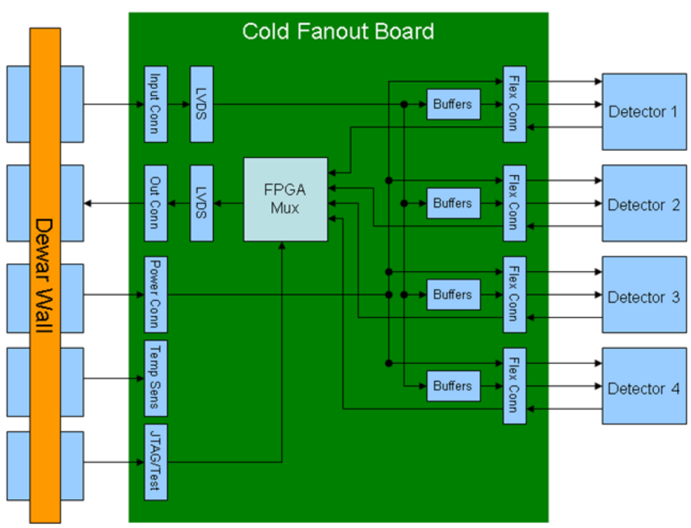


Figure 15. Block diagram of the cold fanout board. The input, out, and power connectors will be 100-pin micro-D connectors. The flex connectors will be SAMTEC high-density connectors.

Signal integrity tests performed in the Rochester Imaging Detector Laboratory demonstrated the need to use low-voltage differential signaling (LVDS) for all control and data signals when operated at temperatures down to 140 K (-208 °F). A picture of the setup used for testing is shown in Figure 16. In it, one can see a green circuit board bolted to the large aluminum cold plate that provides the cooling power. Three copper tabs can also be seen protruding from the board. Sensors are inserted into those tabs to provide temperature information as the board is cooled. The signal cable is made of multi-colored twisted pair wire that minimizes radio frequency emission and susceptibility to locally changing magnetic fields.

To balance between the I/O requirements needed to simultaneously test four detectors and the finite number of vacuum interface ports available on our dewar, simple FPGAs are used to condense the information going in and out of the dewar.

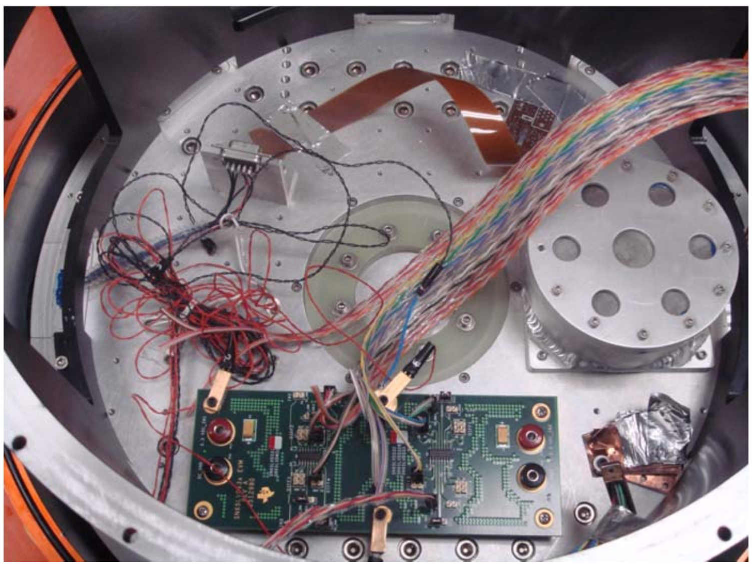


Figure 16. Cryogenic signal integrity test setup.

The layout of the components for the cold fanout board is shown in Figure 17. In this figure, the left-hand side of the 8"x8" board shows the three 100-pin micro-D connectors used for input, output, and power. The right-hand side shows the four high-density connectors that mate with the detector flex packages. In between are the LVDS receiver and driver chips, FPGAs, temperature sensors, and the test connector.

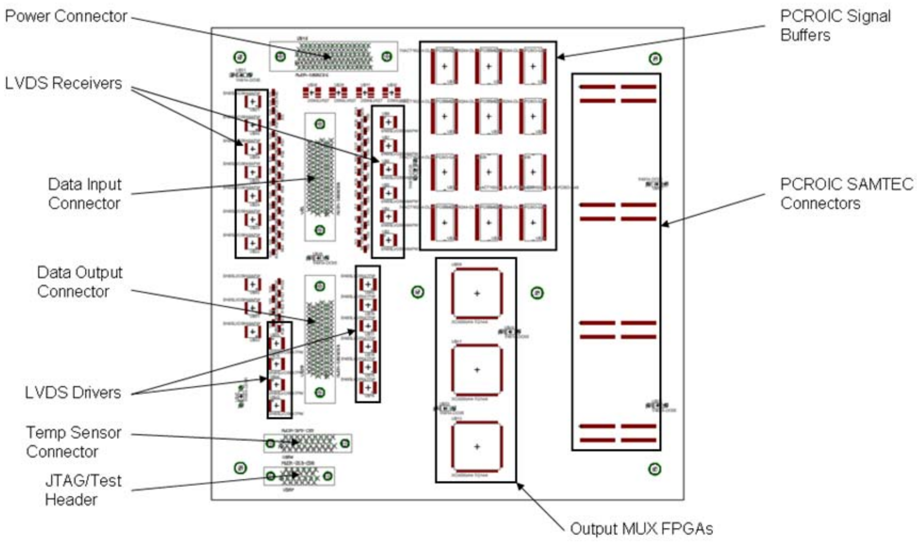


Figure 17. Cold electronics fanout board layout.

Mechanical fixtures were designed and fabricated to facilitate testing the detectors at both the radiation facility and the RIDL. The design allows the detectors to be operated at temperatures of approximately 70 K up to room temperature (300 K). CfD Student Research Andrew Komendat performed a thermal finite element analysis of the mounting structure shown in Figure 14. His analysis (see Figure 18) demonstrates that the detectors can be staged at the appropriate temperature, given the radiation load on them.

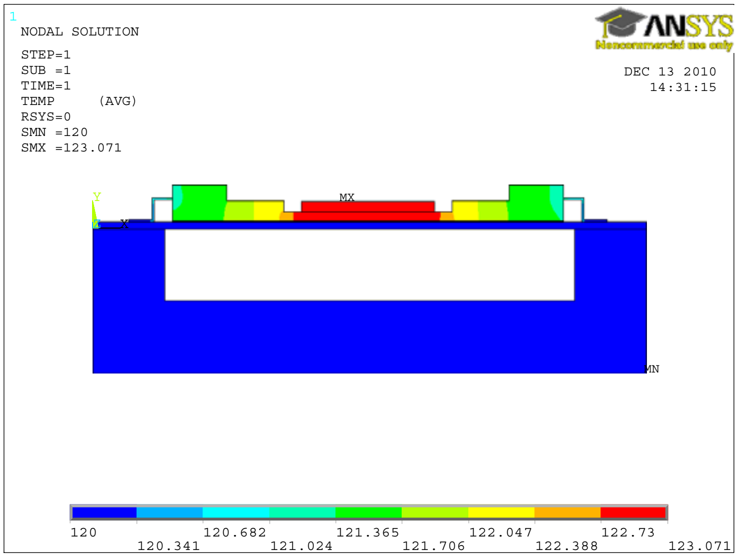


Figure 18. Results of thermal finite element analysis showing steady state temperature gradients between the mounting raft (blue) and the detector (red). The amplitude of the gradient is acceptable.

High School Student Explorations of Planetary: Surfaces in Digital Immersive Worlds

NASA

A group of 15-20 high school students came to the Rochester Institute of Technology campus to create explorations of planetary surface data that can be displayed in a digital immersive environment "as if you were really there." In this way, we engaged the high school students in planetary science topics and involve them directly in using and exploring the vast array of SMD planetary data.

A Photon Counting Detector for Exoplanet Missions

NASA/Technology Development for Exoplanet Missions

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. A photon counting detector will provide zero read noise, ultra-high dynamic range, and ideal linearity over the relevant flux range of interest. It could be the best realizable detector for a planet finding spectrograph, and it would have outstanding properties as a wavefront sensor or detector in the imaging focal plane. The benefit of this device is that it will dramatically improve sensitivity beyond what is capable with non-photon counting detectors, thereby increasing science return for a fixed mission life. Also, for low-light-level cases such as spectroscopy, the device will reduce the necessary exposure time for detecting planetary features by 50-80%. The device always operates in photon counting mode and therefore it is not susceptible to the excess noise factor that afflicts other technologies. It continues operating with shot-noise-limited performance up to extremely high flux levels. Its performance is expected to be maintained at a high level throughout mission lifetime in the presence of the expected radiation dose.

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. To estimate the radiation effects, it is necessary to first calculate the total ionizing dose (TID) and the displacement damage dose (DDD) seen by the detector on orbit and relate those quantities to the radiation effects on the detector. The expected radiation dose on the detector is calculated by performing simulation using a radiation transport code called

Mulassis, a GEANT4-based simulation package. Simulation results are shown in Figure 19. The radiation dose at L2 (and by extension, the other orbits) is relatively benign, equivalent to ~1 krad for the five year mission assuming 1 cm thick aluminum shielding. Given this level of dose, ~5-10 ions/s/cm^2 will produce "false" events. Having simulated the associated damage to the detector, 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.

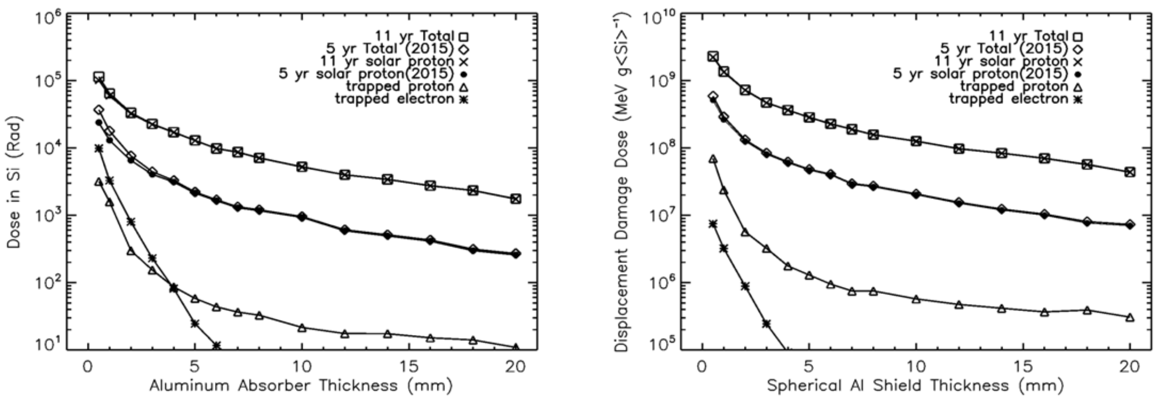


Figure 19. Cumulative total ionizing dose (left) and nonionizing dose (right) of space radiation for a five-year and an eleven year mission at L2 versus shield thickness, for spherically-shaped aluminum shielding. For a shield thickness of 1 cm, the total expected ionizing dose is approximately ~1 (5) krad (Si) for a 5 (11) year mission.

Completed Projects

A Very Low Noise CMOS Detector Design for NASA

NASA/Astronomy and Physics Research and Analysis

The goals for this project were to design, fabricate, and test a novel new detector for NASA space missions. These missions rely on low noise array detectors that must operate in the harsh radiation environment of space. Our device was intended to deliver lower noise, lower power consumption, and greater radiation immunity than presently available CCD and CMOS detectors. The low noise readout is achieved by using a sigma-delta (ΣΔ) analog-to-digital (A/D) circuit. The keys to the low noise readout are the close proximity of the conversion circuit to where the photogenerated charge is stored, its oversampling nature, and the noise-shaping property of the ΣΔ A/D converter. These properties allow our design to highly attenuate the photodetector reset noise, DC offset related fixed-pattern noise, and readout transistor thermal and 1/f noise. We estimated single read noise of <1 electrons, consistent with model predictions. We have demonstrated power consumption of 0.88 nW per pixel, or three orders of magnitude less than in the most advanced CCDs and more than one order of magnitude less than in presently available CMOS detectors. In addition, our design shows inherent linear response to the incident photon flux (i.e., the design is insensitive to non-linear capacitance of the photodetectors). This feature allows further reduction in power supply voltage (i.e., photodetectors do not require high biasing voltages to stay in their linear regime), which in turn reduces junction and gate leakage currents of the readout transistors and improves low-light response.

Progress was on schedule, in budget, and consistent with performance predictions in the original proposal. The project is done, and most work has been completed. During the project, five new ROICs were fabricated (MOSIS1 through MOSIS5). MOSIS1 through 3 contains test readout circuits and hybridization features. MOSIS4 is a final device that contains integrated photodiodes, i.e. it is "monolithic," and was made for another project. MOSIS5 shares the same readout circuit as MOSIS4, but it has metal pads that allow for bump bonding to an external diode array, i.e. it is a "hybrid."

The final designs significantly improved upon designs (MOSIS1 through 3) made earlier in this project by integrating an on-board digital-to-analog converter (DAC). This feature should reduce read noise by eliminating the need to transmit small analog voltages from external electronics to the device. It also provides for an "all-digital" focal plane in which input signals are in parallel digital format and the output signal is in serial digital format. The only analog signals are related to device power and the rail voltages of the on-board DAC.

There was significant progress in developing the photodiode array during the project. The array was designed and simulated using in-house semiconductor simulation tools. The part was fabricated at the RIT foundry, and after several iterations, it has very low dark current. Demonstrating a complete development sequence, from requirements to the final part, using in-house capabilities was a major achievement of this project.

The hybridization process was developed during this project. After iteration with dummy parts, the process was found to be largely successful, repeatable, and affordable. It relies on unique assets at a nearby partner organization that is state-funded and a small east coast company. There remains one puzzle related to hybridization concerning apparent high contact resistance which is reduced by a factor of one million when significant current is passed through the contact. This phenomenon has been seen before in other hybridization efforts, and it can likely be eliminated through additional engineering.

Another significant development was the fabrication of digital external readout electronics. This system is based on field-programmable gate arrays (FPGAs) and provides very flexible control. A new system was integrated, and two iterations of circuit boards were developed to interface the FPGA system to the detector. The first board was wired by hand, resulting in relatively high noise, whereas the second board was printed and fabricated by a circuit board manufacturer. This second board reduced the measured noise. In addition, new detector circuit boards were designed and fabricated. These boards have sockets for the detectors, and they are used in the vacuum cryogenic environment.

The most important performance characteristic for this project is read noise. It has been shown to be ~<10 e^- RMS. The measured noise is likely dominated by external electronics system noise, and the device noise is likely <4 e^-, as shown by testing with alternate external electronics. While this is significantly lower than the read noise for existing designs, it is still not as low as the proposed goal of 1 e^-. Further development and testing would be required to ensure that this is the case. The remaining performance characteristics need to be measured with the hybridized array.

A Radiation Tolerant Detector for NASA Planetary Missions

NASA/Planetary Instrument Definition and Development Program

In collaboration with the University of Rochester, the RIDL developed a very low noise CMOS imaging detectors for NASA space astrophysics and planetary missions. These devices promise sub-electron read noise in a direct-readout architecture that is resilient against the transient and long-term effects of radiation. The novel readout circuit (see Figure 20) uses a one-bit ΣΔ oversampling comparator design developed by Zeljko Ignjatovic and Mark Bocko (University of Rochester). The light-sensitive silicon wafer was designed and fabricated by CfD and the RIT Semiconductor & Microsystems Fabrication Laboratory (SMFL). NASA Jet Propulsion Laboratory (JPL) delta-doped the backside of the detector for enhanced ultraviolet sensitivity.

During the course of the project, we successfully tested the functionality and the performance of the project's second CMOS ROIC design (hereafter referred to as MOSIS3). Tests were done in both active pixel sensor (APS) analog and ΣΔ digital readout modes and included full array readout, row and column reset, photosensitivity, gain, dark current, and read noise. JPL developed the backside-thinning and delta-doping process which was used to fabricate the final back-illuminated detector. These processes enhance response to ultraviolet light. JPL thinned multiple MOSIS3 chips using two different etch processes. RIT has tested the functionality and performance of pre- and post-thinned chips to assist in determining the final process. JPL is also making progress in the development of the delta doping process and the final packaging. The final CMOS ROIC (MOSIS4) was delivered to RIT in March 2010 for characterization and testing. The capacitance of the final photodiode was lowered from approximately 30 fF to 23 fF to increase the unit cell gain and lower the effective read noise in units of electrons. We incorporated an on-chip DAC to reduce input noise to the ΣΔ circuit, which should also lower the effective read noise of the detector. JPL thinned, delta-doped, and packaged the final detector in February, 2011. The final packaged detector was then tested at RIT.

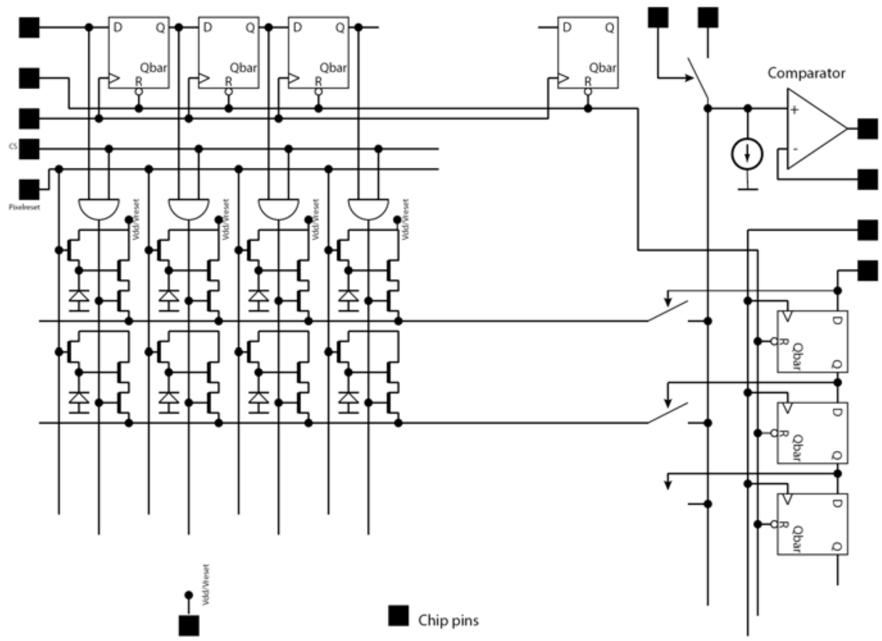


Figure 20. Partial schematic of the readout integrated circuit design. Note that in this picture, the diode symbol represents the photodiode in the light sensitive material.

The Journey of a Photon

NASA

CfD engaged students from the high school class of 2010 in developing an immersive planetarium experience - The Journey of a Photon - focused on astronomy and detector science. The students developed an exhibit for the Rochester Museum and Science Center to correspond with the International Year of Astronomy and the COPUS Year of Science (and also with the students' senior year). The project fostered relationships between students, their science teachers, their local scientific community, their local science center, and their local community in general (as the audience of their final production).

A NICMOS Survey of Newly-Identified Young Massive Clusters

NASA/Space Telescope Science Institute

We are on the cusp of a revolution in massive star research triggered by 2MASS and Spitzer/GLIMPSE, and this project capitalized on these projects by performing the first survey of massive stars in young stellar clusters throughout the Galactic plane. A search of the 2MASS and GLIMPSE surveys has produced over 450 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 in broad and narrow band filters using NICMOS. The observations will be complemented with approved Spitzer and Chandra programs, numerous approved and planned groundbased 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 nature of the first stars in the Universe.

The Nature of GLIMPSE 81a Star Cluster to Rival Westerlund 1

CXC/Chandra

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.

Characterization of Silicon Geiger-Mode Avalanche Photodiodes with Novel Device Architecture

BAE Systems, Inc.

Geiger-mode avalanche photodiode (GM APD) detectors are capable of counting single photons, measuring arrival times in high resolution, and generating zero read noise (when operated with a CMOS digital readout circuit) due to their unique internal gain characteristics. These capabilities make them exceptionally suited to tasks that require precise arrival time measurements or characterization of faint signals (low photon flux). Laser ranging systems use their arrival time measurement capabilities to build three-dimensional images, while adaptive optics applications have recently begun to capitalize on their low noise and high-speed operation for correcting wavefront imperfections due to atmospheric interference. There is now growing interest in using GM APDs for imaging applications where accurate measurements of faint signals are necessary, such as in astronomy. MIT/Lincoln Laboratory and the RIT Center for Detectors have developed silicon GM APDs with unique architecture, utilizing scupper regions, to minimize spurious signal.

This project investigated the performance of these detectors in terms of dark count rate (DCR). 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.

Specialized test circuitry was used with a customized data acquisition technique, and PhD Student Kimberly Kolb developed a method for deriving detector performance characteristics from the raw experimental data. Kolb also developed a simulation program to approximate the dark count rate (among other parameters) of a device based on semiconductor characteristics and testing conditions. This simulation allowed some investigation into the underlying mechanisms that and how individual carrier generation mechanisms affect device performance.

Historical Projects (Completed Before Last Year)

Applying Detector Advances to LSST Camera

NSF/UC Davis

The LSST focal plane array (FPA) consists of an order of magnitude more pixels than any imaging array realized so far. The sensors must produce low read noise, high QE at 1 micron, and a very tight PSF. This is necessary to do the science at the LSST. For an FPA having over 200 large format (4K×4K) sensors, an industrial approach has to be developed and adopted. In this initial phase of sensor development, we targeted specific technology experiments at selected vendors, with the goal of establishing both the technical characteristics of actual sensors, based on our projected requirements, and the industrial feasibility of their production. CfD did the first characterization of silicon PIN CMOS array detectors for this project. This included lab testing and testing at the National Observatory 2.1 m telescope in three separate observing runs.

The Most Massive Stars

NASA/Long-Term Space Astrophysics Program

Until the Spitzer Space Telescope, there was no wide area survey that could identify massive stars at all distances in the Galaxy. Indeed, the sample of known O-stars is woefully incomplete, as it has largely been generated using optical observations that suffer from the absorption produced by dust in the disk. We found and measured the physical properties of the most massive stars in the Galaxy using HST, Spitzer, Chandra, SOFIA, and ground-based observatories, using a survey technique that probes the majority of the Galaxy. This program provided five years of funding to address fundamental questions whose answers are basic requirements for studying many of the most important topics in Astrophysics: the formation and evolution of the most massive stars, the effects of massive stars on lower mass protostellar/protoplanetary systems, gamma-ray burst progenitors, nature of the first stars in the Universe, chemical enrichment of the interstellar medium, Galactic gas dynamics, and star formation in starbursts and merging galaxies (particularly in the early Universe). The results of our program will influence the science programs for future NASA projects, i.e. JWST, SOFIA, SIM, TPF-C, and TPC-I.

Faculty Development Program

New York State Technology and Innovation Foundation for Science

Through the Faculty Development Program of the New York State Office of Science, Technology and Academic Research, the Rochester Institute of Technology recruited Dr. Donald Figer to build the Rochester Imaging Detector Laboratory in 2006. The funding leveraged the State's research expertise in imaging and grew the intellectual and technological capital of our state. This funding culminated in the founding of the Center for Detectors. The amount of additional external funding received as a result of this grant was a factor of ten times greater than the amount of funding in the original grant.

Mid-Infrared Spectroscopy of the Most Massive Stars

NASA/Spitzer Science Center

The most massive star that can form is presently defined by observations of a class of very rare stars having inferred initial masses of ~200 solar masses. There are only a few such stars in the Galaxy, including the Pistol Star, FMM362, and LBV 1806-20, the first two being located near the Galactic center, and third located in the disk near W31. Each has only recently been identified as so massive within the past 10 years through the analysis of infrared observations, but they are otherwise too faint, due to extinction, to observe at shorter wavelengths. These stars appear to be very luminous ($L>10^{6.3}$ solar luminosities), "blue" ($T>10,000$ K), and variable ($\Delta K \sim 1$ mag.), and the Pistol Star has ejected 10 solar masses of material in the past 10000 years. In addition, these stars have near-infrared spectra similar to those of prototypical Luminous Blue Variables, i.e. Eta Car and AG Car. Given their apparent violation of the Humphries-Davidson limit, they are presumably in a short-lived phase of stellar evolution that is often associated with rapid mass-loss through episodic eruptions of their outer atmospheres. We determined the physical properties of these stars and the velocity and ionization structure in their winds by using spectra obtained with the high resolution modes of the Infrared Spectrograph on the Spitzer Space Telescope. The 10 to 40 μm wavelength region is ideally suited for accessing a variety of lines from transitions of hydrogen, helium, iron, silicon, sulfur, among others; indeed, through our models, we predict that sufficiently sensitive spectra will yield over 300 spectral lines. We found that the mid-infrared continuum is dominated by free-free emission generated in the thick winds associated with these stars, an effect that should be clearly detectable in the spectra.

Massive Star Clusters

NASA/Spitzer Science Center

CfD used 13 hours of observing time on the Spitzer Space Telescope to image candidate massive star clusters in all four Infrared Array Camera channels. We increased the numbers of massive stars known in the Galaxy, including main sequence OB stars and post-main sequence stars in the Luminous Blue Variable and Wolf-Rayet stages. Like the HST/NICMOS project, this program addressed fundamental questions whose answers are basic requirements for studying many of the most important topics in Astrophysics: the slope to the initial mass function (IMF), an upper mass cutoff to the IMF, the formation and evolution of the most massive stars, the effects of massive stars on lower mass protostellar/protoplanetary systems, gamma-ray burst progenitors, nature of the first stars in the Universe, chemical enrichment of the interstellar medium, Galactic gas dynamics, star formation in starbursts and merging galaxies (particularly in the early Universe). The program was timely in that the young cluster targets have only recently been discovered and are going to be the subject of intense observations with Spitzer and Chandra, as well as numerous approved and planned ground-based spectroscopic and radio observations. In this project, CfD led an experienced team who have previously performed similar studies on much smaller samples, including the massive young clusters in the Galactic center, the Arches and Quintuplet cluster.

The Pre-Supernova Mass-Loss Behavior of Red Supergiants

NASA/Spitzer Science Center

The mass lost by massive stars as they pass through the Red Supergiant (RSG) phase is a crucial determinant in the terminal mass of the star, the nature of the resulting supernova explosion and the stellar end-state. However, up until now studies of this quantity have been problematic, owing to the low numbers of known RSGs and the difficulty of observing in the mid-IR. In this project, we capitalized on the recent discoveries of two remarkable Galactic clusters containing unprecedented numbers of RSGs, and use the capabilities of Spitzer to undertake a comprehensive and unique study of the pre-supernova (SN) mass-loss of massive stars. We used Spitzer Infrared Spectrograph observations in conjunction with state-of-the-art dust models to provide the first quantitative investigation of the mass and composition of the pre-SN ejecta as a function of age and metallicity. This study was vital in determining the mass-loss behavior of RSGs and the nature of supernova progenitors.

Research and Development related to the Large Synoptic Survey Telescope (LSST) Camera

DOE/Stanford Linear Accelerator

This work included evaluating the Large Synoptic Survey Telescope (LSST) guider prototypes in the Rochester Imaging Detector Laboratory. RIT's role in the camera effort was to develop, in partnership with the Stanford Linear Accelerator, and partner organizations, the guider sensor needed to complete the R&D phase of LSST. CfD evaluated Teledyne H4RG or H2RG plus a SIDECAR ASIC, and a final report was delivered to the LSST project. The test report included performance measurements for parameters that are relevant to the LSST Guider application, including: dark current, read noise, quantum efficiency, inter-pixel capacitance, well depth, and linearity. These measurements were reported for full-frame readout, as well as window mode readout. In addition the measurements were reported over a range of operating conditions, i.e. flux levels, wavelengths, temperature, and readout speed.

Sandia FPGA Imaging Acquisition Software Development

DOE/Sandia National Laboratories

CfD Student Researchers wrote HDL (Hardware Description Language) software for a FPGA (Field Programmable Gate Array) evaluation board for Sandia National Laboratories. The HDL software programs the FPGA chip to transfer digital video rate image data from the evaluation board to a windows based PC using the Camera Link, Ethernet, Firewire, and USB protocols. Data acquisition software for the PC was developed to capture and display the imagery on the PC.

Multi-wavelength Observational Astrophysics Program

The observational astronomy group in the CfD has been very successful at winning the telescope observing time that is crucial for making further discoveries. A list of this observing time is given in the following table.

List of Observing Runs over Past Five Years				
2006	*An elevated lower mass cutoff in the Galactic Center*	Keck	Kudritzki/Figer	2 nights
	A possible supermassive cluster in the Milky Way	TNG	Najarro/Figer	2 nights
	Infrared Spectroscopy of Two Extraordinarily Massive Clusters of RSGs	Keck	Kudritzki/Figer	1 night
	IRMOS Spectroscopy of the Most Massive Stellar Clusters	KPNO	MacKenty/Figer	5 nights
	A Star Cluster as a Supernova Factory	Chandra	Muno/Figer	40 ks
	MAssive Stars in Galactic Obscured MAssive clusterS (MASGOMAS)	WHT	Najarro/Herrero	4 nights
	Searching for Pulsars in Massive Young Star Clusters	GBT	Muno/Figer	16 hours
2007	*Massive Star Clusters*	Spitzer	Figer	11 hours
	A NICMOS survey of newly-discovered young massive clusters	HST	Figer/Davies	29 orbits
	The IMF cutoff: testing the singularity of the most massive stars in the Galaxy.	Keck	Kudritzki/Davies	1 night
	MAssive Stars in Galactic Obscured MAssive clusterS (MASGOMAS)	WHT	Najarro/Herrero	3 nights
	The Blue Supergiant population of Galactic clusters	UKIRT	Kudritzki/Messineo	3 nights
	Sofl Spectroscopy of Newly Discovered Star Clusters	ESO/NTT	Davies	3 nights
	Constraining the Distances to Massive Galactic Star Clusters	VLA	Law/Figer	14 hours
2008	*The pre-supernova mass-loss of RSGs*	Spitzer	Figer/Davies	17 hours
	Gas Motions in UCHII Regions Indicated by H2 Pure Rotational Lines	IRTF	Zhu/Figer	2 nights
	MAssive Stars in Galactic Obscured MAssive clusterS (MASGOMAS)	WHT	Najarro/Herrero	4 nights
	The Initial Mass of a Magnetar	Keck	Kudritzki/Figer	0.5 nights
	Radio Emission From Young Massive Stellar Clusters in our Galaxy	VLA	Lang/Messineo	7 hours
	SiO maser emission from red supergiants in the RSG3 open cluster	IRAM	Messineo	3 hours
	The stellar content and formation history of the Giant HII region W51	KPNO	Davies	6 nights
2009	*The Nature Of Glimpse 81: A Star Cluster To Rival Westerlund 1?*	Chandra	Figer/Davies	30 ks
	Formation of massive stars	VLT	Messineo	11 hours
	MAssive Stars in Galactic Obscured MAssive clusterS (MASGOMAS)	WHT	Najarro/Herrero	3 nights
	Low-mass Wolf-Rayet stars: searching for the products of close-binary evolution	VLT	Davies	3 hours
	Chemical Cartography of the Milky Way	VLT	Puga	32 hours
2010	*Clumping in OB-star Winds*	Herschel	Rubio/Najarro	9 hours
	Pilot Study of LGSAO Infrared Slitless Spectroscopy for Determining the High Mass IMF of Young Star Clusters	Keck	Figer/Trombley	1 hour
	Massive Stars in the Quintuplet	Gemini	Geballe/Figer	1 night

The Future Photon Initiative: A National Center Proposal

The CfD, and a large group of collaborating institutions, submitted a proposal to the National Science Foundation entitled, "The Future Photon Initiative." The research institutions teamed to propose a new national center for advancing quantum detectors, quantum photovoltaics, and quantum photonics (Figure 21). This $50M national center will fuse breakthroughs in nano and quantum science to exploit all the properties of a photon and transform human perception, energy generation, and communication. FPI will catalyze the transition of light detection from traditional analog techniques that average many photons to a new paradigm in which each photon is digitally detected or converted into energy. Within the next ten years, and with a mandate for establishing the future of photon devices, the FPI will create the intellectual basis for near "perfect" detectors that will be noiseless and quantum-limited, constrained only by the fundamental nature of photons. These devices will detect each photon that strikes them, with spatial uniformity and ~100% detection sensitivity to all wavelengths from ultraviolet to infrared. They will characterize each photon – measuring energy, polarization, and arrival time – vastly improving capabilities to answer some of today's most intriguing scientific questions and vexing societal problems. Advances in other devices will allow for much more of the photon energy to be converted into electricity.

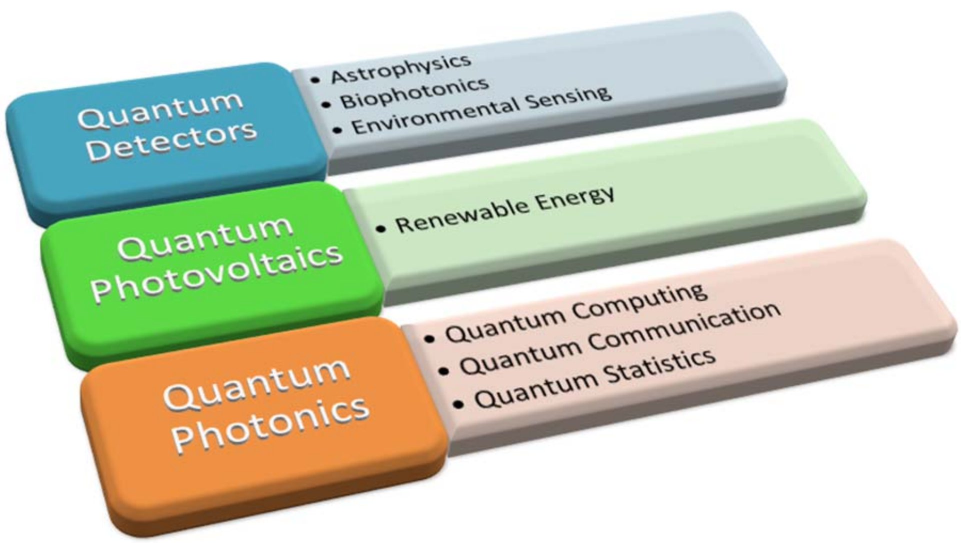


Figure 21. The Future Photon Initiative will research photon science with applications ranging from study of the Universe, to more down to Earth solar cell technology, homeland security, and quantum communications.

CfD Partners for the Future Photon Initiative		
Category	Organization	
Academic Institutions	Rochester Institute of Technology	
	University of Hawaii	
	University of California, Irvine	
	University of New Mexico	
	University of Rochester	
National Laboratories	Jet Propulsion Laboratory	
	NREL	
	NASA/Glenn	
	ARL/Adelphi (SEDD)	
	NRL	
	MIT/Lincoln Lab	
Industry	Ball Aerospace & Technology	
	ITT Corporation	
	Kodak	
	Teledyne Imaging Sensors	
	Alcatel/Lucent	
	Raytheon Vision Systems	
	Goodrich	
	Intel	
	FLIR	
	Princeton Lightwave	
	Emcore Photovoltaics	
	GE Global Research	
	BAE Systems	
International Institutions	Australia	U. Sydney
	China	U. of Science and Tech. of China
		Tsinghua U.
		Institute of High Energy Physics
		National Astronomical Observatories
	Korea	Kyung Hee U.
	India	The Inter-University Centre for Astronomy and Astrophysics
	Brazil	Laboratório Nacional de Astrofísica
		Instituto de Astronomia, University of Sao Paulo
		Polytechnic School of University of Sao Paulo
	Spain	Consejo Superior de Investigaciones Científicas
		Instituto de Astrofísica de Canarias
	UK	Heriot-Watt University
	Netherlands	Kavli Institute of Nanoscience, Delft
	Japan	National-Tsukuba University of Technology
	China	Tianjin Technical College for the Deaf
	Russia	Bauman Moscow State Technical University

Christine Trombley

Christine Trombley is a graduate student member of the Center for Detectors who is pursuing a PhD in the Astrophysical Sciences and Technology program. She completed a BS degree in Astrophysics and Physics at Michigan State University in 2007.

Her first involvement with 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.

Christine has experience reducing and analyzing a variety of multiwavelength astrophysical observations, from radio to X-ray. Expanding on code developed by Dr. Donald Figer, she has reduced near-infrared spectroscopy from NIRSPEC at Keck. As her work is primarily on young, massive stellar clusters, Ms. Trombley has done extensive research involving crowded-field photometry (measuring the light from each star which falls onto the detector). An example of a crowded field is shown to the right (Figure 22), the stellar cluster Mercer 5, a laser guide star adaptive optics near-infrared image taken by NIRC2 at Keck II.

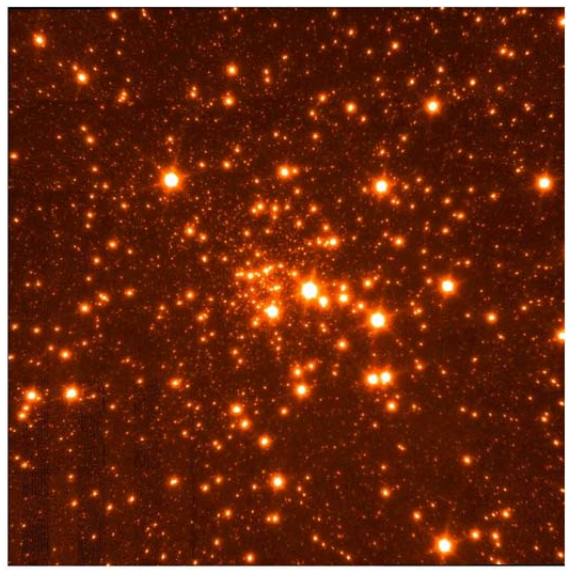


Figure 22. Laser Guide Star Adaptive Optics Keck II near-infrared image of the Mercer 5 stellar cluster.

Ms. Trombley is investigating the slope of the high end initial mass function (IMF) in a sample of 12 young, potentially massive stellar clusters for her PhD thesis. She will utilize 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 will calibrate the mass-magnitude relation of stars in each cluster, then construct IMFs. The IMF has been shown to be nearly universal at lower mass ranges, and Christine's work will investigate whether that relation holds at the high mass range.

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 summer, 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 through fabrication, characterization, and implementation.

Her first involvement with CfD was 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 prestigious 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 an SPIE paper and conference presentation (summer, 2010) of her work. Kimberly also completed an internship at BAE Systems in the summer of 2010, working on infrared detector fabrication and process improvement.

For her master's work, Kimberly characterized GM-APDs by using specialized test circuitry with a customized data acquisition technique, developing a method for parameter extraction from the raw data, and examining device characteristics derived from the experimental results (see Figure 23). 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. Ms. Kolb investigated the dark count rate of these detectors and reported the results in her thesis.

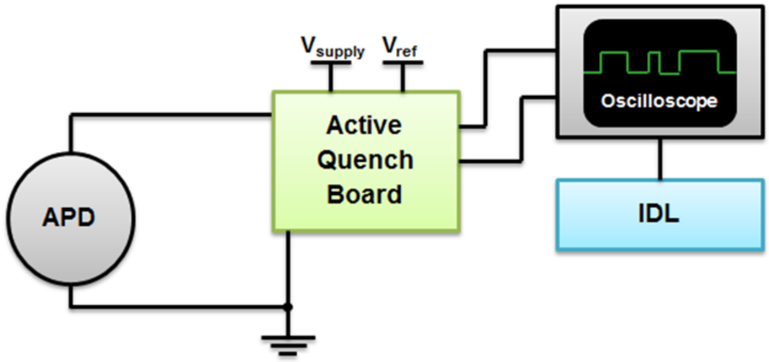


Figure 23. The schematic shows the customized data acquisition method for Ms. Kolb's measurements.

Figure 24 shows an example of experimental results derived from raw data collected. 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 (the contribution of which is shown in Figure 24), 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.

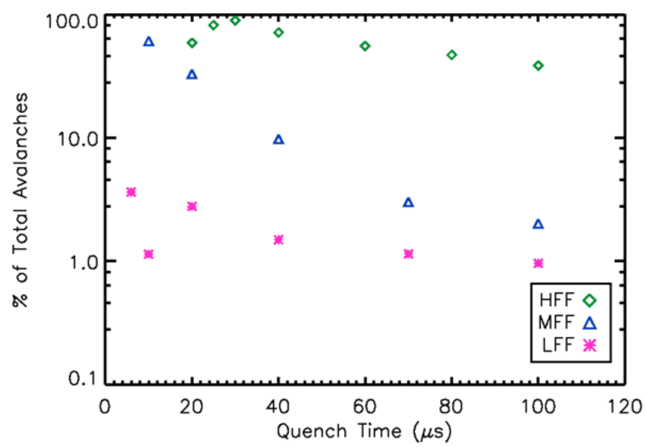


Figure 24. The plot shows experimental results for self-retriggering noise contributions; LFF, MFF, and HFF represent different device types.

Chris Maloney

Chris Maloney, a recent graduate of the undergraduate Microelectronic Engineering program at RIT, completed his senior capstone project in the Center for Detectors in 2011. His project entailed the characterization of a 32×32 pixel Geiger-mode avalanche photodiode (GM-APD) array for LIDAR imaging. GM-APDs are a promising technology for photon-starved applications due to their high sensitivity and zero read noise. Chris endeavored to extract key parameters, verifying effective and efficient operation of the detector in a LIDAR system. In particular, Chris measured diode uniformity, IV characteristics, trap quantity, and dark count rate. He has gone on to join the RIT Microsystems Engineering PhD program.

Chris also tested the detector for afterpulsing, a type of dark event, or false-positive. His results, which showed negligible afterpulsing contributions, indicated either a complete absence of traps or a very long trap lifetime. The project resulted in the means to test afterpulsing in devices provided by MIT/Lincoln Laboratory (Figure 26).

In addition to characterizing the GM-APD detector, Chris aided in the design of the imaging system. More specifically, Chris designed both the camera enclosure and optical system. This process involved definition and derivation of requirements, modeling, parts selection, and assembly.

In October 2010, Chris attended the Frontiers in Optics 2010/Laser Science XXVI conference in Rochester, NY. As Chris was researching LIDAR systems in the Center for Detectors, he was very interested in attending this conference and wrote a short article for the student chapter of the American Physical Society (APS) detailing his experiences. One of the talks he attended was the Environmental Applications of Lasers portion of the Industrial Physics Forum, which featured an invited talk by James B. Abshire from the NASA Goddard Space Flight Center (Figure 25). Abshire discussed NASA's use of LIDAR imaging for measurements of Earth and other planetary surfaces; this included an overview of past, present, and future applications of LIDAR for measurements of planetary surfaces. The majority of these applications use laser altimetry in order to build a topographical map of any surface, from the canyons of Mars to arctic ice sheets.

Figure 25. NASA Goddard's James Abshire (left) poses with APS reporter Chris Maloney.

Afterwards, Chris had the opportunity to personally speak with Abshire. Chris learned that Abshire's co-op work at NASA as a student allowed him to continue working there full-time after graduation.

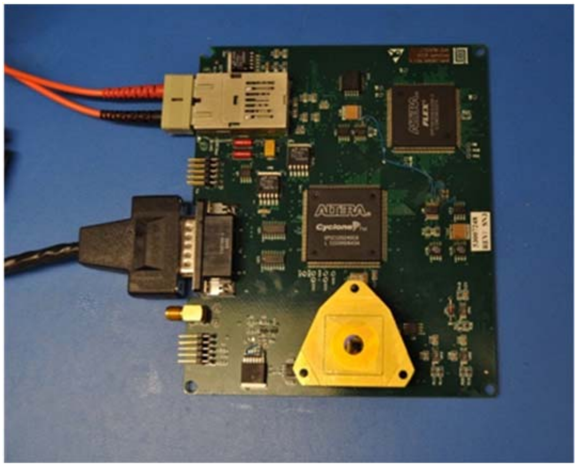


Figure 26. Readout board and detector, both from MIT/Lincoln Laboratories.

Ross Robinson

Ross Robinson is a graduate student who is pursuing a PhD in the Imaging Science program. Ross is enhancing focal plane array quantum efficiency with quantum dots. Current silicon CMOS or CCD based detectors used in standard digital cameras do a poor job of recording UV light. The ability to detect UV light may be improved by using exotic materials or by polishing the detector until it is so thin that it is flexible and almost transparent. Both of those options are very expensive to fabricate. A different approach is to apply a coating of nanometer-scale materials to the surface of a detector to convert the UV light into visible light, which is more readily recorded by standard detector chips (Figure 27). This research has developed a method of coating detector arrays with nanomaterials and applied it to improve the ability of detectors to record UV and blue light.

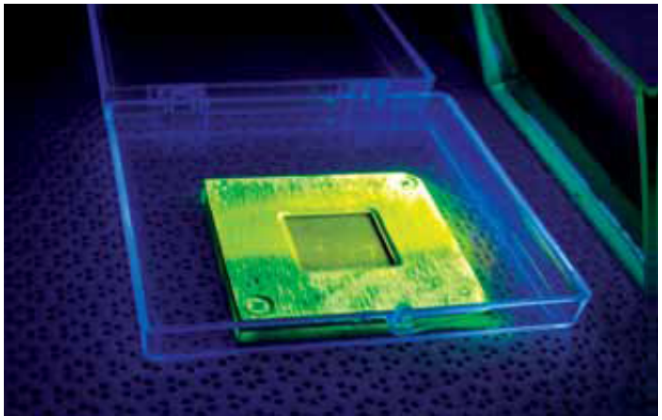


Figure 27. Quantum Dot coated detector in aluminum mask under UV illumination.

Christopher G. Shea

Christopher G. Shea recently obtained his Master of Science degree in Microelectronic Engineering at RIT. In 2009, Chris completed his Bachelor of Science in Microelectronic Engineering at RIT that included a six-month internship at the Interuniversity Microelectronics Center (IMEC), an international semiconductor research center located in Leuven, Belgium. During his time at RIT Chris was a member of Dr. Karl D. Hirschman's Research group where he fabricated thin-film transistors (TFT) on glass substrates.

Chris first became involved with the CfD when he performed device simulations, an opportunity that led him to his thesis topic. A grant to develop a very low noise hybrid CMOS imaging system was awarded to CfD by NASA through the Astronomy and Physics Research and Analysis (APRA) Program of the Science Mission Directorate.

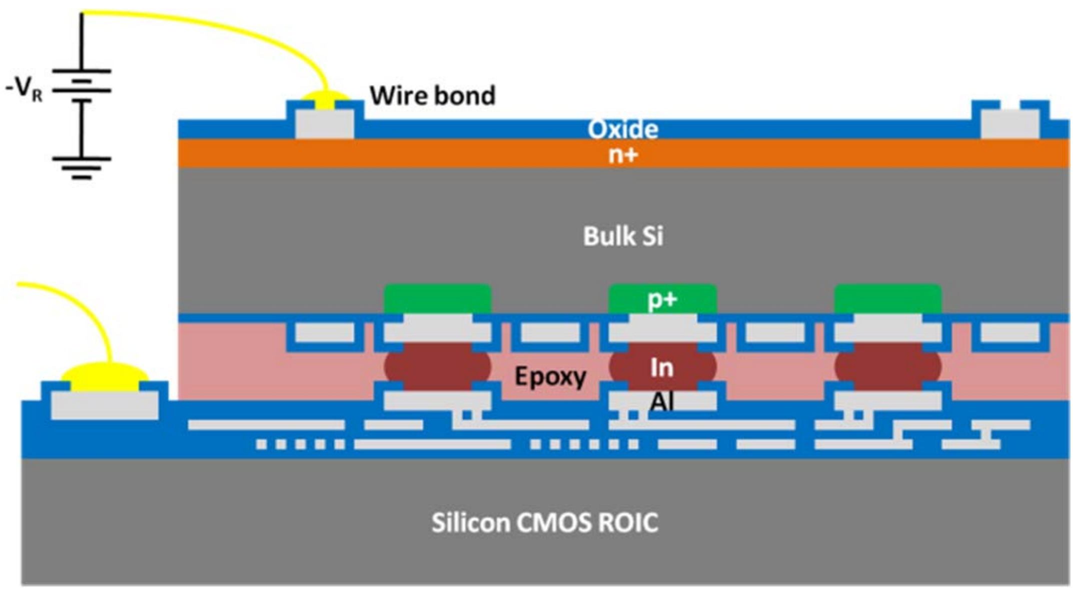


Figure 28. Schematic cross-section of hybrid detector

For his thesis, Chris developed the photodetector fabrication and hybridization process for the imaging system. The physics-based numerical Poisson solver Atlas from the technology computer-aided design (TCAD) software package SILVACO was used to simulate the optical and electrical behavior of a defined structure. Based upon previous work by Kim Kolb, a revised layout and fabrication sequence were created for the *p-i-n* diode array (Figure 28). Devices were characterized through electrical testing to determine reverse bias leakage uniformity and temperature dependence.

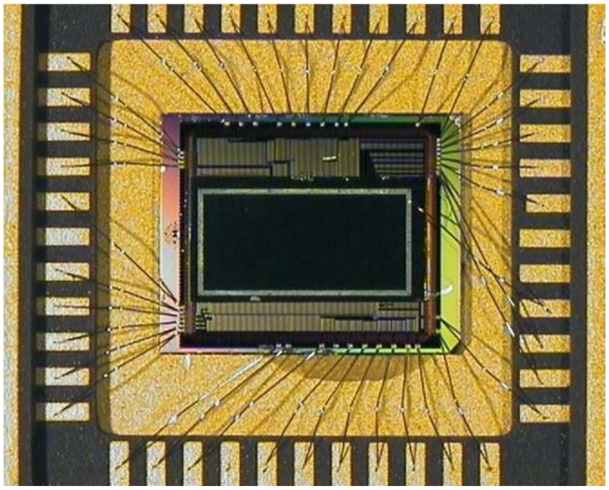


Figure 29. Top-down view of hybrid detector wire-bonded into package.

A hybridization scheme for the detector and ROIC was developed using indium as a bonding material in a flip-chip process. A multi-layer lift-off resist process was developed to pattern a thick indium layer in bump-bonds. The ROIC was prepared for hybridization by etching holes in the passivation layer. A Seuss FC-150 flip-chip bonder was used to mate the chips (Figure 29).

Brian Glod

Brian Glod earned his Bachelor's degree in Computer Engineering at RIT (2010) and is currently an Electrical Engineering master's student (expected 2012) working at the Center for Detectors. Brian's focus area is primarily within digital systems, but he also has an interest in analog design techniques. His skills include FPGA and embedded software development, as well as hardware and PCB design for low-noise applications.

Brian began at the Center for Detectors in March of 2009 as a lab technician responsible for general lab tasks and basic software development. During the summer of 2009, Brian continued as an undergraduate co-op responsible for designing the DDR memory interface and buffering schemes used for controlling the Low-Noise CMOS Imaging Detector project for NASA. After the co-op experience, Brian continued to develop FPGA acquisition code and became heavily involved in hardware design. Early-on, this involved the design of several printed circuit boards (PCBs) and mount apparatus for the Low-Noise Imaging Detector (Figure 30). These PCBs were intended to be operated within a dewar with exposure to temperatures and pressures as low as one nanotorr and 30 Kelvin. After much success in this area, his PCB design experience culminated in the schematic capture, verification, and PCB layout of a data acquisition board for the same CMOS detectors. The acquisition board was designed to interface with a TerASIC DE3 Development System featuring a Stratix III FPGA. The goal was to significantly reduce detector acquisition noise and was achieved by using careful layout techniques and ultra-low noise surface mount components. When completed, the board successfully reduced acquisition noise by 73%. With additional modifications, the board has potential for further noise reduction.

Brian is currently working on the "Zero Read Noise Detector for Thirty Meter Telescope" project funded by the Gordon and Betty Moore Foundation. For his Master's research, Brian is characterizing the fully integrated detector electronics system. Because the system is new and custom-designed for controlling and interrogating the high-fidelity detector array, it is crucial to understand its performance. Some points of interest include power consumption in various modes of operation, bit error rate testing (BERT) as a function of temperature and operating frequency; cable length and twist ratio (for twisted pair interconnects), and various communication paradigms. System performance will continue to be monitored during indirect radiation exposure. Armed with this data, the lab will better understand the system's behavior so that improvements to hardware design and data acquisition techniques may be developed.

Figure 30. Low-noise data acquisition board for use with the NASA Low-Noise Imaging Detectors.

John Breese

John Breese is an undergraduate student pursuing a dual degree in the BS/MS program for Computer Engineering (expected 2013) at Rochester Institute of Technology (RIT).

John did research in the CfD from March, 2010, to May, 2010, and from September, 2010, to the present. He assisted with the design of an FPGA-based system to control imaging detector characterization experiments. He also implemented a USB communications library in C/C++, which allows interaction with an FPGA experiment board from within the IDL programming environment. His other work includes the design of a helium strain relief plate, the fabrication and testing of cables, software installation and setup, identification and mitigation of security vulnerabilities.

John Frye

John Frye is a graduate student working at the Center for Detectors and is currently pursuing a MS degree in Computer Engineering at RIT. In addition to his skills in digital system design and implementation for ASICs and FPGAs, John has had significant experience with software development, embedded systems programming, and design automation. His specialization lies in fault and variation tolerant architectures for VLSI.

John began at the Center for Detectors in December, 2008, designing a hardware and software platform for multi-interface video acquisition with Sandia National Laboratories. Sandia commissioned the CfD to develop such a system in order to facilitate the field testing of specialized infrared cameras.

The system decodes several different camera video formats, buffers the data, and retransmits the data using the Camera Link and GigE protocols for digital video acquisition. Additionally, the video input is output via VGA and DVI for inspection. An integrated LCD display presents the system status at all times. Video acquisition and processing software was developed in the form of adapters for the MATLAB Imaging Acquisition Toolbox and a specialized MATLAB graphical user interface application. The system was successfully deployed by Sandia in September, 2010 (Figure 31).

Figure 31. RIDL-Link hardware and software platform for multi-interface video acquisition

John most recently worked on the NASA-funded Planetary Instrument Definition and Development Project (PIDDP) at the CfD. The project was funded with the goal of developing a novel LIDAR detector with properties surpassing what is currently available for NASA planetary missions. Consequently, the project involves developing a LIDAR detector, characterizing the detector, and designing a system with which to operate the detector. Collaborators at MIT/Lincoln Laboratory developed a detector array employing Geiger-Mode avalanche photodiodes (GM-APDs) with single-photon sensitivity. John has aided in development of the detector electronics, which include a readout board and a custom PCI frame grabber (Figure 32). These electronics are controlled via onboard Altera FPGAs and CPLDs, necessitating the development HDL code for successful operation. Additionally, he developed functionality and performance test plans, wrote a test suite in IDL, and characterized the detector for dark count rate, timing jitter, photon detection efficiency, and crosstalk.

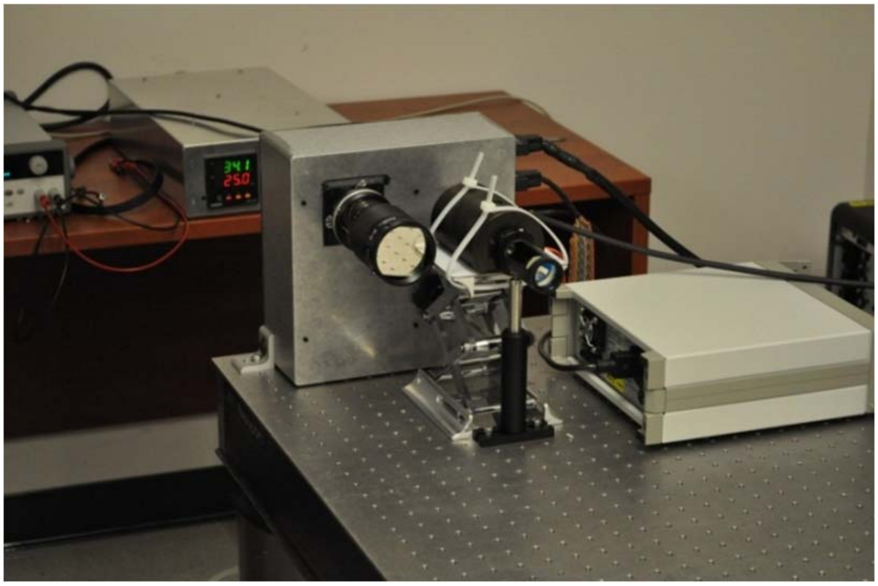


Figure 32. Photograph of the detector imaging setup showing the camera enclosure with mounted lens and filter, the laser head and power supply, the beam expander and collimator, and the power supply unit with mounted TE controller.

Kenny Fourspring

Kenny Fourspring is a graduate student who is pursuing a PhD in the Imaging Science program. This year, a NASA Graduate Student Research proposal was awarded to PhD student, Kenny Fourspring. He spent part of the year at NASA GSFC involved in low temperature testing of a Digital Micromirror Device (DMD) 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 investigate dark matter. The telescope will contain an infrared spectrometer. For a DMD to work effectively, it must be cooled to minimize the background. A packaged DMD was placed within a dewar, and the flatness across the array measured as the device was cooled. A functionality test was also performed before and after the cooling procedure to ensure that all pixels still functioned.

External Funding and Collaborating Partners

External funding has been strong in the most recent two years, when total funding has increasing by about 10% per year. Figure 33 shows funding per year since the inception of the Rochester Imaging Detector Laboratory in 2006. Colors correspond to projects. A breakdown of individual grants and contracts is given in the following pages.

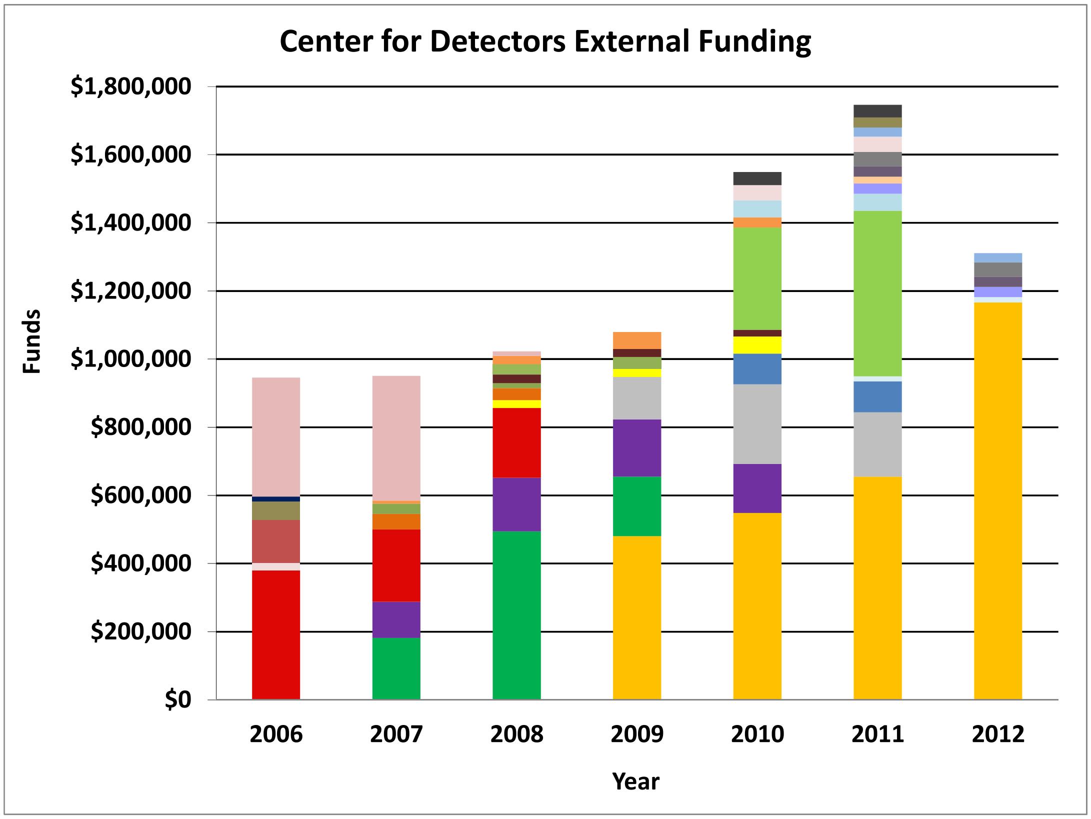


Figure 33. Since its inception in 2006, the Center for Detectors has received over $8.1 million in research funding. The largest contributions are from the Gordon and Betty Moore Foundation ($2.8M) and NASA ($5M).

Grants and Contracts - New

Title	Funding Source	Dates	Amount
Clumping in OB-star winds	NASA/Herschel	2/14/11-2/13/13	$9,112
NASA GSRP (Trombley)	NASA/GSRP	9/15/11-9/14/2012	$30,000
Enhancing Focal Plane Array Quantum Efficiency	Thermo Fisher Scientific and NYSTAR/CEIS	7/1/2011 - 6/30/2012	$27,000

Title	Funding Source	Dates	Amount
Virtual Scene and Target Generation and Tracking in the Infrared	ITT Corporation and NYSTAR/CEIS	7/1/2011 - 6/30/2012	$90,000
Advanced Imaging Arrays for Multi-Object Spectrometers Utilizing Digital Micromirrors	NASA	9/15/2010 - 9/14/2012	$60,000
Thermal Modeling of Vehicles	NYSTAR/CEIS	7/1/2010 - 6/30/2011	$85,000

Grants and Contracts - Ongoing

Title	Funding Source	Dates	Amount
A LIDAR Imaging Detector for NASA Planetary Missions	NASA/PIDDP	8/01/08-7/31/12	$546,712
Next Generation Imaging Detectors for Near- and Mid-IR Wavelength Telescopes	Gordon and Betty Moore Foundation	9/1/2008-8/31/2012	$2,839,190
High School Student Explorations of Planetary: Surfaces in Digital Immersive Worlds	NASA	9/1/09-7/31/12	$44,986
A Photon-Counting Detector for Exoplanet Missions	NASA/TDEM	2/19/10-2/18/12	$783,981
NASA GSRP (Fourspring)	NASA/GSRP	9/15/10-9/14/2011	$30,000
Enhancing the UV Sensitivity of CMOS Image Sensors	Thermo Fisher Scientific and NYSTAR/CEIS	7/1/2010 - 6/30/2011	$27,000
Multi-Object Spectrometer for Space Object Identification	ASE Optics Inc.	4/1/2010 - 3/28/2011	$29,092
[CEIS-CAT] Sensor Modeling and Demonstration of a Multi-Object Spectrometer	NYSTAR/CEIS	7/1/2009 - 6/30/2011	$75,000

Grants and Contracts - Completed within the Past Year

Title	Funding Source	Dates	Amount
A very low noise CMOS Detector Design for NASA	NASA/APRA	2/08/07-5/06/11	$847,000
Radiation Tolerant Detector for NASA Planetary Missions	NASA/PIDDP	6/25/07-6/24/11	$807,681
The Journey of a Photon: High School Student Involvement in Developing their Community's Understanding of Detector Science	NASA	6/25/07-7/24/11	$74,977
A NICMOS Survey of Newly-Identified Young Massive Clusters	NASA-STScI/HST	1/01/09-12/31/11	$180,449
MRI: Acquisition of two special-purpose computers for simulation of the galactic center environment	NSF	8/01/2008-7/31/2010	$116,131
The nature of GLIMPSE 81: a star cluster to rival Westerlund 1	CXC/Chandra	6/21/10-6/20/11	$35,768
Characterization of Silicon Geiger-Mode Avalanche Photodiodes with Novel Device Architecture	BAE Systems, Inc.	9/1/2009-5/31/2011	$80,806

Grants and Contracts - Historical (Completed Before Last Year)

Title	Funding Source	Dates	Amount
Applying Detector Advances to LSST Camera	NSF	1/01/06-7/31/07	$125,879
The Most Massive Stars	NASA/LTSA	2/15/06-2/14/10	$795,378
Faculty Development Program	New York State Technology and Innovation Foundation for Science	5/01/06-6/30/09	$727,900
IDTL SNAP Collaboration	DOE	5/01/06-11/30/06	$15,000

Title	Funding Source	Dates	Amount
Mid-Infrared Spectrometry of the Most Massive Stars	NASA-SSC/JPL	6/29/06-5/31/08	$21,812
Massive Star Clusters	NASA-SSC/JPL	8/14/06-9/30/09	$30,445
The Pre-Supernova Mass-Loss of RSGs	NASA-SSC/JPL	7/01/07-6/30/10	$80,801
KPNO Observations	Stanford University	10/01/07-2/28/08	$53,880
Research and Development related to the Large Synoptic Survey Telescope (LSST) Camera	DOE/SLAC	5/07/08-9/30/08	$25,000
Sandia FPGA Image Acquisition Software Development	Sandia National Laboratories	6/05/08-9/15/10	$95,115
[CAT] A Deterministic Approach to Back Thinning CMOS Sensors	NYSTAR/CEIS	7/1/2007 - 6/30/2008	$30,000
Enhancing Blue Response of Imaging Arrays Using Quantum Dots	Thermo Fisher Scientific	7/1/2008 - 6/30/2009	$10,000

Collaborating Partners

The Center for Detectors has a rich history of collaboration with organizations outside of RIT. These include partners in academia, such as University of Rochester, at national laboratories, such as NASA, and in industry, such as ITT. Our desire to collaborate flows from the fact that no single organization could accomplish the goals of our projects. Instead, the project teams are distributed across several organizations, each with its own world-class expertise and often significant infrastructure developed over decades of past projects.

As a side benefit of this collaboration, our students are exposed to a wide range of research and development environments. 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.

CfD is now seeking to expand its reach to collaborating organizations around the world, in particular, through the Global Initiative described in the Future Photon Initiative proposal to the National Science Foundation. If successful, this initiative would unite 17 organizations in 11 countries in the pursuit of photon detection technology.

Figure 34. Russell Bessette, left, executive director of the New York State Office of Science, Technology and Academic Research, presents a faculty development award to RIT astronomer Don Figer during a ceremony on campus Feb. 8., 2006. Figer recently joined RIT as a result of NYSTAR's $750,000 grant, highlighting the agency's commitment to assisting universities develop new areas of expertise leading to economic development.

Logos of current and past partner organizations are shown on the following page. Figure 34 shows the handshake that brought Director Figer to RIT through a NYSTAR Faculty Development Grant.

Universities and Foundations

UC DAVIS
University of Hawaii Institute for Astronomy
University of Rochester
NYSTAR
Gordon and Betty Moore Foundation

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
CSIC
SLAC
JPL
Spitzer Space Telescope
Space Telescope Science Institute
nhsc
Sandia National Laboratories
Berkeley Lab

Industry

Teledyne Scientific & Imaging, LLC — A Teledyne Technologies Company
Infotonics technology center inc
BAE Systems
Thermo Scientific
Kodak
Raytheon
Ball
ase optics
ITT — Engineered for life

Communications

Detector Virtual Workshop

In fall 2011, the Center for Detectors will introduce the Detector Virtual Workshop. The Detector Virtual Workshop is dedicated to the advancement of UV/O/IR detectors with primary benefit for astrophysics, and additional benefit to biomedical imaging, solar energy, and photonics (Figure 35). The objectives of this workshop are to enable future national capabilities by disseminating knowledge, increasing interdisciplinary opportunities, enhancing interactions between academia, industry, and government, and providing student and professional training opportunities. There will be a particular emphasis on informing the scientific community regarding potential detector developments in the next ten years. The workshop will include avenues for brainstorming by all participants, and it will culminate in a report that summarizes promising detector developments.

A committee of technology and discipline experts will select speakers who can deliver material to support the objectives of the workshop, especially those with the ability to present the most promising detector technologies. The talks will be delivered to audiences around the country through a streaming audio/video facility, and they will also be recorded and archived for later public use. The talks will be given twice per month, with RIT hosting one, and the speaker's home institution hosting the other. RIT's facility for delivering talks (Adobe Connect) can be used remotely through a simple browser interface. It is the primary facility for delivering distance learning and remote meetings at RIT.

This Virtual Workshop will be delivered to organizations and populations outside of the lead institution and broadly across institutions and throughout many fields. It will be directed by a multi-institutional committee composed of experts from many fields and different types of organizations. The intention is to extend this workshop into a continuing speaker series that would be self-funded through hosting partners.

Center for Detectors (CfD) will lead this effort, leveraging deep connections that it already has with scientists, engineers, industry, government labs, students in academia, and across multiple application areas. The CfD, and its associated laboratory RIDL, have already successfully executed a similar, but abbreviated, concept in the Quantum-Limited Imaging Detector Symposium held at RIT in 2009.

The objectives of the Detector Virtual Workshop are to:

a) produce a summary report that describes the grand challenges, potential breakthroughs, and the most promising detector technologies for astronomy over the next ten years
b) enable future scientific breakthroughs through better understanding of detectors
c) disseminate knowledge of new detector concepts, existing detector performance, and detector applications
d) increase interdisciplinary opportunities
e) train undergraduate and graduate students
f) connect students with potential future employers
g) increase interactions between academia, industry, and government

The Detector Virtual Workshop participants will produce a summary report that describes the grand challenges, potential breakthroughs, and the most promising detector technologies for astronomy over the next ten years, enable future scientific breakthroughs through better understanding of detectors, and disseminate knowledge of new detector concepts, existing detector performance, and detector applications. It will also focus on increasing interdisciplinary opportunities, training undergraduate and graduate students, connecting students with potential future employers, and increasing interactions between academia, industry, and government.

Figure 35. (left) Cognitive functioning in infant brain, as sensed by single photon detectors. Photo Credit: Andrew Berger, University of Rochester. (right) Artist conception of the Thirty Meter Telescope, a project that will require new advanced imaging detectors. Image Credit: TMT project.

Dr. Donald Hall, Professor, University of Hawaii

HgCdTe Array technology development at the University of Hawaii for astronomical observations

Abstract: The talk focused on recent developments in two investigations for which the speaker is Principal Investigator; both aim to advance HgCdTe array technology for the most challenging astronomical observations in the 1 to 5 μm region of the infrared. An NSF-funded program to develop the 16 Mpixel H4RG-15 array in partnership with Teledyne Imaging Sensors is about to begin cryogenic evaluation of the first hybrid arrays. A NASA-funded program to optimize linear mode HgCdTe APDs for photon counting applications, in partnership with Raytheon Vision Systems, has reduced dark count rates in small arrays originally developed for LADAR applications. These programs are likely to advance infrared astronomy both from the ground, and in space, but have a far broader range of potential applications.

Speaker Bio: Dr. Hall received his B.Sc. in Physics from the University of Sydney and Ph.D. in Astronomy from Harvard. At Kitt Peak, he developed advanced infrared instrumentation for the McMath Solar Telescope and the Mayall 4-meter telescope. In 1977, he was awarded the Newton Lacy Pierce Price of the American Astronomical Society. In 1982, he became Deputy Director of NASA's Space Telescope Science Institute. In 1984, Dr. Hall became Director of the Institute for Astronomy at the University of Hawaii, developing the Mauna Kea Observatory as the best site known for optical, infrared, and sub-millimeter astronomy. Since returning to his research career, Dr. Hall has developed very large array detectors for infrared astronomy from both the ground and in space. He pioneered the use of MBE HgCdTe for astronomy, especially for the Hubble Space Telescope and the James Webb Space Telescope, for which he received a NASA Congressional Space Act award. Dr. Hall was recently awarded the American Astronomical Society's 2010 Weber Award for Astronomical Instrumentation "for the design, invention, or significant improvement of instrumentation leading to advances in astronomy."

Dr. Chris Packham, Associate Scientist, University of Florida

IR Instrumentation as Probes of AGN & Their Host Galaxies

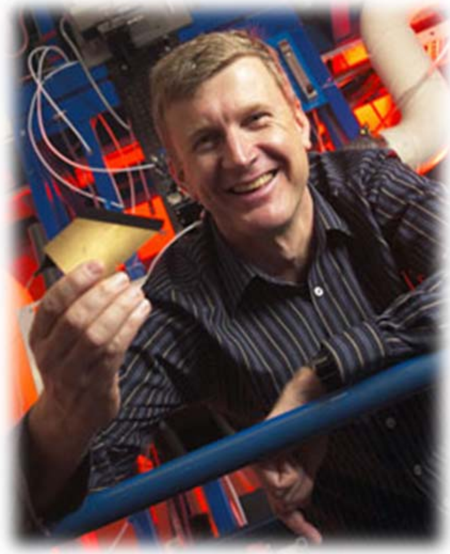
Abstract: In the next decade, IR astronomy is poised to continue its rapid pace of discovery. From planet searches and debris disks to AGN and cosmology, new IR optimized telescopes, instruments and techniques will hasten the pace of progress in these and many other areas. Perhaps one of the most exciting projects in the coming decade is the TMT, and RIT is in an exemplary position to capitalize on their capabilities and reputation in order to help develop outstanding IR instruments for the global TMT community. I discuss recent, near and medium-term future IR instrumentation for large and/or advanced telescopes I am involved in, operating in the 1-25µm wavelength region. The international science team that I lead offers crucial guidance and drive to my instrumentation work, and I present our goals and results as a way to introduce the capabilities afforded by these instruments through close synergies between science and instrument teams.

Speaker Bio: Chris Packham received his Ph.D. from the University of Hertfordshire (UK) based on IR polarimetry of Active Galactic Nuclei (AGN). He then took a short term fellowship at the NAOJ (Tokyo, Japan), working with staff who were constructing instruments for the 8.2m Subaru telescope. He then moved to the Isaac Newton Group of Telescopes (ING, Spain; formally part of the RGO, University of Cambridge, UK) where he was the PI for a 1-2.5µm adaptive optics optimized camera for the 4.2m WHT. In 2000, he moved to the University of Florida, where he has been/is PI or deputy-PI for both near-IR (1-5µm) and mid-IR (7.5-25µm) instruments for Gemini, MMT and the GTC. He is currently working on a TMT-based mid-IR instrument with Japanese and Hawaiian colleagues and pursuing AGN research with an international group of astronomers.

Dr. Joss Bland-Hawthorn, Professor, University of Sydney

Astrophotonics

Abstract: Astrophotonics—the interface of photonics and astronomy—will revolutionize astronomical instrumentation in the coming decade. Recent developments include the PIMMS multimode photonic spectrograph which is arguably the most radical development in spectroscopy in almost a century.



Speaker Bio: Joss Bland-Hawthorn is an astrophysicist and specializes in galactic research and instrumentation. In 1986, he obtained his PhD in astrophysics from the Royal Greenwich Observatory prior to taking up appointments in Hawaii and Texas. In 1993, he moved to the Anglo-Australian Observatory where he was Head of a highly successful group that pioneered astronomical concepts with names like Nod & Shuffle, Dazle, Starbugs, Honeycomb, and so on. In 1995, he developed TTF, the first general user tunable filter in astronomy. In 2002, he wrote papers on the prospect of optical lasers being used to communicate data from satellites back to Earth. The concept was finally demonstrated by the MESSENGER satellite in 2006 on its way to Mercury. In 2003, he proposed the new field of astrophotonics that sits at the interface of astronomy and photonics. In Feb 2009, this field was featured in the Focus Issue of Optics Express. With Ken Freeman, he developed the field of Galactic Archaeology and they lead the new HERMES project to obtain 8D chemical information on 1-2 million stars at the AAT over the next decade. His group at the University of Sydney is now close to solving three longstanding problems: (i) how to suppress the bright infrared sky; (ii) how to build miniature spectrographs; (iii) how to image the sky simultaneously at hundreds of distinct locations over a wide field. Joss is a recipient of the 2008 Muhlmann Award and is this year's Leverhulme Professor to Oxford. In 2011, he is the Brittingham Scholar at the University of Wisconsin.

Bruce Tromberg, Professor, University of California, Irvine

Spectroscopy and Imaging in Medicine: Moving Benchtop Optical Technologies to the Bedside

Abstract: This talk presents principles of tissue optical contrast using examples that highlight sensitivity to cellular metabolism, extracellular matrix composition, and vascular dynamics. These capabilities will be placed in the context of several emerging clinical applications, including increasing surgical accuracy, imaging tissue function, predicting therapeutic drug efficacy, and detecting early disease.

Speaker Bio: Bruce J. Tromberg, PhD is a Professor of Biomedical Engineering at the University of California, Irvine and Director of the Beckman Laser Institute and Medical Clinic (BLI), one of five national Beckman Centers established by the Arnold and Mabel Beckman Foundation. He is the PI of a National Institutes of Health (NIH) National Biomedical Technology Center, the Laser Microbeam and Medical Program, and has pioneered development and application of optics and photonic technologies in Biology and Medicine for 20 years. Dr. Tromberg has made original contributions to biophotonic technologies, e.g. the role of oxygen and light dose modulation in photodynamic therapy, and the importance of broadband spatial, spectral, and temporal modulation in diffuse optical spectroscopy and imaging. He is PI of a National Cancer Institute multi-center program grant, "Breast Cancer Multi-Dimensional Diffuse Optical Imaging" that brings together investigators to develop advanced optical technologies for breast cancer detection. Dr. Tromberg has nine issued patents and more than 200 publications. He has trained more than 45 students and postdocs from multiple disciplines, including biomedical engineering, electrical engineering, biology, chemistry, and physics. He is a Fellow of the International Society of Optical Engineering (SPIE) and the American Institute for Medical and Biological Engineers (AIMBE). Several of Dr. Tromberg's technologies have been licensed by industry and his research has contributed to the formation of four start-up companies. Dr. Tromberg is editor-in-chief of the Journal of Biomedical Optics, a peer-reviewed journal with the third-highest impact factor (of 64) in the field of Optics.

Shouleh Nikzad, Staff, NASA Jet Propulsion Laboratory

The Intricate Interplay Between Materials, Interfaces, and Devices, High Performance Imaging For Astrophysics, Planetary Studies, Defense, and Medical Applications

Abstract: Semiconductor-based imaging detectors offer a rich spectral range, tailorable spectral response, high resolution, and sensitivity; however, these capabilities are not often available in a single material or class of material. For example, while silicon imagers have reached amazing performance levels in terms of format, pixel size, and signal to noise, they are blind to UV light.

Indeed, often even a class of materials' intrinsic potential is not realized because of seemingly small phenomena at surfaces or interfaces of dissimilar materials. In the case of silicon, it is charge accumulated at the silicon/oxide interface that prevents sensitivity to UV photons. While empirical approach to overcoming materials problems enjoys a degree of success, it is fundamentally limited. Only by understanding gleaned through an interdisciplinary approach, is it possible to manipulate the natural state of material and produce devices with extraordinary and reproducible performance. Using non-equilibrium processes, we can manipulate materials at nanometer scale, form quantum structures, and alter band structures. The additional bonus of this approach is that it can be applied to other materials systems and classes of devices. In this talk, Nikzad discussed the case of well-studied and well-known silicon/silicon oxide interfaces and her work on the use of molecular beam epitaxy to develop high quantum efficiency ultraviolet, visible, and near IR silicon detector arrays and the applications of these arrays to such disparate fields as astrophysics, cosmology, defense, and medicine.

Speaker Bio: Dr. Nikzad leads the Advanced Detector Array and Nanoscience Technologies Group at JPL where she has initiated and developed many successful detector programs, including high performance back illuminated imaging arrays, end-to-end post fabrication processing, curved focal plane arrays, III-N photocathodes, low-energy particle detectors, and more.

Michael Hoenk, Staff, NASA Jet Propulsion Laboratory

Synthetic Foveal Imaging Technology: Toward Real Time Perception and Response in Ultrahigh Resolution Imaging Systems

Abstract: High performance focal planes are currently being developed to achieve extraordinarily high resolution and wide fields of view. Gigapixel and larger focal planes promise unparalleled visual acuity in diverse applications, including medical imaging, biological imaging, optical inspection systems, military surveillance, planetary instruments, and astronomical observatories. At the same time, large focal planes present unique challenges to data handling and processing systems, especially in applications that require rapid response to transient events that might otherwise be buried in a flood of data.

Despite the apparent technological difficulties in achieving real-time perception and response, biological evolution offers abundant proof that such systems are possible. Just as a falcon uses the foveal regions of its retina for enhanced visual acuity in dynamic environments, synthetic fovea offer a new capability for quickly and efficiently extracting useful information in real time from a high-resolution data stream.

Our vision is to combine the speed, flexibility, and adaptability of foveal imaging systems with ultrahigh resolution focal planes. Our approach is to design a powerful new parallel-processing computer architecture that is flexible and scalable to mosaic arrays of high performance CCD and CMOS imagers. SyFT will not replace the transmission and storage of raw image data which are essential for many applications, but it can transform high performance focal planes into intelligent visual systems, and, as in biological evolution, open new opportunities and pathways of perception in scientific imaging.

Speaker Bio: Dr. Hoenk's research interests range from materials science and physics to high performance imaging detectors and biomimetic microsystems. At Caltech and JPL's Microdevices Laboratory, Dr. Hoenk developed many sensors and instruments for the in situ exploration of Earth and Planetary atmospheres, including the development and demonstration of the first delta-doped CCD and CMOS imaging arrays

Quantum-Limited Imaging Detector Symposium

On March 2, 2009, the Center welcomed academic, government, and industry scientists and researchers to join the RIT community for the Quantum Limited Imaging Detector Symposium. Over two days, the highly recognized event rose awareness about the advancements in the field of quantum-limited imaging detectors and the dexterity they have in enabling some of today's most demanding measurements.

Some of the speakers included Jim Beletic of Teledyne Imaging Sensors, Dan Newman of ITT, Brian Aull of the MIT/Lincoln Laboratory, Tim Tredwell of Carestream Health, Jeff Puschell of Raytheon Space and Airborne Systems, and Andrew Berger of The Institute of Optics at the University of Rochester. The talks emphasized the importance of detectors in a broad array of fields. Don Figer, the event coordinator, stated "By bringing together such exceptional talent and experience, we were able to spark new ideas and create new opportunities that will bring our field just another step forward." The Center conveyed to the nation-wide leaders why they are motivated and excited to continue advancing detector technology through two beliefs. First, that the most demanding future applications will require new advanced detectors, and second, that we are at the cusp of an era of quantum-limited imaging detectors.

In the News

RIT Center for Detectors Advances Detector Technology

In February 2011, the RIT University News featured an article on the newly created Center for Detectors. The article introduced the mission and promise of the Center. It noted the Center's desire to make scientific discoveries, strengthen our national security, improve the quality of life, and stimulate commercial innovation through detectors and associated advanced instrumentation. It was also noted that collaboration among multiple colleges within RIT and external research partnerships play a crucial role in advancing this new detector technology.

Another section of the press release was devoted to the Center's plans for the future. The Center will work on developing detectors for the next generation of 'Extremely Large Telescopes' and will also work on development of detectors for the 'Wide Field Infrared Survey Explorer.' In the future, the Center seeks to make advances in biophotonic imaging and conduct research within RIT's new Institute of Health Sciences and Technology.

In the article, Figer states "Something very interesting has been happening in science; it's the increasing trend toward team science—tackling problems that could not be solved by any one discipline alone."

"New center at RIT finds novel ways to use photo sensors"

In March 2011, the Center for Detectors was featured in the Rochester Business Journal. The article summarized what detectors are and how they can aid us in everyday life. It also highlighted the background of the Center and what it aspires to become. A major section of the article was based on the funding opportunities that the Center has received. The Center won about $7.5 million in external funding, primarily from companies or government entities. The article stated "Since its opening, the laboratory had been one of the best performers at the university in garnering money for sponsored research." The Center has continued to use external funding to advance detector technology and hopes to attract national attention to RIT with their research.

“The Universe” Television Series on the History Channel

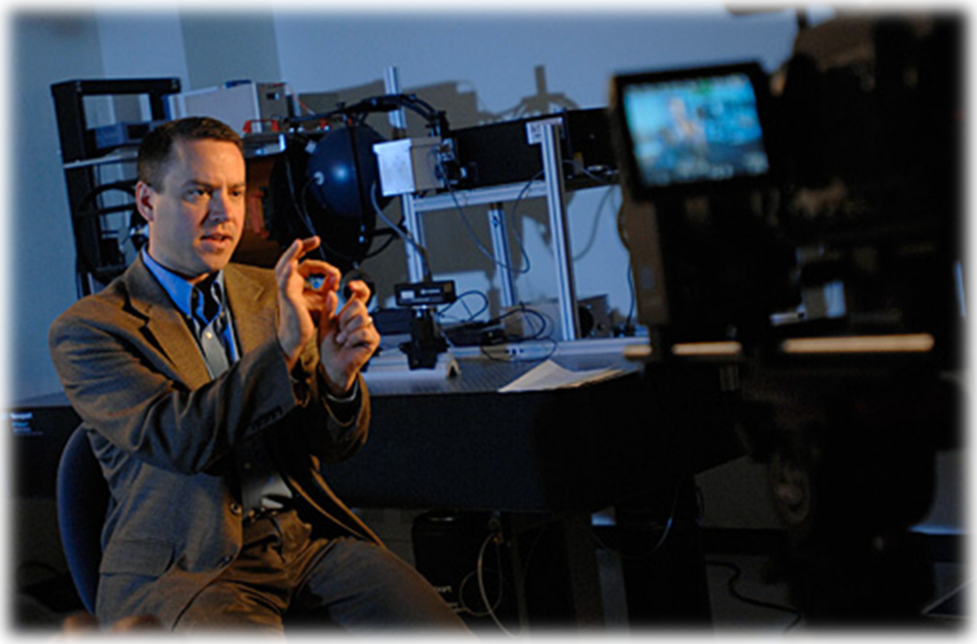
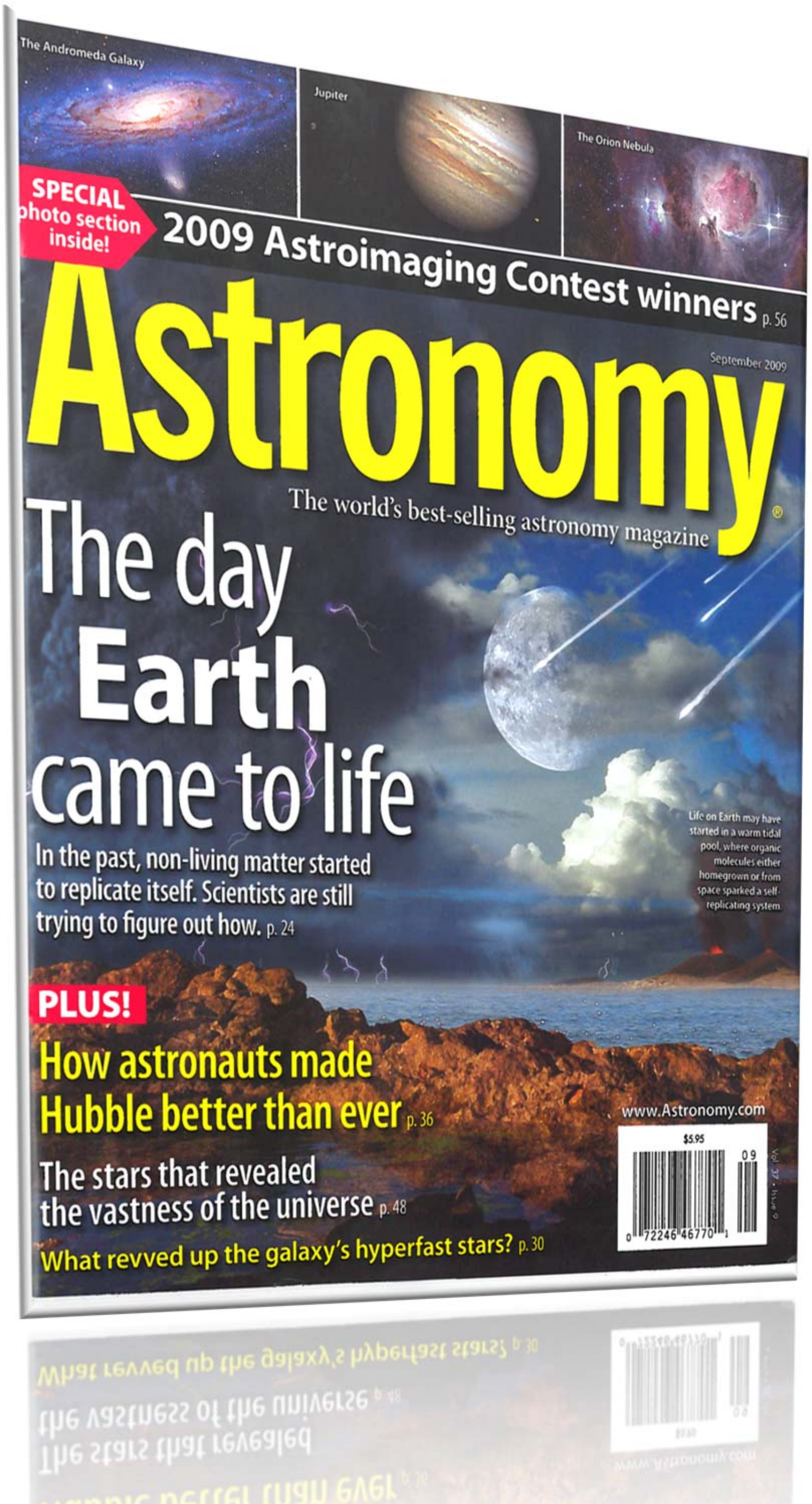


Figure 36. CfD Director Don Figer discusses massive stars in the RIDL for a History Channel documentary. Photo by Sue Weisler.

A film crew from the History Channel visited campus on July 2, 2009, to interview Director, Don Figer, for the series, “The Universe” (Figure 36). They shot footage for two episodes, one on star clusters, and another on astronomical objects called pulsars and quasars. The first episode, “The Search for Cosmic Clusters,” chronicled Figer’s research over the past 15 years to identify the most massive young star clusters in the Galaxy:

“They are the one-stop-shopping places for learning all about the nature and variety of stars in the Universe. They're unique, because in clusters, all the stars were born at about the same time, from the same material and all are at the same approximate distance from Earth. This means we can be sure that any differences among them are due to their true natures and not distorted by different distances from Earth and other factors. In this episode, two kinds of star clusters in the galaxy are explored. "Open Clusters" are young, live in the spiral arms of the galaxy and give us insight into the birth and formation of stars. "Globular Clusters" are old, live in the outskirts of the galaxy and could be nearly as old as the Universe itself. In addition, explore Galaxy clusters to reveal the large-scale structure of the Universe, which is expanding so fast that eventually all other galaxies, except for our own, will literally disappear from our sight.”



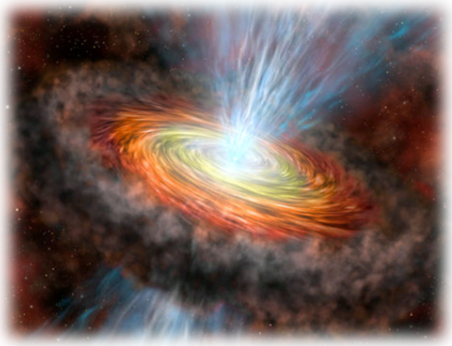
A DAY IN THE LIFE OF ...

Don Figer

Director of the Rochester Imaging Detector Laboratory (RIDL) and professor at the Rochester Institute of Technology (RIT) in New York

- **8 A.M.** Watch daughter board the school bus, and then get in my own school "bus" to go to RIT.
- **9 A.M.** Prepare lecture for undergraduate Detectors course.
- **10 A.M.** Meet with students during office hours.
- **11 A.M.** Finish paper describing the discovery of a massive star cluster in the Milky Way.
- **Noon** Have lunch on campus with RIDL co-workers.
- **1 P.M.** Write data reduction and analysis software for the NASA-funded low-noise detector project in the RIDL. This $1.7 million project will develop a new generation of low-noise detectors for astrophysics and planetary space missions.
- **2 P.M.** Write first draft of proposal for funds to create the National Center for Imaging Detectors.
- **3 P.M.** Attend weekly RIT Massive Star research group meeting.
- **4 P.M.** Meet in RIDL to discuss single-photon imaging detector project for the Thirty Meter Telescope, funded by the Gordon and Betty Moore Foundation. This $2.8 million project will develop a new detector that will quadruple the power of a telescope for detecting the faintest objects in the universe.
- **6 P.M.** Have dinner with family and recount favorite things that happened today.
- **7 P.M.** Tuck girls into bed.
- **8 P.M.** Review draft papers from astronomers in the Massive Star research group.
- **9 P.M.** Review NASA research proposals and referee paper for *The Astrophysical Journal*.
- **11 P.M.** Count my lucky stars until I fall asleep!

A Massive Star is Born



Astronomy
The world's best-selling astronomy magazine

Figure 37. Artist's conception of W33A showing the accretion disk (yellow/orange), torus (dark ring around disk) and bi-polar outflow jets (blue) within the dense clouds of its stellar nursery. Gemini Observatory, artwork by Lynette Cook.

January 27, 2010

Explaining how the most massive stars are born, deep within their stellar nurseries, is one of the most persistent mysteries in modern astronomy. Observations at the Gemini Observatory provide convincing new evidence that these stellar heavyweights may be born in much the same manner as lightweights like the Sun.

"The problem is that when the most massive stars form it happens very quickly compared to stars like our Sun, and by the time they break free of their natal clouds they are already the finished article," says Ben Davies, assistant research scientist at Rochester Institute of Technology's Rochester Imaging Detector Laboratory, and formerly of the University of Leeds in the United Kingdom. "If you want to see a massive star in the process of forming, you need to be able to see through the obscuring clouds to where the action is."

Davies led an international team of researchers who brought infrared sensitivity and the extreme resolution of adaptive optics to bear on the problem. This allowed the team to penetrate the obscuring gas and dust clouds surrounding the massive proto-star W33A (Figure 37).

Davies' team calculates that the prenatal star is at least 10 times more massive than our Sun, and is still rapidly growing. According to Davies, this is the first time scientists have been able to unravel the dynamics deep inside a heavyweight stellar nursery at this level of detail. "We've caught a massive star in the act of formation and find signatures of an accretion disk embedded within a torus of gas and dust," Davies says. "We also see material being blasted away from the poles at speeds of up to 300 kilometers per second. These features are all common to formation process of much smaller stars."

The massive star forming inside of W33A is completely obscured in optical light (as seen by the human eye) but, as Davies explains, “while the optical light is attenuated by about a factor of 10,000, much of the infrared light can pass through the intervening material. This affords us a glimpse of what is happening deep inside W33A’s natal cloud.”

Several conflicting theories strive to explain how massive stars are born, whether it is a scaled-up version of low-mass star formation, or whether a completely different physical process is involved. Observations with adaptive optics and infrared spectroscopy are catching massive stars as they form.

Davies’ team used the power of adaptive optics to remove atmospheric blurring and then dissected the light using the Near-Infrared Integral Field Spectrograph (NIFS) on the Frederick C. Gillett Gemini North telescope on Hawaii’s Mauna Kea. NIFS creates what is sometimes called a spectral image consisting of about 2,000 individual spectra in a square array covering the heart of W33A. These data are assembled into a “data cube” which allows the scientists to look at individual features of the spectra at each point and assemble a multi-dimensional image of the environment around the birthing star.

“We were not only able to resolve the inner nebula on small spatial scales but also probe its dynamics by measuring the Doppler-shift of light from the glowing gas to determine its velocity and how it flows around the forming star,” says Davies. “This is an amazingly powerful tool for understanding the inner workings of how stars actually form.”

Known as a Massive Young Stellar Object, W33A is located about 12,000 light years away, toward the constellation of Sagittarius. Previous studies of this object only hinted at its dynamic nature but, until now, no stellar objects have been studied at this level of detail using the combination of adaptive optics and integral field spectroscopy used by the Davies team.

Colin Aspin of the Institute for Astronomy at the University of Hawai’i adds, “This result provides us with one of the first clues that high-mass stars form in similar ways to their low-mass counterparts and shows the power of integral-field near-infrared spectroscopy as a way of probing the youngest phases of stellar evolution.”

Scientists Find Giant Ring Encircling Exotic Dead Star

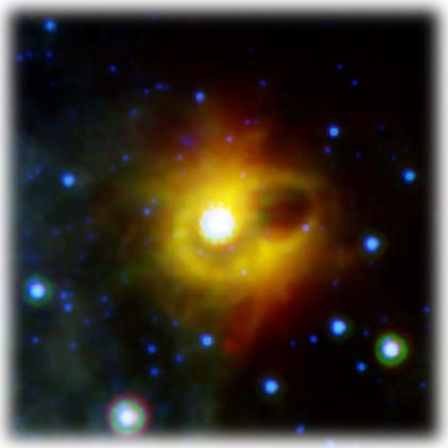


Figure 38. This image shows a ghostly ring extending seven light-years across around the corpse of a massive star.

May 28, 2008

One of the most powerful eruptions in the universe might have spun an infrared ring around a rare and exotic star known as a magnetar, a highly magnetized neutron star and the remnant of a brilliant supernova explosion signaling the death throes of a massive star (Figure 38).

A paper published in the May 29 issue of Nature announces the detection of the elliptical ring or shell around the dead star known as SGR 1900+14. Observations obtained from NASA's Spitzer Space Telescope in 2005 and 2007 suggest the ring was produced by a giant flare originally detected in 1998. Stefanie Wachter, research scientist at NASA's Spitzer Science Center at the California Institute of Technology, led the study, which links the origin of the magnetar to a nearby cluster of massive stars, whose light is dominated by two red supergiants at the center.

"Out of 400 billion stars in our galaxy, there are about a dozen magnetars that we know of," says Donald Figer, professor at Rochester Institute of Technology's Chester F. Carlson Center for Imaging Science and a co-author of the study. "Discovering the ring is groundbreaking because it discovers some other phenomenon associated with, and physically near, a magnetar. And when you know so little about an object, each new morsel you can gather up is very important."

Figer is also part of a team, led by Rolf Kudritzki of University of Hawaii, who recently won time on the world's largest telescope, the W.M. Keck Observatory, to make additional measurements of the magnetar.

"Magnetars possess magnetic fields a million billion times stronger than the magnetic field of the Earth," Figer says. The magnetic field of a magnetar is one petagauss (10 to the 15th or 1,000,000,000,000,000 gauss) while, in comparison, Earth's magnetic field strength registers at 0.5 gauss, the Sun at one gauss and a sunspot at about 1,000 gauss. These extreme fields stretch the very fabric of matter, contorting atoms into thin cigar-shaped structures.

An accepted model for magnetars was introduced in the early 1990s to describe the mysterious and frequent flashes of repeating gamma ray emissions first detected in 1979. The stellar eruption may result from stress induced by the magnetic field dragging on the rapidly spinning star. A fissure in the surface of the magnetar creates a "starquake," akin to earthquakes. The biggest variety of these eruptions can temporarily produce over a thousand times more energy than all of the stars in a galaxy.

Adds Wachter: "We think that the ring was created when a giant flare from the SGR (soft gamma repeater) carved a cavity into the dusty environment surrounding the magnetar, thus naturally explaining why the ring is centered on the magnetar."

Pinwheels in the Quintuplet Cluster

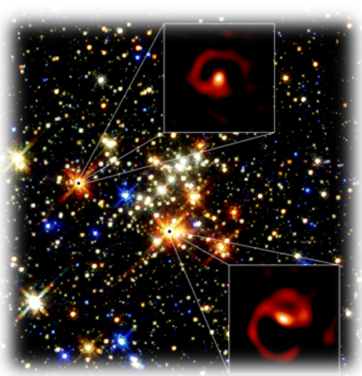


Figure 39. A Yin and Yang in the Galactic Center. High-resolution infrared images of the dusty pinwheel nebulae.

August 16, 2006

For the first time, scientists have identified the cluster of Quintuplet stars in the Milky Way's galactic center, next to the super massive black hole, as massive binary stars nearing the end of their life cycle, solving a mystery that had dogged astronomers for more than 15 years (Figure 39).

The nature of the stars was not entirely clear until now. In a paper published in the Aug. 18 issue of Science, co-authors Peter Tuthill of the University of Sydney and Donald Figer of Rochester Institute of Technology show that the Quintuplet cluster consists of young massive binary stars that produce large amounts of dust. Their data reveal that five bright red stars are nearing the end of their "short" lives of approximately 5 million years. These quickly evolving stars burn fast and bright, but die younger than fainter stars, which live for billions of years. The study captures the Quintuplet stars just before disintegrating in supernovae explosions.

Using advanced imaging techniques on the world's biggest telescope at the W.M. Keck Observatory in Hawaii, the scientists captured the stars at the highest attainable resolution for the instrument, far exceeding the capability of the Hubble Space Telescope, which imaged the cluster a decade ago. The extra-resolution gives scientists a new glimpse of the dust plumes surrounding the stars and the swirling spirals Tuthill likened to pinwheels when he identified the first one in 1999 elsewhere in the galaxy.

"Only a few pinwheels are known in the galaxy," Figer says. "The point is, we've found five all next to each other in the same cluster. No one has seen anything like this before."

According to Figer, the swirling dust in pinwheel stars is key to the presence of the most evolved massive stars and points to the presence of pairs of stars. The geometry of the plume allows scientists to measure the properties of the binary stars, including the orbital period and distance.

"The only way that pinwheels can form is if they have two stars, swirling around each other. The stars are so close that their winds collide, forming dust in a spiral shape, just like water sprayed from a garden hose of a twirling sprinkler," Figer says. "A single star wouldn't be able to produce the dust and wouldn't have the spiral outflow."

An earlier study by Figer in 1996 claimed the Quintuplet cluster consists of evolved massive stars that produce dust. Figer's research could not be confirmed until now with the use of the Keck telescope.

"If you want to understand star formation, you have to understand if they are forming alone or if they have partners," Figer says. "The answer gives us a clue as to whether stars form alone or with companions."

Grants from the Australian Research Council, the National Science Foundation Stellar Astronomy and Astrophysics Program, and the NASA Long-term Space Astrophysics Program supported this project.

Education and Public Outreach

Journey of a Photon

The CfD partnered with the RIT Insight Lab for Science Outreach and Learning Research in an educational supplement to a NASA ROSES grant, "Radiation Tolerant Detector for NASA Planetary Missions." With support from this supplement, 15 high school students from the Rush Henrietta School district were offered an opportunity to become engaged in a great project. The students developed a story that describes the journey a photon, from creation in the nucleus of a star to detection by a telescope.

RIT undergraduate students guided the high school students, as they learned the necessary science that is critical for developing and producing a show for the Insight Lab's Digital Immersive Cube (SCUBE). When finished, the project was presented at several different venues nationwide. It was first presented at the annual meeting of the National Science Teachers association. It then went on to The Rochester Museum and Science Center, The Pasadena Conference Center in California, The National Zoo in Washington DC, The Miami Public Library in Florida, The Boston Museum of Science, and of course, the annual Imagine RIT festival for two years. Most of the high school students have gone on to enroll in undergraduate STEM programs across the country. This project helped CfD fulfill a main part of its mission statement to engage younger students in the fields of STEM in the hopes that they will become future scientists and engineers.

This project also brought together a diverse group of fields within the RIT undergraduate community. Undergraduate students from a variety of departments including, Imaging Science, Mechanical Engineering, Biomedical Science, Biotechnology, Computer Science, and Information Technology, developed useful skills through working with younger students and using novel educational technologies.

Planetary Surfaces in 3D

The "Exploring Planetary Surfaces in 3D" project was funded through another educational supplement to a NASA grant, "A LIDAR Imaging Detector for NASA Planetary Missions." The award supported another excellent opportunity for RIT to collaborate with high school students (Figure 40). RIT undergraduates developed technologies that a group of high school students used to present explorations of planets in 3D. These presentations will be shown to public and school group audiences.

Two RIT Software Engineering Honors Freshmen, Brandon Cole and Christopher Carey, worked to develop a projection system called the "Planeterrainium." The Planeterrainium shows 3D planetary surfaces on the floor in front of viewer's feet (Figure 41). Recently, high school seniors have been recruited to spend the next academic year engaged in project based learning where they will develop content and support materials for the Planeterrainium. Specifically, they will be developing content through comparative planetary science and developing ways in which three dimensional images of planetary surfaces can be obtained. The project is set to run until the end of the 2011/2012 school year when the high school students will graduate and go on to college.

Figure 40. High school students tour the RIT clean room where CfD makes detectors.

Figure 41. (left) High school students learn about detectors. (right) The 3D "Planeterranium" is used to create a mobile learning environment that easily grabs the attention of most students.

Invitations to Speak

CfD Director presented an invited review talk on “Silicon single photon imaging detectors” and a contributed talk on “A photon-counting detector for exoplanet missions” at the Society of Photo-optical Instrumentation Engineers conference.

(left) CfD Director was invited to speak at Detectors for Astronomy 2009 in Garching, Germany and (right) in Braunschweigh, Germany, in 2011, at the Single Photon Workshop.

CfD Director was invited to speak at AstroMed09 in Sydney, Australia.

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Kimble, R.A. (NASA's GSFC), MacKenty, J.W. (STScI), Hill, R.J. (NASA's GSFC), Robberto, M.(STScI), Delo, G., Foltz R., Malumuth, E.M., Reed, S., Russell, A.M. , Waczynski, A., Wen, Y. (NASA's GSFC), Figer, D. F. (STScI), 2006. Improved Infrared Focal Plane Arrays for HST/Wide Field Camera 3, AAS, #125.01

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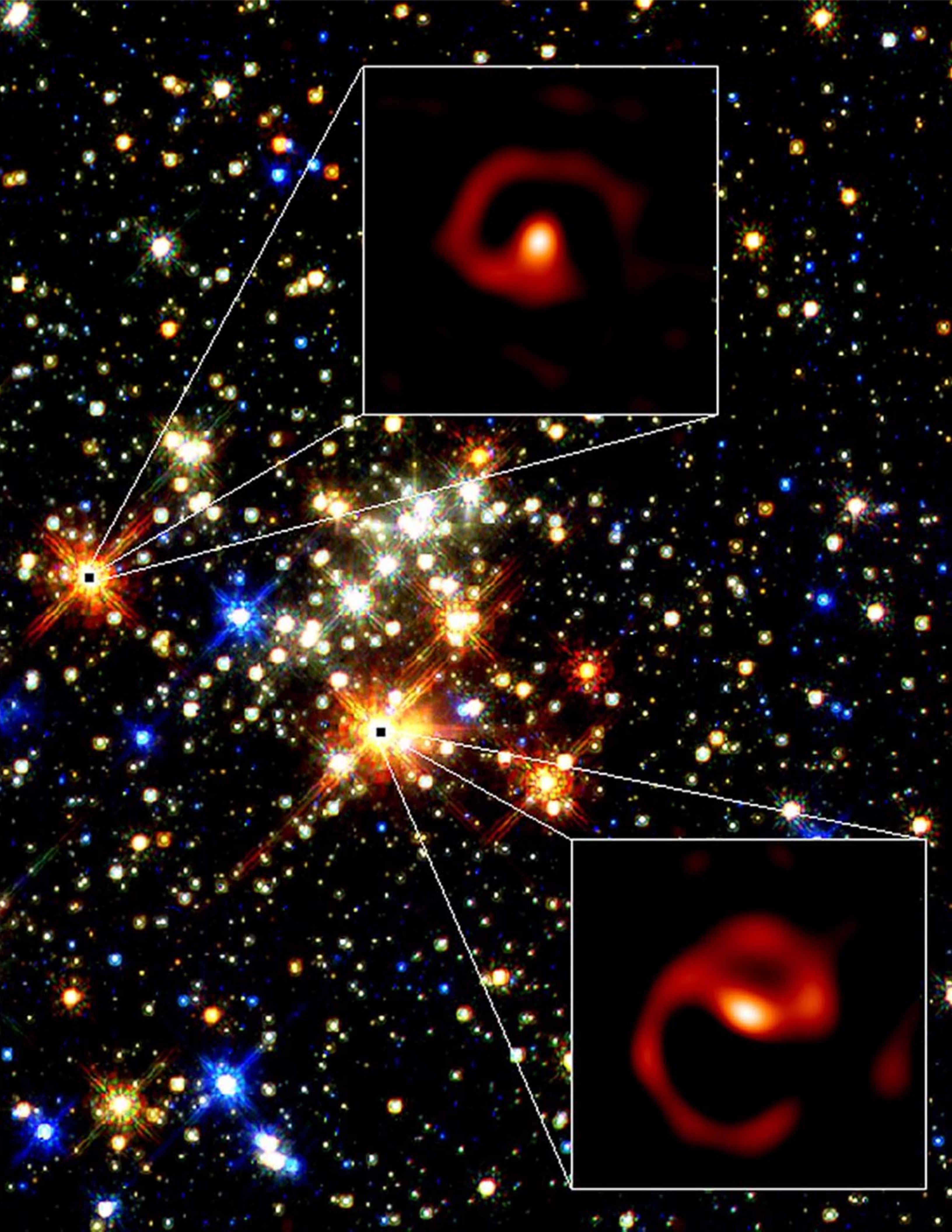
M. G. Brown, M. Schubnell, G. Tarle (U. Michigan), R. Smith, M. Bonati, D. Guzman (Caltech), D. Figer (IDTL), N. Mostek, S. Mufson (Indiana), D. Cole, S. Seshardi (JPL), SNAP Collaboration, SNAP Simulation Team, P. 2006. Development of NIR Detectors and Science Driven Requirements for SNAP, AAS, #73.04

Cross-RIT Collaborations

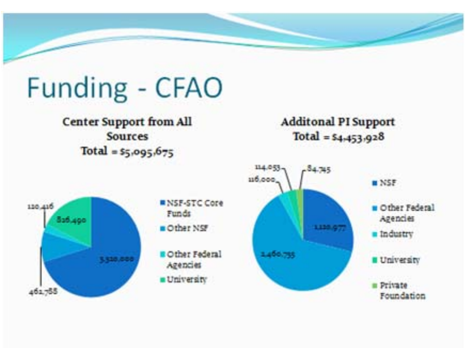


Benchmark Analysis by the RIT College of Business

As a way of enhancing the communications plan for the Center and expanding collaboration within the RIT community, during the spring 2011 quarter the RIT E. Philip Saunders College of Business created an in-depth report on the benchmarking of research centers similar to the Center for Detectors. Two faculty members and one student from Saunders Student Consulting, Marty Lawlor, Richard Notargiacomo, and Shivam Bansal, worked together to conduct a high level competitive assessment to compare the CfD with similar university research centers.

The team chose six research centers that they believed possessed qualities that are similar to those of the CfD. Some of these research centers included, the University of New Mexico's Center for High Technology Materials, Boston University's Photonics Center, and Northwestern University's Center for Interdisciplinary Exploration and Research in Astrophysics. The main components that were evaluated regarding these centers were primarily related to marketing, structure, and finances. Therefore, the main assessments in the final report were on how each center presented itself online, communicated its motives, structured its industrial relationships, and funded its organizational needs.

This work culminated in a comprehensive report and presentation that recommended actions to best align the Center for Detectors communication plan with its mission (Figure 42). The benchmarking report has become a great resource for the Center.



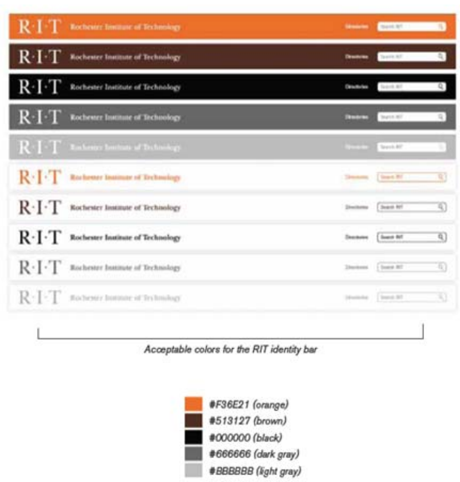


Figure 42 (left) A slide from the final presentation that shows the Center for Adaptive Optics' (CFAO) funding sources. (right) A slide from the final presentation showing acceptable headers for the main Center website.

Re-imagining Our Space with the RIT School of Design

Figure 43. Main entrance design concept by senior design student Chelsea Semelka.

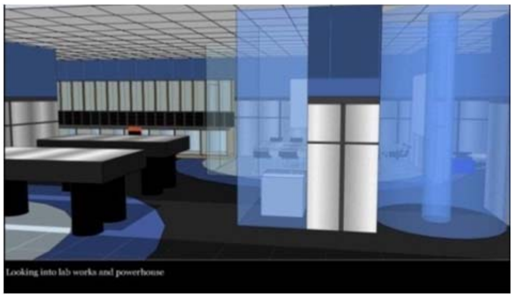
The RIT School of Design requires a senior design project for their students. The Center for Detectors saw this as a great opportunity to collaborate with creative RIT students to redesign the Center's office/lab area into a more innovative, productive, and functional environment (Figure 43 and Figure 44). At the beginning of the spring 2011 quarter, the Center invited a group of 21 School of Design students to focus their senior design projects on the redesign of the office and lab space.

Figure 44. (left) A hallway design idea by senior design student Vivian Shin. (right) An office space design idea by senior design student Allison LaChance.

The group started the assignment with a visit to the Center (Figure 45). Then they divided their work into two specific categories, with some students concentrated their efforts on the lab and some on the office space. After much hard work, the students concluded their project with extensive final presentations.

Figure 45. (left) Senior design students visited the Center for Detectors in order to get a sense of what areas would be most important for redesigning. (right) The students presented design ideas in formal presentations to conclude their senior design projects.

Throughout the presentations, each student individually presented suggestions and strategies for redesigning CfD space, demonstrating creativity, and talent through sharp visual computer-aided graphic art and hand-drawn sketches. The office concepts ranged from modern furniture and paint options, to floor plans with open conference areas that would contribute to increased collaboration. The lab ideas ranged from organized cabinets and drawers, to useful wire tray systems and safety ladders (Figure 46).



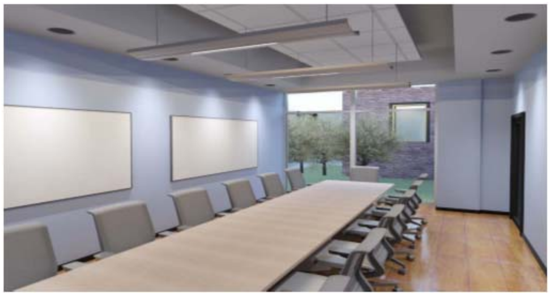


Figure 46. (top left) Laboratory design concept by senior design student Jacob Eddy. (top right) Lab design idea by senior design student Casey O'Neill. (bottom left) Office design concept by senior design student Vivian Shin. (bottom right) Conference meeting office design concept by senior design student Vivian Shin.

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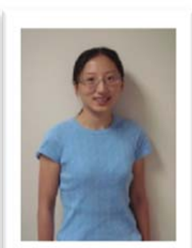

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Charter

About the CfD

The Center for Detectors designs, develops, and implements new advanced sensor technologies through partnership with academic researchers, industry engineers, government scientists, and university/college students. Currently, the Center has approximately a dozen funded projects funded by a range of sponsors, including the Gordon and Betty Moore Foundation, NASA, and NSF. Center technologies target an immense range of diverse applications, with an emphasis on astrophysics, biomedical imaging, Earth system science, and inter-planetary space 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. The focus areas are represented graphically in Figure 47. The research thrusts in each focus area are described in the following text.

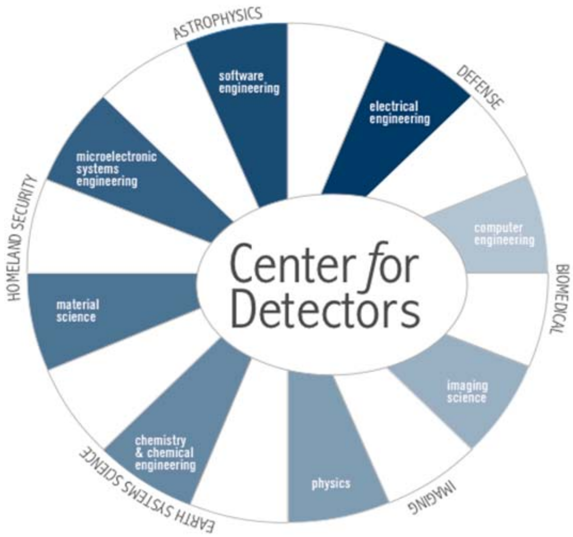

Figure 47. Application domains and collaborating departments for the Center for Detectors.

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. New members are invited, in writing, to join by the Center Director.

Education and Training

The Center educates and trains students to become the next generation of the scientists and engineers who develop new detectors and associated technologies. In the Center, both undergraduate and graduate students learn the fundamentals of detector science and their specific application. They become familiar with the culture of team-based and interdisciplinary research by being embedded in the Center and working with a broad range of academic, industry, and government partners. Each student does research in projects based on their previous education, training, and degree aspirations. The Center not only trains students, but it also serves as a conduit for professionals who seek continuing education through individual classes or degree programs at RIT.

Communications and Funding

Another important goal of the Center is to educate potential stakeholders about detector technologies and their application, particularly relating to the Center's initiatives. This information is communicated through the annual report, the web site, presentations, press releases, and scholarly papers.

The Center is grant-funded. In a short four years, the Center has received an estimated $7.5 million in external research funding to advance detectors in their broad array of applications. Two main investors are the Gordon and Betty Moore Foundation and NASA. The Moore Foundation has invested $2.8 million to support the development of a zero noise detector, while NASA awarded $5 million in research grants.

Capabilities, Equipment, and Facilities

The Center for Detectors is located in the IT Collaboratory (Building 17). It has 5000 square feet of space for offices and labs, including offices for 17 people, and three research laboratories: the Rochester Imaging Detector Laboratory (see Figure 48) the Quantum Dot Detector Laboratory, and the clean room laboratory. The laboratories contain special facilities and equipment dedicated to the development of detectors.

Figure 48. 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 (see Figure 49) use 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 49. 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 laser illumination. The lab also 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 50 shows a laser spot projection system on a 3D motorized stage that produces a small (~few microns) point source for measurements of intrapixel sensitivity.

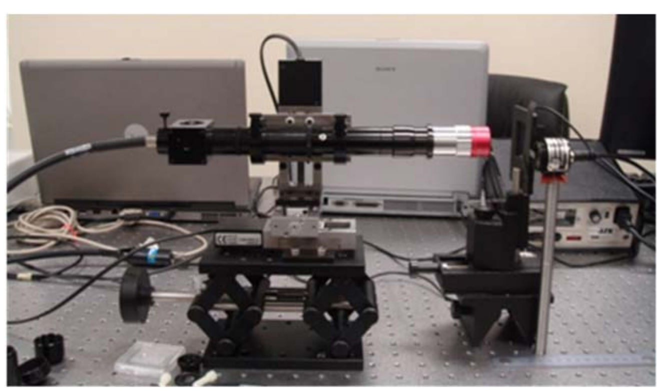

Figure 50. Laser spot projector with three axis motion control system.

The lab contains eight data reduction PCs each with eight processors and up to 16 GB 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 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 (see Figure 51). 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 52), 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.

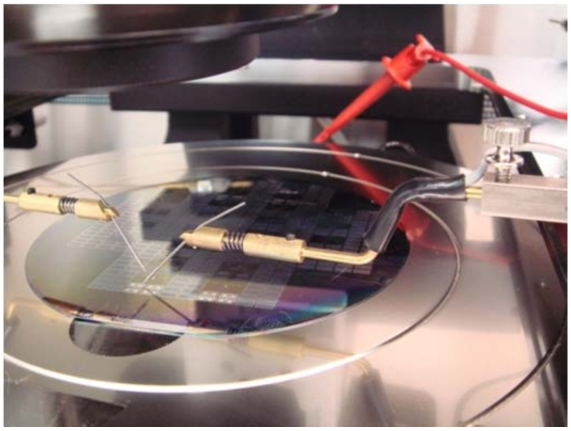

Figure 51. Device wafers are tested in the clean room lab probe station.

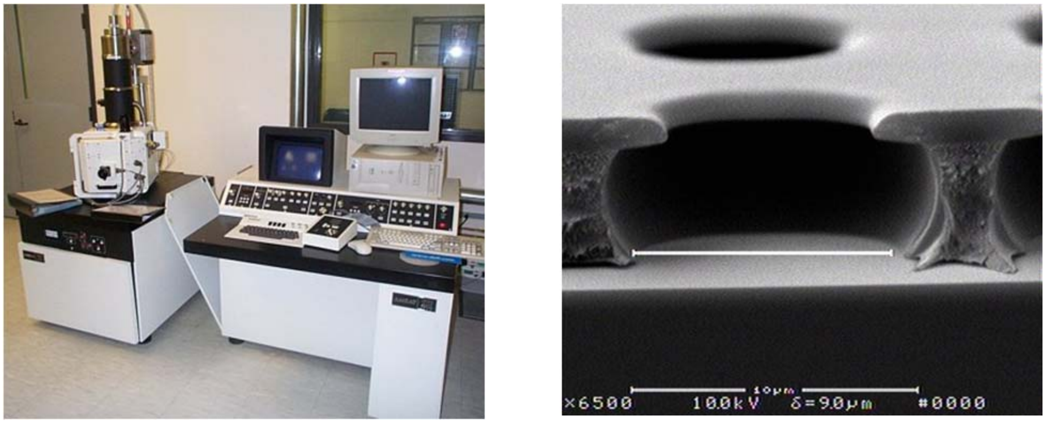

Figure 52. (left) The Amray 1830 Scanning Electron Microscope is used to image devices. (right) SEM image of device that has been prepared for indium bump deposition.

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

The Center for Detectors uses many other RIT facilities, *e.g.*, the Brinkman Lab, a state of the art facility for precision machining and the Center for Electronics Manufacturing and Assembly (CEMA), a facility for electronics packaging (see Figure 53).

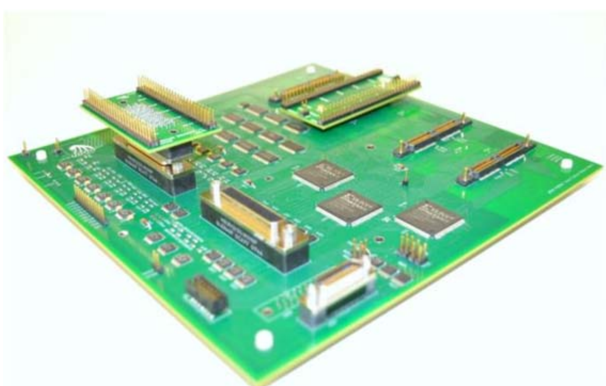

Figure 53. This image shows a cryogenic multi-layer circuit board designed in the CfD and populated in CEMA. All of the components on this board will be exposed to temperatures as low as 40 K, nanoTorr pressure levels, and high energy particle radiation.